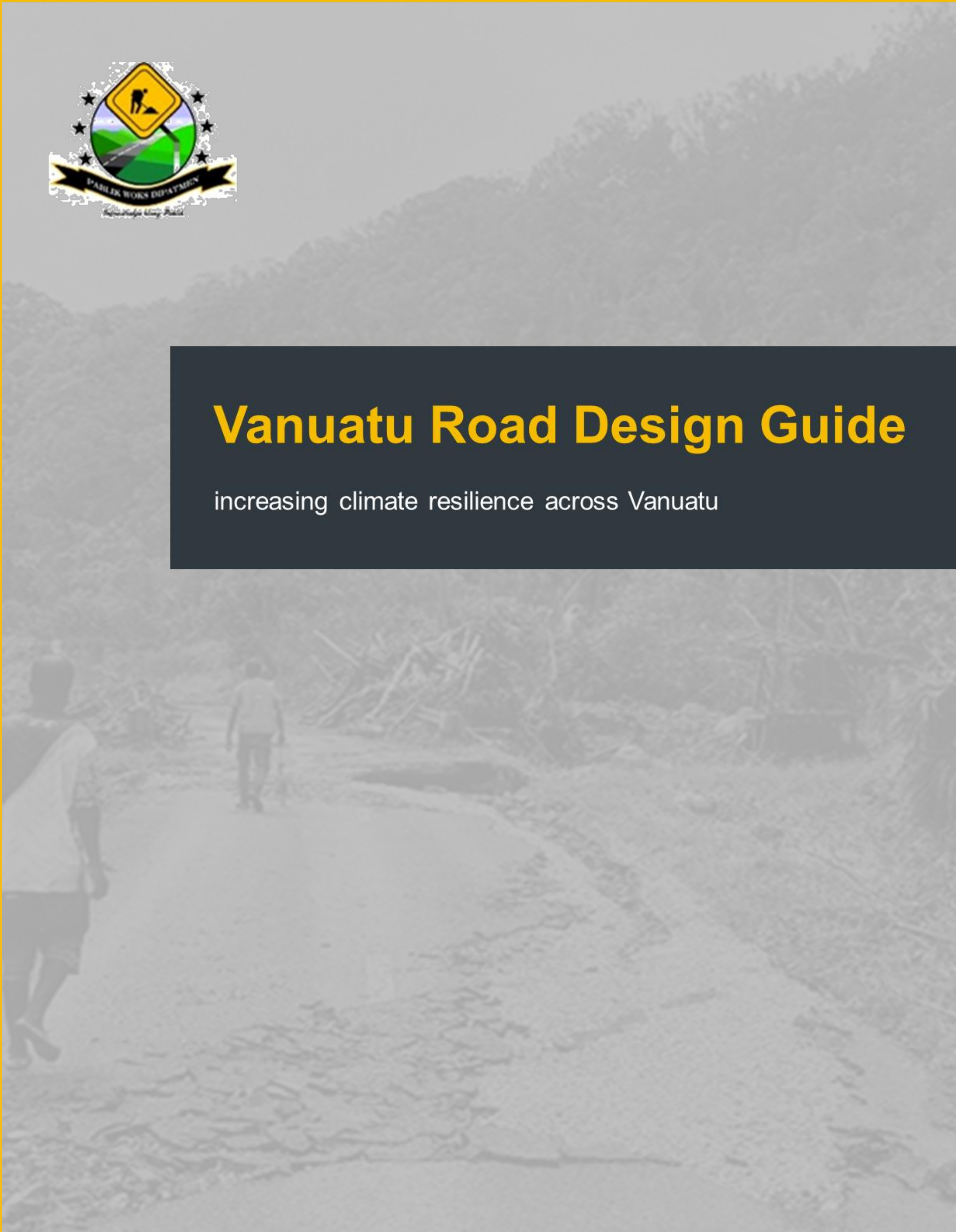
Vanuatu Road Design Guide

Increasing climate resilience across Vanuatu

Sustainable, transformative and resilient for a Blue Pacific



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increasing climate resilience across Vanuatu

September 2023

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1.0	30 July 2023	First Draft Submission for SPREP and PWD Comments	Robert Hardy	SPREP, R4D2 & PWD
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DISCLAIMER

Robert Hardy, 7Dee Consult Ltd
United Kingdom, September 2023

ACKNOWLEDGMENTS

This updated Road Design Guide for Vanuatu has been made possible by the valuable contributions and support of the Secretariat of the Pacific Regional Environment Programme (SPREP), the Vanuatu Klaemet Infomesen blong Redy, Adapt & Protekt (VanKIRAP) team and the Public Works Department staff within the Vanuatu Ministry of Public Utilities and Infrastructure. The author gratefully acknowledges the contributions and guidance of staff from all three organisations without which the development of this revised design guide would not have been possible.

ENDORSEMENT FOR USE

This new guide has been developed as an update to the Vanuatu Rural Road Design Guide previously issued in 2017. The main objectives of this revised Road Design Guide are:

- to support the Public Roads Policy and Strategy, and
- to increase climate resilience of road assets to the impacts of climate change events.

The scope of this guide has been widened to include the design of all public roads in Vanuatu, from rural earth roads to asphalted urban roads.

The guide attempts to provide the designer with simplified practical design advice and includes worked examples where these are useful. The guide should be used in conjunction with the latest PWD set of standard design drawings for roads which have been updated and republished with this guide. The standard drawings are cross-referenced throughout the design guide where appropriate.

Users of the guide are invited to submit comments or to suggest changes, especially if users find that designs provide inadequate resilience in the face of more severe climate events. Feedback and comments should be directed to the Director, Public Works Department, so that changes, if appropriate, may be incorporated into future revisions of this guide.

Henry Worek
Director, Public Works Department

CONTENTS

1. Introduction to the Guide

1.1 Background

Road designers have always designed ‘resilient infrastructure’. However, what is now different is that assets must be designed to be resilient to future climate conditions, whereas previously, designers would base designs on reliable historic climate data. This is particularly true of the assessment of storm flows used to inform drainage design, with designers previously able to refer to intensity-duration-frequency (IFD) curves which were derived from historical rainfall data. Designing roads to be resilient in the face of future climate events requires the designer to rely upon climate predictions, thus introducing significant levels of uncertainty into the design process.

This updated design guide for roads in Vanuatu has been developed and launched to reflect this fundamental change in the road design process with the objective of increasing the resilience of Vanuatu’s road infrastructure to the increasing impacts of climate events, especially tropical cyclones.

This new road design guide has been made possible by the Van-KIRAP project, funded by the Secretariat of the Pacific Regional Environment Programme (SPREP), which provides updated Climate Information Services (CIS) through the Van-KIRAP portal shown in Figure 1. The portal provides enhanced scientific data, information and knowledge of the past, present and future climate to facilitate the design of more resilient infrastructure. This road design guide draws upon the climate predictions available through the portal.

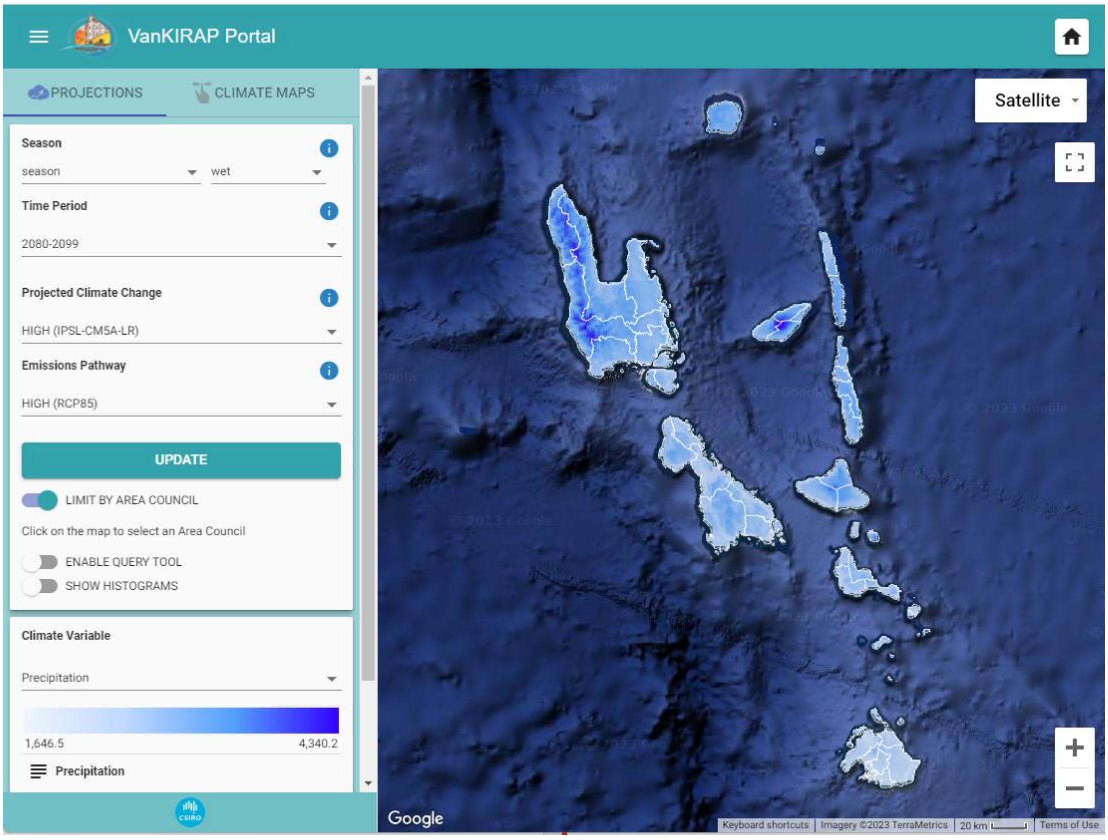


Figure 1: Screenshot of VAN-Kirap Portal

1.2 Climate Change Impacts on Roads in Vanuatu

On 20 March 2023, the Intergovernmental Panel on Climate Change (IPCC) published its AR6 Synthesis Report[1] which makes plain the urgent need to address the escalating climate crisis. As expected, the report urges governments and leaders to take urgent, deep mitigation action to reduce CO_2e emissions. However, the report also recognises the need to focus on increasing the resilience of assets and systems, often referred to in the infrastructure sector as 'adaptation'.

Vanuatu is one of the most vulnerable countries on earth to the increasing impacts of climate change, including climate related natural disasters and the effects of slow-onset events such as the sea-level rise and ocean acidification. Of particular importance to road infrastructure in Vanuatu is the impact of tropical cyclones which create significant damage to roads, usually through the action of extremely strong water currents caused by intense, prolonged rainfall. Recent anecdotal evidence shows that rainfall intensity from tropical cyclones is increasing because roads are being damaged on a scale not previously experienced. Most recent damage to road infrastructure has occurred at the intersection points between roads and water courses. Many of the changes included in this new design guide are related to the improved resilience of these critical intersection points.

1.3 Adopting a Risk-Based Approach to Climate-Resilient Design

It is important that road designers recognise that it is possible to improve the resilience of infrastructure to climate events, but it is neither practical nor affordable to fully eliminate the risk of climate-related damage and disruption. Some damage to the road network is inevitable during each tropical cyclone season. Climate risks to infrastructure can be reduced by locating assets in areas that are less exposed to climate hazards (e.g., avoiding new construction in flood plains or near the coast) and by making the assets better able to cope with climate impacts when they materialize (e.g., strengthening pavements, strengthening structures or providing scour protection).

Such an approach requires a balance to be struck between risk minimization and cost. Road designers need to select the most appropriate point on the line AB in Figure 2, with A being a low-cost, low-resilience solution and B being a high-cost, high-resilience solution. Building appropriate climate resilience into road design means that the risks have been duly considered and designs have been managed carefully to achieve an acceptable level of performance considering latest climate change predictions. The costs of strengthening or protection need to be weighed against the consequences of damage or disruption.

The risk-based approach to design outlined in this guide therefore prioritizes the resilience of critical road assets over less critical assets. This aligns with the latest Public Roads Strategy which identifies critical road assets as 'core roads'. Maps of core road networks on 23 of Vanuatu's main islands are included in the Appendix to the Public Roads Strategy.

[1] Available here: https://www.ipcc.ch/assessment-report/ar6/

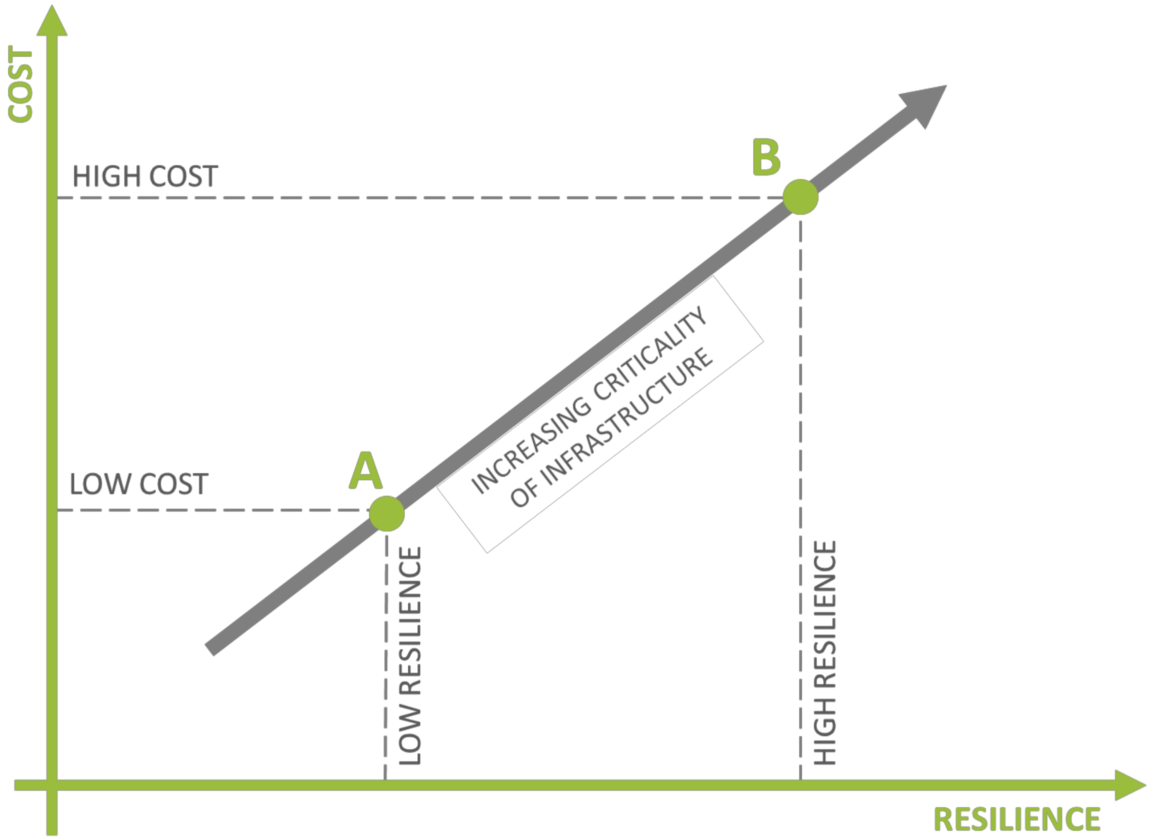


Figure 2: Cost versus Resilience of Infrastructure

1.4 The Road Design Process

All roads, whether an upgrade to an existing road, or a completely new road, should be designed by following a logical step-by-step process, with each step adding information and detail to the previous steps. The road design process and key questions to be answered by the designer at each stage are shown in Figure 3 below. The remainder of this Road Design Guide is structured to take the user through these logical design steps. The full process including all design stages should be applied to each road project design.

In the light of recent damage to roads caused by increasingly strong tropical cyclones all road designs, whether earth, gravel or sealed, must include the consideration and design of appropriate drainage. Roads designed without drainage are no longer acceptable as evidence shows that they will fail prematurely if subject to strong stormwater flows. A typical example of recent damage is shown in Figure 4.

In addition to technical design guidance, this document also includes additional sections for designers on:

- Community Consultations
- Completing Technical Documents for Tendering and Construction
- Other Actions to Increase Infrastructure Resilience.

Design Step 1: Define Road Function and Type

- Why is the road required?
- What is the economic benefit of the road – is It worth the investment?
- Is it an urban or rural road?
- Is it a core road or non-core road? Where are the optimum watercourse crossing points?
- What is the likely daily traffic flow?
- What type of vehicle will use the road?
- What are the likely developments in the area and how will they affect traffic?
- Does the road carry public transport?
- How many lanes does the road need?
- What properties does the road serve?
- What is the appropriate design speed for the road?
- Are there likely to be pedestrians and are footpaths required?
- What is an appropriate cross-section or cross-sections?
- What is the target pavement type or types as per the Public Road Stratagy?
- Are there current congestion or safety issues to be resolved?

Design Step 2: Locating the Road

- Are there alternative location options for the road – if so, what are they?
- Are there areas to be avoided – steep slopes, unstable ground, soft ground, close to the sea, inaccessible land, nearby cultural/taboo sites, etc.?
- Do local communities have a view of the selected road corridor?
- What are the advantages and disadvantages of each option – safety, connectivity, accessibility?
- What are the environmental and social impacts of each option?
- Are there particular construction challenges associated with each option?
- How does each option interface with other local roads and accesses?
- How are current and future development areas serviced by each option?
- What are the approximate costs of each option?
- What is the optimum location for the road?

Design Step 3: Alignment and Layout

- What is the design speed for alignment design?
- What is the topography along the road?
- What are the horizontal alignment constraints?
- What are the vertical alignment constraints, especially flood levels?
- If following an existing alignment, what adjustments are needed? Are sightlines restricted?
- What is the optimum horizontal layout for the road?
- What is the optimum vertical alignment for the road?
- Are the horizontal and vertical alignments well coordinated.
- Can we achieve a practical cut/fill balance?
- What is the superelevation design for the road?
- Where are junctions to be located?
- What are the safest junction layouts?
- Where are the optimum watercourse crossing points?
- Are there safety considerations which affect the alignment?
- Will future developments affect the alignment?

Design Step 4: Drainage and Slopes

- After completion of earthworks, what will be the drainage flow paths?
- Is there known flooding in the area?
- What are the various drainage design elements required along the road, crossing the road and needed to protect slopes?
- What are the catchment areas contributing to storm flows?
- What is the appropriate Average Recurrence Interval for each drainage element?
- What is the design year for each drainage element?
- What is the design rainfall intensity?
- How much water will flow during an extreme event at each location/element in the design year?
- What are the slopes required for cuts and embankments?
- What additional drainage and slope protection measures are needed for resilience of slopes?
- What size is each drainage element?
- What are the predicted water velocities, and do we need scour protection?
- Do we need slope protection?
- Are there land areas where we should not dispose of run-off water?

Design Step 5: Structures

- What form of structure is most economic/appropriate at each location?
- What is the design code?
- What size does the structure need to be?
- What local materials/capacity is available at each location?
- What are the ground conditions and bearing capacity at each structure location?
- Is the structure subject to scour?
- What are the details for each structure – foundations, structural elements, finishes, etc. ?
- Can I use the standard drawings or are additional drawings required?
- For bespoke designs, which design code should be followed?
- How can we improve climate resilience?

Design Step 6: Pavement

- What is the target pavement for this type?
- What materials are available and are the haul distances realistic/achievable?
- What workforce/equipment is available?
- What are the subgrade conditions and strength?
- Are there issues with wet ground or local flooding?
- What is the predicted traffic loading (Equivalent Standard Axles, ESAs)?
- What is the design life?
- What are the pavement construction layers?
- How do the pavement layers drain effectively?
- Is the selected pavement compatible with topography, climate resilience?

Design Step 7: Road Safety Features

- What are the safety hazards along the completed road for vehicles and pedestrians?
- Did the local communities raise any specific safety concerns?
- Is there any history of local road safety issues?
- What safety features can be added to the road to improve safety – barriers, signs, markings, etc.?
- How do we allow for universal access (disabled, etc.)
- Are there many pedestrian and crossing points? How are they dealt with?
- Are any local speed limits required to improve safety?
- What traffic calming measures should be installed to reduce speeds at safety-critical locations?
- What detailed design guide should be used for signs and markings?

Figure 3: The Road Design Process - A Step by Step Approach

Figure 4: Typical Roadside Damage to Road Section without Drainage (Vanuatu, 2023)

1.5 Supporting Design Guides - Austroads

Austroads is the collective of the Australian and New Zealand transport agencies, representing all levels of government. It is funded by both the Australian and New Zealand governments. The guides published by Austroads[2] inform the design, construction, maintenance and operation of the road network across both Australia and New Zealand. Austroads aims to provide high-quality, practical and impartial advice, information, tools and services to help its members deliver efficient, reliable and safe roads, with a focus on making transport infrastructure sustainable and future-proof. The various Austroads Guides are:

- Guide to Asset Management
- Guide to Bridge Technology
- Guide to Pavement Technology
- Guide to Project Delivery
- Guide to Road Design
- Guide to Road Safety
- Guide to Road Tunnels
- Guide to Traffic Management, and
- Guide to Temporary Traffic Management
- Cycling Aspects of Austroads Guides
- Guidelines for Environmental Reporting
- Austroads Design Vehicles and Turning Path Templates

[2] Available at: https://austroads.com.au/about-austroads/austroads-guides

- Bituminous Materials Sealing Safety Guide

The Austroads Guide to Road Design[3] provides road designers with a framework that promotes efficiency and safety in design and construction. The guide moves away from rigid design limits as the basis for achieving these goals and promotes the concept of 'context-sensitive design'. The intention is to allow designers the flexibility to exercise their critical, engineering judgement, for example, by choosing design values outside of normally accepted limits when prevailing constraints require, provided they recognise their responsibility to be able to produce strong, defensible evidence in support of their engineering judgement. There are many situations in Vanuatu, where similar context-sensitive approaches to design may be required.

The Road Design Guide comprises the following parts:

- Part 1: Objectives of Road Design
- Part 2: Network Wide Design
- Part 3: Geometric Design
- Part 4: Intersections and Crossings - General
- Part 4A: Unsignalised and Signalised Intersections
- Part 4B: Roundabouts
- Part 4C: Interchanges
- Part 5: Drainage – General and Hydrology Considerations
- Part 5A: Drainage – Road Surface, Networks, Basins and Subsurface
- Part 5B: Drainage – Open Channels, Culverts and Floodway Crossings
- Part 6: Roadside Design, Safety and Barriers
- Part 6A: Paths for Walking and Cycling
- Part 6B: Roadside Environment
- Part 7: New and Emerging Treatments

Road designers in Vanuatu are encouraged to refer to the Austroads Guides as a source of additional detailed design information where this is required to supplement this design guide.

[3] Available here: https://austroads.com.au/safety-and-design/road-design/guide-to-road-design

2. Road Function, Cross-Section and Design Speed

2.1 Understanding the Need for the Road Project

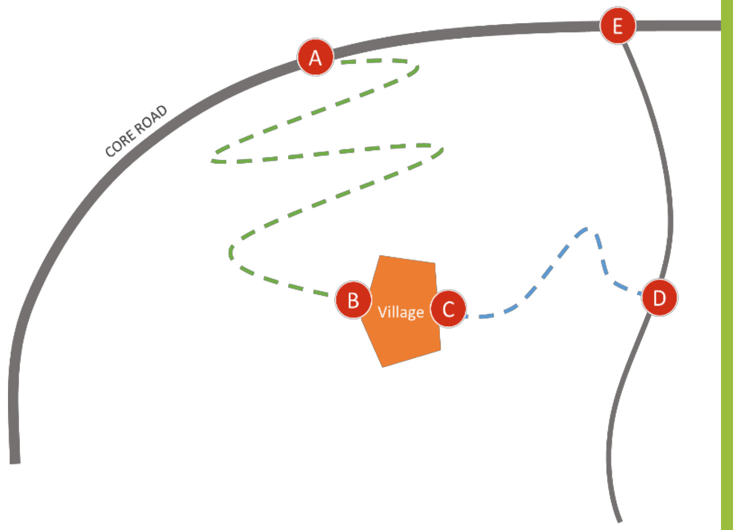
Before commencing the design of an upgraded or new road project, it is important to establish the purpose of the project by answering basic questions about the proposed project. Designers should seek to minimise the cost and the material resources expended on road projects so that road budgets are not unnecessarily wasted and embodied project carbon[4] is minimised. The designer should ask and obtain answers to important questions including:

- What is the stated need for the project?
- Is this project really required or could the need be met more efficiently in some other way? (See the example in Box 1)
- If the project is necessary, what are its key objectives:
    - providing a reliable economic link?
    - providing all-weather access?
    - improving road safety?
    - relieving local traffic congestion?
    - improving climate resilience?
    - or a combination of the above?

Box 1 : Project Options

A new road is proposed as a connector from a Core Road to a remote village along route AB.

However, an alternative route which provides the same connectivity could be created by constructing alternative route CD and upgrading local road DE.



Road designers should assess which option provides the optimum solution when considering the balance of costs, impacts and benefits. Such early options analyses should be documented.

[4] Embodied carbon means all the CO_2 (or equivalent greenhouse gases) emitted in extracting, producing, transporting, processing and placing construction materials. The embodied carbon in a road project will therefore include all the emissions from the production and transport of the construction materials and the emissions from the construction process. The CO_2 produced for the manufacture of structural concrete (using 14% cement) is around 410 kg/m^3. The cement sector is the third-largest industrial energy consumer in the world, responsible for 7% of industrial energy use, and the second industrial emitter of carbon dioxide, with about 7% of global emissions. Road designers therefore have a duty to minimise the use of concrete.

2.2 Core Roads and Non-Core Roads

The Government of Vanuatu's highest priority is the sealing and upgrading of those roads which contribute the most to national and local economies. This is reflected in Priority 1 of Vanuatu's Public Roads Policy and supporting Public Roads Strategy[5]:

"building a sustainable and efficient core road network".

The volume and type of traffic on island 'core' roads differs according to the island's economy and population. To ensure equity, the Strategy guarantees that every island with a public road network has at least one designated 'core' road. Maps of core road networks on 23 of Vanuatu's main islands are included in the Appendix to the Public Roads Strategy. Core road designations will be reassessed by the Public Works Department every two years.

Core roads include all urban and township roads and the most economically important rural roads. Throughout the remainder of this design guide, where appropriate, different design rules will be applied to core roads and non-core roads to reflect their differing economic status and to prioritise the integrity of the core road network in line with the Public Roads Policy and Strategy. The Public Roads Policy requires that all core roads are designed to be all-weather passable. This will require all core roads to be sealed, and may require replacing drifts with box culverts, upsizing some culverts and drains, constructing bridges over larger watercourses, and improving road alignments.

2.3 Setting the Road Cross-Section

2.3.1 Core Road Cross-Section

The starting point for any road design is to establish an appropriate road cross-section. Table 1 sets out the design parameters for establishment of the basic road carriageway cross-section, selecting the appropriate pavement type and determining whether shoulders should be replaced by footpaths to accommodate pedestrians. Both sides of all core roads will have either a shoulder or a footpath. The pavement types given in Table 1 align with those required by the Public Roads Strategy.

Table 1 also suggests target design speeds for core roads based upon traffic volumes and whether the road is in an urban/township or rural setting. Urban/township roads in Vanuatu do not need to be designed for high-speed vehicles, so a standard 30 km/h target design speed has been set. Target design speeds for rural core roads vary between 60 km/h for high traffic routes to 40 km/h for low traffic routes. The target design speed will be used as an input to alignment design in Section 4. An example of a cross-section derived from Table 1 is provided in Box 2.

2.3.2 Non-Core Road Cross-Section

Table 2 below provides a similar cross-section design table for rural non-core roads. Non-core roads shall not have footpaths but do require additional shoulder width if pedestrians are present. Preferred pavement types are provided in Table 2, but these are subject to local soil conditions and availability of gravel for each project location. More design guidance on rural road pavements is provided in Section 7. An example of a cross-section derived from Table 2 is provided in Box 3. Target design speeds for rural non-core roads vary between 50 km/h for high traffic routes to 20 km/h for low traffic routes.

[5] The Public Roads Strategy was formally approved and adopted by the Council of Ministers in August 2023.

Table 1: Core Roads - Cross Section Design

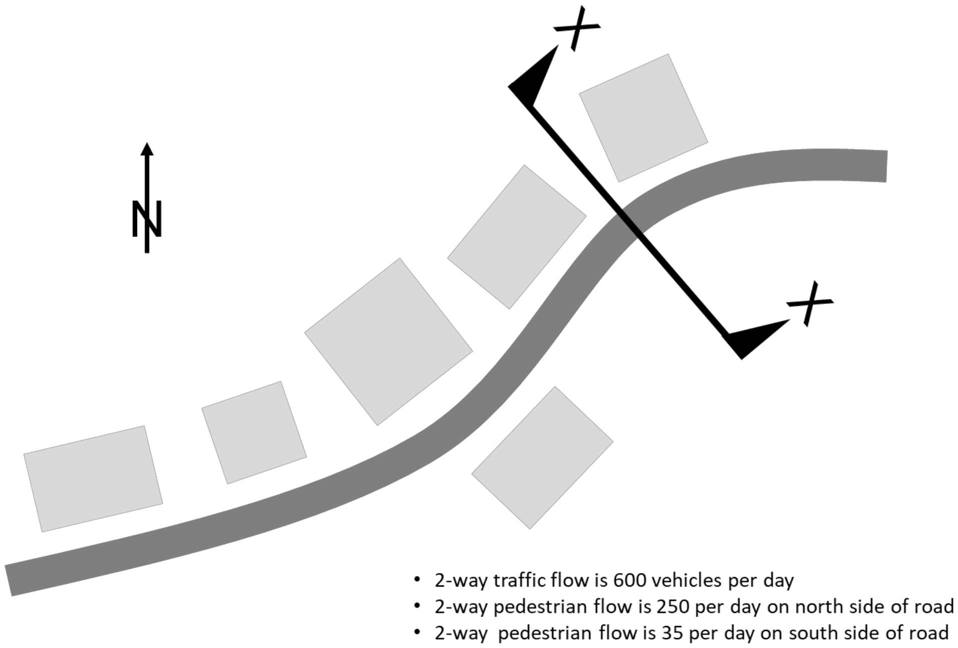
	Urban Roads in Port Vila, Luganville and Lenakel				**Township Roads** in Sola, Saratamata, Lakatoro, Craig Cove, Dillon's Bay, etc.			**Rural Core Roads**		
Sizing Carriageway and Shoulders										
2-way Average Daily Traffic	>1000	500-1000	200-500	<200	>500	200-500	<200	>500	200-500	<200
No. of Lanes	2	2	2	1	2	2	1	2	2	1
Lane Width (m)	3.0	2.5	2.5	4.0	2.5	2.5	4.0	2.5	2.5	4.0
Shoulder Width if no footpath (m)	1.0	1.0	1.0	0.5	1.0	1.0	0.5	1.0	1.0	0.5
Target Design Speed (km/h)	30	30	30	30	30	30	30	60	50	40
Selecting Pavement Type										
Surface Treatment Sealed/Unsealed	Sealed				Sealed			Sealed		
Pavement Type - with underground utilities	AC	AC	Bit. Seal	Bit. Seal	Bit. Seal	Bit. Seal	Bit. Seal	n/a	n/a	n/a
Pavement Type - without underground utilities - flat and rolling	AC	AC	FRC	FRC	FRC	FRC	FRC	Bit. Seal	Bit. Seal	Bit. Seal
Pavement Type - without underground utilities - steep grades > 10%	FRC	FRC	FRC	FRC	FRC	FRC	FRC	FRC	FRC	FRC
Footpaths (consider each side of the road separately)										
If regular pedestrian access to properties is required or >200 pedestrians/weekday	1.5m (min) footpath			1.0m (min) f/path	no footpath, shared carriageway			no footpath, shared carriageway		
If 50-200 pedestrians/weekday	1.0m footpath			no f/path, shared c/way	no footpath, shared carriageway			no footpath, shared carriageway		
If <50 pedestrians/day	no footpath, shared carriageway				no footpath, shared carriageway			no footpath, shared carriageway		

Notes:

1. AC – asphaltic concrete, Bit. Seal – bituminous seal such as DBST, FRC = fibre-reinforced concrete.
2. Both sides of all core roads shall have a shoulder unless replaced by a footpath.
3. The assessment of whether a footpath is required for urban roads shall be based upon consideration of pedestrian movements on each side of the road separately.

Box 2 : Core Road Cross-Section Design Example

An urban road in a flat area carries traffic and pedestrian flows as shown.



Using Table 1, cross-section elements can be derived as:

- 2 lanes of 2.5m width each
- Shoulder width 1.0m (south side only)
- Design speed 30 km/h
- Asphaltic concrete pavement
- Footpath width 1.5m (north side only)

The resulting cross-section X-X is:

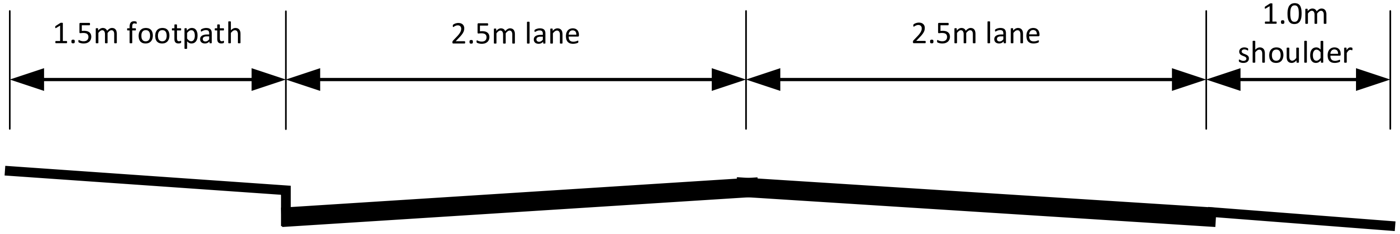


Table 2: Non-Core Roads - Cross Section Design

	Rural Non-Core Roads			
Sizing Carriageway and Shoulders				
2-way Average Daily Traffic	>500	200-500	50-200	<50
No. of Lanes	2	2	1	1
Lane Width (m)	2.5	2.5	3.0	2.5
Shoulder Width if no pedestrians	0.5	0.5	0.5	0 with passing bays
Target Design Speed (km/h)	50	40	30	20
Selecting Pavement Type				
Surface Treatment Sealed/Unsealed	Unsealed			
Preferred Pavement Type - flat and rolling	gravel	gravel	earth	earth
Pavement Type - steep grades > 10%	FRC	FRC	FRC	FRC
Additional Shoulder Widths for Pedestrians				
>200 2-way pedestrians/weekday	Additional shoulder width of 0.5m both sides			
If 50-200 2-way pedestrians/weekday	Additional shoulder width of 0.5m both sides		Additional shoulder width of 0.5m one side	
If <50 2-way pedestrians/day	No additional width			

Notes:

1. FRC = fibre-reinforced concrete.
2. To protect lane edges against storm damage, to facilitate vehicle passing and to allow a safe space for pedestrians, all roads carrying more than 50 vehicles per day shall be provided with a shoulder.

Box 3 : Non-Core Road Cross-Section Design Example

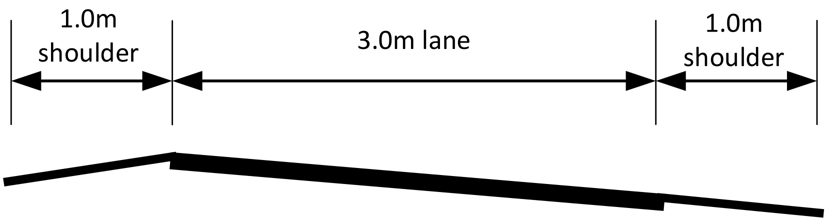
A rural non-core road in a flat area carries traffic and pedestrian flows as shown.

Using Table 2, cross-section elements can be derived as:

- 1 lane of 3.0m width
- Shoulder width 1.0m both sides
- Design speed 30 km/h
- Earth road (preferred if soils are suitable)

- 2-way traffic flow is 150 vehicles per day
- 2-way pedestrian flow is 220 per day

The resulting cross-section is:



3. Selection of Optimum Road Corridor

3.1 Introduction

All road designs should be subject to a road corridor assessment to ensure the most optimum route for the new or upgraded road has been selected in terms of its resilience to climate events. This process should be undertaken for all road design projects, regardless of whether they are the upgrade of an existing road or the creation of a new road corridor. It should not be assumed that all existing roads are located in the most appropriate location in terms of minimising the risk of damage from climate events.

3.2 Constraints Mapping

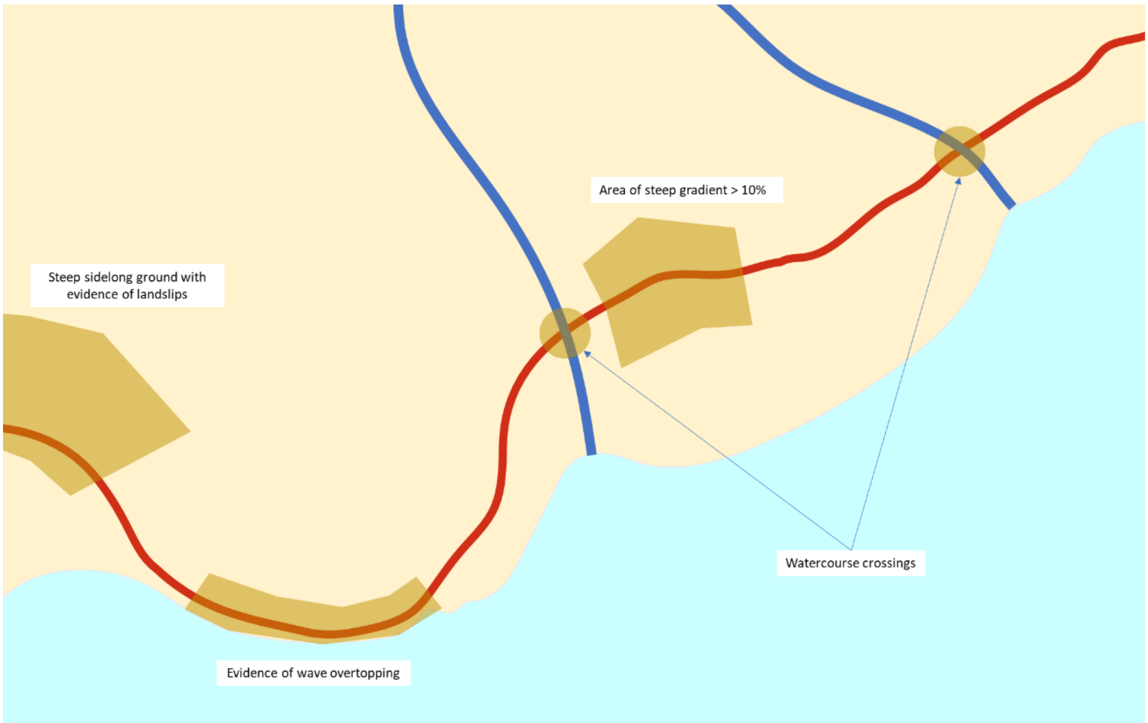
A detailed assessment of the area around a road project should be undertaken with the results recorded on a vulnerability constraints map. This assessment should include a review of available information including, as available, topographical maps, satellite images, topographical surveys and LIDAR surveys. Where the designer does not have sufficient information to undertake an adequate assessment, consideration should be given to undertaking appropriate surveys to supplement existing information. A site visit should always be undertaken to gather additional photographic evidence and to discuss conditions with local residents. The hazard zones listed in Table 3 below should be identified and mapped as shown in the Box 4 example.

Table 3: Vulnerability Zoning

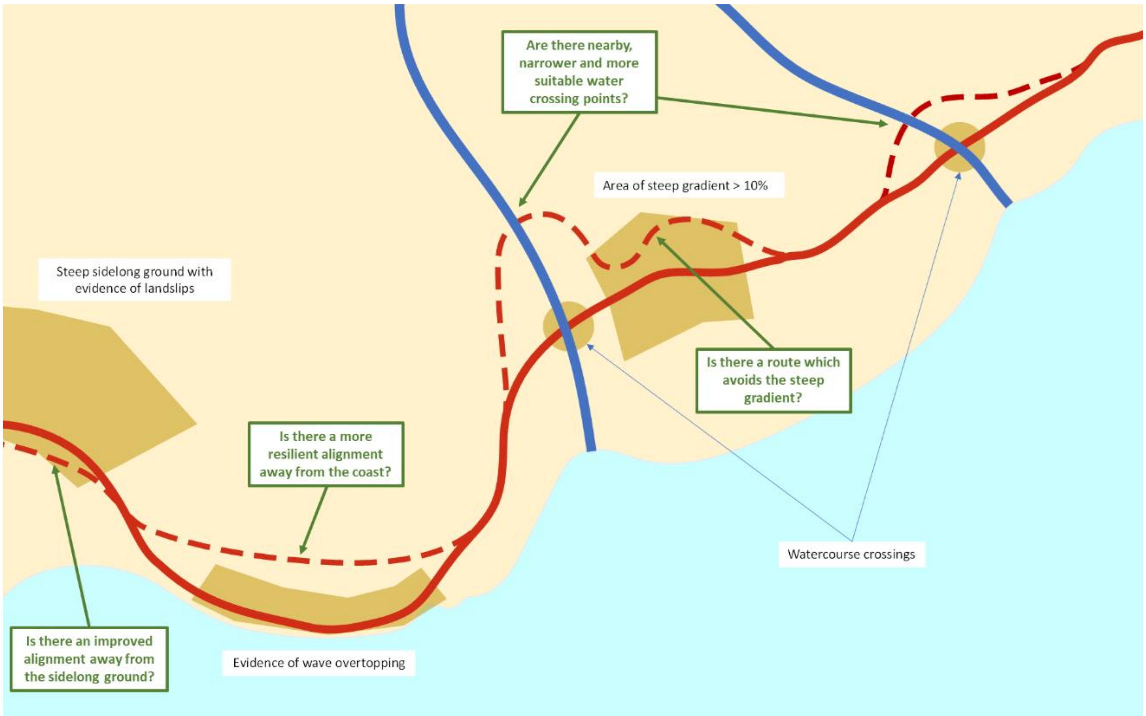
Hazard Zones	Vulnerabilities and Risks	Possible Evidence Sources
Coastal Roads	• Areas of potential wave overtopping	• Local resident and road user interviews • Road damage from sea overtopping • Proximity of sea waves to road carriageway
	• Areas of sea advance and coastal erosion	• Local resident and road user interviews • Trees or stumps in the sea • Other land features in the sea
Hills and Slopes	• Steep road alignments (>10%)	• Topographic/LIDAR surveys and maps • Site visits
	• Sidelong ground (>25%)	• Topographic/LIDAR surveys and maps • Landslips or potentially unstable slopes • Site visits
Flood Plains	• Flat areas prone to flooding, especially if takes a long time to drain/dry out after rainfall	• Local resident and road user interviews • Topographic/LIDAR surveys and maps • Site visits
Watercourses	• Larger watercourse crossings, especially those causing damage to roads or potentially able to cause damage to roads	• Existing road damage from storm action • Local resident and road user interviews

Box 4 : Example of Vulnerability Constraints Mapping

Step 1: From an assessment of available mapping, satellite images and interviews with locals along the proposed road corridor, the following vulnerable zones were identified:



Step 2: Alternative alignments or asset strengthening should be further explored at each identified vulnerable zone.



3.3 Mitigation for Vulnerability Hazards

Table 4 lists the tools available to road designers to increase the resilience of infrastructure at each identified hazard zone. If a vulnerability is identified, designers must take some measures to increase resilience. Realignment away from the vulnerable zone is the most effective mitigation but it is not possible in all situations.

Table 4: Mitigation Measures to Increase Resilience

Hazard Zones	Vulnerabilities and Risks	Possible Mitigation Measures
Coastal Roads	• Areas of potential wave overtopping	• Realign the road inshore. Preferably realign the road well away from the sea rather than making a minor local realignment. • Raise the road height well above the predicted wave overtopping height. • Provide beach protection by placing boulders, wire mesh gabions or textile mesh gabions to form a seawall on the coastal side of road. Provide a concrete seawall for critical infrastructure if funds allow. • Ensure cross-drainage culverts are provided to allow overtopped or trapped water to flow from landside to seaside.
	• Areas of sea advance and coastal erosion	• Realign the road inshore. Preferably realign the road well away from the sea rather than making a minor local realignment. • Provide beach protection by placing boulders, wire mesh gabions or textile mesh gabions to form a seawall on the coastal side of road. Provide a concrete seawall for critical infrastructure if funds allow.
Hills and Slopes	• Steep road alignments (>10%)	• Explore alternative alignments which keep the road gradient as low as possible, preferably below 10% (1 in 10). • If gradients are greater than 10%, construct the carriageway as fibre-reinforced concrete.
	• Sidelong ground (>25%)	• Explore the realignment of the road away from steep sidelong ground. • If vulnerable slopes cannot be avoided explore options for slope stabilisation by reshaping slopes, improving drainage and using strengthening such as walls or gabions (see Fig 5 example)
Flood Plains	• Flat areas prone to flooding, especially if it takes a long time to drain/dry out after rainfall	• Realign the road away from the low-lying area. • Increase the height of the road on a protected embankment so that the road pavement layers sit above highest expected flood water level with cross-drainage culverts provided through the embankment at regular intervals.
Watercourses	• Larger watercourse crossings, especially those causing damage to roads or potentially able to cause damage to roads	• Usually watercourse crossing cannot be avoided, but an assessment should be made of nearby alternative crossing points considering issues such as width of crossing, depth of channel, approach alignments, geotechnical conditions for foundations, etc.

Figure 5: Gabions used to Stabilise Unstable Slope Base

4. Road Layout – Alignments and Junctions

4.1 The Importance of Alignment Design

Designing an appropriate road alignment is an essential part of the road design process to increase resilience of infrastructure assets. This is because alignment design defines how the road structure, consisting of embankments, cuttings and pavement layers, interfaces with the drainage network, watercourses, low-lying areas subject to flooding, and in the case of coastal roads, how the road is positioned in relation to the adjacent sea and its exposure to wave action. No road should therefore be constructed without detailed consideration of the road alignment and preparation of detailed road alignment design drawings. Alignment design also plays a key role in improving road safety.

4.2 Topographical Surveys and Site Data Collection

Road alignment designs cannot be undertaken effectively without first undertaking a topographical survey which records ground levels and other natural and man-made features within the vicinity of the road. This is an essential step in the alignment design process and will greatly improve sustainable outcomes for each road project. Investment in high-quality surveys is a good investment. In practical terms the need for good quality surveys and detailed design drawings generally requires road projects to be designed well in advance of planned construction[6].

With support from the Van-KIRAP project[7], the Public Works Department (PWD) has recently attained drone capability for undertaking topographic surveys. The DJI Matrice 300 RTK Drone has the capability to collect LiDAR[8] data, in addition to the capture of high-definition images and videos. Post-processing allows the creation of geo-referenced orthomosaics and digital elevation models (DEMs). Designers should make best use of drone technology wherever possible, but if unavailable should undertake topographical surveys using traditional methods.

It is suggested that surveys for road upgrades (i.e., where the horizontal alignment of the existing road is unlikely to change) should cover a survey corridor width of around 40m and for new roads, where only an approximate corridor alignment is known, surveys should cover around 80m width as shown in Figure 6. In some cases, where a number of alternative alignment options are still being explored, the survey area will need to be increased to cover the full study area.

Topographical surveys should record the following information:

[6] This will usually require surveys and design need to be budgeted and undertaken in the year(s) prior to the year of construction. Surveys, design and construction should not be attempted in a single financial year, except for very small projects.

[7] Van-KIRAP is improving climate information services and making them more accessible for the people of Vanuatu. The Project supports Vanuatu's resilient development by increasing the ability of decision-makers, communities and individuals to plan for and respond to the impacts of climate variability and change, using these improved climate information services (CIS).

[8] LiDAR is Airborne Light Detection and Ranging. It is an optical remote sensing technology that provides extremely accurate, high resolution elevation data. LiDAR is commonly used to make high-resolution maps with applications in surveying, atmospheric science, climate information services, geography, and aerial climate and disaster assessments.

- ground levels on an appropriate grid for the type of terrain (points on a 50m grid may be suitable in flat terrain, while points on a 20m grid may be required to define an undulating or hilly surface
- existing road edges and road centre lines
- existing watercourse, tops of banks, water edges, and where possible water depths
- existing drainage channels
- buildings, walls and fences
- land boundaries
- utilities including features such as poles and manholes
- farmland and types of crops farmed
- natural forested areas
- rock outcrops
- beaches and known shoreline during high tides
- existing street furniture (guardrails, signs, etc.), and
- any other features which could constrain the alignment.

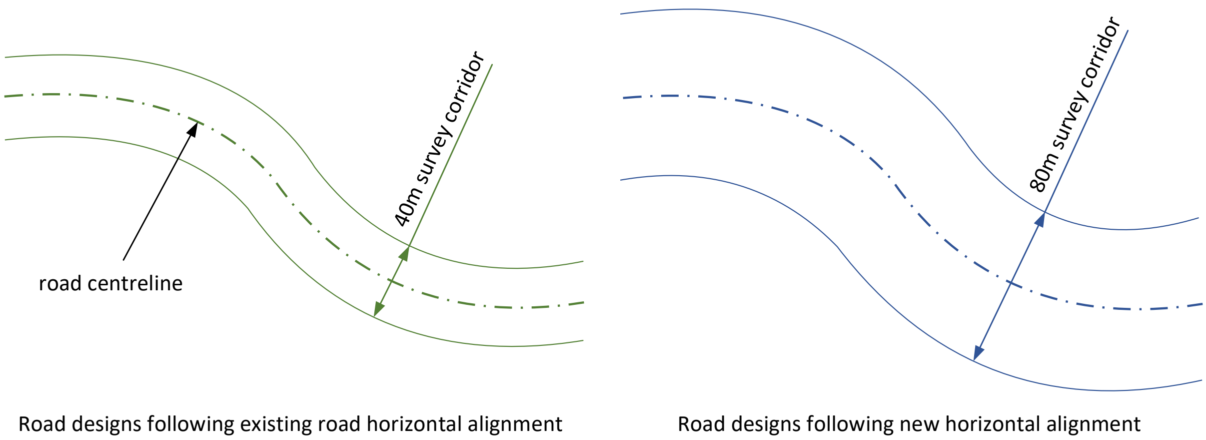


Figure 6: Suggested Survey Corridors

4.3 Design Speed Considerations

Section 2 of this guide recommends target design speeds for different types of core road and non-core road. These are summarised in Table 5 below:

Table 5: Summary of Target Speed Limits (km/h)

	All Urban and Township Roads	Rural Roads			
		2-way average traffic >500	2-way average traffic 200-500	2-way average traffic 50-200	2-way average traffic <50
CORE ROADS	30	60	50	40	40
NON-CORE ROADS	n/a	50	40	30	20

Road designers should attempt to design roads which provide these target design speeds. However, in areas of steep terrain it may be necessary to adopt a lower design speed to deal with horizontal and vertical alignment constraints within reasonable construction costs. The relaxation in design speed at the transition between a flat or gently undulating area and a hilly area should be limited to 10 km/h, but in very exceptional circumstances the change in design speed can be increased to 20km/h. Where such a change in road design speed takes place, warning signs must be placed to advise drivers to lower their speed. More guidance on treatment of speed change transitions is provided in Section 8 of this guide.

4.4 Coordination of Horizontal and Vertical Alignment

On rural roads, horizontal and vertical alignments should be coordinated for both appearance and safety. In practice, this is achieved by having horizontal and vertical curves either superimposed or completely separated. When superimposed it is recommended to contain the vertical curve completely within the horizontal curve as shown in Figure 7. This arrangement improves safety by indicating the direction of horizontal curvature before the start of the vertical crest curve so that the horizontal curve is not obscured from view.

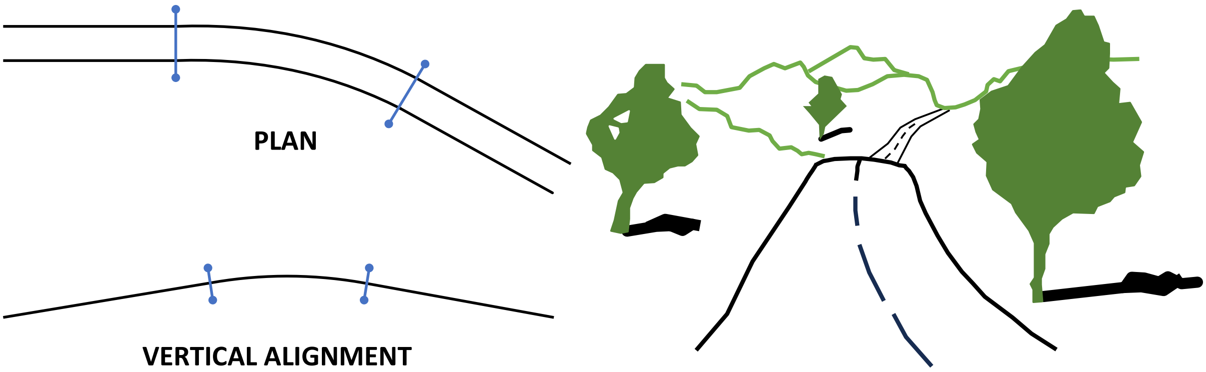


Figure 7: Good Practice - Vertical Curve within Horizontal Curve

The key rule is that crest curves should not obscure any unsighted surprises for the driver. Examples of such bad practice include:

- horizontal curves obscured by crest curves, especially sharp bends and reverse curves
- junctions obscured by crest curves
- lateral shifts in the road obscured by crest curves, and
- changes in road cross-section obscured by crest curves.

In urban and township situations it is frequently the case that such alignment coordination considerations will be very difficult or expensive to apply. Most urban and township roads are developed by widening or upgrading existing roads and are therefore usually constrained by the existing street location and access to properties. Because horizontal and vertical coordination is difficult, the design speed (and therefore the speed limit) for urban and township roads has been set to 30 km/h. Appropriate speed limit signing should be provided on all urban and township roads.

4.5 Horizontal Alignment and Superelevation

A road's horizontal alignment is made up of a series of straights and segments of circular curves[9]. The key consideration in setting an appropriate horizontal alignment for each section of road is to ensure that curves allow safe and comfortable passage of vehicles at the designated design speed. Therefore, all horizontal curve radii must be equal to or above the minimum values set out in Table 6 below[10].

Table 6: Minimum Radii of Horizontal Curves

	Design Speed (km/h)				
	60	50	40	30	20
MINIMUM HORIZONTAL RADIUS (m) at 6% SUPERELEVATION	94m	55m	35m	16m	16m

As shown in Figure 8, long horizontal curves are preferable to short curves because a short curve between two straight sections will appear as a kink near the intersection point and could be confusing to drivers. The longer curves allow a more constant speed along the road and therefore provide a safer solution than using tighter short length curves.

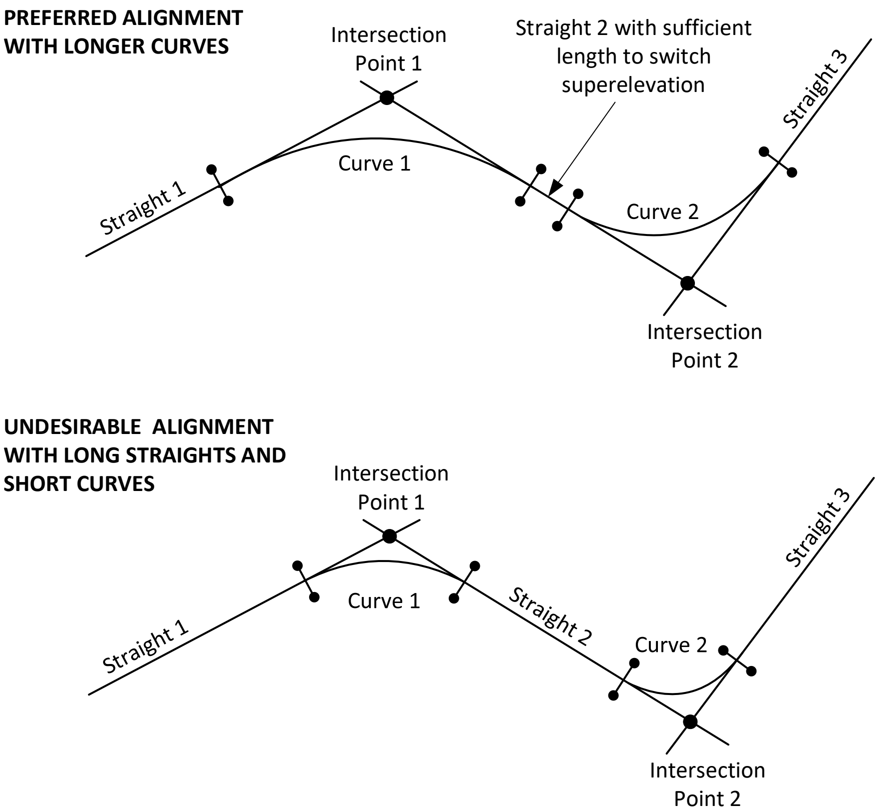


Figure 8: Horizontal Alignment Elements

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[9] Spirals (sometimes called transition curves) are not used in Vanuatu due to low design speeds.
[10] Minimum radii for 40-60 km/h are taken from Austroads Road Design Guide Part 3. With the low-speed traffic in Vanuatu a maximum 6% superelevation has been selected. A practical minimum radius of 16m based upon the UK's 'Manual for Streets' has been selected for design speeds of 30 km/h and 20 km/h.

A reverse curve is a section of road alignment consisting of two adjacent curves turning in opposite directions. Reverse curves should be avoided wherever possible. However, curves in opposite directions may be used if there is sufficient distance between the curves to introduce full superelevation of the two curves as indicated in Figure 9 below. The straight section between curves should be of a length to allow at least 5 seconds of travel at the selected design speed.

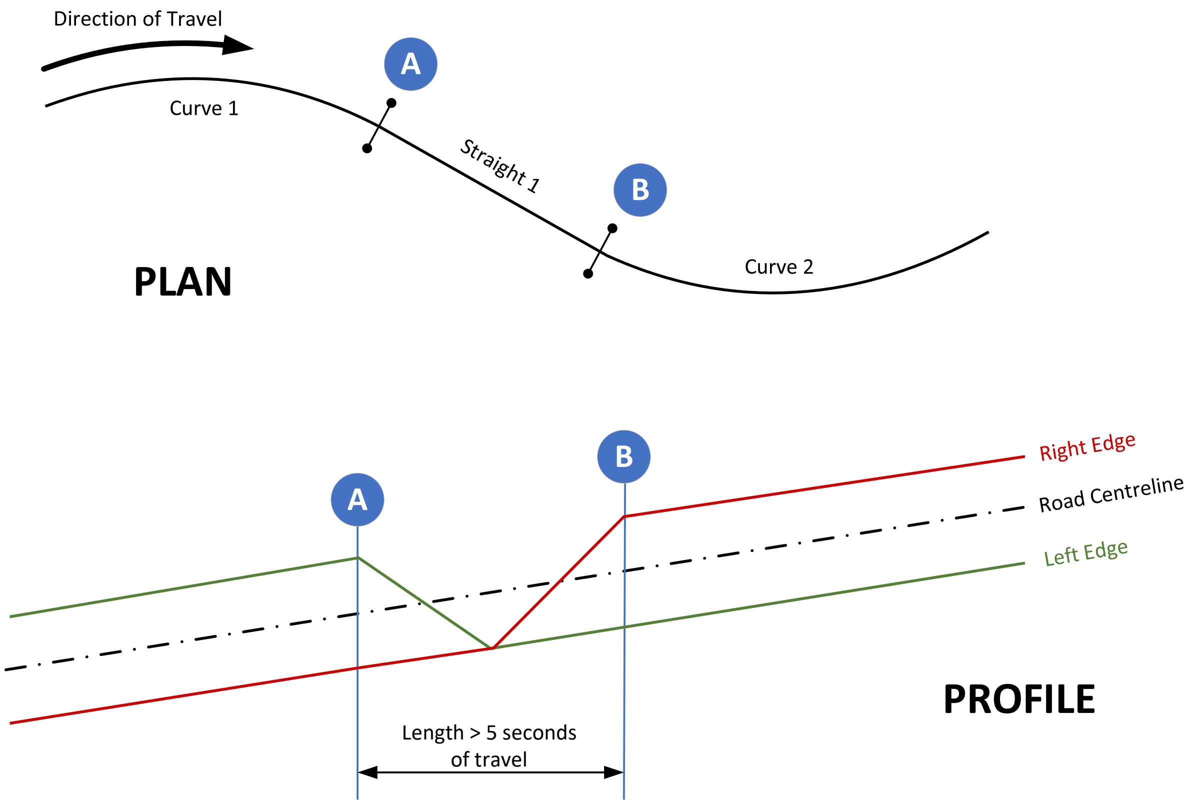


Figure 9: Superelevation Application between Curves

4.6 Vertical Alignment

Vertical alignment is the longitudinal profile along the centreline of a road. It is made up of a series of grades and vertical curves. The profile is determined by consideration of planning, access to roadside properties, topographic features, ground conditions, drainage, design constraints and earthworks. Grades are generally expressed as a percentage of the vertical component divided by the horizontal component[11].

The first step in developing a road's vertical alignment is to develop a profile of the existing ground levels along the designed horizontal alignment. Profiles are usually drawn with an exaggerated vertical scale so that ground level differences along the route can be easily identified. A suggested suitable scale for road plans and profiles in Vanuatu is 1:500 horizontal

[11] For instance, an uphill grade of 10% means that a road is rising at a rate of 1m for every 10m of horizontal travel.

and 1:50 vertical, but these can be changed by the designer to suit local conditions, topography and level of detail required.

Before designing an appropriate vertical alignment, the designer will identify all the constraints to the vertical alignment. Some suggested alignment constraints are provided in Table 7. Figure 10 shows an example ground profile marked up with alignment constraints.

Table 7: Vertical Alignment Constraints

Constraint Type	Recommended Vertical Alignment	Description and Notes
Coastal Roads	• When the road is adjacent to the sea, the vertical alignment must be at least 2m above potential highest wave height to avoid overtopping.	• Interviews with locals in the area should be used to determine the highest wave heights experienced during recent year storms. This could be expressed as a height above mean sea level or against a fixed datum which could then be surveyed.
Flood Plains	• Road vertical alignment must be at least 1m above the highest predicted flood water level.	• Interviews with locals in the area should be used to determine the highest flood levels experienced during recent years. • This might be rechecked during later drainage design and if the flood level assumption is found to be incorrect, a local adjustment to the vertical alignment should be made.
Small Watercourses in Culverts	• For small watercourses designed to pass through a culvert, the road vertical alignment should be set at least 2m above the highest expected water level.	• Interviews with locals in the area should be used to determine the highest water levels experienced during recent years. • This might be rechecked during later drainage design and if the high-water level assumption is found to be incorrect, a local adjustment to the vertical alignment should be made.
Large Watercourses at Bridges	• For large watercourses designed to pass through a bridge, the road vertical alignment should be set at least 3m above the highest expected water level.	• Interviews with locals in the area should be used to determine the highest water levels experienced during recent years. • This might be rechecked during later drainage design and if the high-water level assumption is found to be incorrect, a local adjustment to the vertical alignment should be made.
Flat or Gently Undulating Surrounding Ground	• To ensure pavement layers do not become waterlogged and are able to drain freely, the road alignment should generally be set at least 0.5m, and preferably 1m, above the surrounding ground level.	• This can be achieved in practice by reshaping the ground to bring the road pavement above the surrounding ground level by using material from side drains (as shown in Figure 11).

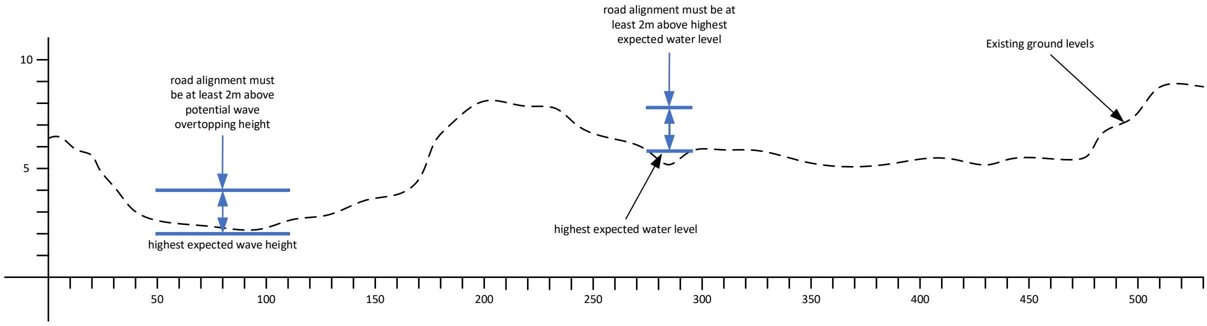


Figure 10: Example of Ground Profile with Vertical Alignment Constraints

Of particular importance in improving resilience to climate change is to adopt the good practice of reshaping the ground to bring the road pavement above the surrounding ground level by using material from side drains. This allows the subsurface pavement layers to drain thus preventing pavement softening and resulting deterioration. As well as considering subsurface pavement drainage, it is also important to ensure that every road surface is well-drained by applying a crossfall, either in one direction or both directions with a crown. It is recommended that all gravel roads are constructed with a crossfall of 6% as gravel roads tend to lose their shape over time. Sealed roads should be constructed with a crossfall of 4%. Provision of crossfall will shed water from the road surface, thus reducing the risk of standing water on the surface, pothole formation and resulting pavement deterioration. Figure 11 demonstrates the principles to be adopted in developing a climate-resilient detailed road cross-section and associated vertical alignment. Of particular importance is to design the cross-section so that subsurface water is allowed to drain freely from all pavement layers.

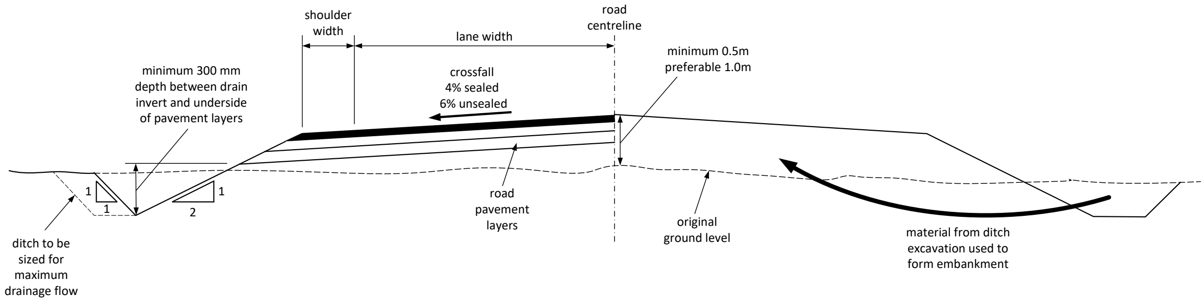


Figure 11: Synchronisation of Cross-Section and Vertical Alignment

As shown in Figure 12, in areas where the overtopping of a culvert is likely, low points in the vertical alignment should be avoided if possible and the road kept as flat as possible to avoid localised turbulent flow over the embankment. The downstream slope of the embankment over the length of potential overtopping should also be flattened to reduce water velocities and minimise erosion and undercutting.

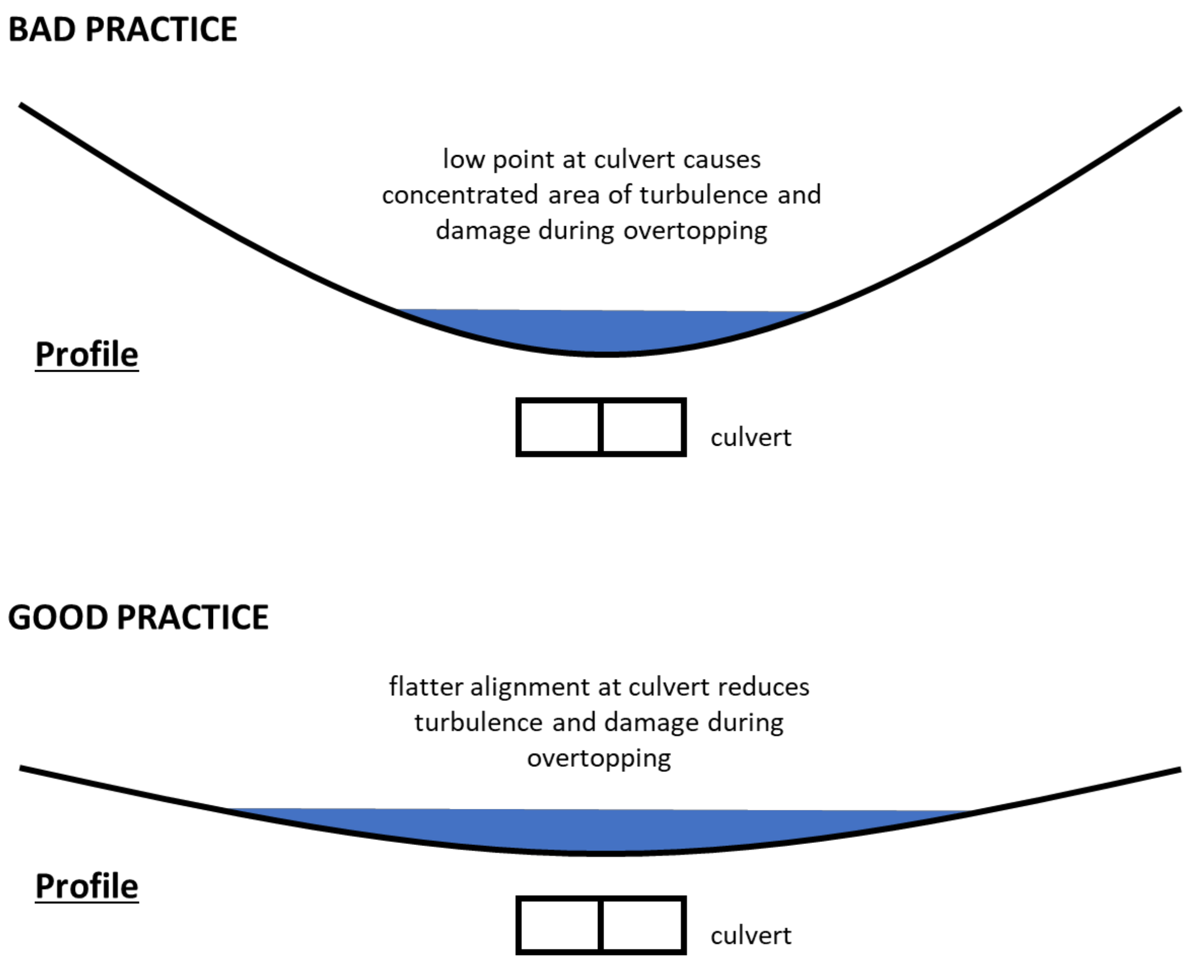


Figure 12: Preferred Vertical Alignment in Areas of Potential Overtopping

Recent evidence demonstrates that roads on steep gradients are often damaged during heavy storms due to the action of water running at high velocity along or alongside the road. Steep gradients are unavoidable in hilly terrain, but gradients and lengths of steep gradients should be limited to the values shown in Table 8. A less steep gradient over a longer distance is always preferable to a steeper gradient over a shorter distance as this reduces the risk of potential road damage caused by high-intensity rainfall.

Table 8: Maximum Vertical Gradients

	Maximum Length of Steep Grade (m)		
	600m	200m	50m
Maximum Gradient for Core Roads	10%	12%	14%
Maximum Gradient for Non-Core Roads	12%	15%	18%

The vertical alignment of a road consists of a series of straight grades joined by vertical curves. Crest vertical curves are selected to provide an appropriate stopping sight distance in relation to design speed. Sag curves are provided to provide adequate driver comfort and headlight visibility in night conditions.

As demonstrated in Figure 13, the vertical alignment should fit into the natural terrain, considering alignment constraints, earthworks balance, appearance and the maximum and minimum vertical curvature allowed (expressed as the K value). The K value, which is defined below is used because it enables vertical curves to be easily specified with a single parameter.

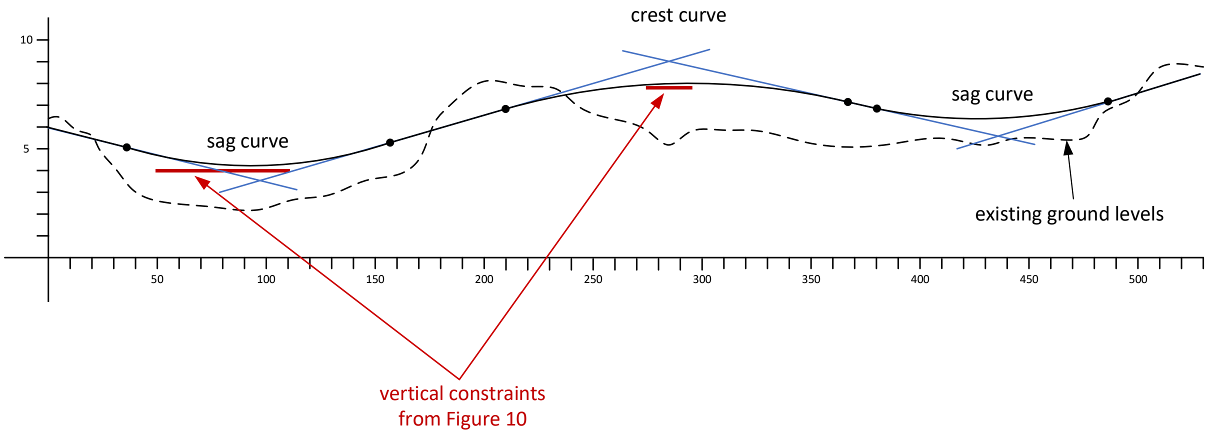


Figure 13: Developed Vertical Alignment

Long vertical curves (with high K values) are preferred to short vertical curves (with low K values) as they generally provide for an improved aesthetic, greater sight distances and a more comfortable ride.

The key features of both crest and sag curves are shown in Figure 14. The terms used to define the curve are:

$$g_1 = \textit{initial gradient (\%)}$$

$$g_2 = \textit{final gradient (\%)}$$

$$A = \textit{change in gradient (\%)}$$

$$L = \textit{length of vertical curve (m)}$$

$$x = \textit{distance to any point, P (m)}$$

$$y = \textit{vertical offset from tangent to curve (m)}$$

$$K^{12} = \textit{length of vertical curve for a 1\% change in grade (m)}$$

[12] Higher values of K signify a flatter curve and lower values signify a tighter vertical curve.

The equations used to define the curve and to calculate the value of 'y' which can be used to define the level of any point on the curve are:

$$L = KA$$

$$y = \frac{x^2}{200K}$$

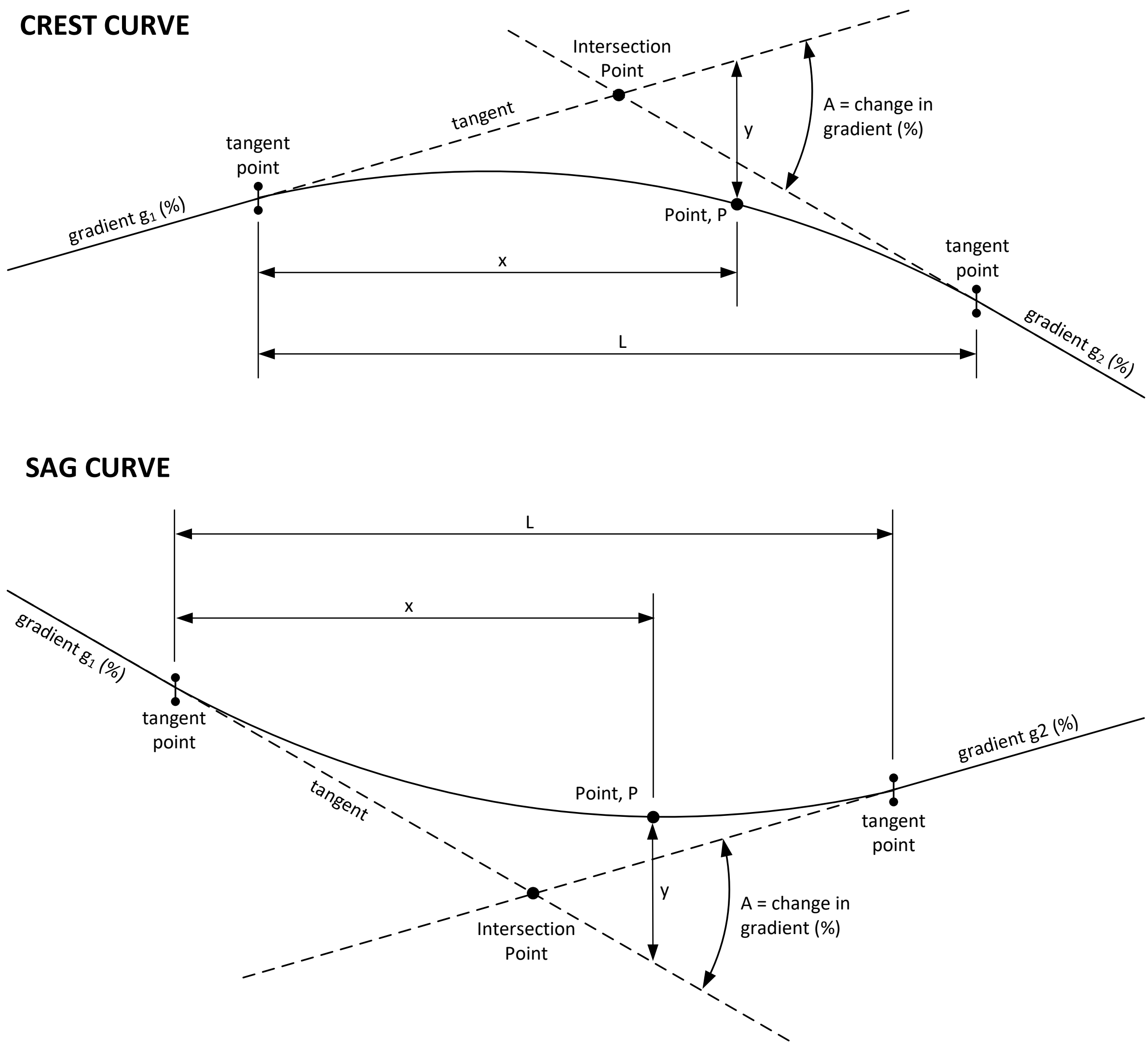


Figure 14: Crest and Sag Curve Elements

Minimum K values for different design speeds are provided in Table 9[13].

[13] derived from a review of Australian, US and UK geometric standards.

Table 9: Minimum Crest and Sag K Values

Design Speed (km/h)	Crest Curve Minimum K Value	Sag Curve Minimum K Value
20	2	3
30	3	6
40	7	9
50	11	13
60	17	18

Designers should be careful to avoid flat spots on the carriageway surface which can occur if superelevation is developed along a level section of carriageway with gradient close to zero. To avoid this, the alignment should be adjusted so that the development of superelevation occurs on a longitudinal gradient of at least 3%.

4.7 Detailed Cross-Section and Layout Development

4.7.1 Rural Roads

Rural road design shall consider the development of the various cross-sections required to create the road as the alignment interfaces with different types of terrain. Figure 15 sets out various cross-section options. Cross-section designs should generally comply with the following:

- all pavement layers should be able to drain freely in the event they become saturated
- crossfalls should be a minimum of 4% for sealed roads and 6% for unsealed roads
- drainage ditches are required in all areas where water may run alongside the road during storms
- to avoid scour, embankment side slopes should not be steeper than 2H:1V
- cut side slopes in rock should be determined based upon the stability of the cut face
- cut slopes in soils should also be determined based upon the stability of the cut face but should not be steeper than 1H:1V
- interceptor drains shall be constructed at the top of cut slopes where water flows may scour cut slope faces
- shoulders should have the same crossfall as the main carriageway
- positive piped drainage is to be used with kerbed carriageways.

To avoid any confusion during construction, design drawings must make clear which cross-section types apply to each section of road.

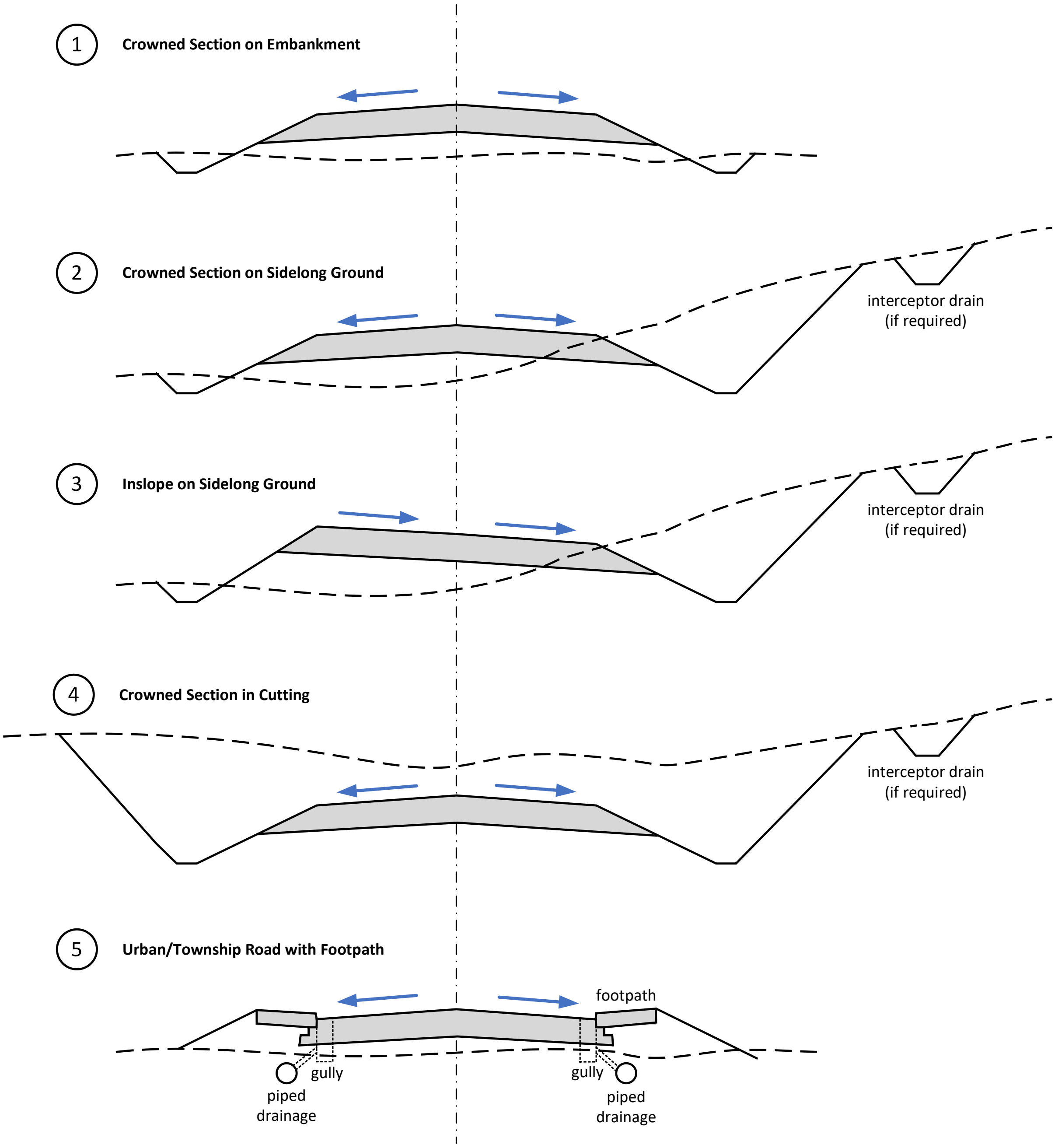


Figure 15: Cross-Section Options

4.7.2 Urban Roads

The cross-sectional design and layout of streets in urban/township areas should be designed by applying a user hierarchy to the design process with the needs of pedestrians placed first. This means considering, above all else, the desire lines for pedestrian movements when designing, constructing, upgrading or maintaining urban/township roads.

Designers should adopt a collaborative approach to the design and construction of urban/township roads as many busy streets require a 'non-standard' approach to respond to local context and this can only be achieved by working as a multidisciplinary team with other road users and infrastructure owners, which might include: local residents, local businesses, local government officers, schools, hospitals and utility authorities/companies with assets within the road corridor.

Street design principles and details are continually evolving and therefore designers are encouraged to undertake international research into latest designs of other similar contexts that may work well in Vanuatu. A key principle of good urban design is to recognise the importance of the community function of urban/township roads as spaces for social interaction. Streets should aim to integrate, not segregate, communities, businesses and facilities. Road designers should therefore look to promote an inclusive environment that recognises the needs of people of all ages and abilities, including the disabled.

On street parking is a regular feature of many urban/township roads. Where this is required, the road designer should make adequate provision for parking by adjusting the road cross section and layout to include marked parking bays. The typical arrangements shown in Figure 16 show that angled parking should be arranged to achieve parking bays of 2.4m x 4.8m and parallel parking should provide bays of 1.8m x 4.8m. Further detailed guidance is available in Austroads Guide to Road Design Part 3: Geometric Design.

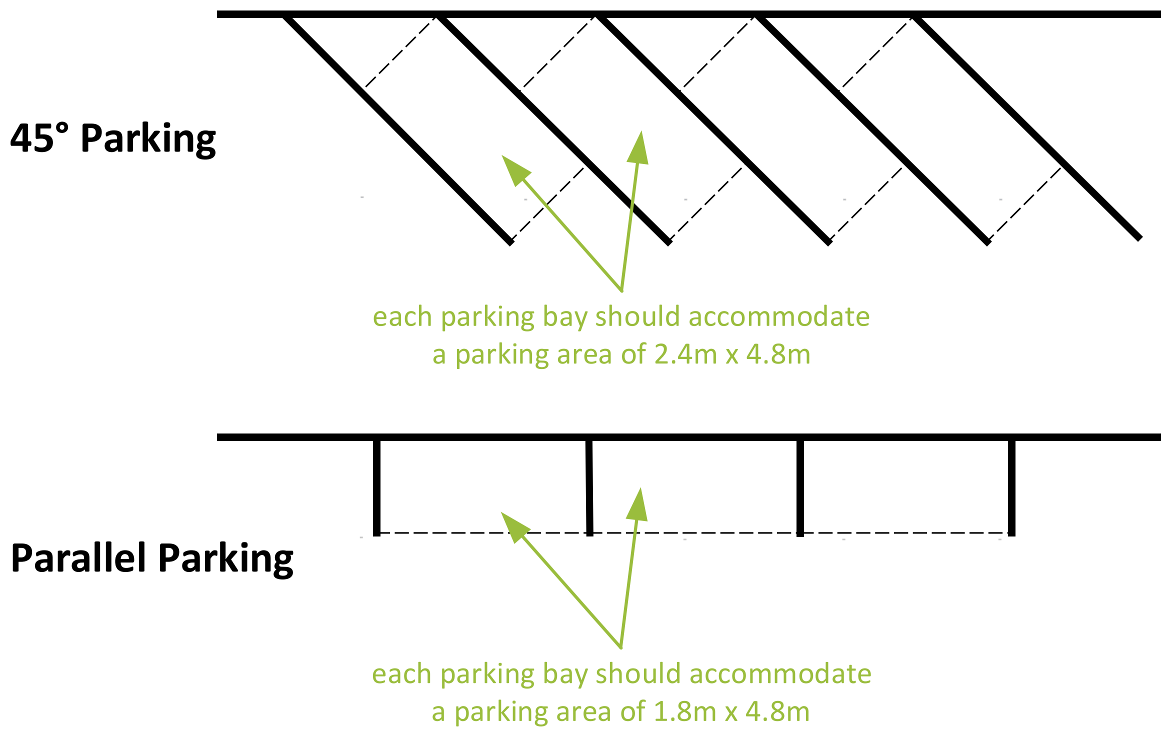


Figure 16: Parallel and Angled Parking

4.8 Junctions

4.8.1 General Requirements

This section includes general guidance for road designers in Vanuatu, mostly drawn from Austroads guidance and standards. For more detail, designers should refer to the detailed guidance which may be found in:

- Austroads Guide to Traffic Management Part 6[14], and
- Austroads Guide to Road Design Part 4: Intersections and Crossings[15].

The primary requirements for road designers in relation to junction design are:

- to consider the variety and number of road users that will travel through the intersection including heavy vehicles, buses, cars, cyclists or pedestrians
- to appreciate the characteristics and relative speeds of the various road users
- to ensure road users are not surprised by the location or layout of each junction, and
- to aid all road users, including pedestrians, in passing through the junction safely.

Achieving these requirements requires road designers to develop road junction designs by considering the design elements listed in Table 10.

Table 10: Junction Design Considerations

Road User Type	Junction Design Considerations

All Vehicles	• Adequate sight distance
	  ○ on all approaches to intersections
	  ○ from a position at stop lines or give-way lines to other potentially conflicting vehicles, including those turning
	  ○ for pedestrians crossing the road
	• Satisfactory observation angles
	• Avoid grading that will cause discomfort or require heavy braking
	• Provide for deceleration on the approach to the junction appropriate to the circumstances and design speed
	• Avoid 4-way junctions wherever possible by staggering minor roads to prevent vehicles on the minor road running across the junction
	• Avoid skewed junctions by making junction connections perpendicular or as near to perpendicular as possible

Heavy Vehicles	• Where practicable, provide a flat grade on junction legs to facilitate acceleration and deceleration of heavy vehicles • Where practicable, avoid steep downgrades on approaches to junctions • Provide sufficient lane widths and carriageway space for vehicle turning movements to occur within the designated carriageway without encroaching shoulders, islands or footpaths • Avoid excessive adverse crossfall and significant variations in crossfall along turning paths

[14] Available here: https://austroads.com.au/publications/traffic-management/agtm06/media/AGTM06-20_Part_6_Intersections_Interchanges_and_Crossings_Management.pdf

[15] Available here: https://austroads.com.au/publications/road-design/agrd04/media/AGRD04-23_Guide_to_Road_Design_Part_4_Intersections_and_Crossings_General_Ed2.2.pdf

Pedestrians	• Provide paths or shared shoulders plus designated crossing points at all urban and township junctions where pedestrians are expected • Provide adequate-width, obstruction-free footpaths along pedestrian desire lines • Ensure pedestrian routes are universally accessible with adequate ramps for wheeled access and avoidance of steps • Place road signs so that they do not obscure views between pedestrians and vehicles
Buses and Minibuses	• Location of bus stops and bus lanes at or near junctions to avoid blocking sight lines. • Adequate lanes and storage for queued buses or minibuses to avoid blocking other junction traffic • Safe pedestrian access to and from bus stops suitable for all users

Along any road corridor or urban/township zone, junctions should be treated consistently so that drivers become familiar with junction arrangements and are not surprised by non-standard layouts.

From a road safety perspective, it is recommended that designers imagine the actions of those drivers who have made an error at the junction. The selected junction layout should allow recovery action which is not hazardous to themselves or other road users.

Road designers should also consider the needs of road users in specific situations, such as junctions which provide access to hospitals or schools where there may be a need to consider a wide range of user types and volumes.

Junctions should be designed and located so that they are readily visible by all users on each approach. This principle is demonstrated in Figure 17. In the bad practice example, the junction is hidden from oncoming vehicles by the bend in the road. In the good practice example, the junction is relocated to make it visible to oncoming vehicles from both directions.

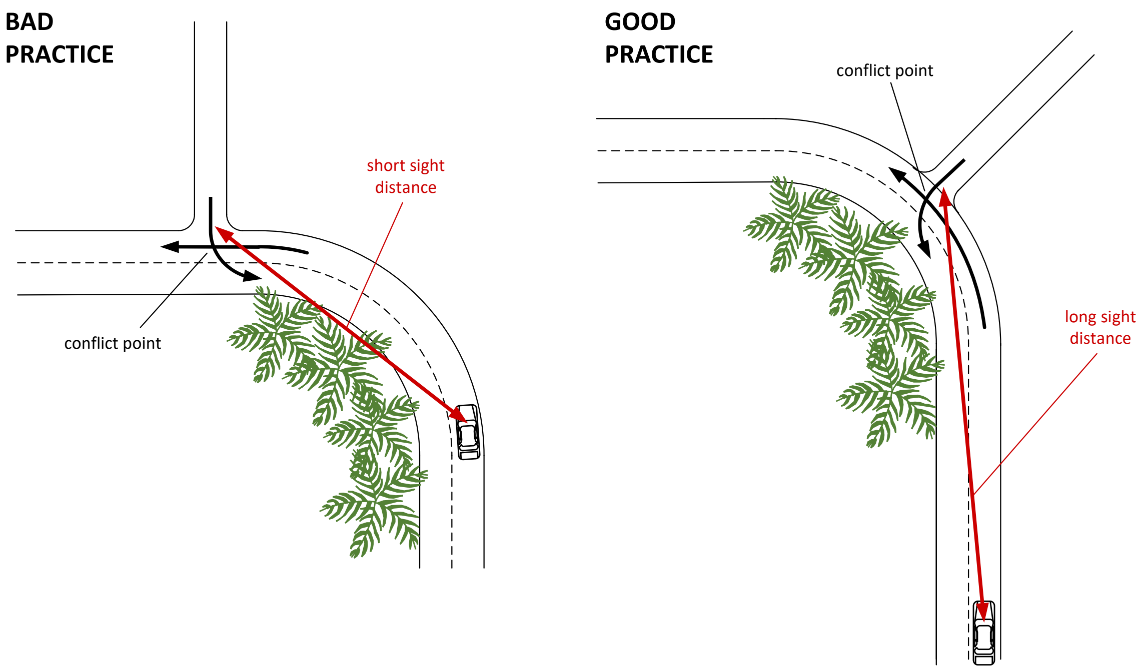


Figure 17: Junction Location Examples

4.8.2 Rural Junctions

On all rural core roads, T-junctions should be designed to provide good visibility to the junction from all directions. The junction should include an 85m length visibility splay, free of obstructions, provided from a point 5m back from the edge of the main road carriageway as shown in Figure 18.

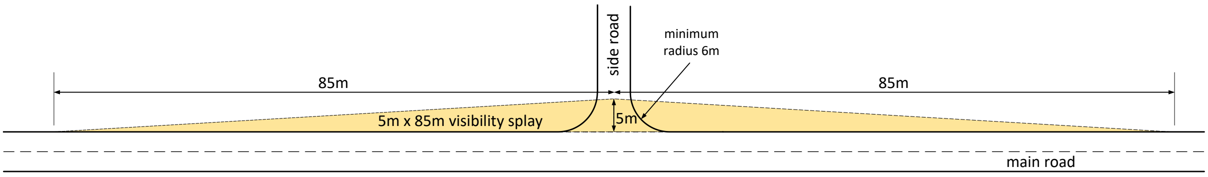


Figure 18: Features of Typical Core Road Rural Junction

On non-core roads, road designers should ideally provide the core road design wherever possible, but if impracticable the junction should include a visibility splay which is as long as possible but adjusted to suit the local conditions and geometry. Visibility splays should never be shorter than 35m.

If the approaches to a junction are unsealed, and 2-way traffic levels on the main road are in excess of 500 per day, designers should consider the sealing of junction approaches to provide a more stable surface for vehicle deceleration and acceleration. Sealing the junction approaches also enables pavement markings to be installed. This improves delineation and increases driver awareness of the junction.

4.8.3 Urban or Township Junctions

Wherever possible, road designers should attempt to provide the visibility splay and minimum corner radii described above for rural roads. However, in many urban or township situations it will not be possible to provide these because of the presence of property boundaries and other infrastructure which constrain the alignment and layout. As shown in Figure 19, if a more generous layout cannot be achieved, rural junctions should try to achieve:

- minimum corner radii of 3m, and
- a 20m length visibility splay measured 2.4m back from the side road stop line.

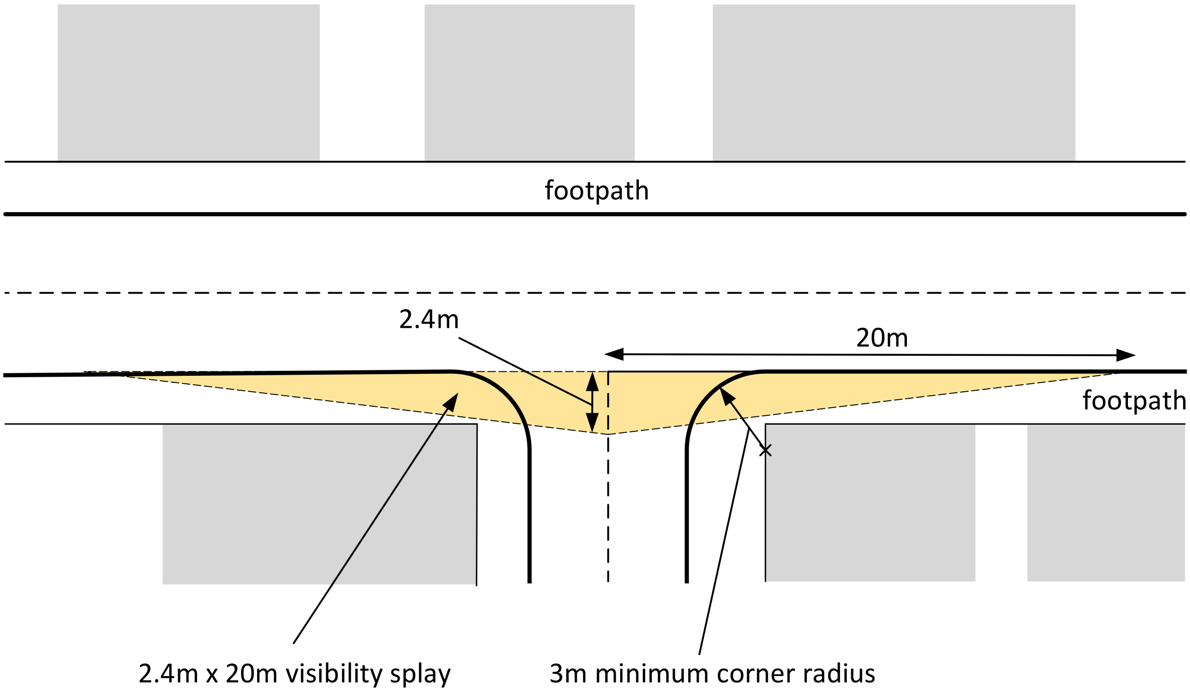


Figure 19: Minimum Layout Requirements for Urban Junctions

Of more importance in an urban/township setting is to design road junctions so that they may allow the occasional passage of larger vehicles, such as buses or trucks. Figure 20 shows typical turning circles for a standard 12.5m vehicle with a 6.8m wheelbase derived from Austroads guidance.

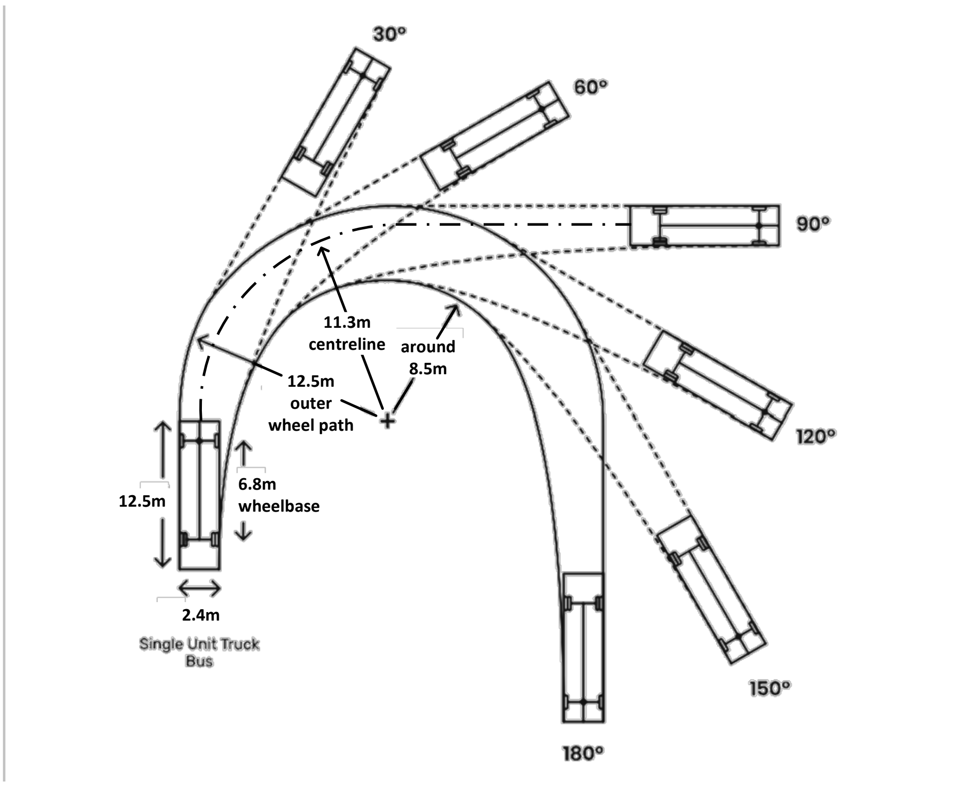


Figure 20: Typical Turning Circles for Single 12.5m Bus/Truck Unit

Turning circles for this vehicle and many other design vehicles are available from Austroads 'Design Vehicles and Turning Path Templates'[16]. For each junction, designers should consider the likely types of vehicles that may be required to use each junction and adjust the design accordingly.

A simplified method of checking whether a junction can allow the passage of a standard 12.5m single unit bus/truck is suggested in Figure 21. The road designer must apply this simplified check to all possible vehicle turning movements. The check should ensure that movements can be made within the available carriageway via a series of 12m radius curves. If this is impossible, the junction design must be adjusted accordingly. This type of check, which allows the bus/truck to encroach into opposing traffic lanes should only be used at junctions where a low number of large vehicles is expected to turn. In situations where large numbers of buses/trucks are expected, the designer should adjust the junction design so that movements are achieved without encroaching opposing traffic lanes.

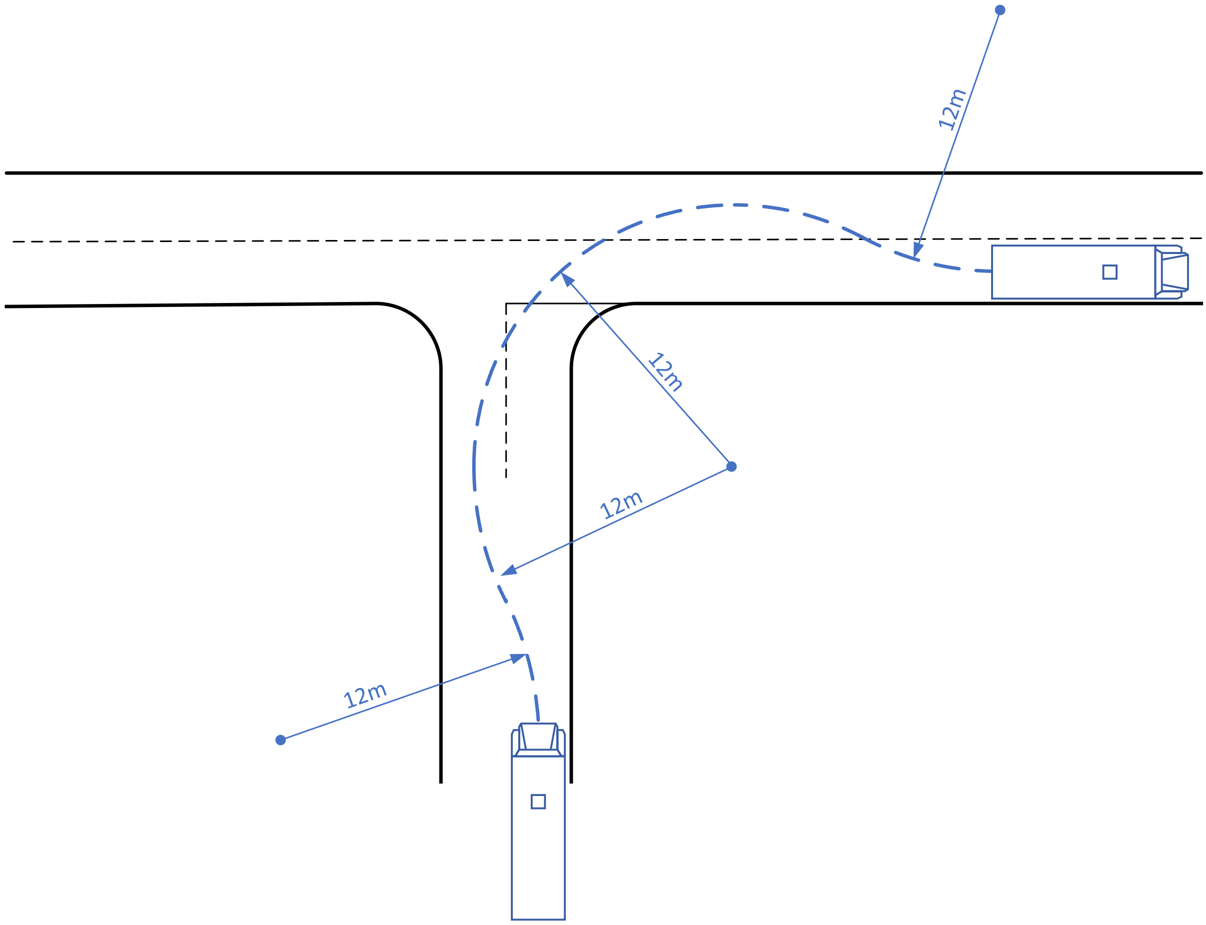


Figure 21: Example of Simplified Bus/Truck Access Check at Urban Junction

[16] May be downloaded from the link provided at: https://austroads.com.au/publications/road-design/ap-g34

5. Designing for Water - Drainage and Slope Design

5.1 Introduction

Water and traffic are the two most dominant factors affecting the performance of any road. For rural roads which carry little traffic, water is the most important consideration for designers. Every road, no matter how small, should be designed with serious consideration of drainage. As witnessed in Vanuatu in recent times, roads usually fail due to inadequacies in drainage which allow ingress of water into road pavement layers causing road surface damage, the scour and washout of supporting embankments which undermine the road structure or the erosion or collapse of slopes which spill onto the road. These failures are caused by a variety of design and maintenance failures including:

- undersized or lack of side drains and interceptor drains
- undersized or lack of drifts, culverts or bridges
- insufficient scour protection and energy dissipation features around water/road interfaces, and
- blocked or silted culverts or bridges.

With the severity of climate events continuing to increase, such failures will increase further unless approaches to design, construction and maintenance are fundamentally adjusted.

Designing roads to be resilient in the face of future climate events requires a new approach to be adopted by road designers. Traditionally, drainage design was based upon historical rainfall records, but with changing climate conditions, the road designer must now rely upon climate predictions, thus introducing significant levels of uncertainty into the design process. It is therefore important that Vanuatu monitors the performance of its road designs and that it continues to update this road design guide accordingly if further adjustments are required.

As described earlier in Section 1.3, this guide adopts a cost-effective risk-based approach to climate-resilient design, applying more stringent, but more expensive, design criteria to critical 'core road' infrastructure, but allowing a lower, more affordable standard to be adopted for non-core roads. Therefore, throughout this section, different approaches to drainage and slope design will be presented depending on whether the road is designated a core road or non-core road.

5.2 Overview of Climate Change Impacts on Rainfall Intensities

Before setting out the steps for road drainage and slope design, this sub-section introduces the implications of predicted climate change in Vanuatu so that the magnitude of expected change is understood by drainage designers. The predicted impacts are significant and will fundamentally affect the sizing of drainage ditches, culverts and bridges over watercourses.

The design of hydraulic engineering infrastructures is usually based on local intensity–duration–frequency (IDF) curves, which provide extreme rainfall intensities (mm/h) for various durations (from minutes to days) and different return periods (years). Typically, IDF curves used in road design cover rainstorm durations from 5 minutes to 24 hours, with return periods from 2 to 100 years. IDF curves used previously by road designers assumed that the climate remains stable over time. However, there is now considerable international evidence that short-duration (sub-daily) rainfall extremes are becoming more intense, and this is confirmed by Vanuatu's own recent experience of worsening storm damage to the road network.

To aid the development of this updated road design guide, the Van-KIRAP project team provided latest projections for extreme daily rainfall. Results for the two major centres in Vanuatu, Port Vila (Efate) and Port Resolution (Tanna), were developed. Two time periods were considered:

- a medium-term time horizon (2040-2070), and
- a long-term time horizon (2070-2100).

These were compared relative to a baseline period of 1970-2000, for low (Representative Concentration Pathways, RCP4.5) and high (RCP8.5) greenhouse gas emissions scenarios. Results were derived from 7 climate models from Phase 5 of the Coupled Model Intercomparison Project (CMIP5)[17].

For extreme daily rainfall with return periods of 10, 50 and 100 years, the multi-model mean results for Port Vila and Port Resolution showed increases in rainfall for low (RCP4.5) and high (RCP8.5) emissions scenarios as shown in Tables 11 and 12 and plotted graphically in Figure 22.

Table 11: Predicted Increases in Rainfall - Low Emissions Scenario (RCP4.5)

	Predicted % Change in Rainfall from Baseline 1970-2000					
	2040-2070 (Medium-Term Horizon)			**2070-2100** (Long-Term Horizon)		
	10-Year Return Period	50-Year return period	100-Year Return Period	10-Year Return Period	50-Year return period	100-Year Return Period
Port Vila	18.43%	22.05%	23.08%	26.32%	31.55%	32.78%
Port Resolution	25.24%	29.59%	30.78%	22.09%	25.46%	26.37%

Table 12: Predicted Increases in rainfall - High Emissions Scenario (RCP8.5)

	Predicted % Change in Rainfall from Baseline 1970-2000					
	2040-2070 (Medium-Term Horizon)			**2070-2100** (Long-Term Horizon)		
	10-Year Return Period	50-Year return period	100-Year Return Period	10-Year Return Period	50-Year return period	100-Year Return Period
Port Vila	35.90%	41.05%	42.52%	63.04%	72.49%	75.17%
Port Resolution	43.18%	48.75%	50.27%	76.10%	86.20%	88.95%

[17] van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt GC, Kram T, Krey V, Lamarque J-F, Masui T, Meinshausen M, Nakicenovic N, Smith SJ, Rose SK (2011) The representative concentration pathways: an overview. Climatic Change 109:5. https://doi.org/10.1007/s10584-011-0148-z.

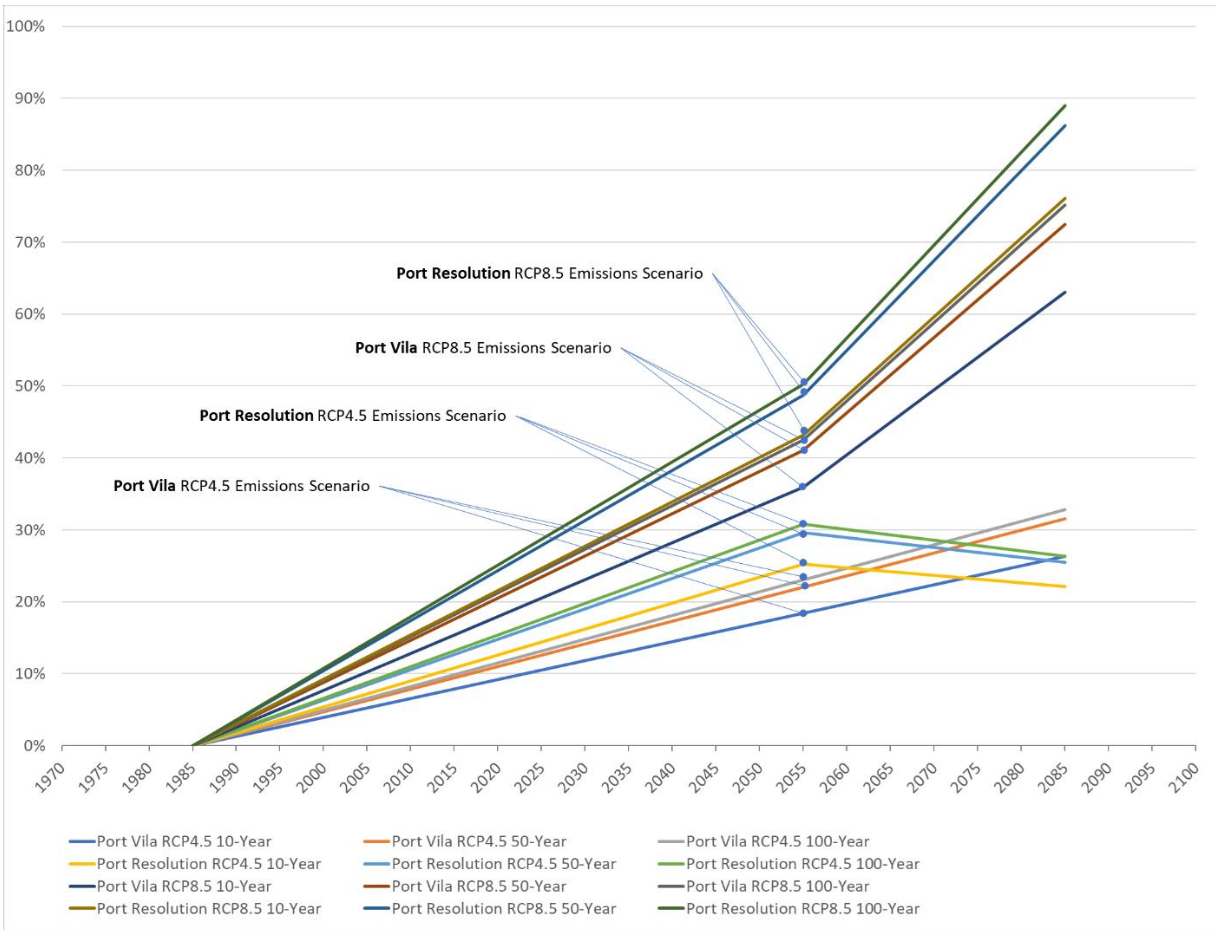


Figure 22: Predicted Increases in Percentage Rainfall - Port Vila and Port Resolution

As can be seen, there is a significant difference between the future predicted rainfall under the low emission pathway scenario (RCP4.5) compared to the high emission pathway (RCP8.5). The RCP4.5 pathway requires governments to honour their current pledges and targets (known as the Nationally Determined Contributions[18]) and would lead to 2.1-3.5°C warming by 2081-2100 (IPCC, 2021). The RCP8.5 pathway is a high emission pathway scenario based upon governments not meeting their current pledges and targets, as seems likely based upon recent climate action performance. This level of uncertainty in future rainfall levels poses significant issues for road designers who need to design infrastructure assets which will last well into the future.

Predicted figures should be treated with caution as they are derived from the mean results of seven different climate models, each with varying results. Also, the percentage increases quoted refer to daily rainfall and may not be directly applicable to sub-daily durations. In recent years, climate model simulations at a finer spatial and temporal resolution, have provided more reliable projections of sub-daily rainfall, and these models suggest that rainfall scaling may also increase as an inverse function of duration, such that shorter duration, longer return period events will likely see the largest rainfall increases in a warmer climate. This introduces further uncertainty into road drainage design in Vanuatu and suggests that the extreme short-duration rainfall may be even more intense than suggested by Figure 22.

[18] For more information see: https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs

Internationally, current measures of dealing with climate change in drainage design and flood protection vary from multiplying historical design rainfall by a simple constant percentage to modulating correction factors based on return periods and to scaling them to the Clausius-Clapeyron relationship[19] based on projected temperature increases.

This design guide is based upon applying percentage increases to current rainfall forecasts as shown graphically in Figure 23. The Figure 23 curves are derived from averages of the forecasts included in Tables 11 and 12.

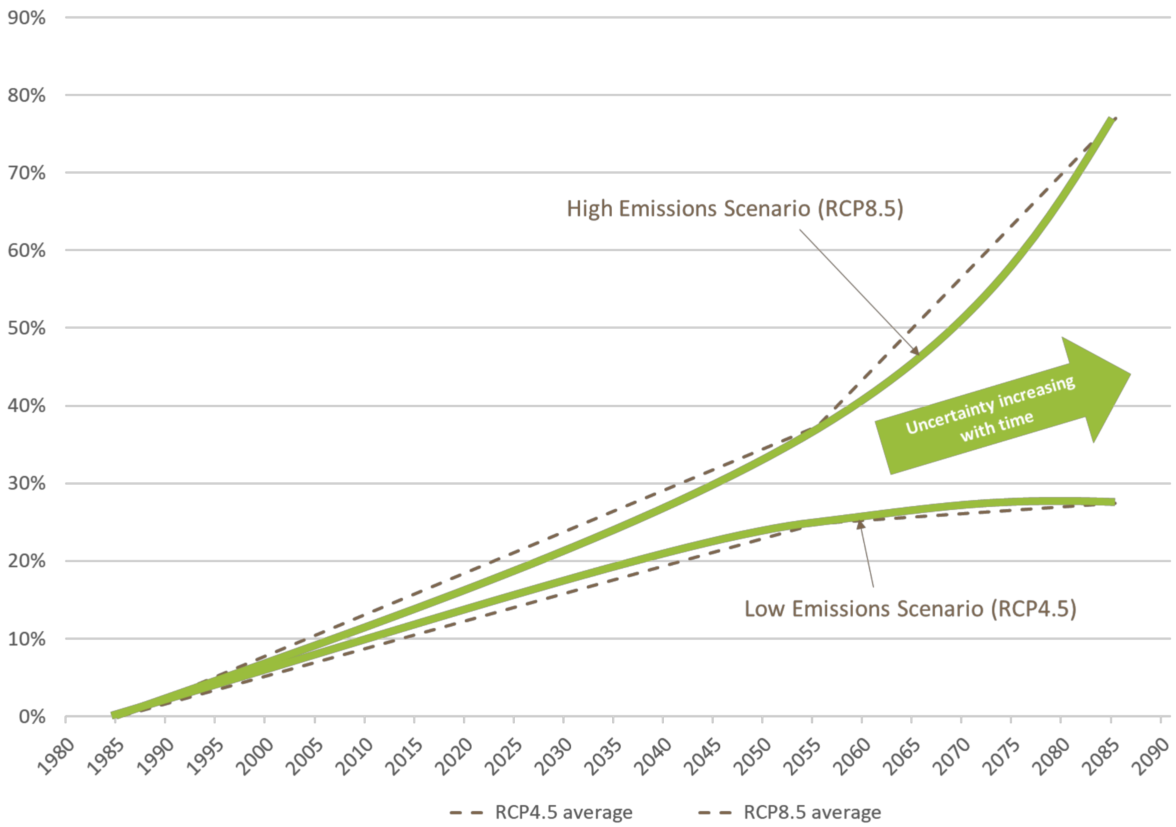


Figure 23: Average Rainfall Increases for Drainage Design

5.3 Objectives and Principles of Drainage Design

The objective of climate resilient drainage and slope design is to reduce road failures due to the action of water to acceptable levels in the face of increasing intensity of rainfall, and, in particular, to design core roads so that they are generally able to remain open during and after extreme climate events.

There are three key objectives of road drainage and slope design:

[19] According to the Clausius-Clapeyron relationship, atmospheric water content increases by between 6 and 7% per 1 °C rise in temperature. Therefore, even just an increase of 1.5°C could result in around 9% more water in the atmosphere, which could have a major impact on storm systems and subsequent rainfall.

- to drain the road carriageway surface - so that vehicles may pass safely and to avoid softening and deterioration of upper pavement layers due to ponding of water
- to allow drainage of subsurface pavement layers to avoid pavement softening and subsequent failure, and
- to protect the integrity of road embankments and cuttings so that the road pavement is protected and remains open to traffic following a major storm event.

To achieve these objectives, and as recommended in Section 4.6 of this guide, the road carriageway surface must be constructed with a crossfall so that it sheds rainwater quickly. It is recommended that all gravel roads are constructed with an initial crossfall of 6% as gravel roads tend to lose their shape over time. Bituminous sealed roads should be constructed with a crossfall of 4% and concrete roads should have a crossfall of 3%. Also, as previously stated in Section 4.6, all road pavement layers must be allowed to drain freely and not be allowed to become saturated over a long period of time. Various acceptable rural road edge treatments which achieve free drainage of pavement layers are shown in Figure 24.

Fast-running water can have a harmful effect on shoulders, slopes, ditches and other features through erosion which, when severe, can lead to the road pavement structure being eroded or undermined. Therefore, consideration of highest water velocities for each drainage element is required as part of drainage design.

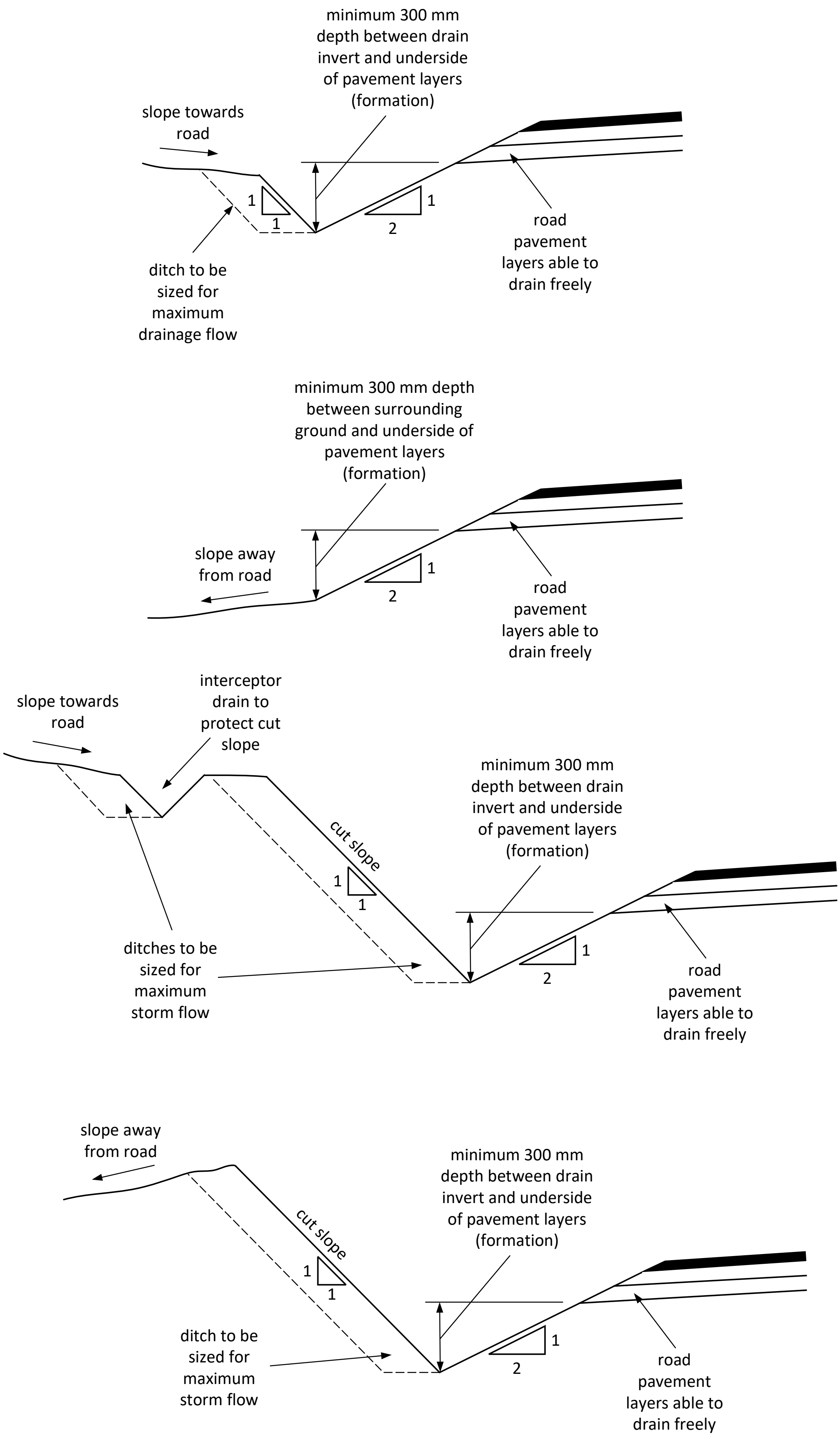


Figure 24: Rural Roads - Recommended Edge Treatments

5.4 Surveys and Data Collection for Drainage Design

Drainage design is not possible without understanding the basic geometry of all catchment areas which impact on the section of road under design. Information may be collected through a mix of existing documentation and data collection in the field.

Collection of existing data or documentation may include:

- topographic maps of the surrounding areas which identify the stream/river crossings and all relevant catchment areas
- geological maps, if available, to identify soil types for determining the runoff coefficient, and
- previous drainage designs undertaken in the area.

These existing records should be supplemented with data collection in the field, which may include:

- details and condition of existing drainage structures in the area (culverts, drifts, roadside drainage channels, etc.), noting invert levels, sizes and any damage or scour caused by storm water action and the level of any visible high-water marks
- details of storm event history including highest flood levels, locations of road overtopping, instances of drainage structures being unable to cope with high flows, etc., obtained through interviews with local communities and local road and drainage teams
- an assessment of land use, vegetation cover and soil type, which is necessary for the estimation of runoff coefficients, and
- detailed topographic surveys to be used to establish ground levels around the proposed road, the location and elevations of existing and proposed drainage structures e.g. bridges, culverts, drifts, drainage channels, etc. including local topography upstream and downstream of proposed drainage structure locations.

5.5 Determining Surface Drainage Flow Paths and Initial Drainage Layout

Using a combination of the proposed road alignment developed in accordance with Section 4 and the information collected through surveys and data collection, the drainage designer should initially develop a plan of an initial drainage layout to deal with surface water flows during storm conditions in the vicinity of the road. This must take into account:

- the route of all existing watercourses
- the route of rainwater which falls within the road corridor, including rainfall falling on cut and fill slopes
- the direction of flow of surface water which is likely to run across adjacent land, and
- the proposed locations of drains and other drainage elements.

This is one of the most important steps in developing a climate resilient road design. The logical sequence of design is demonstrated in Figures 25 to 27 for a section of road:

- **Figure 25** shows the proposed road alignment within the surrounding topography including earthworks slopes and proposed major culvert locations and notes the direction of flow of surface water both within the road corridor and surrounding areas
- **Figure 26** demonstrates how the drainage designer should use the Figure 25 base plan to identify all surface water flow paths, and

- **Figure 27** shows how the drainage designer uses the flow paths identified in Figure 26 to develop an initial drainage layout.

At this stage the design provides directional flows of all drains and culverts but does not attempt to define the size of each element. Sizing occurs in later stages of drainage design.

The drainage designer should take into account the following principles during development of the initial drainage layout.

- water always flows downhill taking the route of least resistance
- the direction of water run-off from the pavement surface must consider the combined effect of superelevation, crossfall and the longitudinal profile of the road
- designs should interfere as little as possible with the natural flow of water with culverts on natural watercourses following the existing alignment as closely as practicable (re-alignment of watercourses resulting in sharp changes in direction should be avoided to avoid bank erosion)
- the flows in drains and culverts should also be kept to a minimum using frequent turnouts or cross-drains where drains running alongside the road cannot be discharged into existing watercourses
- in areas of sidelong ground, where there is a need to discharge water from the side drain on the high side to the low side of the road, it is best to use frequent small culverts rather than occasional large ones
- where surface water is likely to run towards a cut slope, an interceptor drain should be used to protect the cut slope, and
- toe drains are generally required to collect and control surface water from embankment slopes, but may be dropped in those areas where the surrounding ground slopes away from the road allowing surface water to run away from the road embankment freely.

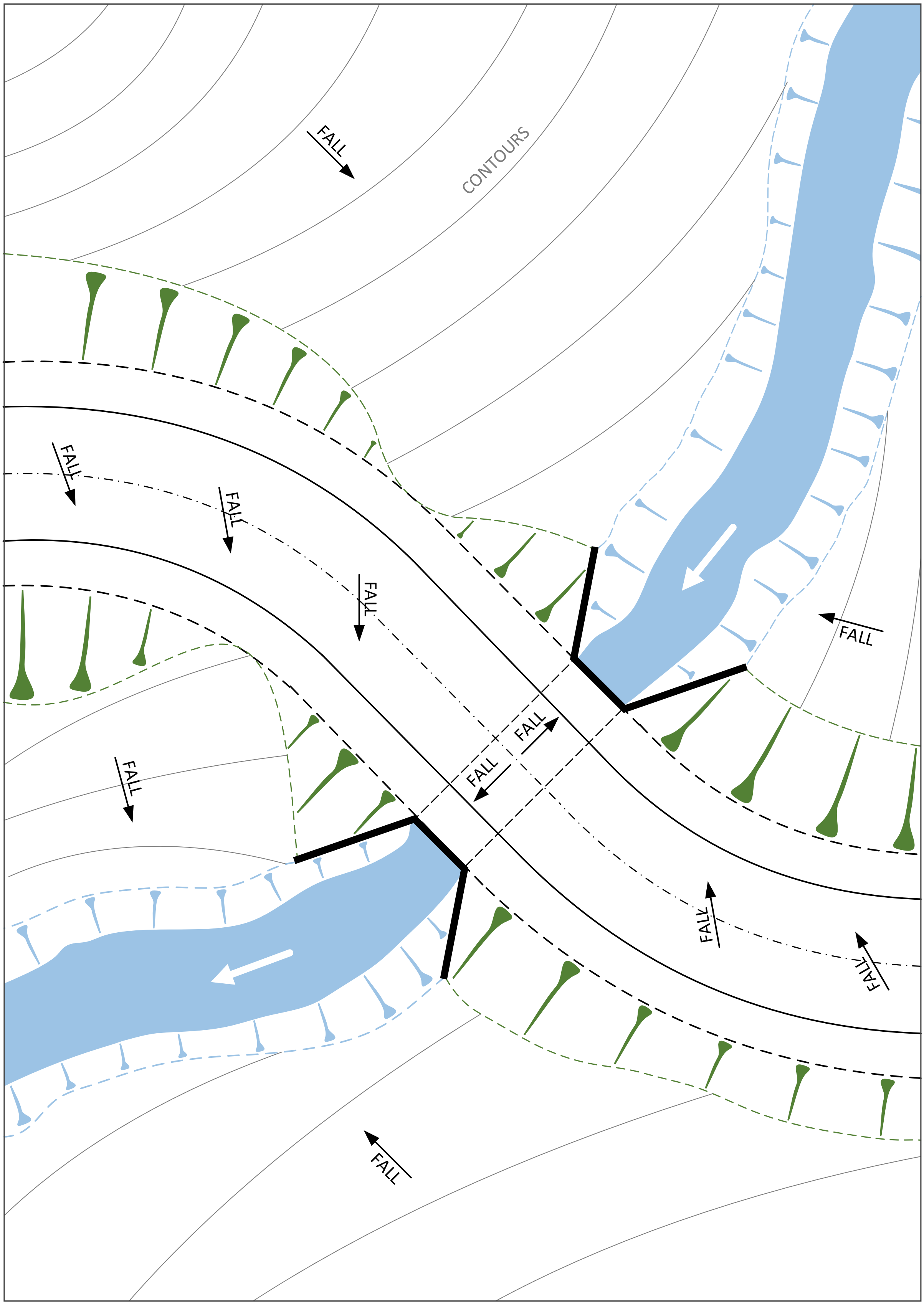


Figure 25: Drainage Design – Establish Road Alignment and Topography

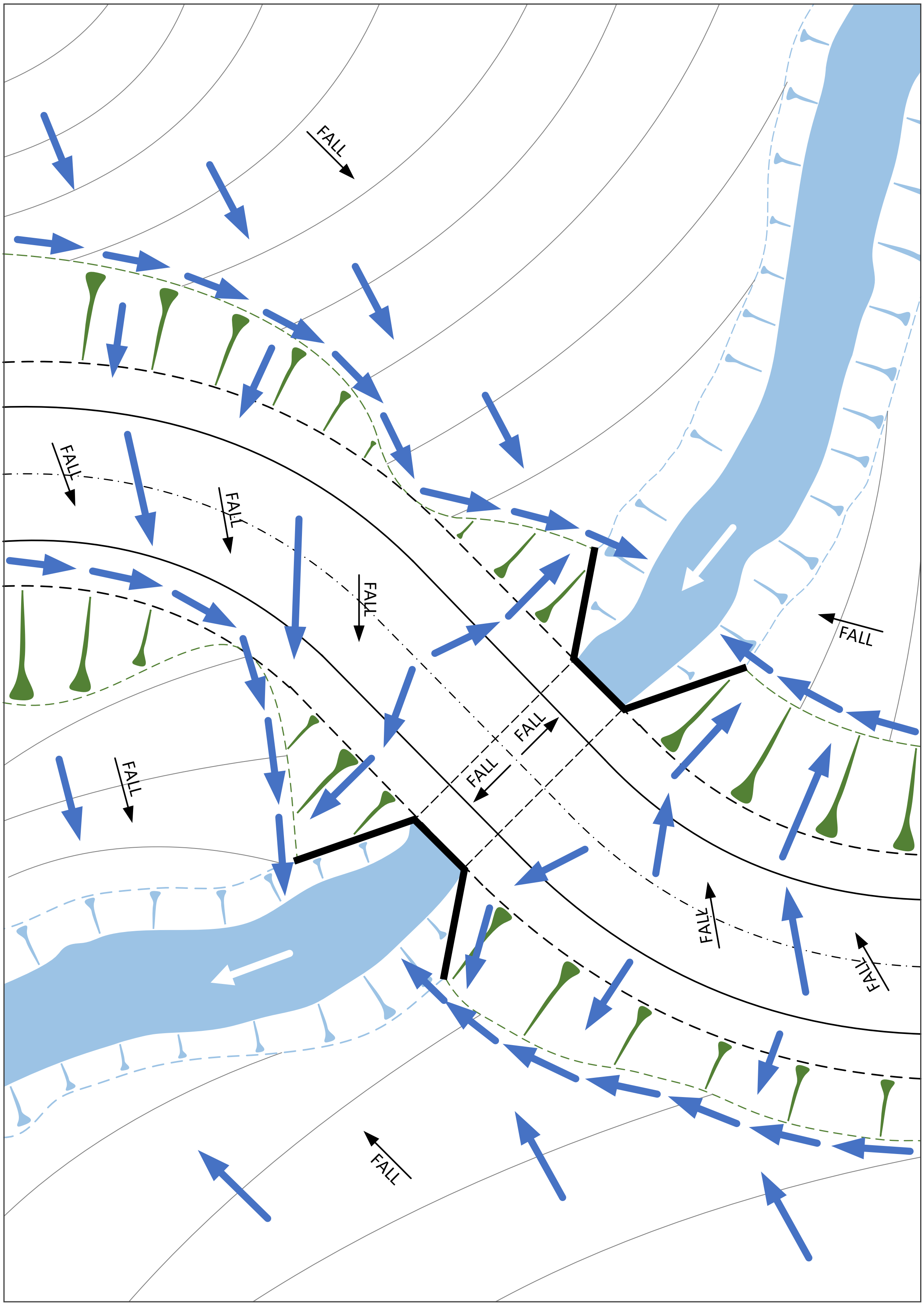


Figure 26: Drainage Design - Flow Paths Identified

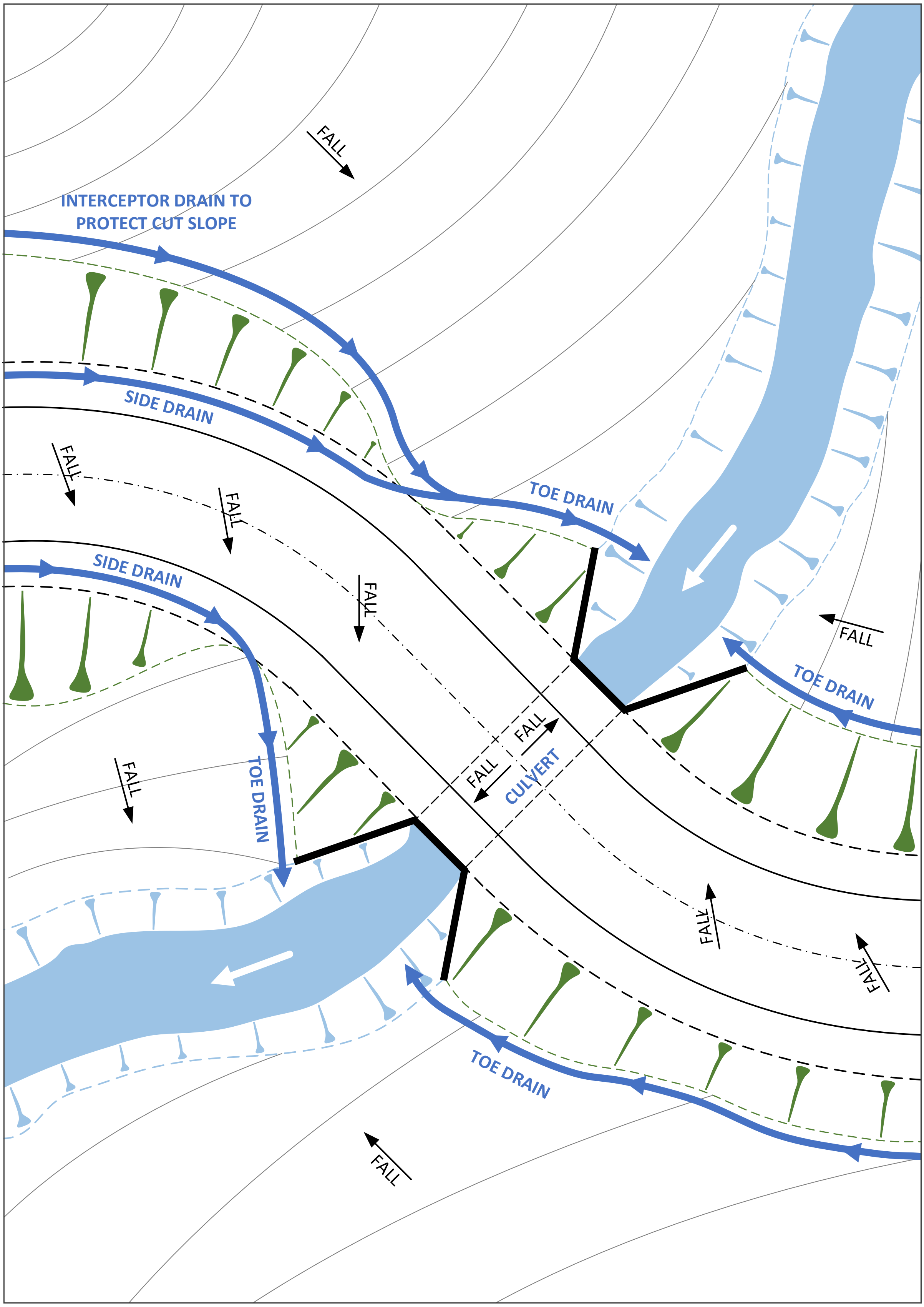


Figure 27: Drainage Design - Initial Drainage Layout

5.6 Defining Catchment Areas

Once the initial drainage layout has been established, the designer may start the process of determining the likely maximum flows expected in each element of the drainage system. This first requires a consideration of the catchment area contributing to the flow in each drainage element, as shown in the example in Figure 28.

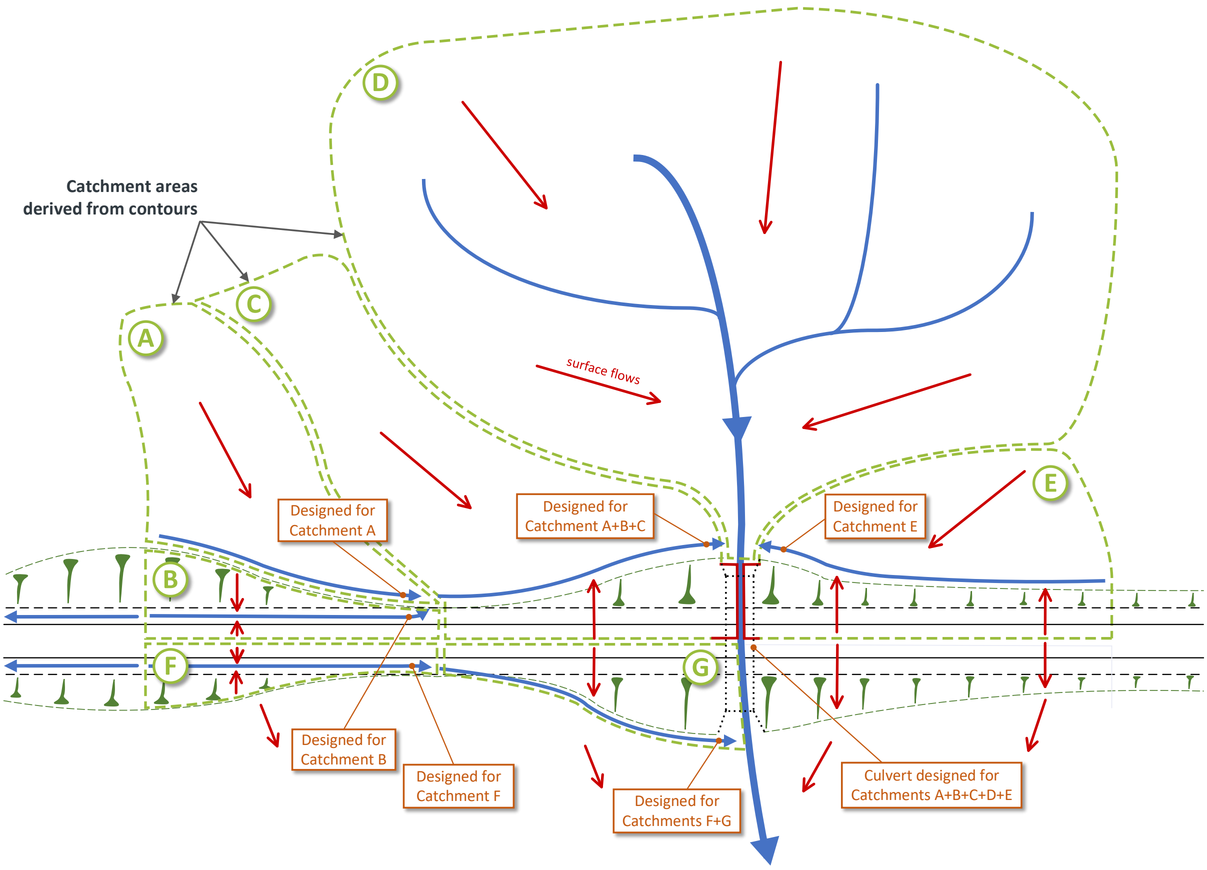


Figure 28: Drainage Elements and Catchment Areas

For each identified catchment area, the designer shall determine:

- the catchment area, A (in km^2)
- the longest flow distance within the catchment area (i.e. from the furthest point in the catchment area to the discharge point), L (in km)
- the fall from the highest point in the catchment area to the discharge point, H (in m)
- the type of ground type, vegetation cover or hard surface type within each catchment, and if a mixed catchment, the area of each type.

5.7 Estimating Peak Flows – the Rational Method

5.7.1 Step 1 : Calculation of Time of Concentration

The time of concentration, t_c, sometimes referred to as the 'inlet time', is the time taken for a particle of water to travel through a catchment area from the remotest part of the catchment area, as shown in Figure 29.

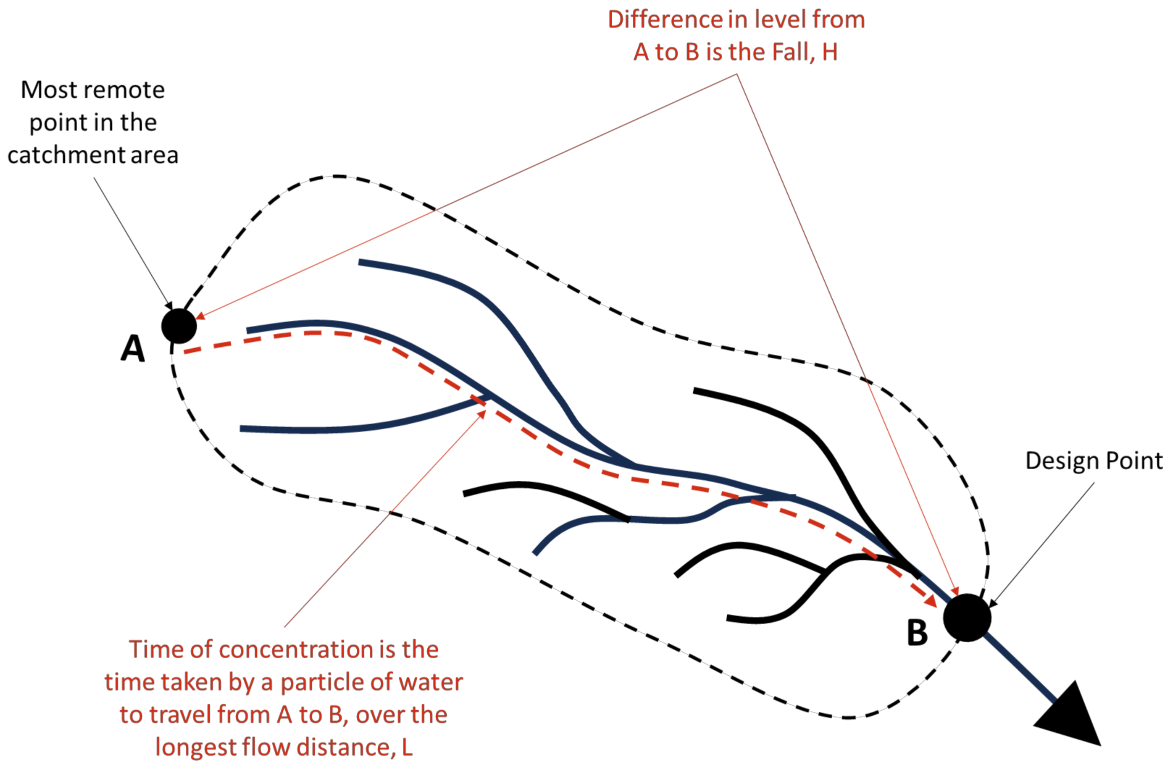


Figure 29: Time of Concentration, t_c

The average slope of the catchment, S (in m/km) is calculated as the fall, H, divided by L, the longest flow distance within the catchment area. The time of concentration in minutes may then be calculated by the Bransby Williams formula[20]:

$$Time\ of\ Concentration, t_c = \frac{58.5 * L}{A^{0.1} * S^{0.2}}$$

where,

$$L = longest\ flow\ distance\ (km)$$

$$A = area\ of\ catchment\ (km^2)$$

$$S = average\ catchment\ slope\ (m/km)\ -\ calculated\ as\ H/L$$

[20] From Austroads Guide to Road Design Part 5: Drainage

5.7.2 Step 2 : Select Relevant ARI

The Average Recurrence Interval (ARI), often referred to as the 'return period' is the average time period between floods of a certain size. For example, a 50-year ARI storm will occur on average once every 50 years. The rainfall intensity during a 50-year ARI storm would be higher than during a 20-year ARI storm. Each element of the drainage system shall be designed for a particular ARI, with the more critical elements being designed for high values of ARI, and less critical elements being designed for lower values of ARI.

For example, because of the significant consequences of overtopping, a major culvert would be designed for a high ARI of 50 years, while a side drain may be allowed to overtop on average every 5 years. Recommended values of ARI for various drainage elements are provided in Table 13 below.

Table 13: Recommended Average Recurrence Intervals

Drainage Element	Recommended ARI
Major Bridge > 20m span on Core Road	100 years
Other Bridges and Culverts >2m span	50 years
Other Culverts (Box and Pipe)	20 years
All Urban/Township Drainage Channels, Pipes, etc.	10 years
All Rural Drifts	10 years
All Rural Drainage Channels, Ditches, etc.	5 years

5.7.3 Step 3: Establishing Appropriate Rainfall Intensity for ARI

Figure 30 shows the maximum daily rainfall experienced each year at rainfall measurement stations located at Port Vila and Bauerfield for the period up to 2010, roughly corresponding to the 1970-2000 baseline period used by the Van-KIRAP team as described in Section 5.2. These records indicate that the rainfall at each location can be very different even though the gauges are only 6 km apart. As an example, on 22 May 2010, 266 mm rain was recorded at Port Vila, the third highest daily rainfall since 1975, but the same day only 26 mm was recorded at Bauerfield, yet there was localised flooding just 2 km south of the airport. This demonstrates the extreme local variability in rainfall intensity by location and time, making the prediction of rainfall intensities extremely difficult in Vanuatu.

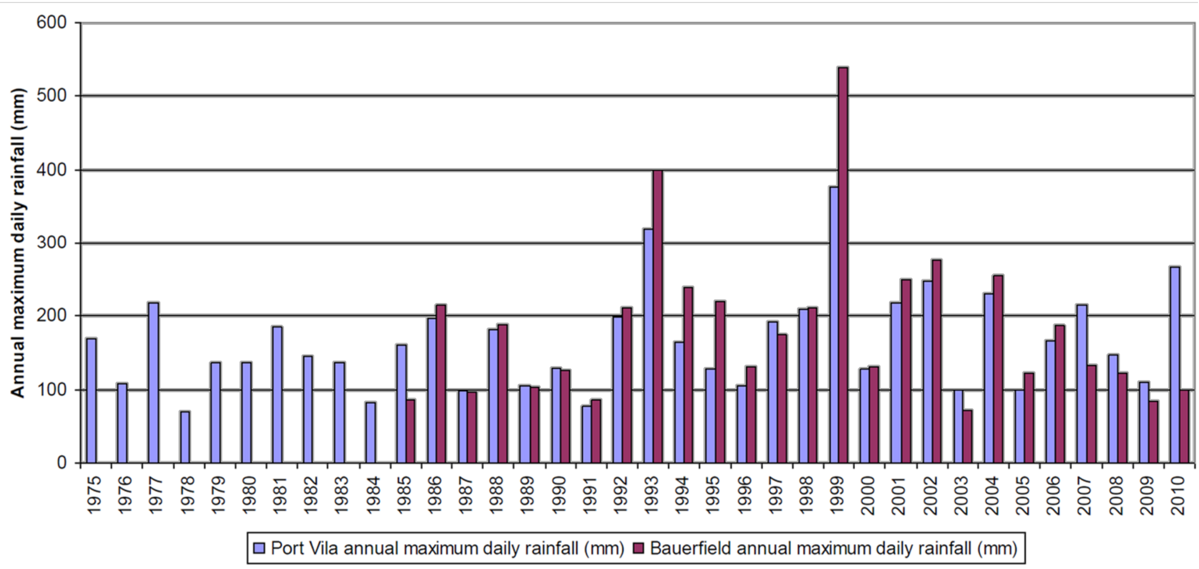


Figure 30: Port Vila and Bauerfied Annual Maximum Daily Rainfall

In 2010, the Port Vila Urban Development Project developed synthetic intensity-duration-frequency (IDF) curves based upon these daily rainfall records for both Port Vila and Bauerfield. The rainfall intensities at Bauerfield, for any particular duration and frequency, were higher than those at Port Vila, and therefore the Bauerfield IDF has been selected as a conservative base case IDF for the purposes of this climate resilient road design guide. The Bauerfield IDF is reproduced as Figure 32.

Figure 31 below shows how road designers should adjust the rainfall intensity derived from this base IDF to select an appropriate design rainfall intensity for each road design project. Each of these steps is described below.

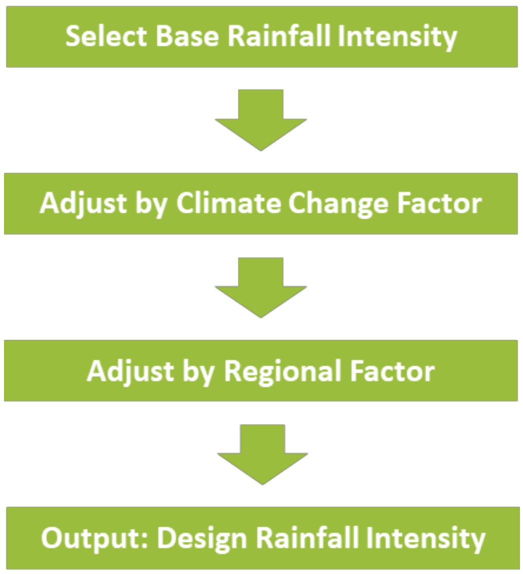


Figure 31: Development of Design Rainfall Intensity

Based upon the selected ARI and time of concentration for the catchment under consideration, the designer shall use Figure 32 to select the base case rainfall intensity.

This shall then be adjusted by a climate change factor to reflect predicted changes to rainfall intensity due to climate change as described in Section 5.2. The designer first needs to select a design life and resulting target end-of-life calendar year for the drainage element being designed. Another way of thinking about this is to ask, ‘when should we expect to replace this asset?’, or ‘how long do we want this asset to last?’, noting that a longer design life adds considerably to cost. Suggested design lives for different classes of drainage asset are given in Table 14, but these may be adjusted by the designer to suit specific circumstances.

Table 14: Recommended Target Design Lives

Drainage Element	Recommended Design Life
Bridges, Box Culverts, Drifts	50 years
Pipe or Armco Culverts	25 years
All Urban/Township Drainage Channels, Pipes, etc.	20 years
All Rural Drainage Channels, Ditches, etc.	10 years

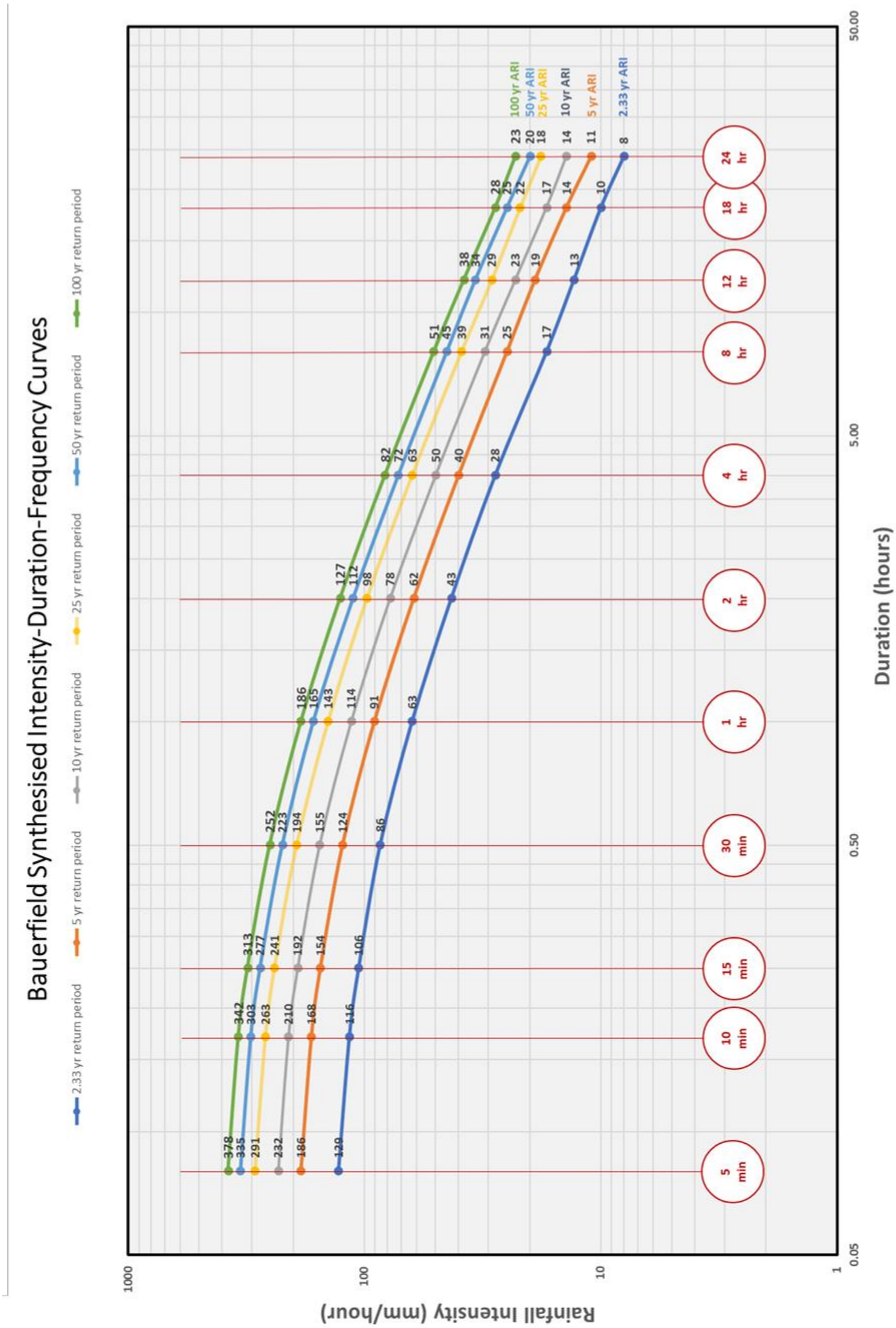


Figure 32: Intensity-Duration-Frequency Curve – Base IDF

Once a target design year has been chosen, Table 15 may be used to select a scaling factor to be applied to the base rainfall intensity. Because of the very low degree of certainty associated with climate predictions beyond 2080, no further predictions of increases in rainfall intensity have been made beyond this date and ceilings of 1.28 (low emissions scenario) and 1.67 (high emissions scenario) have been set for the period beyond 2080. This design manual will be changed in the future if it becomes clear that rainfall intensities will continue to increase beyond 2080.

Table 15: Rainfall Intensity - Climate Change Scaling

Design Year	Climate Change Scaling Factor to be applied to Base Rainfall Intensity	
	Low Emissions Scenario (RCP4.5) for all **non-core** road assets	**High Emissions Scenario (RCP8.5)** for all **core** road assets
2030	1.17	1.22
2040	1.21	1.27
2050	1.24	1.33
2060	1.26	1.41
2070	1.27	1.52
2080 and beyond	1.28	1.67

(derived from Figure 23)

A further factor is then applied to rainfall intensity to take into account broad rainfall variations across Vanuatu. Road designers may undertake their own assessment of the regional variation between Bauerfield Airport and the design area by reference to the rainfall predictions available through the Van-KIRAP portal, or alternatively use the regional adjustment factors shown in Figure 33.

Figure 33: Rainfall Intensity - Regional Variation Factors

Box 5 : Example of Assessment of Rainfall Intensity

The design project is a large culvert of 2.5m width on a core road in Malekula.

From investigation of topographical maps and site visits, the catchment area feeding into the culvert has the following characteristics:

- Area 5.6 km^2
- Longest flow length 2.8km
- Fall (difference between highest point and culvert invert 75m
- Ground type: rural rolling grassland with some trees

Using,

$$Time\ of\ Concentration, t_c = \frac{58.5 * L}{A^{0.1} * S^{0.2}}$$

$$tc = 58.5 * 2.8 / (5.6^{0.1} * (75/2.8)^{0.2} = 113 \text{ minutes} = 2 \text{ hours } \textit{(rounded)}$$

The maximum rainfall intensity for a storm duration of 2 hours is therefore required for the culvert design.

From Table 13, the Design ARI (or return period) is 50 years.

From Table 14, the target design life is 50 years. If the construction year is 2025, the end-of-life year is 2075.

From Figure 32, the base rainfall intensity (for ARI 50 years and 2 hour duration) is 112 mm/hour.

From Table 15, the appropriate climate scaling increase is around 1.6 for the high emissions scenario and target year 2075.

From Figure 33, the appropriate regional variation factor is 1.15 for Malekula.

Therefore, design rainfall intensity is 112 * 1.6 * 1.15 = **206 mm/hour.**

5.7.4 Step 4 : Rational Method Formula and Selection of Runoff Coefficient

The next step in design is to use the design rainfall intensity to calculate the peak flow for the drainage element under design.

This design guide is based on use of the Rational Method as it avoids the need for special computer software and is easy to use. The Rational Method is the most well-known method for estimating peak storm flow. It is based on a direct relationship between rainfall and runoff. The maximum discharge is given by the expression:

$$Q = 0.278 * C * I * A$$

where,

$$Q = Maximum\ Discharge\ or\ Peak\ Flow,\ (m^3/s)$$

$$C = Runoff\ Coefficient$$

$$I = Rainfall\ Intensity,\ (mm/h)$$

$$A = Catchment\ Area,\ (km^2)$$

The Runoff Coefficient, C, is dependent upon the ground type, vegetation cover or hard surface type. Values of runoff coefficient for different surfaces for use in the Rational Method Formula are shown in Table 16. For catchments with different land uses, a coefficient may be calculated based upon the proportions of each land use type by area.

Table 16: Typical Values of Runoff Coefficient

Surface Type	Runoff Coefficient, C
Concrete or asphalt pavement	0.9
Bituminous macadam and double bituminous surface treatment	0.8
Gravel surface	0.5
Urban centre	0.7
Residential area	0.5
Rocky surface	0.7
Hilly rural area with vegetation (10-30% slopes)	0.3
Rolling rural area with vegetation (2-10% slopes)	0.2
Flat Rural Dry with vegetation (0-2% slopes)	0.1
Flat Rural Wet with vegetation (0-2% slopes)	0.5

Box 6 : Example of Calculation of Peak Flow

Continuing with the example from Box 5:

The design rainfall intensity is **206 mm/hour.**

From Table 16, the runoff coefficient is 0.2 for rural rolling ground.

Using,

$$Q = 0.278 * C * I * A$$

$$Q = 0.278 * 0.2 * 206 * 5.6 = 64\ m^3/s$$

Therefore, the culvert should be designed for a peak flow of **64 m^3/sec**.

5.7.5 Final Points on Calculation of Peak Flows

It is recognised that undertaking an assessment of peak flows for each drainage channel, ditch, drift, culvert and bridge is a time-consuming task requiring significant effort for designers. However, for road designs to achieve improved resilience requires that this important step be undertaken diligently. A road cannot be considered to be 'designed for resilience' if this important step is not carried out. The following sections take a closer look at the design of each type of drainage element:

- drainage channels and ditches
- drifts (low-water crossings)
- piped culverts
- box culverts
- bridges, and
- slopes (and slope protection).

Generally, this design guide provides guidance on the sizing and form of drainage elements and does not include guidance on structural design. Designers should refer to the latest PWD standard drawings and the relevant Austroads standards or other acceptable international standards for structural design guidance.

5.8 Drainage Channels and Ditches

Following the steps set out in the previous sections, designers should estimate the peak flow for each length of drainage channel. The three most important aspects of channel design are:

- ensuring the channel is positioned to collect local surface water flows
- ensuring the channel has sufficient volume to carry the estimated peak flow, and
- ensuring the channel is designed to deal with likely velocity and energy of water at peak flow by providing an appropriate lining or scour checks.

5.8.1 Channel Positioning and Layout

All drainage channels must be positioned so that they collect surrounding surface water. This will often require regrading of the ground levels around the channel. Some examples of good and bad practice are provided in Figure 34. Drainage channels should not be positioned very close to the carriageway where they could pose a safety hazard for errant or passing vehicles.

It is preferable to avoid long lengths of drainage channel to reduce the peak volume to be carried within the channel. This can be achieved by the frequent use of cross-drains and mitre drains as shown in Figure 35. Table 17 provides useful 'rule-of-thumb' guidance on typical mitre drain and cross drain spacings to avoid sedimentation and scour, although each design location will have its own specific characteristics requiring careful consideration and a bespoke design.

Table 17: Typical Mitre Drain and Cross Drain Spacings

Side Drainage Channel Slope	Typical Spacing of Mitre/Cross Drains
<1%	50m
1 – 4%	200m
5 – 6%	160m
7 – 8%	120m
9 – 10%	80m
>10%	40m

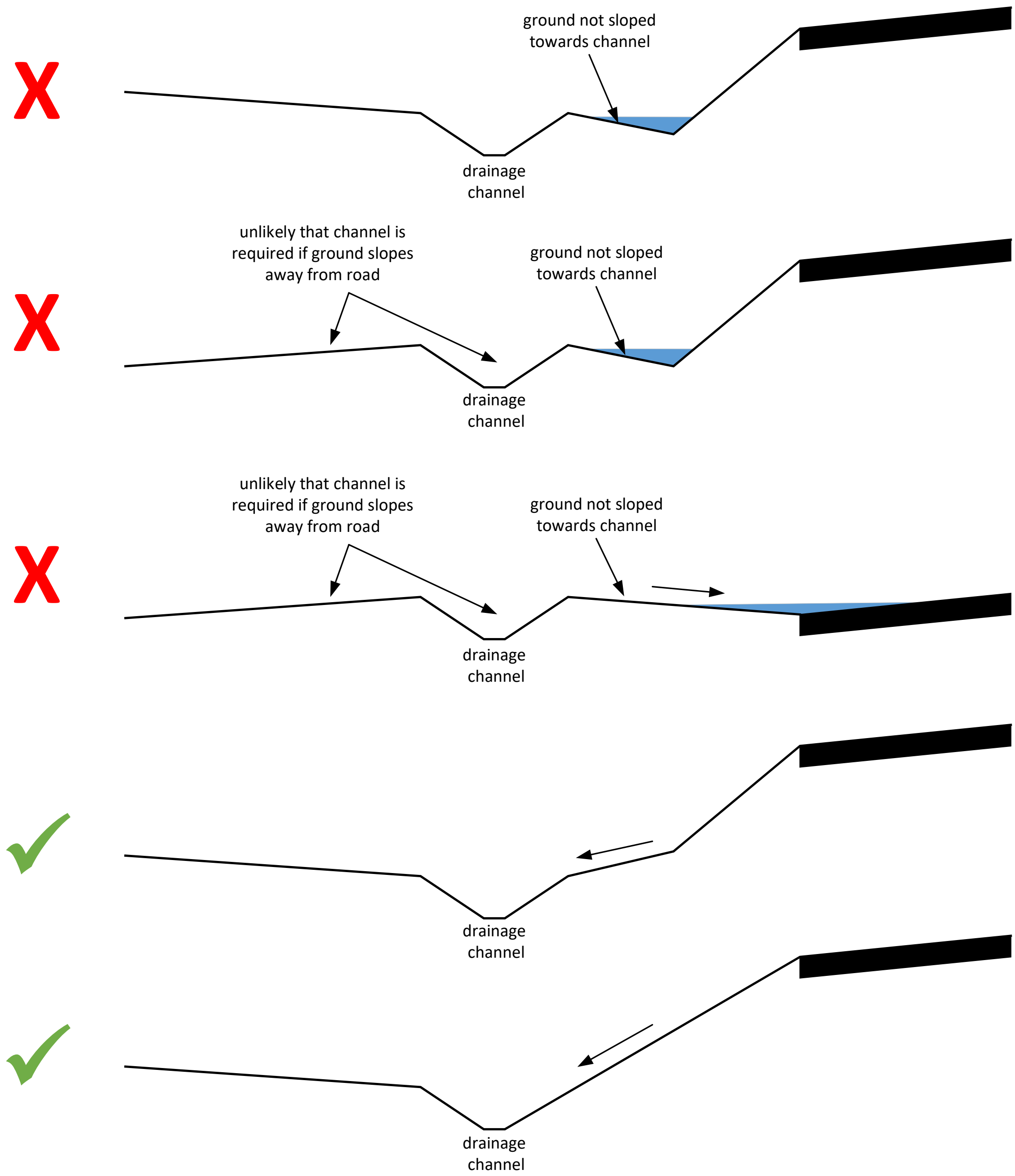


Figure 34: Channel Locations and Positioning – Examples of Good and Bad Practice

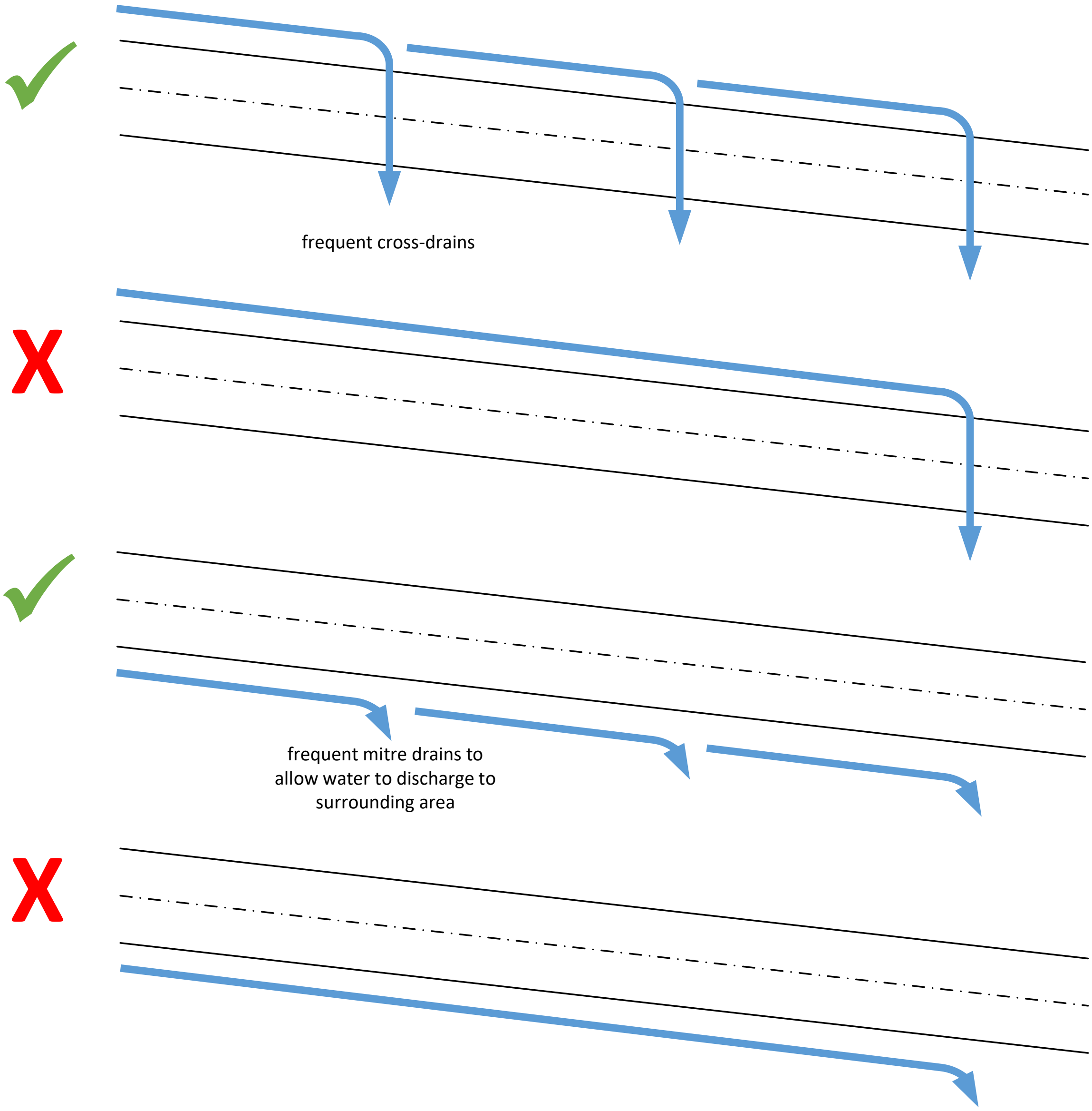


Figure 35: Frequent Cross-Drains and Mitre Drains

5.8.2 Designing Channels for Estimated Peak Flow

The most basic equation in the analysis of open channel flow defines the relationship between flow rate (discharge), velocity and the cross-sectional area of flow and is represented by:

$$Q = V * A$$

where,

$$Q = \text{Flow rate } (m/s)$$

$$V = \text{Average velocity } (m/s)$$

$$A = \text{Cross-sectional area of flow } (m^2)$$

The formula most commonly used for the calculation of steady, uniform flow in open channels is Manning's Equation. This equation is used to determine the velocity of flow at a specific point in the channel, and therefore the variables in the equation must be representative of the point being assessed.

Manning's Equation is:

$$V = \frac{R^{2/3} * S^{\frac{1}{2}}}{n}$$

Where,

V = Average velocity (m/s)

R = Hydraulic radius (m)

S = Slope of energy line (m/m) - usually assumed to be slope of drain[21]

n = Manning's roughness coefficient.

The hydraulic radius, R, is given by:

$$R = \frac{A}{P}$$

where,

A = cross-sectional area (m^2)

P = wetted perimeter (m).

Suggested values for Manning's roughness coefficient, n, for various channels are provided in Table 18. A more detailed table of roughness coefficients is available in Austroads Guide to Road Design Part 5B.

Table 18: Recommended Manning's Roughness Coefficient Values

Type of Channel Lining	Manning's n value
Earth (clean)	0.024
Earth (with vegetation)	0.028
Stone Masonry	0.022
Concrete	0.014

The design steps for calculating the size of an open channel are shown in Figure 36. An example calculation is provided in Box 7.

[21] The slope is expressed as (vertical distance drop)/(horizontal distance travelled) using the same units for both, so for a drain falling 2m over 100m, S would be 2/100 = 0.02.

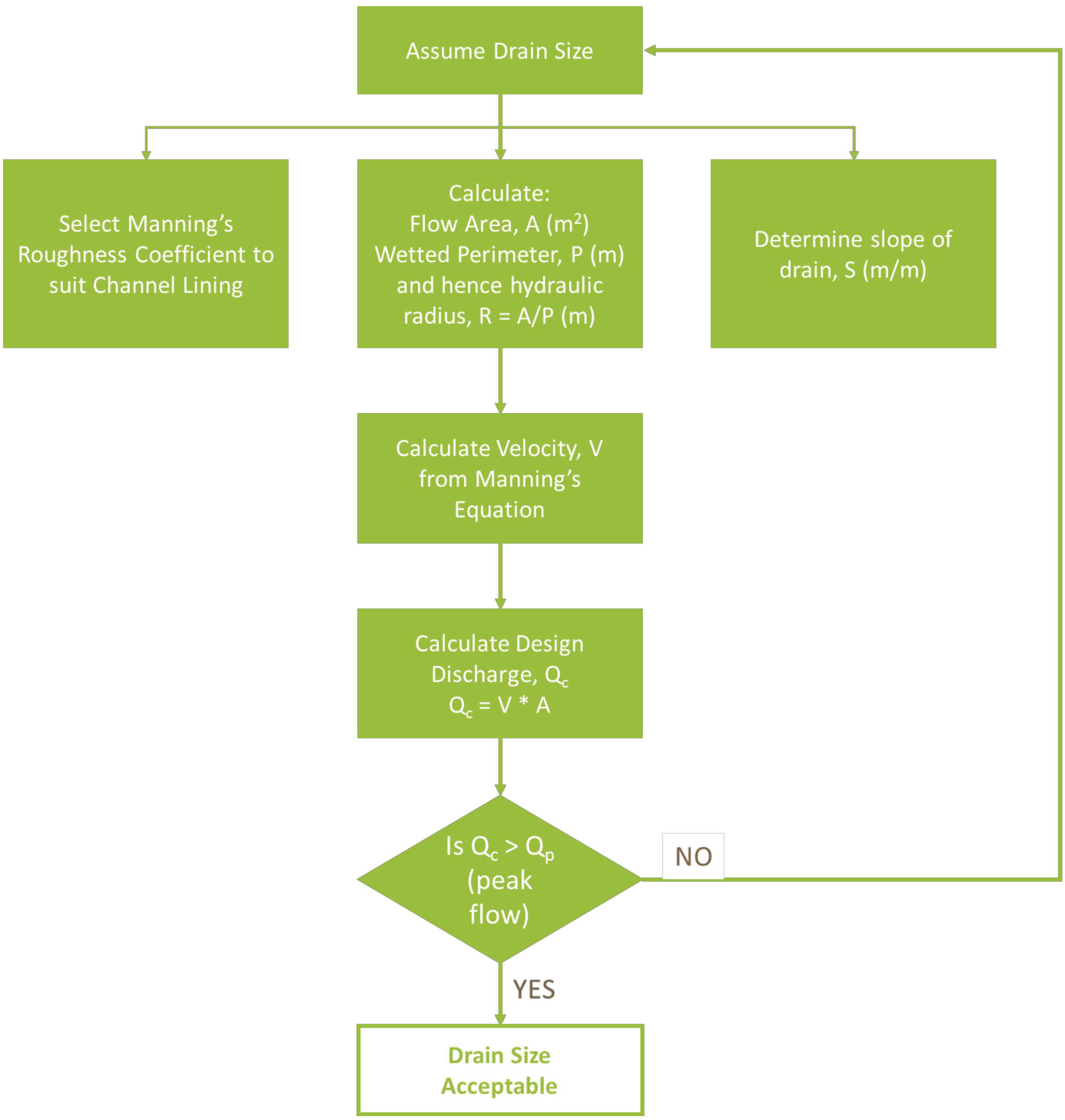
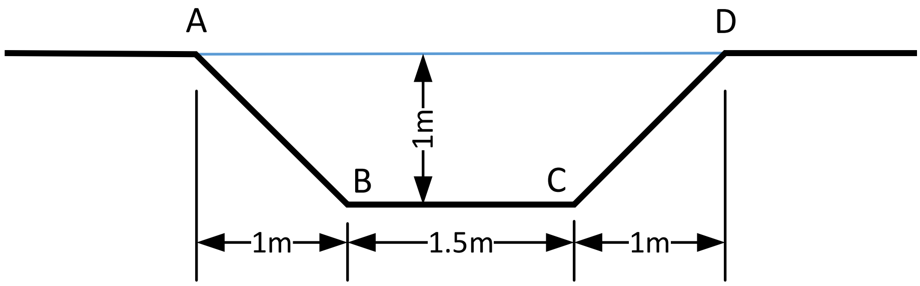


Figure 36: Open Channel - Design Capacity Flowchart

Box 7 : Example of Open Channel Flow Capacity Calculation

A grass-lined open trapezoidal channel has a fall of 3m per 100m and dimensions as shown below.



From Table 18, Manning's Roughness Coefficient is 0.028

Flow Area, A = (1.5 * 1) + (1 * 1) = 2.5 m^2

Length AB = $\sqrt{(1^2 + 1^2)} = 1.414$

Wetted Perimeter = (1.414 * 2) + 1.5 = 4.328

Hydraulic Radius, R = A/P = 2.5/4.328 = 0.578

Slope is given above as 0.03

Using Manning's Equation,

$$Velocity,\ V = \frac{R^{2/3} * S^{\frac{1}{2}}}{n}$$

$$V = (0.578^{2/3} * 0.03^{1/2})/0.028 = 4.3\ m/s$$

Design Capacity, $Q^c = V * A = 4.3 * 2.5 =$ **<u>10.75 m³/s</u>**

[The designer would then check this against the calculated peak flow to determine whether the channel is suitable or not. If the channel is under- or over-sized, the designer should repeat the calculations with an alternative channel section].

5.8.3 Designing Channels for Water Velocity

The longitudinal slope of drainage channels must be sufficient to avoid silting which causes blockage of the channel. This is generally achieved by applying a minimum gradient of 0.5% to unlined channels and 0.33% to lined channels.

Also important in channel design, is to review the maximum velocity of water under peak flow conditions so that the channel may be protected from scour damage if necessary. The peak flow velocity is available from the Manning's Equation in the previous design step. Drainage channels should be lined if the sides of the channel are susceptible to erosion and the peak flow velocity is greater than 1.8 m/s. On rural roads, unlined channels are preferable to lined channels as they are easier to maintain using a grader or other mechanical equipment. Unlined channels are unlikely to be appropriate in an urban/township setting. Growth of grass should be encouraged within unlined channels as this reduces scour of the channel sides, but grass must be regularly cut and channels cleared to avoid blockage of the channel. If drainage channels can be reconfigured within the road design to avoid high velocity flow and resulting scour at peak flows, this is preferable to either lining or providing scour checks.

Scour checks (sometimes called check dams) reduce the speed of water in a drainage channel and help prevent erosion. The scour check acts as a small dam. When naturally silted up on the upstream side it effectively reduces the gradient of the drain, and therefore the velocity of the water. Scour checks are usually constructed with natural stone, masonry, concrete or wooden or bamboo stakes. By using construction materials available along the road, they can be constructed at low cost and can be easily maintained.

After the scour check has been constructed, an apron should be built immediately downstream using stones. The apron will help resist the forces of the mini-waterfall created by the scour check. Sods of grass should be placed against the upstream face of the scour check wall to prevent water seeping through it and to encourage silting on the upstream side. The goal is to establish a complete grass covering over the silted scour check to stabilise it. Examples of a scour check designs are provided in Figure 37.

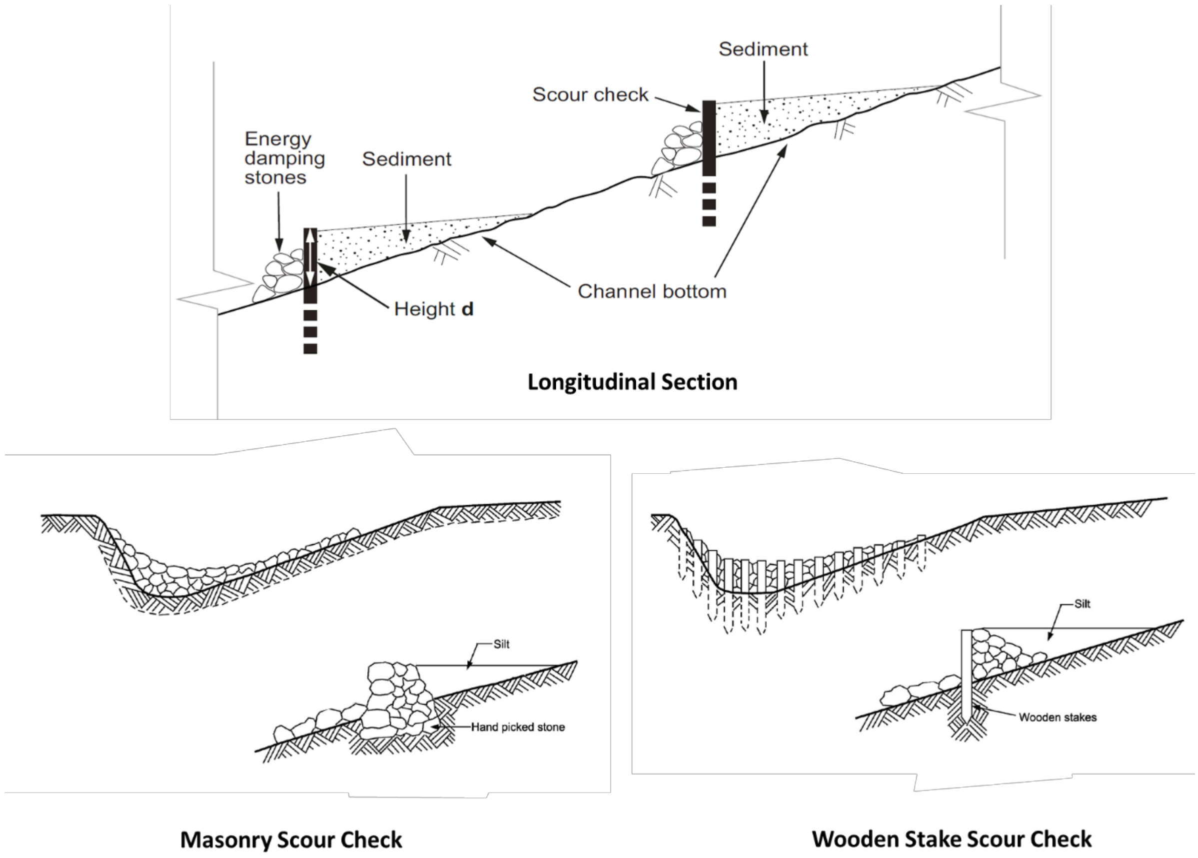


Figure 37: Example Scour Checks

Scour checks should only be provided in channels on gradients of 5% and steeper. They should not be provided on flatter, lower velocity channels as they cause excessive sedimentation. The distance between scour checks depends on the road gradient as shown in Table 19.

Table 19: Recommended Spacing of Scour Checks

Gradient of Channel	Spacing of Scour Checks
< 5%	No scour check
5 – 6 %	20m
6 – 10%	10m
> 10%	5 m

5.9 Drifts

In recent years, Vanuatu has made significant progress in improving all-year accessibility through the construction of drifts which allow the passage of vehicles across watercourses on most days, but not during tropical cyclone or other major storm conditions. Drifts are designed to accept overtopping without damage and are ideally suited for rural roads in locations where full all-weather passage is unnecessary and some delays are acceptable to road users and local communities for a few days each year. Because of the importance of retaining all-weather connectivity on core roads, drifts shall only be used on non-core roads.

Drifts are designed to provide a firm driving surface along the bed of the watercourse, where traffic can pass when water levels are moderate. This is achieved through the construction of a lowered concrete pavement through the watercourse, with vehicles driving through the shallow water. The primary objective in the design of a drift is to provide a suitable surface for vehicles to drive across while creating minimal disturbance to the water flow. Drift slabs should therefore follow, as closely as possible, the bed of the watercourse, and should never be more than 200 mm above the existing bed level. Slabs which are constructed more than 200 mm above the existing bed level are likely to cause severe erosion downstream of the drift, requiring frequent maintenance. A typical drift constructed in Vanuatu is shown in Figure 38.

Figure 38: 'Before and After' Drift Construction

Drifts shall only be used for small watercourse road crossings where the design can be configured to ensure the depth of water flowing across the road during most conditions is kept below 200 mm. During cyclones and storms, when the drift would be closed to traffic, the depth of flow may be allowed to exceed 200 mm.

It is essential to erect guideposts and flood gauges at each drift so that the edges of the road are clearly defined, and water depth can easily be determined by vehicle drivers before deciding whether to drive through the drift. The flood gauges should be marked to show clearly when the depth of water is greater than 300mm and warning signs should warn drivers not to cross the drift if the depth exceeds 300mm. Water depths greater than 300mm are able to sweep a vehicle off the drift and into the downstream watercourse.

The structural performance of concrete drifts during cyclone conditions in Vanuatu has generally been good, with some erosion to surrounding embankments and approaches but very little damage caused to concrete elements. Drifts are therefore considered to be a good option for achieving long-term resilience but can only be used on non-core roads which can be allowed to close occasionally.

Using the design methods described in previous sections, the designer should estimate the peak flow and associated water velocity at the drift for an ARI of 10 years (see Table 13). Although vehicles may not be able to cross the drift during periods of high water it is essential that the drift slab extends beyond the highest flood level to ensure that scour and erosion will not take place at each end of the drift.

The drift should also be designed to limit downstream peak flow velocity to the values given in Table 20 to avoid downstream turbulence and resulting erosion.

Table 20: Allowable Water Velocities Downstream of Drift

Material Downstream of Drift	Allowable Water Velocity (m/s)
Stable Rock	4.5
Stones and Boulders > 150mm	3.5
Gravel or Established Grass Cover	2.5
Stiff Soils (Clays)	2.0
Loose Soils (Sands, Silts, Silty Clays)	1.5

The length and longitudinal profile of the drift should therefore be adjusted during design to be able to contain the peak flow and to limit downstream velocity as shown in Figure 39.

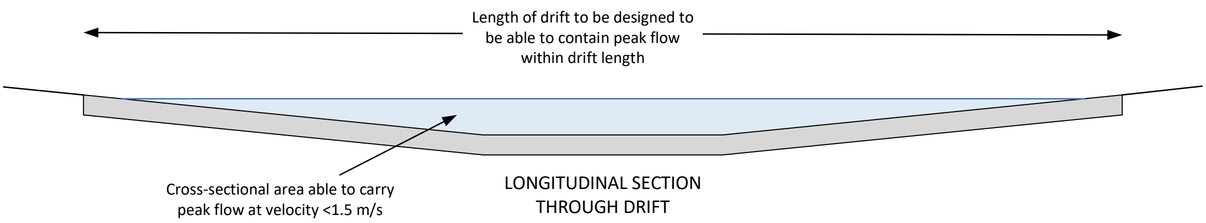


Figure 39: Longitudinal Profile through Drift at Peak Flow

5.10 Piped Culverts, Box Culverts and Bridges

5.10.1 Selection of Appropriate Crossing Type

In situations where the construction of a drift is inappropriate, the watercourse shall cross the road through a culvert beneath the road or through a bridge which carries the road over the watercourse.

Table 21 suggests appropriate solutions for various road/watercourse interface contexts. However, the designer is responsible for ensuring the final selected solution has sufficient capacity to be able to handle the peak flow.

Table 21: Suggested Crossing Types

Watercourse Type	Suggested Crossing Type
Small watercourse crossing up to 3 m width on non-core road	Drift or pipe culvert
Small watercourse crossing up to 3 m width on core road	Pipe culvert
Small/Medium watercourse crossing 3m – 6m width	Single or multiple pipe culvert
Medium watercourse crossing 6m – 15m width	Simple bridge, single box culvert or multiple cell box culvert
Large watercourse crossing 15m – 25m width	Multiple cell box culvert or single span bridge
Very large watercourses > 25m width	Multiple span bridge (although prestressed solutions may allow spans up to 45m)

5.10.2 Layout and Geometric Guidance

The minimum diameter for pipe culverts carrying natural watercourses to allow maintenance and to avoid blockages is 600mm. Similarly, the minimum dimensions for a box culvert carrying a natural watercourse are 600mm width and 600mm height. Smaller pipe diameters may be used for local cross-drains which carry road corridor run-off, but these should be a minimum of 450mm diameter to allow maintenance.

Culverts shall be located to follow the line and level of the existing watercourse as closely as possible. Sharp changes of direction should be avoided as this leads to erosion of the outer bank. The ideal grade line for a culvert is one that produces neither silting, excessive velocities or scour. Normally, the grade of the culvert should coincide with the stream bed. However, designers should try to set the minimum gradient for any culvert to 2% to prevent silting.

It is often possible for the road designer to adjust the alignment of the road to select an optimum crossing point. Where this is possible, the designer should consider the following design principles in selecting a suitable road/watercourse crossing point:

- select an area with well-defined banks. The watercourse is generally narrower at these locations and stable banks indicate a stable stream flow
- select a crossing point away from curves in the watercourse alignment. These areas are often unstable and subject to erosion on the outside of the curve. Also, a watercourse is often wider on a curve
- select an area with uniform stream gradient. An increasing gradient increases erosion and scour potential. A decreasing gradient can cause siltation and build-up of debris

- select a location where the watercourse bed is made up of relatively non-erodible materials to reduce scour potential
- align the road horizontally to cross at right angles to the stream to reduce the length of the culvert crossing, and
- cross the stream at the minimum road elevation necessary to stay above the design flood flow.

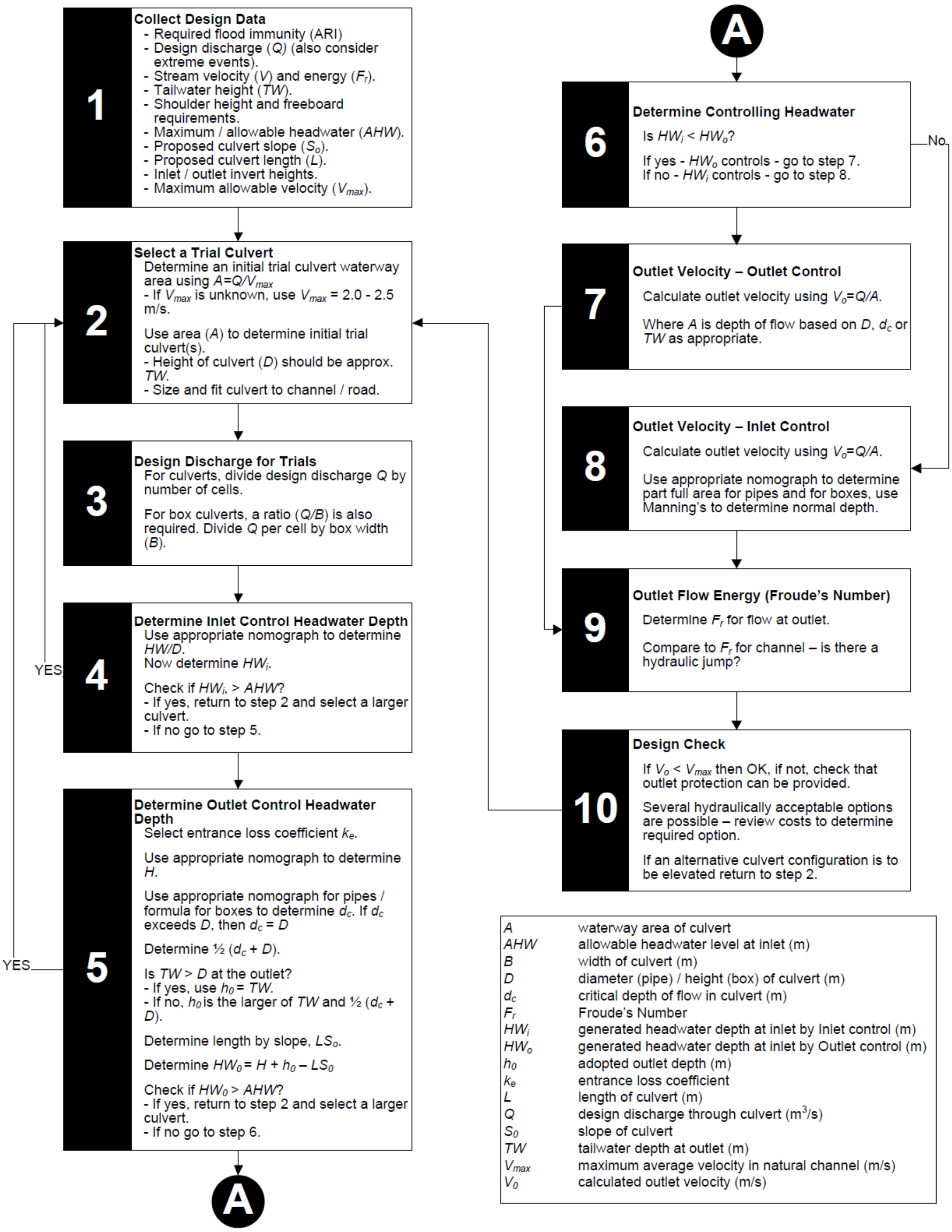
These principles also apply to the location of bridge crossings.

In Vanuatu, concrete pipe culverts have been found to be much more resilient over time than corrugated (Armco) pipe culverts which are subject to corrosion and are less resilient to storm damage. Therefore, designers should generally select concrete pipe culverts for all new pipe crossings. Pipes manufactured of other materials may also be considered if they provide the required design life and strength to withstand road embankment and traffic loading. Manufacturer’s recommended use and installation details including minimum cover above the pipe should always be followed.

5.10.3 Hydraulic Design

Inadequate culvert capacity can result in severe damage and expensive remedial works to roads. At the location of all natural watercourses an appropriate culvert or other crossing, such as a drift, must be provided to be able to deal with the estimated design peak flow.

Full hydraulic design of culverts is a complex design process requiring inlet control and outlet control checks. This is described in detail in Section 3.10 of Austroads Guide to Road Design Part 5B so is not repeated here. The design flowchart extracted from the Austroads guidance is shown as Figure 40.



Source: Adapted from DTMR (2010).

Figure 40: Culvert Design Flowchart from Austroads Guide to Road Design Part 5B

A simplified approach to pipe culvert hydraulic design is to derive the capacity of a pipe when flowing full from the relevant Colebrook-White hydraulic design charts. The design chart for a pipe roughness of 0.6 mm, which is appropriate for a concrete pipe, is shown as Figure 41. This has been annotated to show the pipes applicable to a Vanuatu road design setting, these being: pipes of 600 mm diameter or larger, pipes laid at a minimum gradient of 2% and pipes with flow velocities of 5.5 m/s or less.

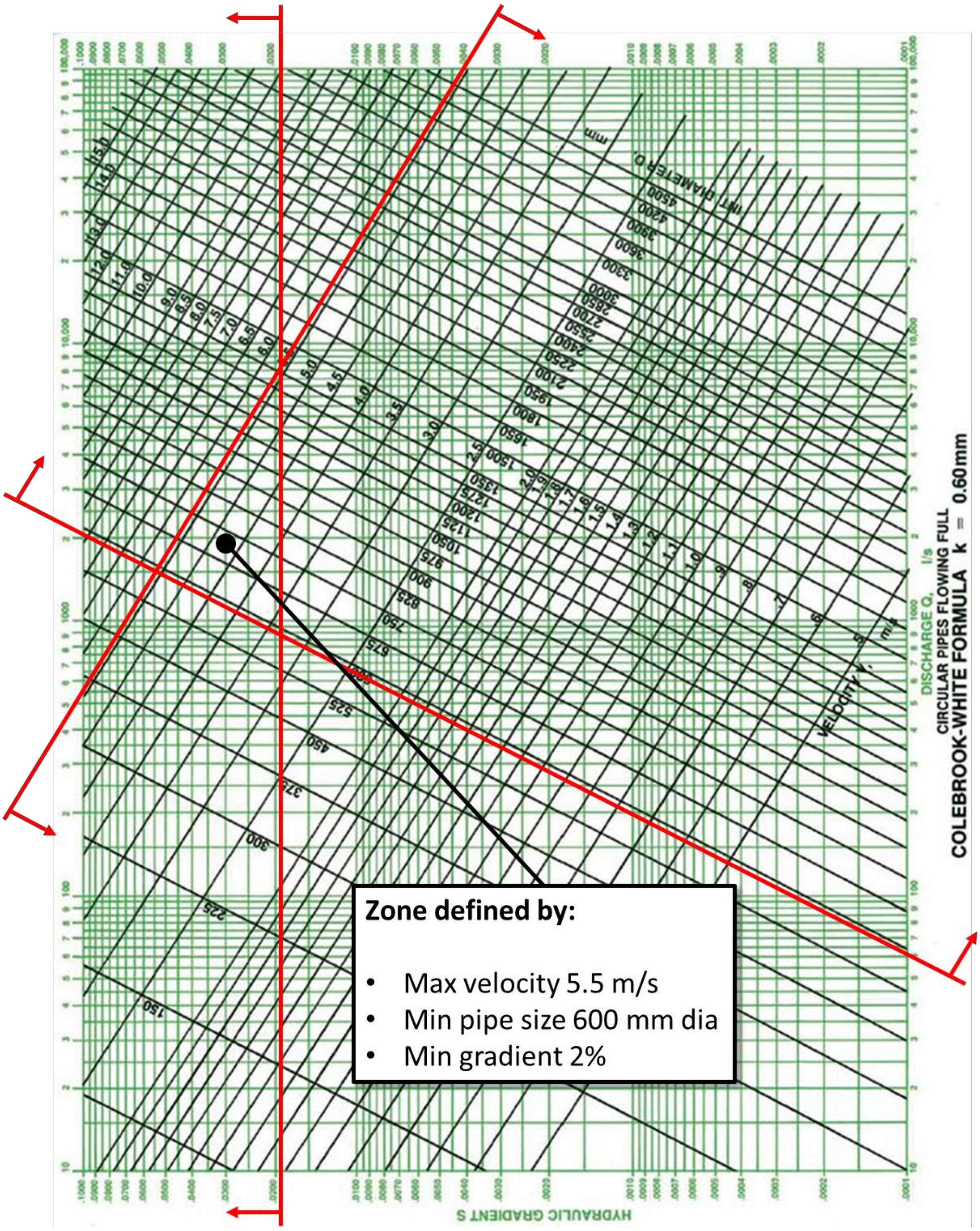


Figure 41: Annotated Colebrook-White Pipe Hydraulic Design Chart

Pipe discharge capacities, Q, and associated flow velocities, V, derived from Figure 41 are presented in Table 22. Using these pipe capacities to design pipe culverts for peak flow is likely to result in a conservative design. A less expensive optimised design is likely to be achieved by following the more detailed Austroads design steps shown in Figure 40.

Table 22: Colebrook -White Discharge Capacities and Flow Velocities for Concrete Pipes Flowing Full

Pipe Diameter (mm)		Pipe Slope			
		2%	3%	4%	5%
600	Capacity, Q (m3/s)	1.0	1.2	1.4	1.5
	Velocity, V (m/s)	3.4	4.3	4.8	5.5
750	Capacity, Q (m3/s)	1.7	2.1	2.5	Do not use – velocity too high
	Velocity, V (m/s)	3.9	4.8	5.7	
900	Capacity, Q (m3/s)	2.8	3.5	Do not use – velocity too high	Do not use – velocity too high
	Velocity, V (m/s)	4.4	5.5		
1050	Capacity, Q (m3/s)	4.2	Do not use – velocity too high	Do not use – velocity too high	Do not use – velocity too high
	Velocity, V (m/s)	4.8			
1200	Capacity, Q (m3/s)	6.0	Do not use – velocity too high	Do not use – velocity too high	Do not use – velocity too high
	Velocity, V (m/s)	5.3			

A simplified approach to the box culverts is to allow a 300mm freeboard above the peak water level and design the culvert as an open channel following the steps described in Section 5.8.2 for open channels. An example of an idealised channel section is shown in Figure 42. However, this simplified method will also usually lead to a conservative design and should therefore be used with caution. If the simplified design results in a large and expensive culvert, the designer should use the detailed design steps described in Austroads Guide to Road Design Part 5B to develop an optimised design (Figure 40).

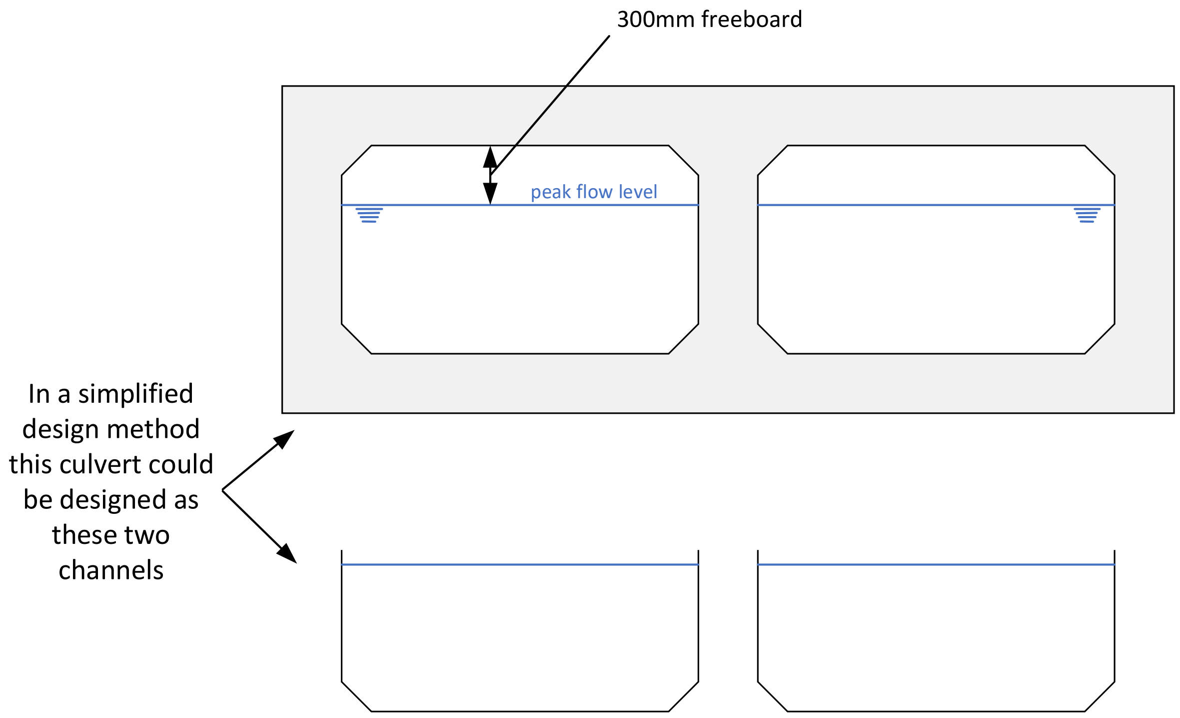


Figure 42: Simplified Culvert Design Method (Idealised as Open Channels)

Designers should develop culvert designs which aim to keep the peak outlet velocity below 5.5 m/s, although this will not be possible in all locations, especially if the culvert is on a significant gradient.

As part of hydraulic design, designers should also identify those watercourse crossings which might be prone to the impacts of storm debris, especially large tree trunks or branches which can block the entrance to culverts as shown in Figure 43.

Figure 43 : Culvert Blocked by Storm Debris - Vanuatu, 2023

In these cases, the designer should adjust the culvert design by:

- increasing the size of culverts to allow the passage of debris
- including clearing of upstream areas of potential storm debris in the construction contract (such as tree clearing along the line of the watercourse), or
- including bar screens fitted to upstream inlets to catch debris (although these will require regular clearing).

5.10.4 Design of Inlets and Outlets

Culvert inlets should provide a smooth entry without abrupt changes in direction or drops that cause turbulence. Where such changes in flow direction are unavoidable, they should be adequately protected by reinforced concrete, gabion mattresses or rip rap. Geotextile material should be placed under gabions or riprap. In areas where water velocities are predicted to be high, gabions should be further strengthened by application of an external mortar coat to cover and protect the gabion mesh.

The invert level at the outlet of a culvert should coincide with watercourse bed 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.

All inlet and outlet structures should include cut-off walls to protect them from being undermined during severe storm flows. The minimum depth of cut-off wall should be 0.6m. Suggested cut-off wall depths for various watercourse conditions and peak water velocities are provided in Table 23. These may be adjusted by designers to suit local experience with the performance of cut-off walls during storms.

Table 23: Suggested Cut-Off Wall Depths

Watercourse Bed Material		Peak Water Velocity (m/s)				
		1.0 m/s	2.0 m/s	3.0 m/s	4.0 m/s	5.0 m/s
		Suggested Cut-Off Wall Depths (m)				
HARD	Stable Rock	0.6	0.6	0.6	0.6	0.6
	Stones and Boulders > 150mm	0.7	0.725	0.75	0.775	0.8
	Gravel or Established Grass Cover	0.8	0.85	0.9	0.95	1.0
	Stiff Soils (Clays)	0.9	0.975	1.05	1.125	1.2
LOOSE	Loose Soils (Sands, Silts, Silty Clays)	1.0	1.1	1.2	1.3	1.4

Energy dissipaters, such as large rocks, to provide sufficient protection against bed scour or erosion, should be placed to protect culvert outlets on watercourses.

5.11 Slope Design

During the investigation and design of new cut slopes, an assessment of potential slope instability problems should be made. This involves a review of the topography, geology, soil and rock properties and weathering, surface and groundwater drainage and inspection of existing slopes and past instability history in the area and is best carried out by a geotechnical or engineering geological specialist. Detailed geotechnical stability analysis leading to the selection of an appropriate cut slope is not included in this design guide. Designers should refer to specialist geotechnical guidance[22] and the guidance on slope stability treatments provided in Austroads Guide to Road Design Part 1, Section B.7.2.

When assessing slopes for climate resilience, it is important to identify:

- the potential water paths and approach angles, and
- whether the water will flow over the slope and the impact of the water on the face of the slope.

By far the best solution to protect cut slope stability is to divert water away from the cut slope by installation of an interceptor drain as shown in Figure 27.

In areas where erosion of the exposed slope is likely, or where erosion has taken place and requires remedial work, the designer should consider the slope protection methods described in Austroads Guide to Road design Part 1, which include:

- benching of cut slopes

[22] For example, the Geotechnical Design Standards of the Queensland Department of Transport and Main Roads, available here: https://www.tmr.qld.gov.au/_/media/busind/techstdpubs/geotechnical/geotechdesignstandardminreq.pdf?sc_lang=en&hash=414C50F7D71D6D6A1CCC33C168142FCD

- use of soil nailing or rock anchors
- use of reinforced soil retaining walls
- use of gabions as walls or slope protection.

In some cases, the installation of simple rip-rap face protection may be sufficient to protect the slope surface from water damage. Depending on the situation, the rip rap could be grouted to provide further against water ingress into the slope. All non-permeable slope protection solutions must include weepholes to allow water to drain from the slope face.

Vegetation should be encouraged on all roadway slopes that will accept plant growth. This usually requires that slopes be constructed at a maximum slope of 1V:1.5H. Vegetation helps to reinforce the soil, prevents excess erosion and reduces rainwater runoff. Designers should consider the introduction of deep-rooted grasses such as Vetiver Grass (Chrysopogon Zizanioides), which was originally native to India, but is now being used for slope protection in Australia, South-East Asia, Africa and South America, as shown in Figure 44. Vetiver grass is a non-invasive bunchgrass whose roots can penetrate between 2 and 4 m deep and is thus excellent at binding soil and resisting erosion.

Figure 44: Use of Vetiver Grass for Slope Stabilisation

Embankment slopes should be designed to suit the stability of the embankment material. For firm soils such as firm clays and coronous material, a side slope of 1V:1.5H is usually acceptable. For looser sands and silty soils, side slopes should be around 1V:3H.

5.12 Other Methods to Increase Resilience

In large catchment areas, the use of upstream flood-control dams and structures (usually in cooperation with other national agencies) could be considered to try and minimise the effects of storms at the road/watercourse interface. This could be considered as part of water harvesting undertaken in cooperation with the Ministry of Agriculture Livestock Forestry Fisheries & Biosecurity (MALFFB).

Even if the drainage system of a new road has been carefully designed, it is likely that for several years after construction it will be necessary to observe its performance closely and to make additions and amendments to suit actual performance. A formal annual drainage assessment should be undertaken by PWD Divisional Teams, especially during the first few years after construction.

6. Structural Design Standards

This design guide does not attempt to replace recognised structural design standards which should be referred to by designers during the detailed design of retaining walls, drifts, culverts and bridges. PWD's standard drawings provide detailed designs for various walls, culverts and drifts and these should be used by designers as much as possible to reduce the need for bespoke designs.

There are many guidelines and codes available for the design and construction of larger structures using concrete and steel, such as Overseas Road Note 9 (TRL, 2000) for bridges[23] or the Australian Guidebook for Structural Engineers[24]. A very useful guide for smaller structures is 'Small Structures for Rural Roads: A Practical Planning, Design, Construction & Maintenance Guide (Larcher et al, 2010[25])' which provides comprehensive information to assist engineers and technicians in the planning, design and provision of small road structures in rural settings. Volume 4 of this guide includes a set of detailed design drawings covering drifts, culverts, vented fords, large bore culverts and small bridges. These can be used to supplement the PWD standard drawings.

[23] Available here: https://trl.co.uk/uploads/trl/documents/ORN9.pdf
[24] Available here: https://www.istructe.org/resources/library/australian-guidebook-for-structural-engineers/
[25] Available here: https://www.gtkp.com/themepage/gtkp-archives/rural-transport/sustainable-engineering-solutions/low-cost-structures/small-structures-for-rural-roads-guideline/

7. Pavement Design

7.1 Pavement Selection

The Government of Vanuatu's first priority in its Roads Policy and Strategy is to seal all designated 'core' roads. Every island with public roads has at least one designated 'core' road. These roads constitute Vanuatu's 'core' road network – the economic backbone of the network. They include all urban and township roads and the most economically important rural roads. Fibre-reinforced cement concrete (FR concrete) and asphalt concrete (AC) are the Government's preferred sealing technologies because they are sustainable and maintainable in the Vanuatu context.

The Government's preferred sealing material is fibre-reinforced concrete (FRC). It is resilient to Vanuatu's natural conditions, requires little maintenance, and is cost effective on a total life-cycle basis. Fibre reinforcing provides sufficient tensile strength for most road situations in Vanuatu. Moreover, local contractors are able to build good quality FRC roads, employing local labour, whereas the construction of asphalt concrete requires specialist mixing plants and pavers making it a difficult choice for paving on most smaller islands. Based on these policy and strategy objectives, target pavement types for core roads and non-core roads were set out in Tables 1 and 2 in Section 2 of this guide. The pavement elements from those tables are reproduced here as Table 24.

Table 24: Pavement Selection Matrix

	Core Roads				Non-Core Rural Roads	
	Urban Roads		Township Roads	Rural Roads		
2-way Average Daily Traffic	**> 500**	**<500**	**all**	**All**	**>200**	**<200**
Sealed/Unsealed	Sealed	Sealed	Sealed	Sealed	Unsealed	Unsealed
Pavement Type - with underground utilities	AC	Bit. Seal	Bit. Seal	n/a	n/a	n/a
Pavement Type - without underground utilities - flat and rolling	AC	FRC	FRC	FRC or Bit. Seal*	gravel	earth
Pavement Type - without underground utilities - steep grades > 10%	FRC	FRC	FRC	FRC	FRC	FRC

AC – Asphaltic Concrete, Bit. Seal – Bituminous Seal such as DBST, FRC = Fibre-Reinforced Concrete.

*FRC is preferred where affordable, but a bituminous seal may also be considered to meet Public Roads Strategy targets for sealing of core roads.

Concrete pavements should be extended at the foot of slopes to include the zone where water may cross the road or cause edge damage to the road pavement. Lengths of concrete pavement either side of each watercourse crossing location may also be useful to improve resilience to damage if the watercourse overtops the road.

7.2 Pavement Layers

A road pavement generally consists of distinct layers as shown in Figure 46. The design may require a three-layer solution comprising sub-base, base course and wearing course, but for some rural roads in Vanuatu, a single course may be sufficient.

The selection of numbers of pavement layers and their thicknesses is selected based upon:

- the strength of the underlying subgrade, and
- predicted traffic loading (especially numbers of heavy vehicles).

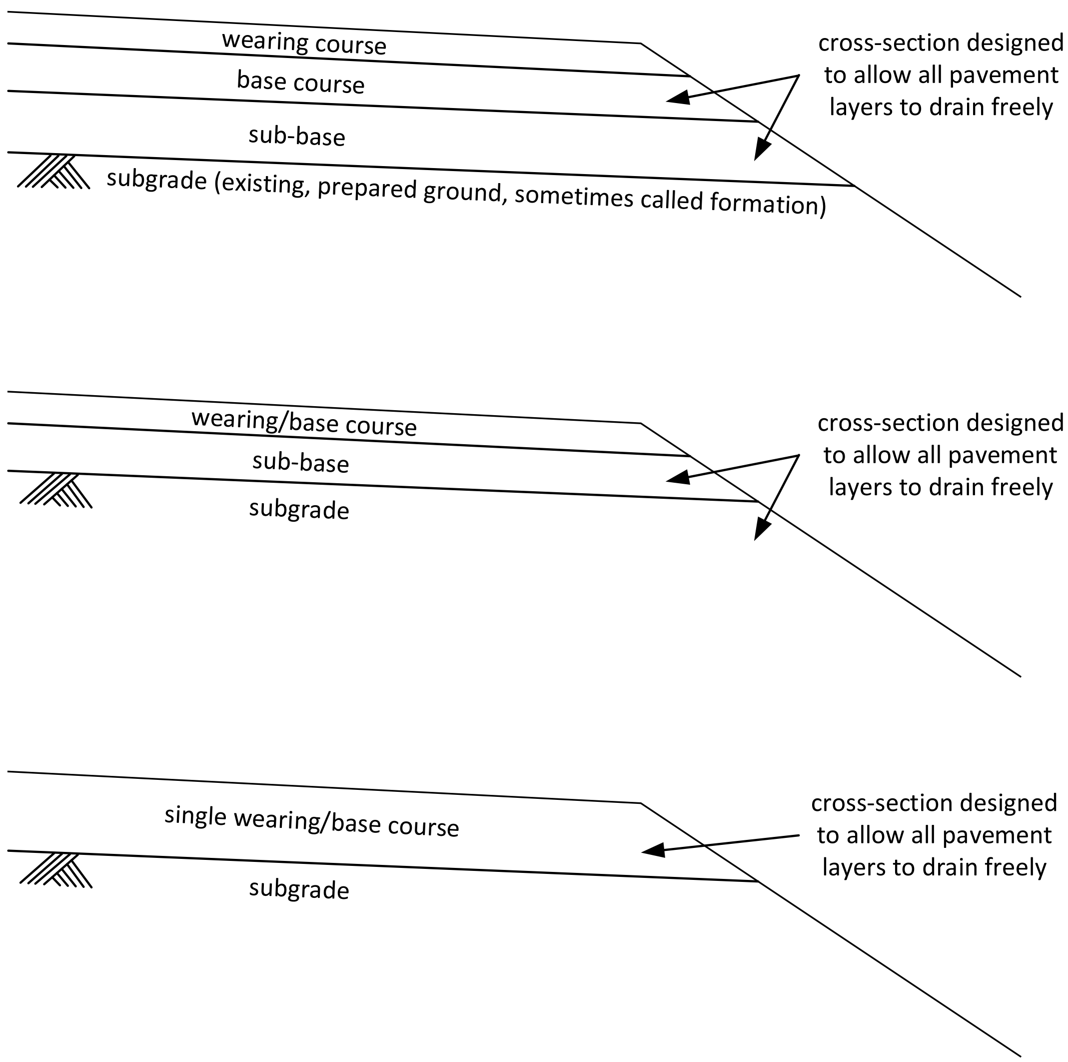


Figure 45: Aggregate Pavement Layer Options

The subgrade consists of in situ soil or rock, or previously placed fill, over which a road is to be constructed. The support provided by the subgrade to the upper road pavement layers is the most important factor in determining pavement design thickness. The level of subgrade support is dependent upon soil type, material density and moisture content both during construction and across the seasonal changes experienced during road operation. Subgrade strength is commonly defined in terms of the California Bearing Ratio (CBR), which essentially compares the penetration resistance of a soil to the penetration resistance of a standard crushed rock. The subgrade surface shall be carefully graded and rolled to provide a hardened foundation surface free of deviations or local depressions in readiness for laying the first pavement layer.

A sub-base is the optional lower layer within the road pavement, used if additional strength is required. It usually consists of compacted, granular material. The main function of the sub-base is to provide additional structural strength, by distributing heavy wheel loads over a larger subgrade area.

The base course is usually a layer of crushed aggregate placed directly onto the subgrade or sub-base if used. Material specifications for the base course are more stringent than for sub-base material to provide greater strength.

The wearing course is the uppermost layer of the pavement that comes into direct contact with vehicle tyres. Unsealed wearing courses should be constructed with well-graded gravel with some plasticity to help bind the material under traffic loads and to minimise dust emissions. The primary function of the wearing course is to provide a more tightly bound surface to provide a comfortable smooth ride and to provide surface friction for braking.

7.3 Subgrade Evaluation

The CBR of the subgrade may be evaluated by field testing, laboratory testing or estimated in the field based upon experience.

One of the principal objectives of subgrade evaluation is to determine, for design purposes, a subgrade ‘design CBR’ value at the density and moisture conditions which are expected to prevail in-service for the long-term. A subgrade design CBR is determined for each identifiable section of road defined according to changing topography, drainage and soil type.

The objective of subgrade evaluation is to estimate the support provided to the pavement during its lifetime. The degree of support is dependent upon the subgrade material type, its moisture content under operation and degree of compaction. The designer should be aware that moisture content variations will occur in the subgrade material, both along the road (due to topography, drainage, underlying soil profile, etc.) and cyclically with time (due to seasonal wetting and drying cycles).

The most common method of determining subgrade design CBR in Vanuatu is from inspection and classification of the subgrade material. This approach is useful when no other relevant information is available and extensive investigations are difficult in remote areas and not warranted. Typical presumptive values of CBR are provided in Table 25.

However, for the design of more expensive asphalt concrete or fibre-reinforced pavements, where an unnecessary increase in pavement thickness would have a significant impact on construction costs, it is recommended to undertake a subgrade evaluation based on field testing. Dynamic Cone Penetrometer (DCP) tests should be carried out in accordance with AS 1289.6.3.2. The use of DCP should be restricted to fine-grained subgrades to avoid misleading results as a result of the influence of large particles. The resulting CBR can be determined from the results of DCP testing using Figure 47 taken from Austroads Guide to Pavement Technology Part 2. This is a general relationship that suits most fine-grained cohesive soil types.

Table 25: Typical Presumptive Subgrade Design CBR Values

Description of Subgrade		Typical CBR Values (%)	
Material	**Unified Soil Classification**	**Excellent to Good Drainage**	**Fair to Poor Drainage**
Highly Plastic Clay	CH	5	2 – 3
Silt	ML	4	2
Silty Clay	CL	5 - 6	3 – 4
Sandy Clay	SC	5 - 6	3 – 4
Sand	SW, SP	10 - 18	10 - 18
Silt - Gravel Mix	GM	40 - 60	40 – 60
Poorly Graded Gravel	GP	30 - 60	30 – 60
Well -Graded Gravel	GW	40- 80	40 - 80

Source: Austroads Guide to Pavement Technology Part 2 and Road Research Laboratory, UK

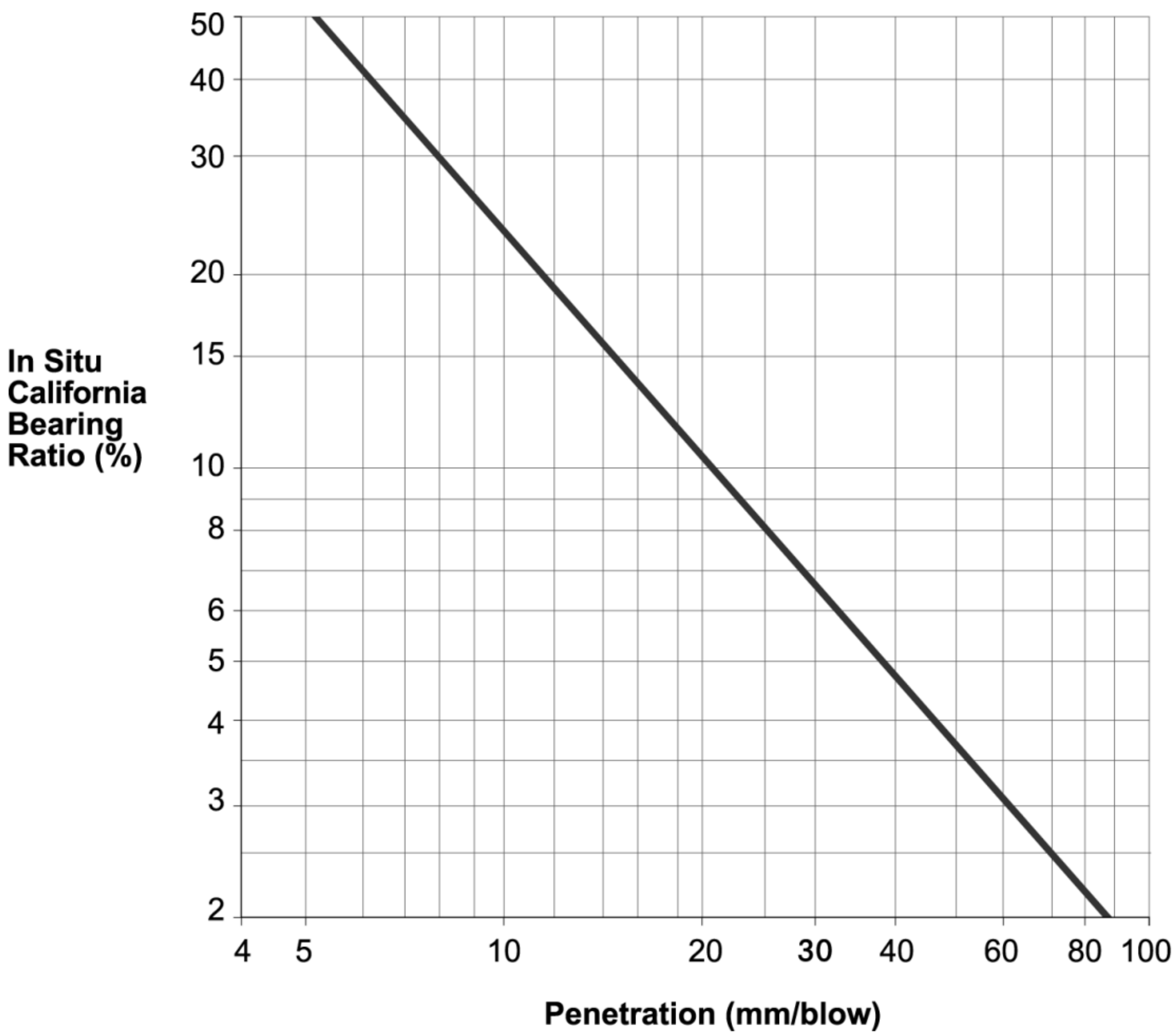


Figure 46: Correlation between DCP and CBR for Fine-Grained Cohesive Soils

DCP tests should be undertaken at around 300 metres spacing along the line of the road under design. A single project must include at least three tests to give confidence in the CBR result. Where testing shows variation along a project, at least three test sites should be selected in each subgrade section, defined by varying topography, drainage and soil type. A design subgrade CBR should then be determined for each section taking the 10th percentile low value of all measured CBRs.

7.4 Design Traffic

Light vehicles such as cars contribute very little to structural deterioration of pavements. Only commercial or heavy vehicles are considered during pavement design. A commercial vehicle is defined as one with more than two axles or with dual rear tyres. Traffic volumes in terms of the number and type of heavy vehicles over a selected design life are required to calculate the number of equivalent standard axles (ESAs). Design lives for various pavement types are suggested in Table 26.

Table 26: Recommended Pavement Design Lives

Pavement Type	Suggested Target Pavement Design Life (years)
Concrete	40 years
Asphalt Concrete	20 years
Bituminous Sealed	15 years
Gravel	8 years

Across Vanuatu, there is generally very little heavy traffic and therefore the number of ESAs should always be below 10^5 ESA, and on average is more likely to be around 10^3 ESA. For ease of design and to improve pavement strength and resilience, roads in Vanuatu are generally designed to carry 10^5 ESA over their design life. However, for stretches of road that may be subject to local heavy traffic, for example near a port or a quarry, designers should make a separate assessment of ESA volume[26].

7.5 Pavement Design

In theory it makes no difference to the structural strength of a pavement whether the road is sealed with a spray and chip seal or unsealed. A spray and chip seal adds no strength to a pavement but provides greater abrasive resistance to traffic and reduces penetration of moisture into the pavement to extend its life. The design of aggregate road pavement layers and thicknesses is based upon the subgrade design CBR and the number of ESAs over the pavement design life.

Australian Pavement Research Group Report No. 21 (APRG 1998) provides pavement thickness design curves for constructing both sealed and unsealed rural roads of low structural integrity with granular materials. The empirical design chart is shown in Figure 48 and is based on a performance probability level of 80% (i.e. the approach gives a 20% risk of rehabilitation of the pavement being required before the end of the design life).

[26] TRL Road Notes 31 and 40 provide useful guidance on calculating the design ESA for a road. Available here: https://www.trl.co.uk/projects/road-note-31---5th-edition and here: https://trl.co.uk/uploads/trl/documents/ORN40.pdf

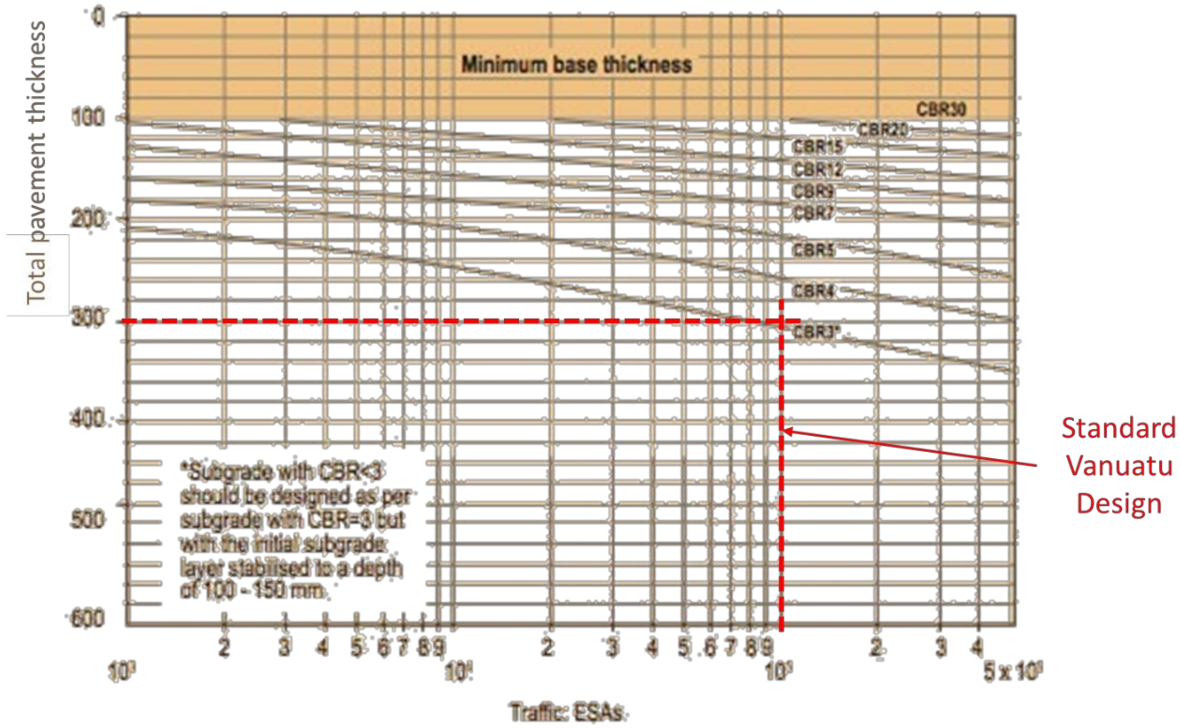


Figure 47: Design Chart for Granular Pavements (APRG 1998)

In Vanuatu, the standard design approach has traditionally been to assume a low subgrade CBR of around 3% and design traffic of 10^5 ESA, which gives total gravel pavement thickness of 300mm as shown in Figure 48. This is reflected throughout the PWD standard drawings which are based on the pavement sections shown in Figure 49.

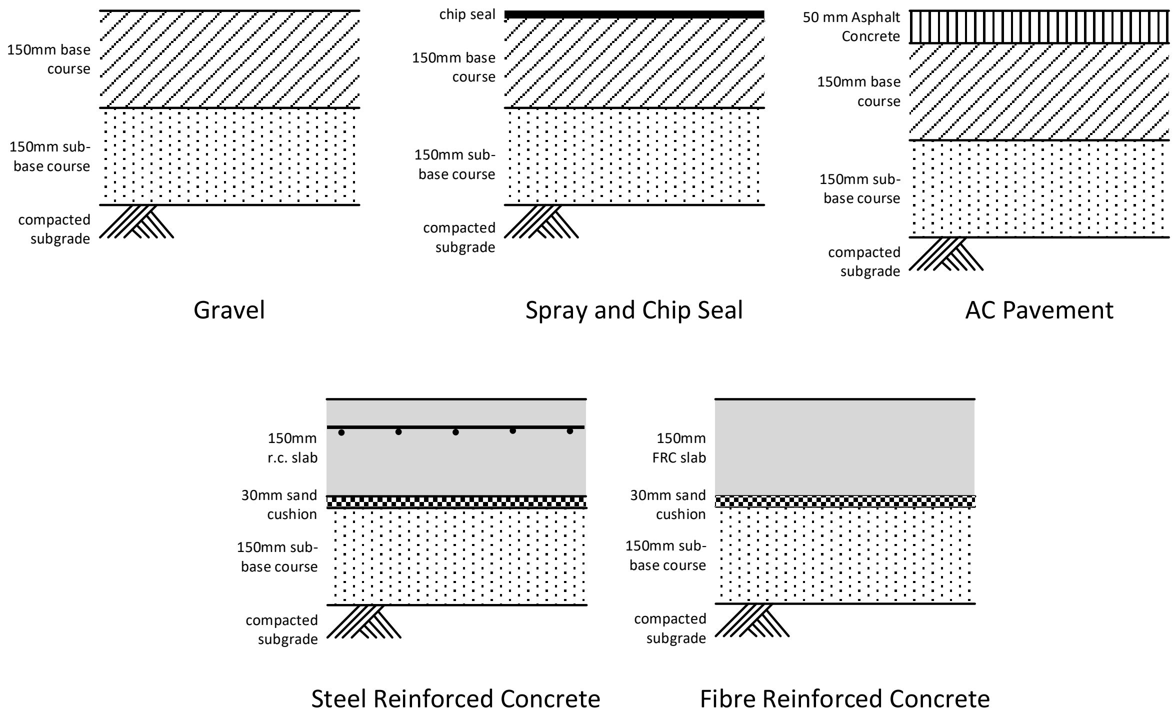


Figure 48: Vanuatu Standard Pavement Designs

Generally, it is recommended that designers follow these standard designs but, in some circumstances, a bespoke pavement design may be more appropriate. Such circumstances include:

- strong subgrade conditions allowing designers to decrease pavement thicknesses thus reducing construction costs
- very weak subgrade conditions requiring special subgrade treatment or thicker pavement design, and
- high volumes of heavy vehicles requiring a more detailed consideration of pavement design life traffic expressed as ESAs.

8. Design for Road Safety

8.1 Road Safety Objectives and Target Areas

PWD's objective is to gradually eliminate safety blackspots on the road network by making improvements to the road network which reduce hazards and encourage safer driver behaviour. This includes the incorporation of safety features for pedestrians. Safety improvements will target the following:

- **Urban Roads** - these are sealed, busy and potentially higher speed roads and may require safety improvement interventions to deal with:
    - poorly configured intersections with unclear priorities for drivers and pedestrians
    - close spacing of intersections and property accesses
    - lack of parking/queuing space leading to congestion and blocked sight lines
    - intersections with obstructed or poor sight lines for drivers and pedestrians
    - road sections with high pedestrian activity and turning movements near activity centres such as schools, hospitals, markets, and shopping malls, and
    - road sections with generally high levels of pedestrian traffic and lack of well-marked safe crossing points for pedestrians.

- **Rural Roads** - Most of these are (or will be) sealed roads. They will carry a mix of traffic types and volumes, which may be relatively high speed. Safety improvements may be necessary to deal with:
    - poorly configured intersections (e.g. acute angle with poor sight lines or high-speed entry to major road)
    - intersections with poor or obstructed sight lines (e.g. crests of a hill, entering on the inside of a major road curve; obstruction of sight lines by vegetation)
    - road sections adjacent schools and other activity centres with high levels of pedestrians
    - tight curves on higher speed sections of road, and
    - narrowing of carriageways at culverts or bridge crossings on higher speed road sections.

8.2 Design Principles for Road Safety

There are several key principles of design that can considerably improve the safety of Vanuatu's roads. These are:

- **Designing for all Road Users -** this includes non-motorised vehicles such as bicycles, and in particular, pedestrians. In Vanuatu, schoolchildren usually walk to their local school and therefore make up a large proportion of pedestrians. The provision for all users has implications which must be considered during development of the cross-section for the road.
- **Providing a Clear and Consistent Message to the Driver** - road layouts should be easily and immediately understood by road users and should not present them with any sudden surprises. Designers should ensure that demands are not placed upon the road user which are beyond his or her ability to manage.

- **Encouraging Appropriate Speeds and Behaviour by Design -** traffic speed can be influenced by configuring an appropriate appearance of the road, for example by providing clear visual clues such as changing the shoulder treatment or installing prominent signage.
- **Conflicts** - cannot be avoided entirely but can be reduced by design, such as staggering junctions, or using guardrails to channel pedestrians to safer crossing points.
- **Creating a Forgiving Road Environment** – which accommodates driver error or vehicle failure to the extent that this is possible without significantly increasing costs.

Paying careful attention to the geometric design of roads as described in Section 4 is important to achieve a safe road environment. However, there are several other steps that could be taken to improve safety. These include:

- use of clear road markings and signage
- traffic calming measures to reduce speeds in populated and highly pedestrianised areas, especially speed humps
- segregating non-motorised and motorised vehicles in populated areas and providing safe, clearly marked crossing points for pedestrians, and
- providing crash barriers at dangerous locations.

Guidance on each of these approaches is provided in the following sections.

8.3 Traffic Signs

Clear signing is an essential part of the road system. Signs used in Vanuatu provide three key functions:

- **Regulatory Signs** - providing traffic control and regulation, such as legal speed limits
- **Warning Signs** - informing and warning drivers of upcoming hazards on or adjacent to the road such as sharp bends or junctions
- **Information/Guide Signs** - providing road users with information and guidance, such as direction signs.

For cost effectiveness, signs should be restricted to situations where there is a real need to inform road users. For an existing road that is to be upgraded, the hazardous locations should be identified at an early stage and, ideally, should be corrected in the new design. If this is not possible, then suitable permanent road signs should be installed.

Road signs in Vanuatu generally follow Australian standards, and therefore road designers should refer to the relevant Austroads publication, Austroads 'Guide to Traffic Management Part 10: Transport Control – Types of Devices'[27]. Standard sign shapes and colours, and typical usage of various types of signs, are presented in Australian Standard AS 1742. A comprehensive index of current standard signs is contained in AS 1742.1[28].

Regulatory signs are used to control the actions of road users in the interest of safety. They include traffic flow control signs that regulate the movement of traffic, command signs that tell you what to do under a given set of circumstances, and prohibition signs that indicate what is not allowed. It is an offence for road users to disobey regulatory signs. The most commonly

[27] Available here: https://austroads.com.au/publications/traffic-management/agtm10
[28] Available for download here: https://store.standards.org.au/product/as-1742-1-2021

used regulatory sign is the speed limit sign which indicates the maximum speed permitted on a road or over a particular section of the road.

Warning signs are used to alert drivers to dangers or potential hazards that are not clearly visible from a safe distance ahead. They are usually found some distance before the hazard to allow the driver enough time to react. The most common use for warning signs is to indicate situations where the geometric standards for a particular class of road have been changed along a short section of road. This is usually caused by a constraint of some kind that has prevented the standard from being applied continuously and therefore causes an unexpected and potentially dangerous situation. Examples are a sharp bend, a sudden narrowing of the road, an unexpectedly steep gradient, an unexpected school crossing or an upcoming speed hump. An important consideration on unpaved roads is that the road markings that are generally used on paved roads to improve safety cannot be applied to unpaved roads. This means that if drivers need to be warned of a hazard that is traditionally done by means of road markings this will have to be done by means of traffic signs.

Information or Guide signs provide information about the road ahead, so road users can plan their road and lane usage accordingly. Guidance signs indicate the route details, for example distances and directions to destinations and public facilities, as well as traffic lane arrangements ahead. Information and guidance signs are less vital on remote rural roads which are mostly used by locals.

8.4 Road Markings

Road markings can be thought of as traffic signs painted onto paved road surfaces, and consist primarily of centre lines, lane lines, no overtaking lines and edge lines. As with traffic signs, these too are classified into Regulatory, Warning and Information/Guidance markings. They have the same meanings as the traffic signs, and road users should react accordingly. Surface markings are painted in white or yellow according to the message they convey.

Other pavement markings such as ‘stop’, pedestrian crossings and various word and symbol markings may supplement pavement line markings. In cases where a warning is deemed necessary for safety reasons, but road markings cannot be used, road signs must be used instead.

The extent to which road markings, signs and other road furniture is required depends on the traffic volume, the type of road, and the degree of traffic control required for safe and efficient operation. Road markings are generally not justified on low volume roads. However, on a paved, two-lane road, a centre line is desirable.

8.5 Traffic Calming Measures

The seriousness of road accidents increases dramatically with speed and hence very significant improvements to road safety are possible if traffic can be slowed down in areas where pedestrians also use the road corridor. This process is called traffic calming. The effect of any traffic calming measure on all the road users should be carefully considered before they are installed.

The main type of traffic calming recommended for use in Vanuatu are the speed hump or raised pedestrian crossing. Speed humps are installed across the road extending uniformly from one side of the road to the other. If speed humps are too high, they can cause considerable vehicle damage, especially to long wheel-base vehicles such as buses. Speed humps may be used very effectively in villages and towns. It is suggested that the locations of speed humps should be discussed with local communities to identify the specific locations where pedestrians use the roads and where vehicles use high speeds.

The following should be considered when adopting speed humps or raised crossings:

- speed humps should only be provided where a clear need to slow traffic has been identified
- speed humps should cover the full width of the traffic running lanes but ponding of rainwater behind speed humps must be avoided
- stripes should be painted on speed humps to make them visible to drivers
- advance warning of speed humps should be provided using a road sign situated 50 metres before the hump. Marker posts could also be installed alongside the hump indicating the actual location of the hump. If used, marker posts should be fitted with reflectors so that they can be seen at night
- the use of speed humps should be avoided on slopes.

8.6 Pedestrian Crossings

Pedestrian crossings may only be applied to paved roads and are used where large numbers of pedestrians cross the road or where there is a special need for protection of vulnerable road users, for instance outside schools. Crossings may also be incorporated into urban junctions. Pedestrian crossings should not traverse more than two traffic lanes, using refuge islands to divide the carriageway if more than two lanes are to be crossed.

8.7 Guardrails

The geometric design of roads should be undertaken to reduce the need for guardrails to a minimum, but there will be some situations where their use is unavoidable, for example on excessively sharp bends on mountainous roads. Steel guardrails are one of the most effective types of safety barrier and commonly used because they are cost effective to install compared to stronger concrete barriers.

Guardrails are designed to physically prevent vehicles from crossing them. Their primary function is to prevent vehicles from leaving the road corridor at dangerous locations. It is suggested that they are used for the following situations:

- where embankment side slopes are more than 3m height and steeper than 1H:3V
- on the outside of tight bends where there is no safe run-off for vehicles
- on an unkerbed road where a vehicle leaving the carriageway could hit a roadside obstruction located in the road verge such as an electricity pole or lighting column.

9. Community Consultations

Although undertaking community consultations is not a technical element within road design, it is important that community consultations take place as part of the design process. Community consultations with affected communities are very useful to highlight local concerns and needs which can then be reflected in the design.

It is recommended that consultations are led by the Provincial Safeguards Officer, supported by the engineering team responsible for the road project design. Consultations should take place during the early stages of design so that feedback can be incorporated into the project.

At the start of the consultation, the design engineers should inform the communities of the objectives for the project, the broad outline of the design and the extents of the project. The consultation team should encourage local communities to input to the design process by providing all relevant information, which could include:

- sections of road areas prone to localised regular flooding
- sections of road subject to flooding during storms
- areas of significant pedestrian activity, especially pedestrian crossing points
- known road safety hazards, especially if this has resulted in accidents, and
- areas where roadside parking may be useful, such as bus laybys or parking near to local markets.

10. Completing Technical Documents for Tendering and Construction

From the start of the design process, road designers should consider the final set of technical documents which are required to convey the design in an unambiguous way to the construction teams which may include PWD construction-stage staff, supervision consultants or a contractor. Technical documentation should make the design intent clear and not leave room for incorrect interpretation on site. Typically, a set of road project drawings should include:

- project location plan showing the limits of the site and areas designated for working areas
- plans and profiles showing horizontal and vertical alignments, the application of superelevation, the position of all structures and any setting out information including temporary benchmark information
- typical and, if required for clarity, specific, cross-sections through the full road corridor width including earthworks and drainage
- drainage layout plans and schedules with types of drainage elements, sizes of each element and proposed invert levels
- slope and watercourse protection locations and details
- pavement thickness details and shoulder/edge/footpath details
- details of all structural components including reinforcement details, strength of concrete, etc.
- landscaping, including any planting for slope stabilization, and
- layout plans and details for signs and markings.

The project drawings should make use of the PWD standard drawings as much as possible, either by inclusion of the full standard drawing or by extracting relevant details into project-specific drawings.

Road designers shall also consider where project-specific changes or additions to the PWD Standard Specification for Road and Bridge Works are required and issue these as a project-specific Addendum to the Standard Specifications. However, designers should only adjust the standard specifications if a new material or work method is not covered in the standard specification. In no circumstances should the Addendum be used to lower specification requirements.

11. Other Actions to Increase Infrastructure Resilience

This design guide sets out the detailed early steps required to increase the climate resilience of road assets through improved design. However, increasing resilience requires a concerted holistic effort across other disciplines, functions and teams beyond road design team. Five strategic pillars required to increase infrastructure resilience are suggested below:

Systems Planning: this should include: risk identification and appropriate risk management; adjustments to transport development policy and planning to address identified risks; shifting development away from disaster-prone areas when possible.

Engineering and Design: this should include: improving design standards of transport infrastructure to reduce disaster risk (this guide); use of innovative materials and design specifications that enhance robustness and flexibility of infrastructure; increased focus on achieving construction standards specifications.

Operations and Maintenance: this should include: developing asset management systems with mapping of transport assets, improving institutional and financial arrangements; integration of climate and disaster risks in the prioritization of infrastructure investments.

Contingency Programming: this should include: developing policy frameworks, communication protocols, and investments in emergency preparedness and response; alignment of transport systems and flows with local and regional evacuation, and recovery needs.

Institutional Capacity and Coordination: Centralizing disaster risk information and data comprehensively; upstream planning of transport systems to reduce the hazard exposure; mitigation of institutional and regulatory challenges, which are cross-cutting in nature, to utilize the life cycle approach effectively.

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