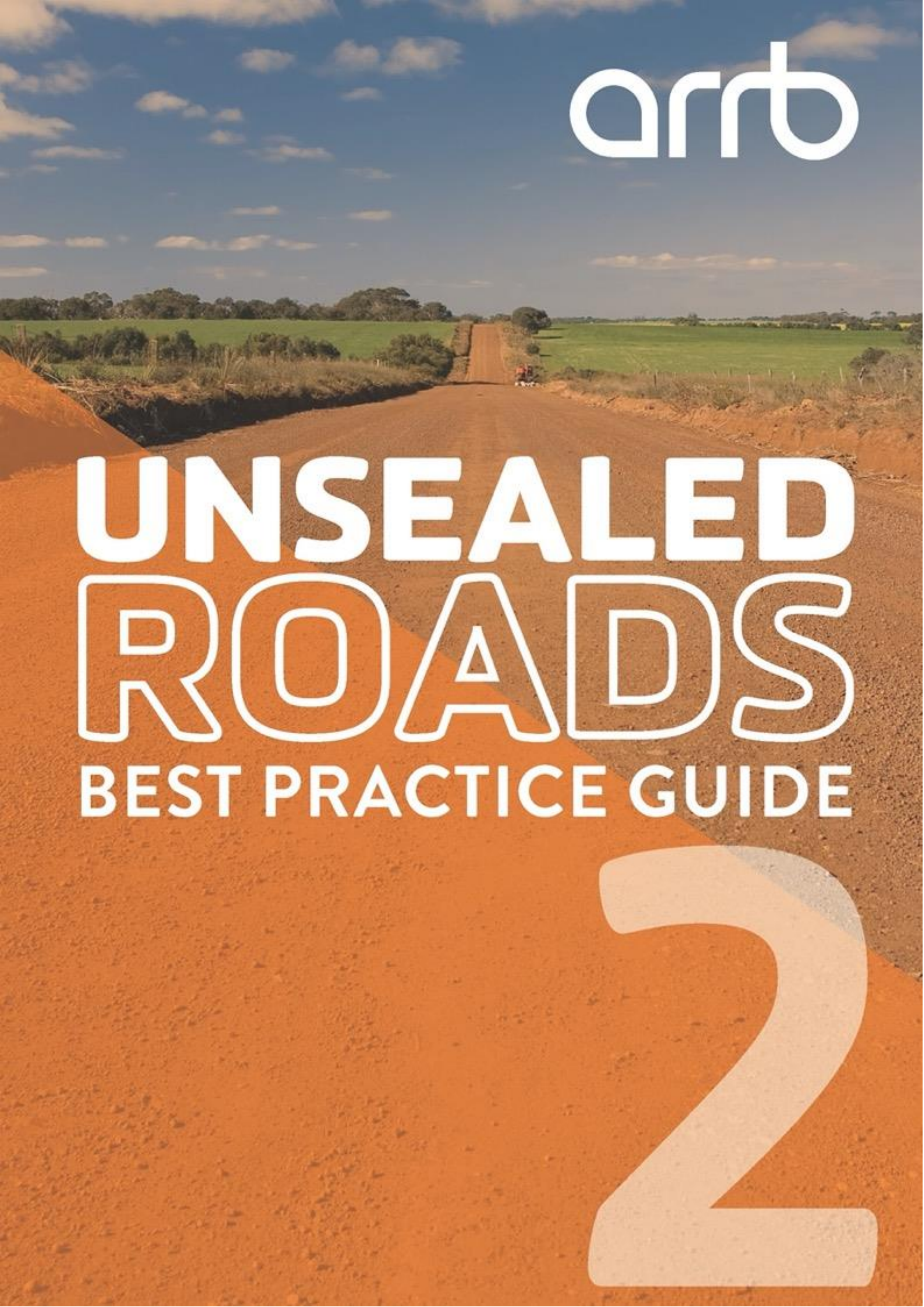

UNSEALED ROADS
BEST PRACTICE GUIDE

2

PRODUCED BY

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INSTITUTE OF PUBLIC WORKS ENGINEERING AUSTRALASIA

The Hon Michael McCormack MP

Deputy Prime Minister and Minister for Infrastructure, Transport and Regional Development

Foreword

I am pleased to support the Australian Road Research Board's suite of Best Practice Guides for Local Governments, which seek to expand Local Governments' understanding and capacity to manage road infrastructure.

Australia's Local Governments manage a majority of the road network, meaning capacity building for our Local Government road managers is vitally important. These Best Practice Guides will support national and international best practice in procurement, design and management of materials for road construction and for essential structures such as bridges.

As our nation's National Transport Research Organisation, the Australian Road Research Board has an important role in road management research and advice.

Road safety is a key priority of mine as the Federal Member for Riverina in regional New South Wales and as Minister for Infrastructure, Transport and Regional Development, especially as rural and regional roads currently account for a disproportionate level of road casualties.

With a user-friendly focus, these Guides aim to provide technical information in a simple-to-understand format that will be readily available and accessible for all road managers.

The Australian Government provided the Australian Road Research Board with $2.6 million as part of the 2019-20 Federal Budget, in recognition of the importance of road management.

This funding enabled ARRB to deliver these Best Practice Guides and a Portable Assessment Device project to assess in-situ road infrastructure conditions across a variety of national Local Government and council infrastructure networks.

I applaud the collaboration between ARRB and Local Government in the development of these Best Practice Guides, which will be an important road management resource.

Australian Government
Department of Infrastructure, Transport, Cities and Regional Development

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The authors greatly appreciate the contributions of the Local Government and other industry representatives who attended the Best Practice Guides workshops and provided initial feedback.

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Updates

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1. Minor editorial changes.
2. Correction to cumulative design traffic in Table 3.13.
3. Amendments to Equation 8.
4. Additional guidance provided in Section 4.13 for shoulder construction.
5. Amendments to references of ‘speed limit’, ‘default speed limit’ and ‘operating speed’.

Summary

Local Government plays a vital role in the provision and management of Australia's road assets, being responsible for more than three-quarters of the road network. Furthermore, of the almost 900 000 km long road network, approximately 63% is unsealed.

Unsealed roads, even though often considered as lower-order roads, play a vital role in Australia in terms of:

- providing access to rural communities
- the movement of primary produce to markets
- the movement within state forests and defence training areas
- access to forests or fire management on public lands
- haulage roads for the mining and timber industries
- recreational, social and tourist pursuits.

Local Government is often under constant funding constraints and in many cases experiences a lack of both financial and human resources. It is therefore essential for the ongoing viability of the unsealed road network that road agencies are provided with the most appropriate tools and methods to manage their road assets.

This *Best Practice Guide for Unsealed Roads* is one of a suite of guides developed for Local Government with the aim of expanding the understanding and capacity to manage road infrastructure. The guides will assist Local Government, and other organisations that manage unsealed roads across Australia, to manage their road assets effectively and to fulfil their obligations to the community while also improving mobility and safety.

Each guide reflects current global best practice and information. They have been tailored to Local Government requirements for application in Australia.

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1 Introduction

1.1 Background

Local Government plays a vital role in the provision and management of Australia's road assets, being responsible for over 80% of Australia's road network. The construction and management of these road assets is challenging considering the significant and diverse assets that Local Government is responsible for. At the same time, it is often under pressure to obtain better value from its budgets.

This *Best Practice Guide for Unsealed Roads* (the Guide) is one of a suite of guides developed specifically for Local Government. The aim of these guides is to assist Local Government, and other organisations that manage lower-volume roads across Australia, to more effectively manage their road assets so that it can meet community obligations while at the same time improve mobility and safety.

Each guide reflects current global best practice and information tailored to Local Government requirements for application in Australia.

1.2 Unsealed Roads in Australia

Australia's population is over 25 million; and it has approximately 900 000 km of road network length (Bureau of Infrastructure, Transport & Regional Economics 2019). The bulk of the road network length, approximately 575 000 km (65%), is unsealed. The remaining network road length of approximately 330 000 km (35%) is sealed with nearly 85% of these roads consisting of a sprayed bituminous seal and an unbound natural or blended gravel or crushed rock base.

Unsealed Road Networks

Unsealed roads play an important transport role in terms of:

- *providing access to rural communities*
- *the movement of primary produce to markets*
- *the movement within state forests and defence training areas, including fire management*
- *access to forests or fire management on public lands*
- *haulage roads for the mining and timber industries*
- *recreational, social and tourist pursuits.*

Poor rural roads (particularly those that are unsealed) can isolate communities, increase fuel consumption, damage vehicles, cause accidents and increase the cost of goods and services (Moore 2000).

In terms of construction type, the unsealed road network is made up of unformed and formed earth and in situ surface materials and formed and gravelled roads, as illustrated in Table 1.1. Road hierarchy details are provided in Section 3.5.5. This guide is primarily intended for formed and gravelled roads.

Table 1.1: Unsealed road types

Unformed road	Formed road	Formed and gravelled road
		
These are non-engineered roads that simply consist of a track that is cleared of vegetation. They are often not all-weather roads and carry very low traffic volumes. These roads may provide access to an individual rural property or be used for administration purposes in forest areas or by emergency vehicles in fighting fires. These roads are seldom maintained and may only be suited for four-wheel drive vehicles.	These roads are desirably designed to the appropriate geometric standards and adequate drainage is provided. They are earth roads comprised of up of local materials sourced from the road reservation. Generally, no imported gravel is used. Periodic maintenance of these roads should be carried out.	These road are designed to appropriate geometric standards with adequate drainage provided. A layer of imported granular material, compacted to the required thickness should be provided to support the estimated traffic loads. Maintenance is carried out on a regular basis.

Experience suggests that practices adopted were developed by field staff and then handed down to the next generation. There is often limited critical review of the methods and standards applied, and little technical input. However, as the number and axle loads of vehicles increases, and as community expectations rise, it is becoming increasingly necessary to apply the latest developments and more scientific methods to the management of unsealed roads.

Improving the performance and management of Australia’s extensive unsealed road network would result in improved safety, ride quality, reduced road use costs and lower whole of life-cycle costs of the network.

1.3 Purpose and Scope of the Guide

Wherever the description ‘Guide’ is used in this publication, it refers specifically to this Guide. The Guide is intended to be an ever-evolving document, building on and updating knowledge as research and industry practices evolve. The Guide was developed based on experience in the application of earlier, relevant guides and research and consultancy studies, including feedback from Local Government, State government and industry practitioners. As such, it has been tailored to fit the requirements of its target audience.

Wherever the generic term ‘road agency’ is used throughout this Guide, it refers to any organisation (government or private) that is responsible for the management of unsealed roads.

Comments, suggestions or requests for information to be included in future updates of the Guide can be directed to guides@arrb.com.au.

1.3.1 Purpose of the Guide

The purpose of the Guide is to provide local roads practitioner with a practical guide for the better basic understanding and management of unsealed roads. This is achieved by consolidating in one document best practice knowledge of the latest methods in asset management, pavement design procedures, construction and network operations for unsealed roads in Australia.

The intended reader of the Guide will generally be a junior engineer, field staff, design and asset management engineer, works supervisor, or contractor responsible for the design, construction and operations of unsealed roads. The Guide also serves as a useful guide to a senior engineer on the latest developments and a reminder of best practices.

In addition to providing general information and guidance, the Guide also serves as a source document because of its comprehensive lists of references from which readers can obtain more detailed information to meet their particular needs.

1.3.2 Scope of the Guide

The focus of the Guide is pavement management requirements relating to unsealed roads. The main topics addressed are asset management, road design, construction and maintenance, safety and environmental considerations. The Guide consists of the following parts:

1. **Introduction:** This section describes the unsealed road network in Australia and outlines the purpose and scope of the Guide.
2. **Asset Management:** The management of road assets is a key component of Local Government and other road agencies. Implementing appropriate asset management procedures and practices is therefore essential to the effective and economic operation of unsealed roads. This section covers the various aspects associated with a comprehensive strategic and systematic approach to road asset management for unsealed roads.
3. **Design:** This section provides best practice guidance for the design of unsealed roads, including planning, safety, geometric, pavement and drainage considerations.
4. **Construction:** This section provides details regarding the main stages in construction, site preparation, drainage, earthworks, subgrade preparation, pavement construction, equipment and quality management systems.
5. **Operations and Maintenance:** The ongoing operation and maintenance of unsealed roads is important for providing safe and sustainable road networks. This section provides specific guidance on managing ongoing maintenance of unsealed roads, including the impact of poor maintenance on road safety.
6. **Appendices:** The Guide also includes several Appendices (i.e. Environmental Considerations, Improved Road Safety Strategies and Guidance, Detailed Geometric and Drainage Design, Typical Road Defects and Maintenance, Best Practice Gradings Operations and Generic Maintenance Specifications). These appendices provide further guidance on the management of unsealed roads for readers that require more detailed information, particularly in areas that the authors believe are not necessarily comprehensively covered elsewhere. These appendices are therefore intended to supplement the main document with additional detailed information.

1.4 Limitations of the Guide

While this Guide presents best practice information for unsealed roads, it is important to understand that there are significant regional differences when it comes to design, construction, maintenance and performance specifications. Therefore, proven local practices should be maintained.

This publication is also not intended to replace any existing mandated design guidance, specifications, operational instructions or other guidelines. It is intended to supplement these resources while providing a foundation of knowledge regarding unsealed roads to a range of readers, both technical and non-technical.

2 Asset Management

Asset management is defined as 'A systematic process of effectively maintaining, upgrading and operating physical assets, combining engineering principles with sound business practice and economic rationale, and providing the tools to facilitate a more organised and flexible approach to making decisions necessary to deliver optimal community benefits' (Austroads 2015a).

Since 1990/91 the annual road freight task across Australia has more than doubled, from 90 billion tonne-km to 220 billion tonne-km in 2018/19 (Bureau of Infrastructure, Transport & Regional Economics 2019). Current annual funding on the construction, maintenance and operation of all public roads is over $30 billion, with about one-third of this spent on road maintenance.

Annual expenditure on unsealed road maintenance is less than 6% of the $30 billion annual expenditure on 63% of the road network length (Australian Local Government Association (ALGA) 2019). It is a major challenge to gain full value from this limited spending across a large and highly dispersed unsealed road network. Consequently, sound evidence-based processes and decisions need to be practised across the technical, economic, financial and environmental issues associated with unsealed roads that road agencies deal with.

Figure 2.1 shows the broad spectrum of the many factors impacting and challenging road agencies. Many of these factors are interrelated, such as climate impacts which requires the road infrastructure to be resilient to the current and changing climate while still providing an acceptable level of service to the road users at the lowest possible whole of life-cycle cost (WOLCC).

Figure 2.1: Factors impacting and challenging road agencies

Source: Austroads (2018a).

2.1 Definitions and Scope of Asset Management

Asset management is a ‘whole of organisation’ business approach that uses decision support systems in creating and maintaining physical assets which deliver the services valued by the agency’s customers in the most cost-effective and efficient manner. It is a means by which the optimal value from the entire road network is obtained. It must be robustly integrated with other business functions, such as finance, human resources, customer management and information technology.

The International Organization for Standardization (ISO) *Standard for Asset Management* 55001:2014 (ISO 2014), specifies requirements for an asset management system within the context of an organisation, and recognises that a broad approach needs to be taken when implementing an asset management system.

Levels of Asset Management

There are three broad levels of asset management:

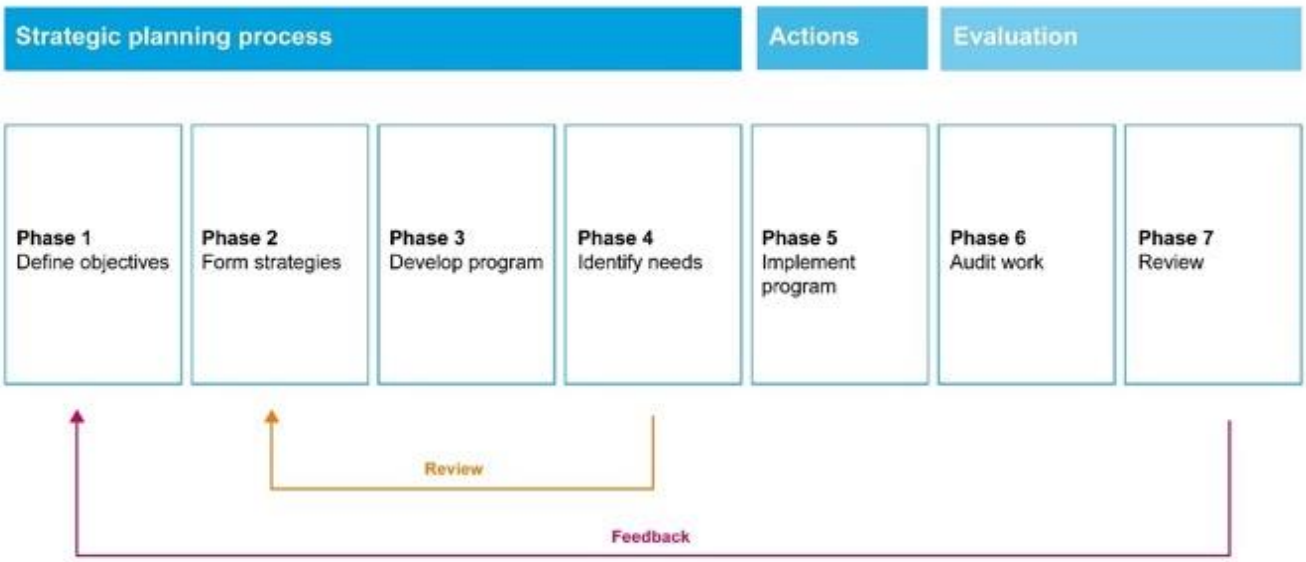
- *strategic – the establishment of policies, objectives, strategies and plans which respond to current and future levels of service expectations*
- *tactical – the development of prioritised work programs which address levels of service expectations and challenges*
- *operational – the implementation of the programs.*

Road agencies in Australia have adapted and incorporated the international approach documented in ISO (2014) within contemporary ‘whole of organisation’ asset management practices for road networks. The Austroads *Guide to Asset Management* (GAM) (Austroads 2018a), was produced to provide such guidance to road agencies. Its 15 parts range from the high level to the detailed technical level by providing the following:

- a management overview
- a description of asset management processes
- detailed technical information.

The GAM also acknowledges earlier progress in this area through the Austroads Integrated Asset Management Framework (Austroads 2002), and notable publications such as the International Infrastructure Management Manual (IIMM) (Institute of Public Works Engineering Australia (IPWEA) 2011). The following text therefore draws on this work and reflects the cyclical nature of the asset management process; for example, the setting of objectives and the development of strategies through needs and program development and implementation means that audit and review stages are essential. As shown in Figure 2.2, the process is both iterative and cyclical, with the latter recognising the need to adjust objectives and strategies, e.g. in response to constraints between desirable and affordable service levels and investment needs.

Figure 2.2: Simplified integrated asset management framework



Source: Adapted from Austroads (2002).

2.2 Objectives of Asset Management

The clear purpose of asset management is to provide the required levels of service at the lowest life-cycle cost to current and future road users and customers, using a 'whole-of-agency' approach to the acquisition, management and disposal of physical assets.

The strategic, tactical and operational levels of asset management practiced within the agency are constrained by budgets as these ultimately dictate what levels of service (LoS) can be delivered for road users and the community. As an input to the subsequent steps in the asset management process, it is important to consider different LoS (ranging from minimum to desirable/optimum) in informing decision makers of the budget implications and performance consequences of any constraints. Quantitative LoS are preferred as they can be applied in strategic planning, reviewing outcomes and informing future objectives.

Figure 2.3 shows that the development of each road agency's operating objectives is a function of both external factors and the internal capacity of the road agency. The external factors are self-evident: they need to comply with laws and regulations within the broader environment of the community, the economy and the road users. The internal capacity of the road agency needs to be aligned with the overriding purpose of the agency.

The strategic, tactical and operational levels of asset management practiced within the agency, in reality, are constrained by budgets as these ultimately dictate what levels of service (LoS) can be delivered for road users and the community. As an input to the subsequent steps in the asset management process, it is important to consider different LoS (ranging from minimum to desirable/optimum) in informing decision makers of the budget implications and performance consequences of any constraints. Quantitative LoS are preferred as they can be applied in strategic planning, reviewing outcomes and informing future objectives.

Figure 2.3: Development of road agency objectives

2.3 Development of Strategies to Manage an Unsealed Road Network

2.3.1 Asset Strategies for Managing the Road Network

Asset strategies are important because they provide the road agency with a structured direction-focus to guide its actions, and to demonstrate and articulate its stewardship and practice in providing outcomes to the community.

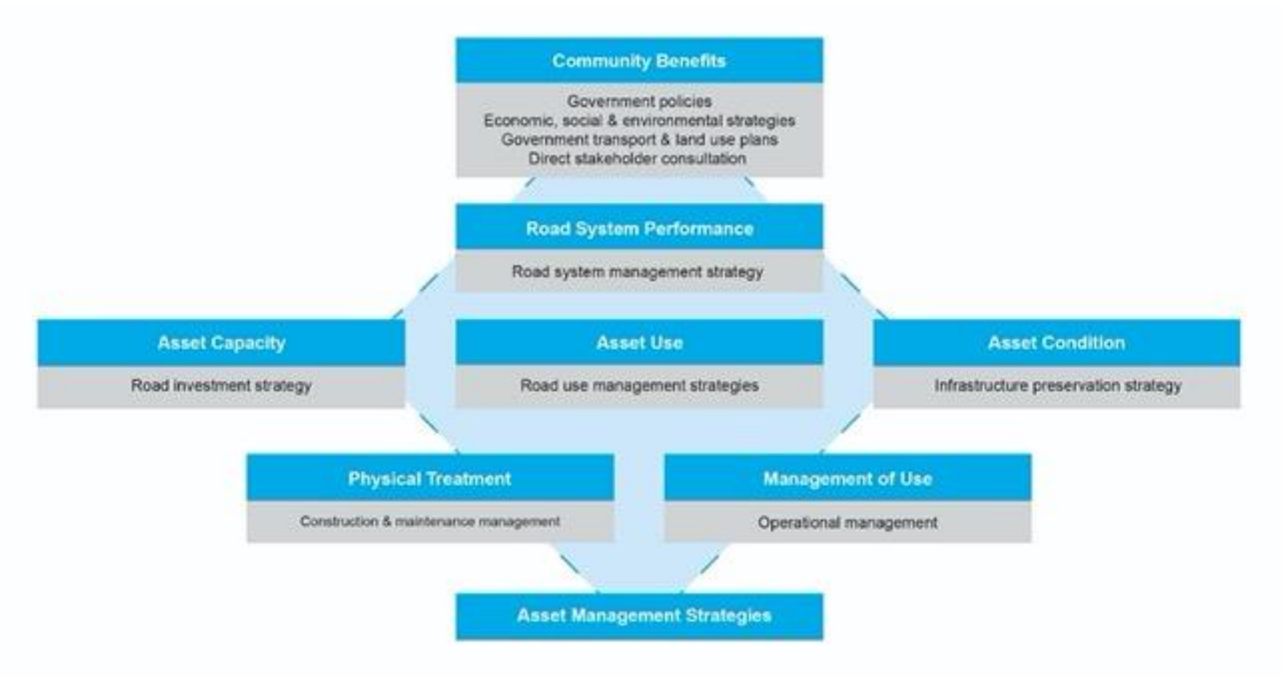
Asset Strategies

Asset strategies ensure that there is:

- *an integrated approach to the management of the capacity, condition and use of assets*
- *a consistent approach across all elements of the network and by all geographic parts of the organisation*
- *transparency and auditable accountability to the community for the rationale of asset management by the road agency, with road system performance standards driven by community objectives and achieved through the efficient and effective management of community road assets.*

Figure 2.4 shows the issues that need to be addressed in the development of asset strategies for investment (capacity), preservation (maintenance) and road use. They are driven by the overall performance of the road network to provide the community and road users with the maximum possible benefits through the LoS provided. They are meant to be fit-for-purpose, in terms of capacity, performance and condition.

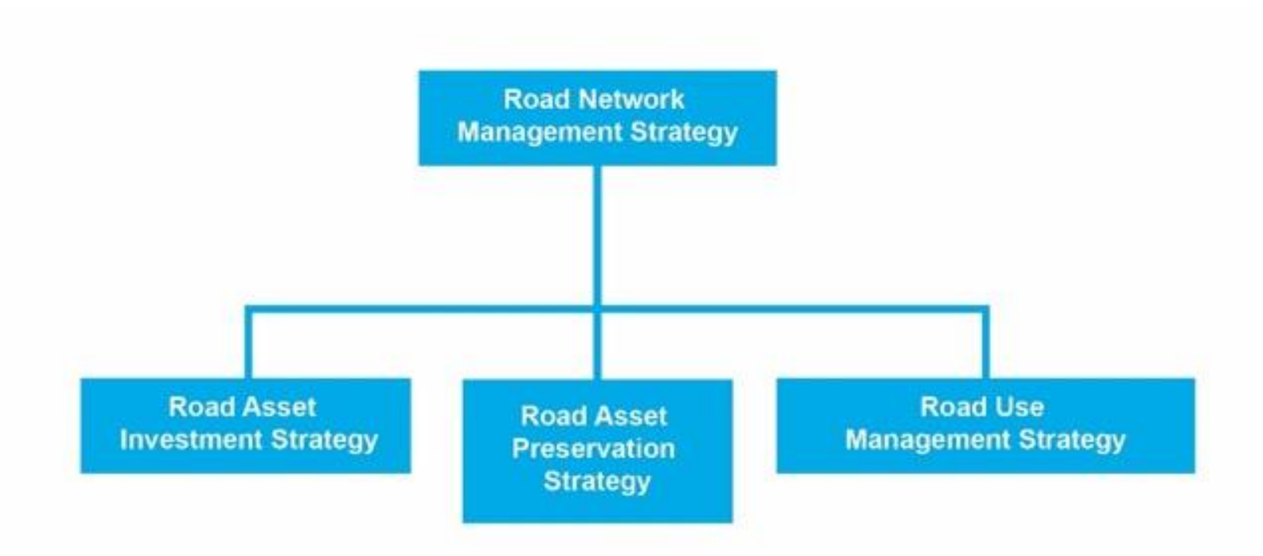
Figure 2.4: Development of road agency strategies



Source: Austroads (2018a).

From Figure 2.4, three main road asset management strategies that are used to manage the overall road network emerge as shown in Figure **2.5**. Each of these road asset management strategies has LoS attributes assigned to them that are regarded as appropriate for each of the strategies.

Figure 2.5: Key road asset management strategies



Source: Adapted from Austroads (2018a).

Levels of service

Levels of Service

Levels of service (LoS) are at the very heart of asset management for road agencies because:

- *they represent road standards and qualities that the asset owner agrees to provide to users*
- *they are the key drivers critical to good asset management practice and the basis upon which recommendations, conclusions, decisions, and budgets are based.*

If services are to be delivered to a required LoS, then the LoS is separated into two LoS categories:

- *Customer LoS (CLoS): focus on how customers experience services. They tend to be outcomes about service attributes that customers understand. These include, safety, ride comfort, the availability of direction signage and the accessibility and reliability of travel.*
- *Technical LoS (TLoS): relate to the service the physical asset provides measured in objective technical terms. It is linked to the CLoS, but expressed using technical language, such as average travel speed, crashes per hundred thousand kilometres travelled, and roughness (rideability) levels.*

Table 2.1 summarises a typical range of CLoS attributes alongside their TLoS technical measures. In order to provide fit-for-purpose LoS, the standards of LoS are assigned in accordance to where the roads sit in the road classification hierarchy: that is, the highest standards of LoS occur on the highest road classification and the lowest standards of LoS occur on the lowest road classification.

Table 2.1: Summary of CLoS attributes, descriptions and TLoS measures

CLoS attributes	CLoS description	TLoS measures
Accessibility	The network is available at most times, except during heavy rainfall and its drainage off the pavement.	Roads aimed to have 100% to 90% annual availability to traffic, except during heavy rainfall and its drainage off the pavement
Function	Different unsealed road types are available to different road users (heavy vehicles, etc.) based on their functional needs	Rideability (roughness, potholes, rutting and dust suppression) Suitable lane width and numbers of lanes
Navigation	Signs, delineation and markings are clear, easy to read and provide information	Suitable reflectivity, conspicuity measure
Safety	The road network is always safe to use, except during heavy rainfall and its subsequent drainage off the pavement Safety risks are proactively managed	Stable wearing surface Limits to lane rut depth and potholes Number of crashes per 100 000 km travelled Suitable shoulder width and surfacing
Reliability	Users can expect consistent travel times with some exceptions	Average travel speed (km/hr)
Resilience	The likelihood of a journey being disrupted by an unplanned incident or hazard event is minimised	Adequate stability rating (factor of safety) of embankments and cutting

Measuring and meeting LoS performance begins with the characteristics of the service that are ‘valued’ by customers and ends with the delivery of actions, through the use of TLoS measures as illustrated in Figure 2.6.

Figure 2.6: Aligning CLoS and TLoS with what customers value

Source: Adapted from Austroads (2018b).

2.3.2 Road Asset Preservation Strategies

A road asset preservation strategy (RAPS) translates road network management strategy (RNMS) objectives (see Figure **2.5**), driven by CLoS outcomes, to priorities for managing the condition and performance of the road system assets. A RAPS identifies and prioritises what asset maintenance and renewal activities are required to achieve and sustain the asset condition and performance standards as identified in the overarching RNMS. It recognises both measured and forecast patterns of deterioration of asset condition, the effects of various treatment strategies on the life-cycle costs of the asset and the effect of asset condition on road user costs, ride quality and safety.

The RAPS provides the strategic framework for managing the condition and performance of the road network. It enables the development of sustainable maintenance and restoration programs to achieve and maintain the asset condition and performance objectives and target TLoS standards developed in the road use management strategy (RUMS) (see Figure **2.5**). It also provides primary guidance for asset managers and maintenance management personnel.

A pavement management system (PMS) is a decision tool that is used in developing these sustainable maintenance and restoration programs (see Section 2.4.1). Coordination between the RAPS, road asset investment strategies (RAIS) and RUMS can aid in improving the efficiency of the delivery of these various programs and the minimisation of disruption to the road network. The balance of investment in each program will also influence overall network outcomes, with alternative programs (and options) being a key input to assessing needs and the impact of different strategies.

Road Asset Preservations Strategy

The key elements in formulating a RAPS are:

- *Conduct inventory and condition data collection and update for road lanes and shoulders.*
- *Review the minimum CLoS acceptable road conditions for ride quality (roughness), safety (rut depth, pothole depth and frequency, wearing surface stability) and the accessibility and reliability of travel identified through community consultation.*
- *Analyse road condition trends over time (patterns of deterioration and improvement). Strategy level analysis can be undertaken by predicting the common performance of broad groups of similar roads in similar operating conditions, e.g. rural and rural remote pavements by road classification.*
- *Develop 5 and 10-year expected performance and condition predictions for each road group.*
- *Analyse the effect of different surface treatments of (generic) routine and periodic maintenance treatments and different intervention levels for maintenance treatments on road asset condition, road user costs and whole of life-cycle costs. Alternative scenarios for annual budget requirements also need review.*
- *Identify the optimum condition intervention level to achieve and sustain acceptable target CLoS conditions at minimum life-cycle cost.*
- *Assess current and projected maintenance treatment needs and costs, recognising the current life-cycle stage of each road, predictions of deterioration and treatment effectiveness under assumed traffic demand growth scenarios.*
- *Prioritise projected maintenance needs as per the impact on road user safety, exposure and costs (strategic route importance, traffic volume), road serviceability and life-cycle costs.*
- *Review forward funding scenarios (local, state, and federal government program sources) and potential private sector contributions.*
- *Document proposed target road network conditions, treatment regimes, and budget requirements for each road.*

The RAPS adopted should suit the unsealed pavement type (unformed road, formed road, and formed and gravel road) and their performance, climatic patterns, characteristics of road use (particularly traffic volumes, number of axle loads), the cost of construction and maintenance treatments.

2.3.3 Road Asset Investment Strategies

A road asset investment strategy (RAIS) translates RNMS objectives (see Figure **2.5**), driven by CLoS outcomes, to priorities for investments in meeting the needs of road system capacity. A RAIS identifies and prioritises what capital investments are required that will progressively achieve the target network configuration and capacity identified in the RNMS, recognising forecast patterns of road use demand and funding availability.

The RAIS articulates the priorities and effectiveness of capital investments in the capacity of the road system. It also provides the framework for the progressive development and evaluation of road system improvements to achieve the performance objectives and target standards developed in the over-arching RNMS. It is used for the guidance of planners, project designers and the developers of road investment proposals.

Road Asset Investment Strategy

The key elements in formulating a RAIS are:

- *Review the RNMS to identify priority locations of current poor road system performance and social and environmental impacts with respect to current CLoS.*
- *Review the RNMS for future travel demand and road system performance predictions for at least 5- and 10-year scenarios based on traffic growth assessments.*
- *Examine the identified performance deficiencies and development of project concepts which would provide potential cost-effective short-term (< 5 years) and medium-term (5 to 10 years) performance considering network connectivity and relevant RUMS.*
- *Develop a planning concept, including the scope, design standards, and estimated costs for such proposed works.*
- *Evaluate the benefits and impacts of proposed works, including indicative marginal benefit/cost ratios (MBCR). Evaluate the effectiveness of implementation of individual projects; implementation of groupings of suitable compatible projects is also required.*
- *Review scenarios for the phased implementation of the RAIS, recognising priorities for progressively achieving road network performance targets and the forward funding scenarios (local, state, and federal government program sources) and potential private sector contributions.*
- *Recognise that capital investments in new road and increased capacity road assets, through the implementation of the RAIS, have long-term maintenance implications, so they need to be integrated into the RAPS. The predictions of asset growth in the RAIS are an important input to the RAPS.*
- *Review and refine the strategy with stakeholder consultation.*

2.3.4 Road Use Management Strategies

A road use management strategy (RUMS) provides a strategic framework to manage the use of the road system (Austroads 2016a). Examples include vehicle registration criteria, mass and dimension limits, operational requirements, licensing of drivers and operators, traffic management, and road space allocation. Such operational management strategies are complementary to the RAIS and the RAPS.

The road system cannot respond to unconstrained use. Strategies to manage use are commonly included in a RUMS and as separate focused strategies for particular road user groups (e.g. freight strategy, port access strategy, timber cartage strategy, grain haulage, etc.).

Road Use Management Strategies

A typical RUMS may include:

- *designated routes for oversize vehicles*
- *speed management strategies*
- *no, or limited, road use during rainfall and post rainfall conditions until the road is deemed trafficable.*

Travel demand management (TDM) strategies – which focus on managing the level of travel demand and influencing modal choice – are a sub-set of RUMS.

2.4 Identify Needs for Investment and Preservation

2.4.1 Measurement of Road Condition and Performance

The measurement, collection and reporting of road condition data, such as roughness, potholes, rutting, transverse shape, corrugations, surface texture and loose and unstable wearing surfaces needs regular routine measurement and assessment to ensure technical levels of service (TLoS) are not being exceeded as part of the IPS RAPS and RAIS. Each of these conditions on unsealed roads are illustrated and defined in Austroads (2019a). Examples of these defects and possible maintenance solutions are also provided in Section 5.1.3.

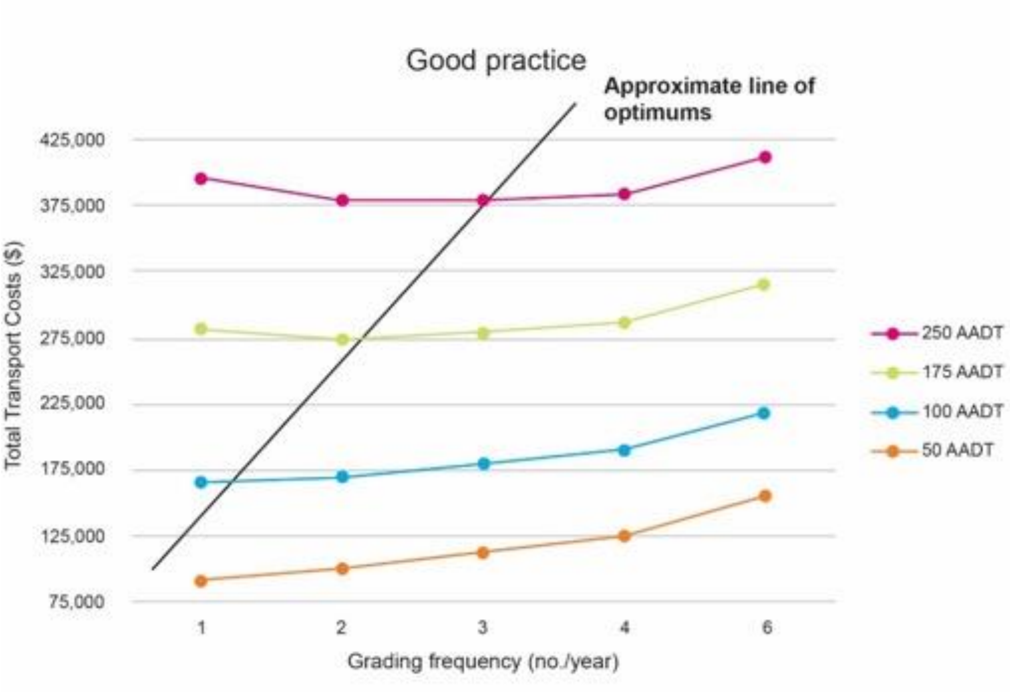
Roughness is a function of potholes, rutting, surface texture and corrugations; consequently, it is a useful measure of the overall rideability and safety of the road. Suggested annual average surface roughness levels for a given range of annual average daily traffic (AADT)are shown in Table 2.2. These roughness levels were established by seeking the minimum total transport costs, based on the sum of the road agency cost of maintenance (grading) and road user costs for given levels of AADT (Austroads 2020a, 2020b) assuming good practice techniques).

Table 2.2: Indicative annual average roughness condition levels

AADT	Annual average roughness (IRI)
50	10
100	9.5
175	8.0
250	7.5

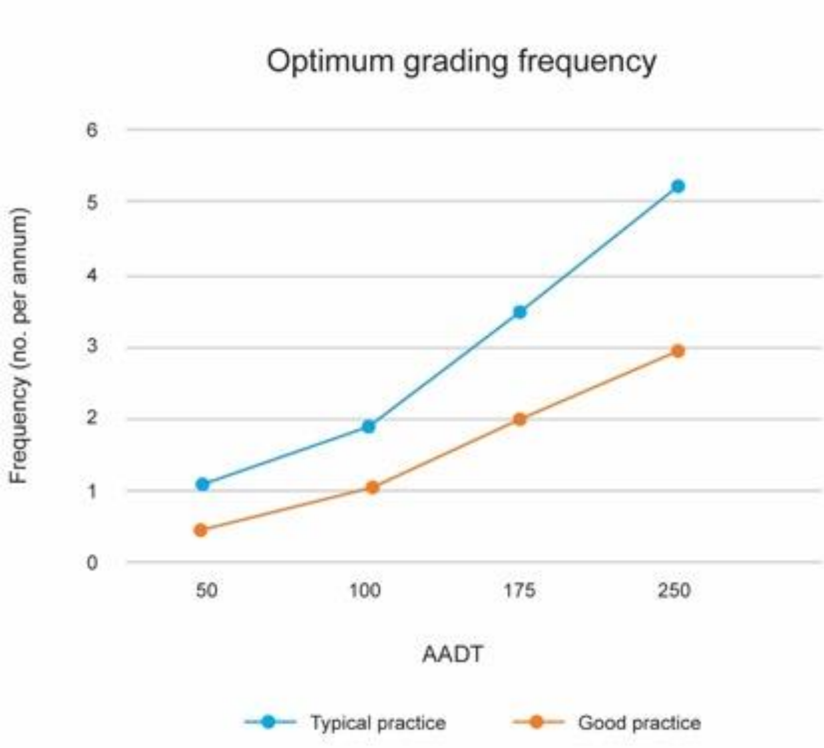
It should be noted that the roughness conditions are also a function of the quality of the surface grading practice, i.e. including appropriate watering and compaction within the operation. Figure 2.7 shows how the ‘good’ grading frequency for the various levels of AADT was determined on the basis of the minimum TTC. An example relationship for selecting an optimum grading frequency is shown in Figure 2.8, noting that adoption of good practice can lead to a reduced frequency of grading compared with typical practice (by approximately one-half). This occurs using appropriate techniques and ensuring good selection and placement of materials. Further guidance is given in the source references which draw on the local road deterioration studies reported by Martin et al. (2013) and Martin, Choummanivong & Thoresen (2016), and in Austroads (2018c).

Figure 2.7: Determination of optimal grading frequency



Source: Austroads (2020a).

Figure 2.8: Example optimum grading frequency relationships using different practices



Source: Adapted from Austroads (2020a).

For unsealed roads, a scheduled frequency of maintenance is preferred as this helps address issues related to the cyclic performance of these roads, and the difficulty of using a reactive approach based on inspections and/or surveys. If local performance data is amassed, then this can inform a schedule, and the derivation of optimum schedules based on local conditions. To do this successfully requires data to be collected at intervals of one to three months over a period of several years. Such surveys should include roughness, shape and gravel depth as these will be the main drivers for informing whether preservation and investment works need to be initiated. Where road access is constrained due to poor trafficability, which typically occurs as a result of excess moisture and weak surface layers, such conditions should be noted, and deficiencies addressed.

Once local knowledge and confidence is established survey frequency can be extended for network-wide general planning and works program development and undertaken at intervals of between one and five years, with a shorter frequency recommended initially as experience is gained. The frequency should also take account of traffic levels and road importance to ensure adequate quantitative data is available for general LoS reporting purposes.

The suggested frequency of road condition surveys for low trafficked local roads with low deterioration is 3–5 years for roughness, shape and material loss.

Pavement condition assessment of rideability

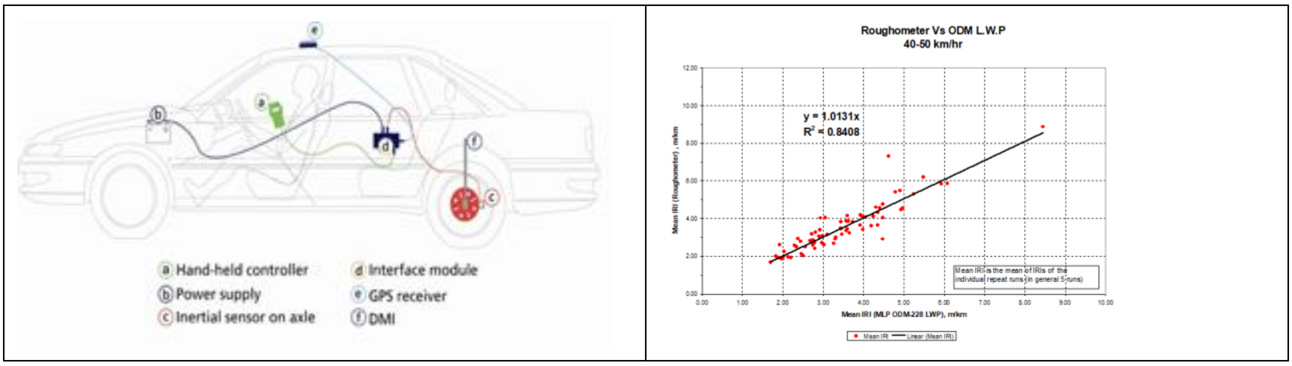
The rideability, or roughness, is a road condition parameter that quantifies the ride quality of a pavement. The measurement of roughness focuses on characteristic dimensions that affect vehicle dynamics, ride quality and dynamic pavement loads. Road roughness characterises deviations from the intended longitudinal profile of a road surface with characteristic dimensions can affect vehicle dynamics (and hence road user costs), ride quality and dynamic pavement loading (Austroads 2018a). The International Roughness Index (IRI), in units of m/km, is the usual measure for reporting roughness.

The roughness of unsealed roads can be measured by monitoring equipment, such as a network survey vehicle (NSV). They are usually equipped with digital cameras that can visually detect potholes and loose and unstable wearing surface distresses and lasers that measure rutting, transverse shape, corrugations and surface texture (Figure 2.9).

Figure 2.9: ARRB network survey vehicle

The ARRB Roughometer, a low-cost portable device that can be installed in a passenger car, was also developed specifically to measure roughness on unsealed roads with an appropriate degree of reliability and accuracy. This device has proven popular with practitioners; it has been used to help build a local evidence base for improved practice, and performance reporting. The device is illustrated in Figure 2.10, showing an almost 1:1 relationship exists between the output of the ARRB Roughometer and NSV outputs.

Figure 2.10: Illustration of the ARRB Roughometer and the relationship between the Roughometer output and a Class 1 multi-laser profilometer



Current practice involves the measurement of the longitudinal profile of the road in both wheelpaths in a selected lane with an inertial profilometer and to mathematically model the response of a hypothetical vehicle (quarter-car simulation) to the longitudinal wheelpath profile. The roughness measured in this way is lane roughness (Lane IRI_{qc}) – it is the average of the IRI quarter car values measured in each wheelpath. Lane roughness is reported at 100 m intervals.

Further details regarding roughness surveys and the subsequent analysis and applications are provided in the technical supplements to the GAM (Austroads 2018a).

Pavement strength

Pavement strength is an important characteristic which defines the general condition of a road. It is also an important input to assessing the need for pavement rehabilitation and resheeting works. Pavement strength is also a significant determinant of the surface performance of the pavement in terms of distresses such as roughness and rutting. However, it should be noted that because unsealed roads are heavily influenced by climatic conditions, the strength can change dramatically in a relatively short time (Table 2.3). The key is to first identify whether a wearing surface or pavement support issue exists, and to consider whether it needs treatment.

Table 2.3: Estimated in-service SNC values for different materials and conditions

Pavement moisture and drainage	Standard pavement materials (SNC)	Marginal pavement materials (SNC)	Non-standard pavement materials (SNC)
Dry well-drained	5.1	5.1	3.2
Dry poorly drained	5.0	3.1	3.1
Wet well drained	3.1	1.8	1.6
Wet poorly drained	2.9	1.6	1.5

Note: SNC is defined as modified structural number of a pavement where higher values indicate stronger pavements.

Source: Austroads (2020a).

Whereas for sealed roads the assessment of pavement strength is typically done by deflection testing under a standard load, for unsealed roads assessment is more commonly done using a Dynamic Cone Penetrometer (DCP) (Austroads 2019b) or through sampling and testing of recompacted materials in the laboratory. For network level asset management, testing should be undertaken on a representative set of sections and on specific locations which display a bearing capacity issue. For project level purposes the guidance in Section 3.6 should apply.

Shape (crown) loss

Shape loss is the measured assessment of the percentage (%) reduction in the slope of the pavement's original crossfall. An ideal crossfall, or crown shape, is around 5% for unsealed roads. Maintenance of the crossfall is important for shedding surface water and maintaining the trafficability of the pavement. Shape loss can be directly measured transversely by a spirit level perpendicular to the direction of the traffic or estimated using visual assessment procedures. The loss of shape also determines the ability of certain maintenance techniques to successfully restore an adequate crown, with the retention of good shape being a key factor in choosing the frequency and type of grading, and ultimately road upkeep costs.

Gravel depth

For an unsealed road with a gravel wearing surface, measurement of the thickness of this wearing surface needs to be made at periodic intervals (typically one to five years) to determine when it needs to be replenished with additional resheeting material. The thickness measurements are typically made either by a 'digout' or augers along the road, or by using a DCP (AS 1289.6.3.2-1997 Rec:2013) to estimate the depth of material. Direct measurements are, however, preferred as moisture conditions can significantly impact the interpretation of DCP data (see Section 3.6.4).

An innovative approach to estimating gravel loss is to use ground penetrating radar (GPR) technology. GPR equipment mounted on a vehicle is able to travel at moderate road speed to provide subsurface information. However, care should be taken in using GPR equipment to ensure that the gravel and subgrade dielectric properties are suitable. An initial test section should be used to ascertain the suitability of this equipment for local pavement conditions.

Pavement Condition Index

Three of the above condition measures – roughness, crown shape and gravel depth – can be converted to index values which are aggregated and weighted to estimate the Pavement Condition Index (PCI) of a particular road section. The PCI is therefore an overall composite measure of the condition of an unsealed road.

Equation 1 can be used to estimate the PCI using the Advanced Maximum Method (COST 2008).

$$PCI = MAX(w_i * Index_i) + p * (\frac{SUM(wi * Index_i) - MAX(w_i * Index_i)}{\sum(w_i) - Avg(w_i)}) \qquad 1$$

where

w_i = weight for individual condition criteria roughness, gravel depth and crown shape (see Table 2.4)

$Index_i$ = index value for individual condition criteria; roughness, gravel depth, crown shape (1–5)

p = condition factor (the current default value is 0.1).

Table 2.4: PCI weighting for unsealed roads

Condition index	Weight (wi) PCI
Gravel depth	1
Crown shape	1
IRI	1

Condition Index

The Technical Level of Service (TLoS) has to be translated into Customer Levels of Service (CLoS) which are often stated as: Very good (1); Good (2); Fair (3); Poor (4); and, Very poor (5). The ratings 1 to 5 represent the condition classes.

Measured values, e.g. roughness, etc. on their own convey an absolute number. The CLoS is required for practical asset management; it reflects the LoS the asset owner desires to achieve for the road user (customer). An example of the relationship between the CLoS and TLoS is presented in Table 2.5 showing the roughness ranges assigned to each Condition Index (CI) range for a single road class. This shows how the Condition Indices for a single road class are derived.

Table 2.5: Example CI ranges for condition ranges for an unsealed road

Class name	CI range	Condition value range		
		Roughness IRI	Gravel depth	Crown shape
Very good	0 – 1	≤ 4	≤ 150	≥ 5%
Good	1 – 2	4 – 6	125	5 – 4%
Fair	2 – 3	6 – 8	100	4 – 2.5%
Poor	3 – 4	8 – 10	50	2.5 – 1.25%
Very poor	> 5	≥ 10	< 50	≤ 1.25%

The measured actual condition values are converted into CI values by using the transformation functions between two index ranges. It is possible to use a single transformation function covering the full range from 0 to 5. However, no single function can fit the individually defined transition points from one band to another. Consequently, a series of linear functions are used that can easily be fitted to the transition points between CI ranges. The generic form of each of the straight lines is represented by Equation 2.

$$y = a * x + b \tag{2}$$

where

a = slope of the line = $(y_2 - y_1)/(x_2 - x_1)$

b = is the intercept = $y_i - a \times x_i$

x_1, y_1 and x_2, y_2 = represent transition points between CI ranges.

When the PCI is determined for road segments in a network it can subsequently be used to inform either the sequence of the candidates for preservation and restoration treatments or the order of investment options when the PCI values equal or exceed a nominated value. Both the preservation and investment options need to be subject to an economic analysis.

2.4.2 Inventory Update, Road and Wearing Course Age

Inventory data describes the road asset, its constituents and other relevant data associated with its identification (location, lane and shoulder width). Recording of road inventory data is critical to the asset data management process, in that all other functions associated with the collection and use of the condition data related to the selected road asset is dependent on the inventory. For instance, the adopted naming convention for road numbers needs to ensure that a consistent yet flexible approach is adopted. Because road networks are always evolving through local and regional development, road agencies may acquire or inherit additional road assets. They therefore need to be able to accommodate these changes in their asset registers.

Inventory Data

Inventory data are also related to aspects of the road asset that may describe its current state such as:

- *the current age of the wearing surface*
- *road category and route designation (bus, freight, national significance, etc.).*

Some of the additional inventory data required to describe the road network may be acquired through using the same equipment undertaking pavement condition surveys:

- *Geometry data such as rise and fall, curvature and grade can be obtained initially from an automated survey.*
- *Further inventory data relating to the roads' dimensions may also be obtained in this same manner through review of digital imaging that may have been captured as part of a network survey.*

While such fundamental information may already be present in the agency's asset register, there are occasions where such information may benefit from validation and confirmation, especially if the origin and source of the base data is uncertain. In this manner, road agencies can extract additional benefit from their data collection exercise to take the opportunity to gather data related to the asset at the same time as obtaining condition related data.

Whereas the use of manual and visual inspection approaches to confirming road inventory data are applied by some agencies, such methods are time-consuming, lack repeatability, and rely on the expert opinion of the inspector and have associated potential personnel safety implications. Whilst such methods have a role in verifying data and in project level assessments, careful consideration should be given to whether these methods remain suitable and are sustainable for general assessments.

2.4.3 Road Use

Pavement deterioration and long-term pavement performance is partly a function of the extent of heavy vehicle road usage. This is characterised by the road use data that includes the traffic volume and loading at selected locations. The collection methods and best practice of road use data collection is described in detail in Austroads (2017a), and key data parameters are defined in Table 2.6.

Table 2.6: Key data parameters

Parameter	Definition
Traffic volume	Traffic volume is reported in terms of AADT. The AADT is a processed and aggregated parameter based on detailed traffic counts assembled over a longer period.
Traffic composition	Traffic composition is reported in different ways, with the Austroads 12-bin classification being an example (Austroads 2017a). Other classifications also exist, including those employed by road agencies. The Australian Transport Assessment and Planning (ATAP) guideline PV2 provides the most comprehensive description where a 20-vehicle fleet is provided as a basis for determining vehicle operating costs and road user costs (DIRD 2016). A number of classifications, including the Austroads 12-bin, have been mapped against each other in ATAP PV2.
Axle load	Axle load data is collected with appropriate measuring techniques. The data is processed and aggregated either into the actual number of vehicle types or into the percentage heavy vehicles (%HV) counted on the road and is used to estimate the cumulative or annual number of equivalent standard axles (ESAs) carried per lane. Typical gross vehicle masses and load damage factors are also reported in ATAP PV2 (DIRD 2016).
Traffic growth	Traffic growth is derived from past data and other economic/demographic forecasts. It is important input data for estimating future pavement performance.

2.4.4 Asset Management Information Systems

An asset management information system (AMIS) is a tool that provides a comprehensive and structured approach to the long-term maintenance of physical road infrastructure using sound engineering, economic, business and environmental principles to facilitate the effective delivery of community benefits (Austroads 2018d). AMIS is a database used by road agencies to systematically collect and store information regarding road and road-related assets so that statutory and discretionary reporting on the performance of these assets can regularly be undertaken.

An AMIS provides the data needed to use decision making tools such as Pavement Management Systems (PMS) that address the programming, budgeting and appropriate pavement treatment selection for road asset management. The PMS aim to achieve an optimised approach to decision making aimed at the preservation (maintenance and rehabilitation) and investment (construction) of the road infrastructure.

In the past it was common to build an AMIS in-house. Whilst these tailor-made systems might have functioned well, they usually failed to keep up with changing technology. Road agencies are not necessarily well equipped to maintain complex software, so these home-made systems are being replaced by commercial systems. Details on the functional requirements for procurement of an AMIS are outline in Austroads (2018d).

A Typical AMIS

Austroads (2018d) indicates what a typical AMIS should comprise, including the following core components:

- *asset reference system, which allows the identification and location of individual components of the road network*
- *asset register, which lists the information relating to various aspects of the road asset such as inventory, condition, traffic and other road use data*
- *historical records of construction and routine maintenance, periodic maintenance and rehabilitation, etc.*
- *other information required within the system may include:*
  - *key operational and performance data*
  - *maintenance data (available treatments and costs and benefits)*
  - *unit costs (maintenance and rehabilitation)*
- *levels of service (CLoS and TLoS) framework linked to the road classification hierarchy.*

2.4.5 Gap Analysis

A gap analysis determines the difference between the current actual road conditions, road use and performance of the road conditions and the expected performance and conditions required by the CLoS and TLoS from road use. This analysis also determines the needs for preservation and investment from which the works programs for these types of funding are derived. A major role of a PMS, after the information for the gap analysis is feed into the PMS, is to determine the programming, budgeting and appropriate pavement treatment selection location and extent for preservation and investment work on the road.

In determining a total needs program for a defined network covering all road classes and surface types, gap analysis can be undertaken to identify more specific needs where rules (measures and criteria) are applied condition/performance or provision deficiencies/compliance in relation to:

- road preservation and renewal (sealed), considering measures such as ride quality, rutting and cracking/distress against stated TLoS
- road preservation and renewal (unsealed/formed), considering roughness, surface condition, shape and gravel adequacy against stated TLoS
- surface upgrading needs, by applying indicative breakeven traffic thresholds to warrant sealing or surface replacement (e.g. to asphalt)
- configuration including lane and carriageway width and numbers, shoulder types, kerb and channel requirements, etc, with these informed by policy guidelines/warrants
- intersection deficiencies informed by policy guidelines/warrants, e.g. for non-signalised and signalised intersections, and other types
- HV route improvements considering configuration and alignment, and the level of access by road class considering heavy vehicle types
- safety improvements based on crash statistics and risk analysis or policy guidelines/warrants.

The intent is to determine a comprehensive view of needs, i.e. not solely for unsealed or sealed roads, with programs and projects with options subject to further analysis and prioritisation. Gap analysis may also be informed by different traffic demand scenarios, as network growth can vary significantly on a geographical basis. Other similar impacts can include flood and climate risks, with these being important in considering future needs.

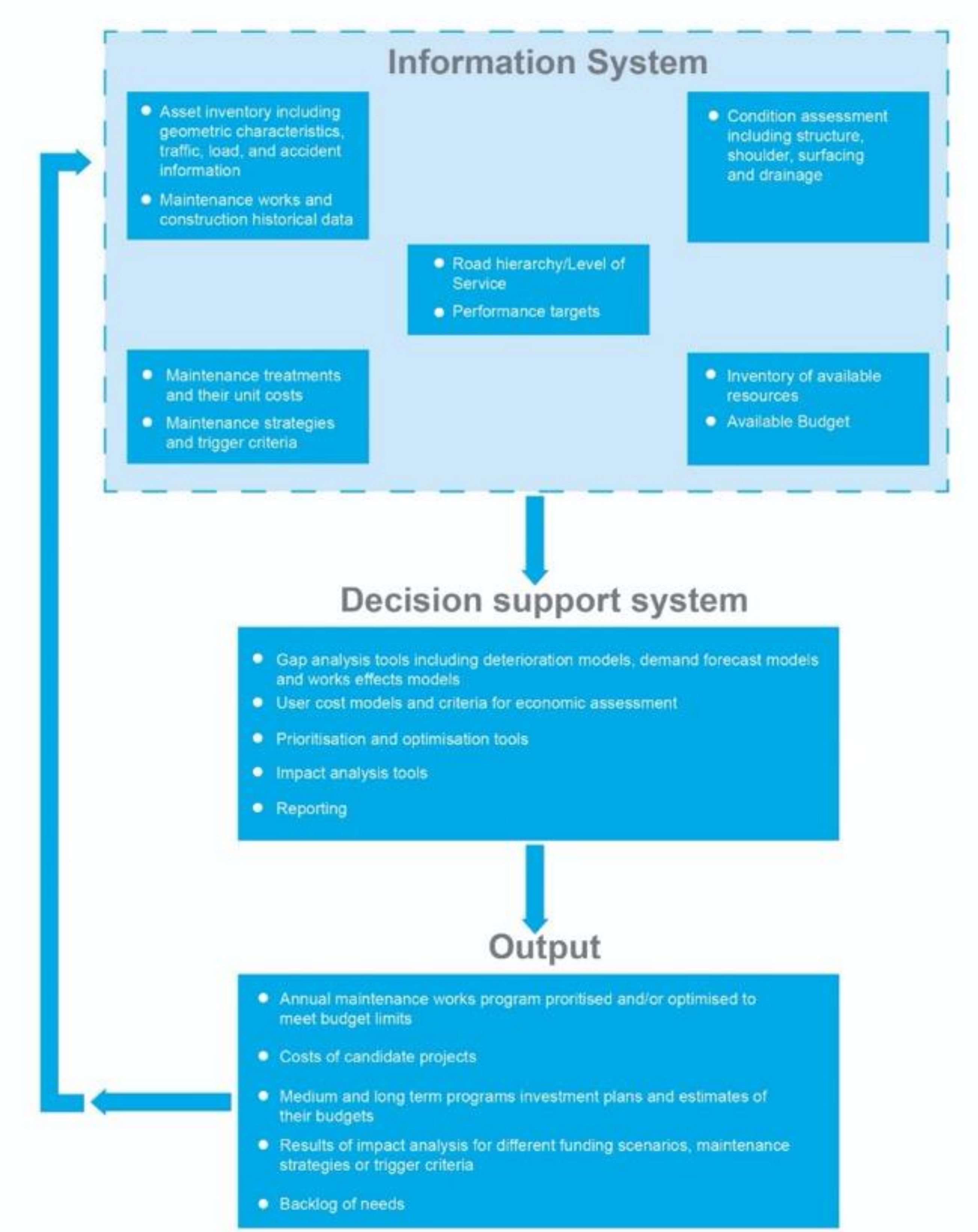
2.5 Developing Works Programs

Developing works programs includes planning, evaluation and programming to identify where and when to invest resources in the most cost-effective manner on the road network for the road users for both the preservation and enhancement of the road network. This process needs to be undertaken in the context of the broad policy frameworks included in the road asset investment strategy (RAIS) that allows the development of the investment works program. The road asset preservation strategy (RAPS) provides the framework for managing the condition and performance of the road network allowing the development of the preservation works program.

2.5.1 Program Analysis Tools – General

Within the framework of an AMIS, most road agencies use a PMS that provides appropriate rigour and additional focus to the management of the pavement assets. A PMS is often a module or component of the wider AMIS that is deployed corporately. The generic components of a PMS are outlined in Figure 2.11 which shows typical elements of an information system for managing pavement assets.

Figure 2.11: Typical elements of AMIS and PMS



Source: Austroads (2018d).

The AMIS database feeds this information to the PMS, the decision support system shown in Figure 2.11 where pavement life-cycle costing (PLCC) analyses over a defined period are conducted. These analyses include the road agency costs of maintenance and rehabilitation, the road user costs and other externality costs such as accidents and greenhouse gas emissions. The PLCC analyses is a discounted cash flow analysis using a real discount rate. It may include pavement salvage costs where maintenance treatment and rehabilitation options are not over the same time period. Omitting such considerations can seriously compromise an analysis, particularly where the benefits of a high-value option are not fully represented, e.g. where the analysis period is too short such that the full benefits are not captured. In such cases salvage value can be applied as a negative cost (effectively a saving), otherwise a longer analysis period should be chosen.

Specific components of a PMS for infrastructure preservation

Specifically referring to the components of a PMS, Figure 2.12 taken from Part 12 of the Austroads *Guide to Asset Management* (Austroads 2018e) illustrates the components of the decision support system within an overall pavement management system. Aspects of these which require consideration with respect to unsealed roads, include the following:

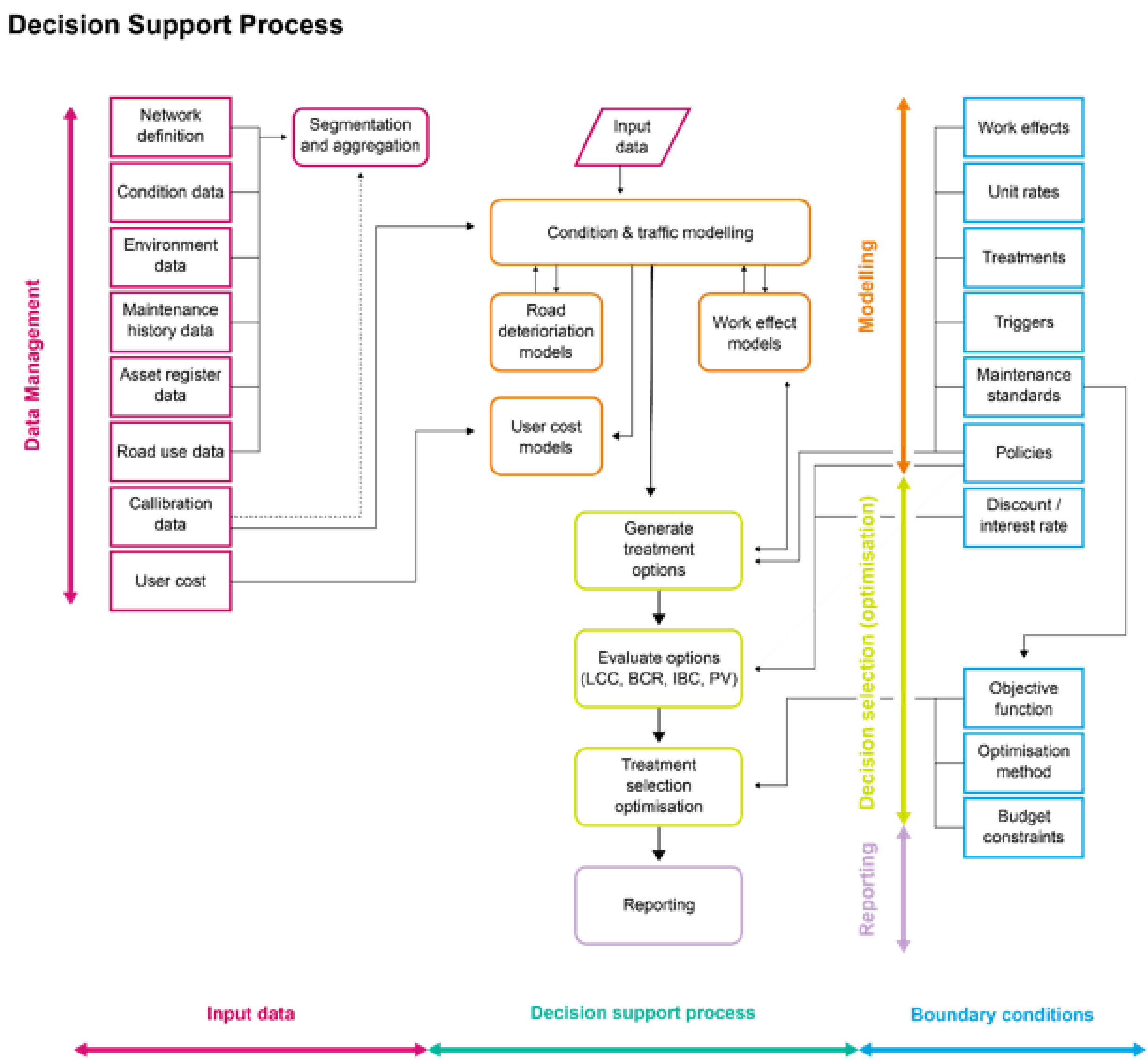
- Data management – with a number of particular characteristics important to unsealed roads described in Section 2.4.1.
- Condition and traffic modelling. This is the heart of the PMS, as this is where the functionality to take the current condition data and predict its future state is undertaken. The prediction models cover road deterioration (RD) models and works effects (WE) models for the various maintenance and rehabilitation treatment options examined (see Table 2.7). Figure 2.13 depicts a four-phase roughness progression model which includes a deterioration phase (1), a restoration phase with grading (2) and further deterioration phases (3) and (4), that depend on the amount of grading. Martin et al. (2013) have documented RD models (gravel loss, shape loss and roughness) whilst Martin et al. (2016) have documented WE models (light and medium grading, resheeting and roughness) based on Australian data for unsealed local roads. A description of the models and further guidance on their application is also given in Austroads (2020a; 2020b) which also report case studies covering a range of different applications and circumstances.

Table 2.7: Key parameters included in the RD and WE models for unsealed roads

Parameter	Roughness (RD model)	Roughness (WE model)	Shape (RD & WE model)	Material loss (RD model)
Time since grading/resheeting	✓	–	–	✓
Number of days between IRI measurements before and after blading	–	✓	–	–
Annual or monthly precipitation	✓	✓	–	–
AADT	✓	✓	✓	✓
% light vehicles	✓	–	–	–
% heavy vehicles	✓	–	–	–
Proportion of soil fines (% < 0.075 mm)	–	–	✓	✓
Soil plasticity	–	–	–	✓
Roughness before grading/resheeting	–	✓	–	–

- Decision and optimisation – this component works with the RD model predictions to determine when a treatment option is applicable, based on a predefined suite of condition intervention thresholds and limits (TLoS). Typically, surface grading (light, medium and heavy), pavement resheeting and pavement reconstruction are defined in this component so that road segments with condition distresses within the range of each of these treatments will be considered as candidates for treatment. In the treatment selection framework, several critical components need to be defined:
  - the rules/criteria defining when a treatment may be applied
  - unit cost information related to the treatment, which can vary depending on the level/standard the treatment is required to deliver
  - the improvement predicted by the WE models for the various condition parameters that the treatment will yield.
- Evaluation of treatments and optimisation following this will depend on annual budget allocation.
- Reporting – with the output of this stage comprising an annual program of potential preservation works from treatment selections is used to estimate of the amount of funding available to the agency to undertake these works. Depending on the budget, the analysis outcomes can determine that:
  - the agency has insufficient funding to address all the selected treatments under a constrained budget and therefore a backlog of works will need to be addressed over the coming years
  - sufficient funding is available to ensure that the desired TLoS is met with an optimal selection of proposed treatments under a constrained budget, although this may mean that the set TLoS cannot be fully delivered over the long-term
  - sufficient funding is available with an optimal selection of proposed treatments under a constrained budget and as a consequence the agency is able to fulfil its LoS obligations now and into the future.
- Finalisation of the proposed works program requires input from the works manager, and includes:
  - finalising of the candidate list of treatments following site inspection, including review of the proposed treatments and their scheduling
  - rationalisation of the works program so that treatments are either brought forward or delayed, facilitating effective and logical works packaging to streamline procurement and reduce overall costs associated with undertaking the treatments
  - works procurement and management, including generation of contract documents, creation of works orders tracking of completed works, closure and inspection of the completed works and maintaining a record of work histories and as-built details.

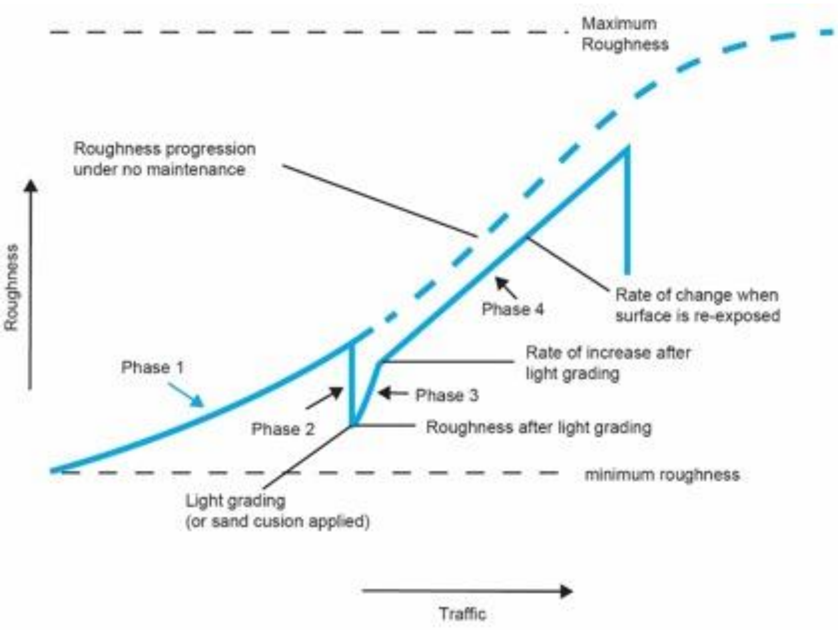
Figure 2.12: Components of the decision support system in a pavement management system



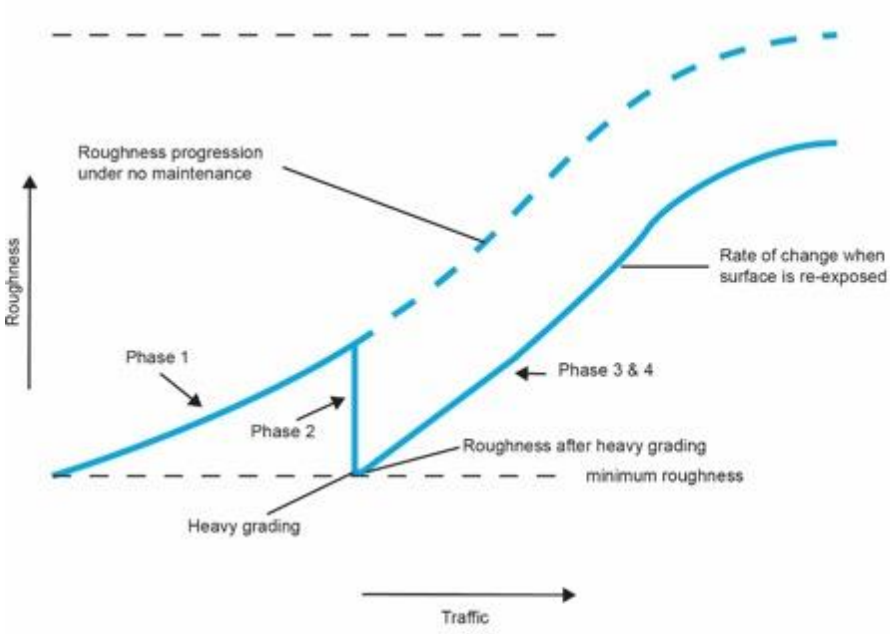
Source: Austroads (2018e).

Figure 2.13: Illustration of four phase roughness progression model for unsealed roads (top) effect of light grading on roughness progression and (bottom) effect of heavy grading (or full reprocessing) on roughness progression

Effect of light grading on roughness progression



Effect of heavy grading (or full reprocessing on roughness progression



Source: Morosiuk and Toole (1997).

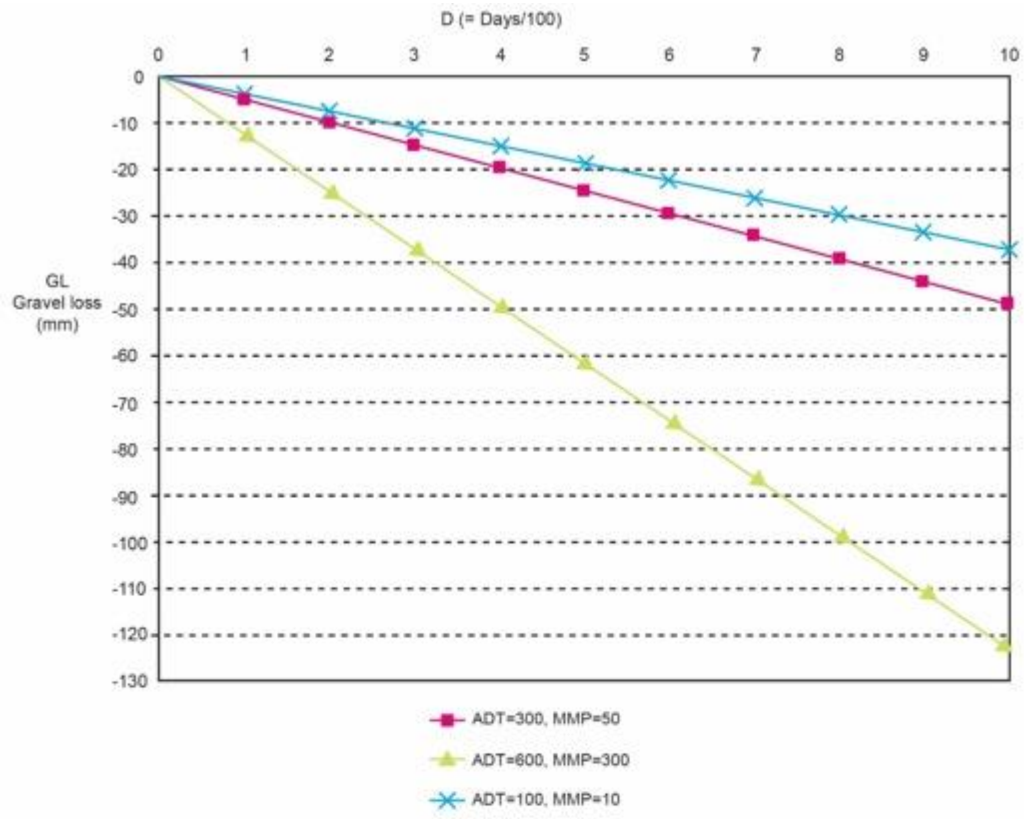
Unsealed roads deterioration and works effects models

There are a number of different RD and WE models available for unsealed roads, both locally and internationally, that aim to estimate the performance of an unsealed pavement wearing surface. The most comprehensive based on Australian studies comprise the results of the Local Roads Deterioration Study (LRDS) (Martin et al. 2013) which involved monitoring sites throughout Australia, and later studies (Martin et al. 2016) to examine the effectiveness of grading and resheeting based on practices in three Local Government road agencies in Queensland, New South Wales and Victoria. The models developed through the studies were reviewed in Austroads (2018c) have also been applied in the development of case studies and fit-for-purpose guidelines on the sustainable use of local materials resources (Austroads 2020a, 2020b). The user of this Guide is referred to these detailed studies for specific details.

The sensitivity of predictions to changes in selected key parameters on road deterioration and the effectiveness of maintenance techniques applied is illustrated below. The user is advised that quantitative evidence, though substantial, is still lacking; therefore, judgement is required in the application of the current evidence. The key models presented in this Guide are for gravel loss, shape loss, roughness and WE. Details of these models are provided below:

- Gravel loss – the variation of the predicted gravel loss (in mm since last maintenance) with changes to the average daily traffic (ADT) and mean monthly precipitation (MMP) is shown in Figure 2.14. The MMP has the most influence on gravel loss compared to the ADT. Plasticity characteristics also have an influence; however, the statistical models show little effect whereas practical experience and international studies suggest this should be stronger.

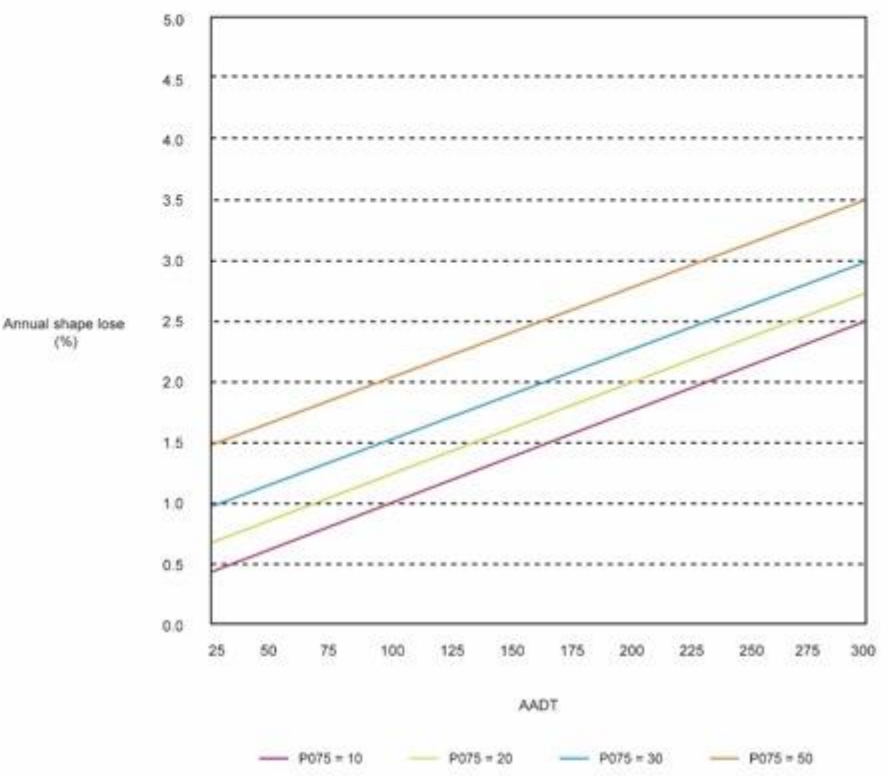
Figure 2.14: Gravel loss variation with traffic and rainfall



Source: Martin et al. (2013).

- Shape loss – the model for shape loss (SL) predicts the percentage (%) change in pavement cross-fall per year which will determine the timing of when grading of the surface should be scheduled. The model is illustrated in Figure 2.15. In contrast to the model for gravel loss it is more influenced by the wearing surface grading property, P075, i.e. the percentage (%) material passing the 0.075 mm sieve.

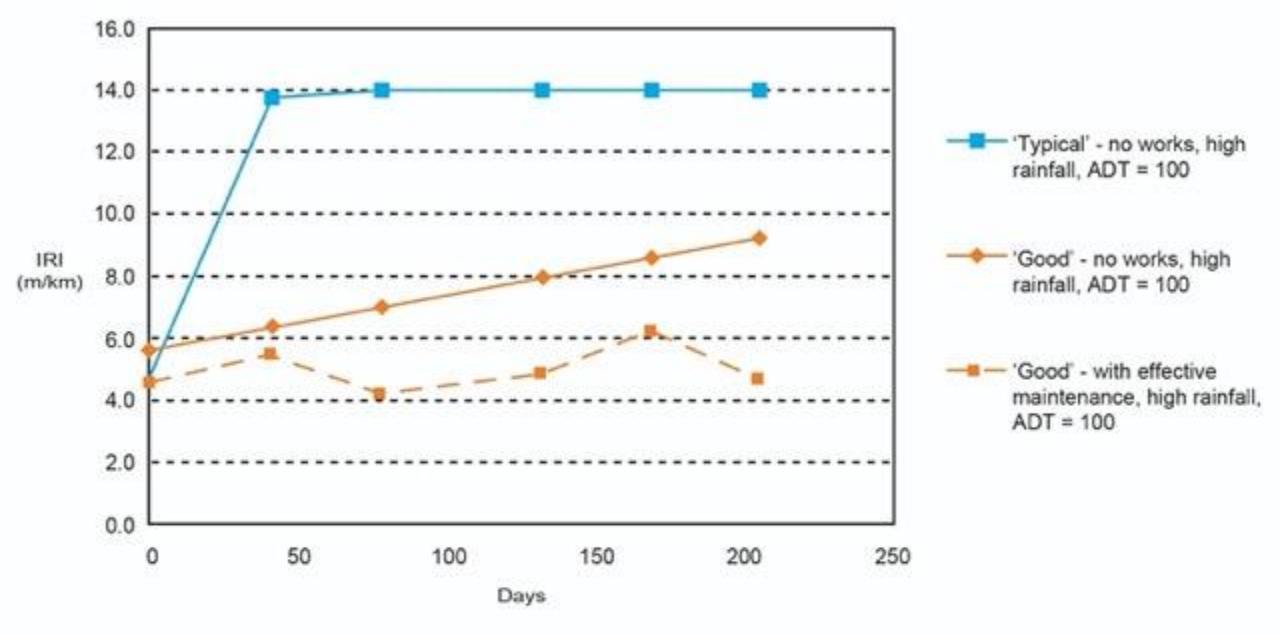
Figure 2.15: Annual loss of shape of an unsealed road with traffic and proportion passing the 0.075 mm sieve



Source: Adapted from Martin et al. (2013).

- Roughness – there are a number of RD models for roughness in use both locally and internationally that predicts the roughness, IRI, which in turn will determine the timing of when surface resheeting and grading should occur to maintain the road at an adequate level of roughness for a safe and acceptable ride. However, the results from the original nationwide studies and those from more controlled studies differ, with the former resulting in more rapid deterioration whereas the latter display slower rates of deterioration. For this reason, the two sets of results have been assigned a description of 'typical', implying relatively poor performance, and 'good' performance with these illustrated in Figure 2.16. The distinction is consistent with the differences resulting from different techniques, as illustrated in .

Figure 2.16: Roughness variation with time since maintenance and rainfall based on the original LRDS studies and subsequent controlled maintenance studies

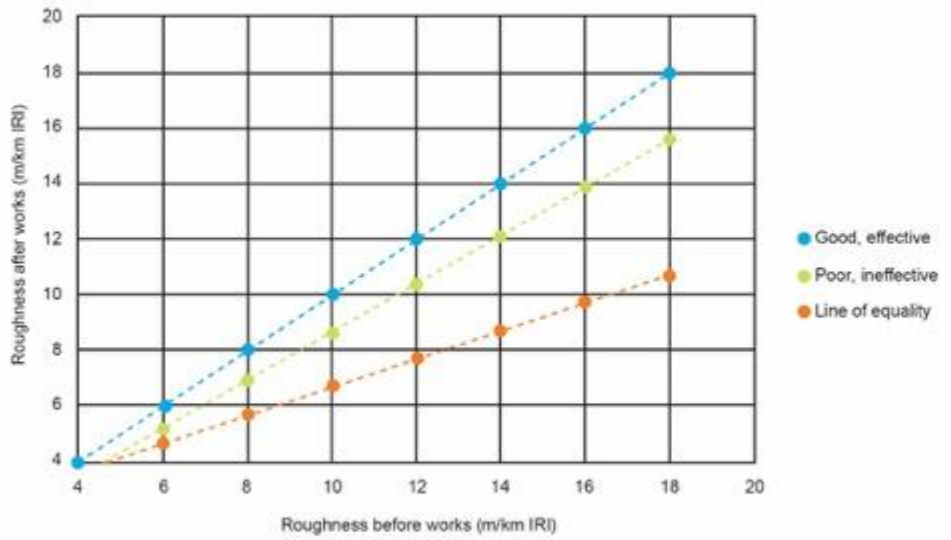


Source: Austroads (2018c).

- Works effects (WE) models – these demonstrate the effect of different grading techniques. The effectiveness has been shown to be location and technique specific, with a need to account for the amount of cutting and reshaping undertaken, along with the use of water and compaction. The improvement also depends on the materials used, with coarse materials being difficult to work and produce a smooth finish. An illustration of the effectiveness of grading is shown in Figure 2.17, which compares the light blading model predictions from two locations. There was a superior outcome for the WE predictions with greater reductions in IRI obtained in a high rainfall climate under conditions where the surface was amenable to effective grading, whereas the dry climate example with over-sized gravelly materials showed little improvement. The different prediction outcomes reflect the practices of each road agency and the conditions under which they are applied.

These factors were considered when designing the case studies reported by Austroads (2020a, 2020b) and in the example of optimum grading frequency for good practice illustrated earlier in Figure 2.7 and Figure 2.8.

Figure 2.17: Blading model comparisons



Source: Martin et al. (2016).

2.5.2 Pavement Maintenance Treatments

As already discussed, unsealed roads have three main forms: unformed road, formed road and formed and gravel road. For the formed and gravel road, the surface is a wearing course of gravel, or equivalent composite material, the purpose of which is to:

- provide surface characteristics to meet CLoS for the particular road class such as ride quality (IRI), and safety (limited potholes and rutting) at acceptable travel speeds
- reduce the rate at which surface moisture reaches the pavement/subgrade
- extend pavement life between resurfacing (resheeting) the wearing surface
- reduce vehicle operating and maintenance costs.

Routine maintenance

Routine maintenance is maintenance conducted on a regular basis, the aim being to keep the road surface conditions within those required by the CLoS. The following activities constitute routine maintenance in increasing order of maintenance effort:

- repairing potholes and ruts
- shoulder grading for improved drainage
- cleaning the surface drainage system (table drains and culverts)
- light grading (including gravel patch and patrol repairs), medium and heavy blading (without and with compaction and watering) to reduce corrugations, ravelling and reinstate the desired pavement crossfall.

As Figure 2.8, Figure 2.16 and Figure 2.17 show, grading practices can vary, with the best practices involving significant reshaping and compaction and watering of the surface materials. This can extend the period between gradings of the surface.

Periodic maintenance

Periodic maintenance activities are a higher level of maintenance than routine maintenance. They are planned to ensure that the CLoS is maintained over the long term. Most periodic activities involve resheeting (also known as regravelling), the wearing surface of formed and gravel roads.

For formed roads, periodic maintenance activities constitute major works addressing the strength of the pavement. It includes ripping, compaction, possible stabilisation and grading to restore crossfall shape.

Major re-alignment of the pavement and its potential replacement are considered to be part of the investment works program.

2.5.3 Program Analysis Tools – Investment Works Program

Investment planning, evaluation and programming is about identifying where and when to invest resources in the most cost-effective manner on the road network for the road users (Neumann & Markow 2004). This process needs to be undertaken in the context of the following:

- A broad policy framework that may cover initiatives such as sustainability, a growing economy, safety, etc. This is embodied in the road investment strategy (RIS) that allows the development of the investment works program.
- Performance measures are identified from the RIS. They form a reference for future network condition and performance that need to be achieved by the investment works program.
- Technical analysis tools and data allow objective economic evaluation and optimisation to select the appropriate strategy from various investment alternatives to preservation works to improve road network performance.

- Monitoring and feedback are needed to assess the impact of past and present investments on the road network.

Considerations for sealing an unsealed road

Sealing of an unsealed road is usually initiated to reduce the road agency's ongoing maintenance costs, allow all-weather access and to reduce the dust from trafficking for safety reasons. Justification for sealing an unsealed road should be grounded in an economic analysis, considering the costs and benefits of the expected outcome in terms of agency costs, vehicle operating costs and road user costs, and other costs including safety (see Section 2.5.4).

Economic Analysis

The economic analysis should consider the following:

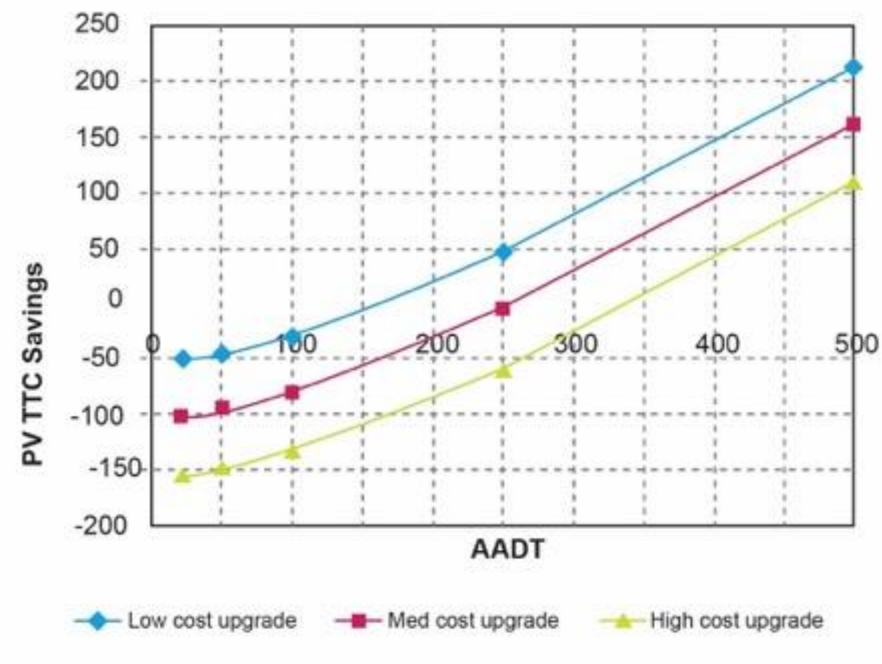
- *the long-term maintenance costs of the existing unsealed road*
- *the expected long-term costs of maintaining a sealed road replacement*
- *the existing traffic levels (AADT and % heavy vehicles) and expected future traffic growth*
- *strategic importance of the road*
- *confirmation, or otherwise, that the existing alignment (horizontal and vertical) and lane widths are adequate for future traffic*
- *the additional costs of realignment, lane width and surface drainage upgrade, if required.*

Many of the costs of upgrading the unsealed road are highly variable, depending on access to suitable gravels, or substitute marginal materials, and the haulage distances involved.

Current practice with some rural councils is not to consider sealing an unsealed road where the current AADT is less than 150, while where the AADT is greater than 500 it is a potential candidate for sealing.

Figure 2.18 shows the impact of the present value of total transport costs (PV TTC) of the cost of upgrading from an unsealed road to a sealed road for various levels of traffic. For AADT values greater than 250, most upgrade costs result in a positive PV TTC.

Figure 2.18: Present value of total transport costs (PV TTC) vs AADT for various upgrade costs



Rules of Thumb on When to Seal

The rules of thumb on when to seal an unsealed road, subject to a follow-up economic analysis, are as follows:

- *If traffic volumes are less than 100 vehicles per day (vpd), it is unlikely to be able to justify sealing unless resheeting the existing unsealed road is extremely costly due to scarcity of suitable locally available gravels.*
- *If traffic volumes are 100 to 250 vpd, sealing the existing road will be highly dependent upon the outcome of a properly conducted economic analysis.*
- *If traffic volumes are greater than 250 vpd, sealing the existing road is highly likely to be justified based on a properly conducted economic analysis.*

Investment program formulation

Investment program formulation is about identifying investment intervention options to close the asset performance gaps. These intervention options comprise the investment program. Owing to budget and resource constraints, only a portion of the investment program usually receives funding.

To ensure an equitable allocation of resources and to achieve the organisation's RIS, prioritisation of the investment program should occur from which an optimised outcome is the result.

Formulation of the investment program involves applying the following process for each asset performance gap (Austroads 2002):

- *Investment planning* involves investigating intervention options including engineering and management solutions such as road use policy initiatives, preventive or periodic maintenance, restoration, reconstruction, construction, education, incentives, or penalties. During this process maintenance works can be integrated with capital upgrades to ensure efficient and sufficient investment of funds.
- *Investment evaluation* involves defining and broadly costing phases of potential projects (both preservation and investment) and identifying the optimal intervention option to close the gap. Investment evaluation is applied to all programs. Coordination of these programs should be considered to ensure no duplication of works and well-integrated preservation and investment works programs. Investment evaluation involves the following:
  - A list of investment options must be developed. For each option, the following need to be defined: the cost, the impact of the option on asset needs, and intervention criteria.
  - Once investment options and intervention criteria are defined, the AMIS database can supply information for the economic evaluation.
  - A list of maintenance and investment strategies that can be applied to the different road TLoS classes and their associated costs needs to be generated. Examples of pavement asset management prediction models include the road deterioration (RD) and works effects (WE) illustrated in Section 2.4.1 and road user cost models (vehicle operating costs, travel time costs and crash costs) from the Australian Transport Assessment and Planning (ATAP) Guidelines (DIRD 2016; DIRD 2018).

The total needs program (preservation and investment) is the final list of projects created from this process.

Budget scenarios defined for asset management predict the amount of money that can be spent in any particular year of the analysis. This prediction uses the allocated money to optimise the network program and budget. Optimisation in this context is a single strategy selected for each of the analysis sections based on the overall benefit to the network as a whole and on the available funds. Optimisation is a mathematical technique for allocating scarce resources within the optimisation criteria that is aimed at gaining the most benefit or return possible in the given context.

The result of optimisation and funding scenarios will lead to the identification of the works program that will receive funding. The funding scenarios need some form of prioritisation based on their marginal benefit-cost ratio (MBCR) ranking[1] and associated risk of not funding the projects within the overall budget constraints.

2.5.4 Economic Evaluation and Optimisation

Preservation and investment

The following is a brief description of the measures and approaches used for evaluating intervention/investment options. Decision-making at the strategic, program and project level can operate with different degrees of sophistication as follows:

- *Current status* – the current condition is the driver in decisions; it is often associated with a worst first approach to investment.
- *Whole-of-life-cycle-costing* (WOLCC) – future performance is the main driver in decision-making; it requires condition prediction modelling over the whole-of-life analysis period (see DIRD 2016, 2018).

[1] For the ranking of maintenance and renewal investment of existing infrastructure the Marginal Benefit–Cost Ratio (MBCR) can be used as an indicator under circumstances where a budget constraint applies. It expresses the benefit to road users for each additional dollar of investment (including maintenance) relative to a given base case. Where new investment is undertaken, the denominator in the BCR is the total cost representing the new investment. Guidance is provided in the National Guidelines for Transport System Management (NGTSM), specifically Volume 3 (ATC 2006). These however will be replaced by the ATAP guidelines due to be published in 2020.

- *Multi-criteria analysis* (MCA) – this analysis covers aspects other than WOLCC, including environmental, social and political issues (see Austroads 1998). Using MCA, the performance of options against qualitative criteria can be assessed together with the present values (PVs) to produce overall scores for the options that consider all relevant criteria. The overall scores can then be used to rank the options. To optimise budget expenditure, the cost to overall score ratio can be used as the measure to rank the options.
- *Risk analysis* – also involves consideration of multi-criteria, where investment options are evaluated using a risk assessment method. The simplest form of a risk analysis is a risk score estimated using Equation 3.

$$Risk\ score = probability\ of\ failure * consequences\ of\ failure \quad (3)$$

The probability of failure ($p \leq 1.0$) is a judgement based on the current condition and performance of the road, while the consequences of failure depends on the level of traffic and the cost consequences of restoring the road to an operational state, including the additional road user costs in not being able to use the road, i.e. diversion or delay costs.

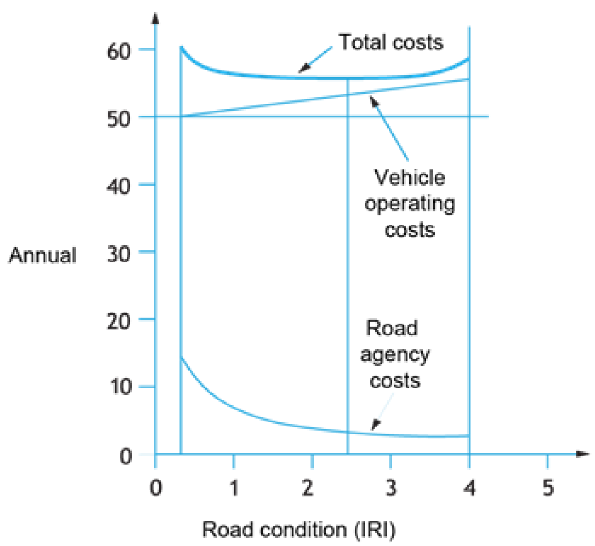
Whole-of-life-cycle-costing

An example of a WOLCC analysis technique is shown in Figure 2.19 for optimising, or minimising total community life-cycle costs, or WOLCC.

> *In the context of asset management economic evaluation, optimisation should be focussed on evaluating what are regarded as the most important aspects of asset management.*

These aspects usually relate to minimising total life-cycle costs while meeting community and broader social expectations. Figure 2.19 shows minimisation of the total life-cycle costs of the road agency costs (maintenance, resheeting and construction) and the road user costs (vehicle operating costs and travel time costs), in annual road agency cost terms.

Figure 2.19: Minimisation of total life cycle costs

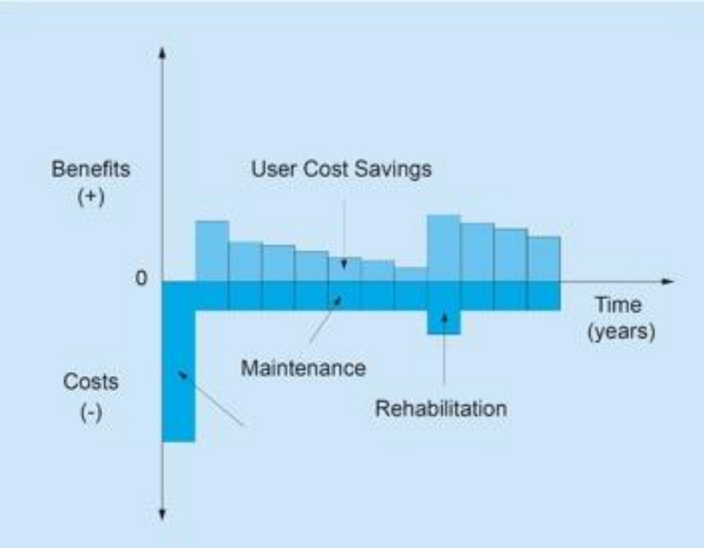


Source: ARRB (2005).

Other costs such as vehicle operating costs, crash costs, salvage and GHG emission costs could be included in minimising the total life-cycle costs. Figure 2.19 is the result of a discounted cash flow analysis over a given analysis period (up to 30 years) for a number of different levels of road agency funding that result in different levels of road condition (IRI roughness), vehicle operating costs and travel time costs.

Figure 2.20 shows details of the discounted cash flow analysis of the stream of costs associated with initial construction, maintenance works (routine maintenance and annualised grading costs between resheeting) and resheeting. Against these costs are the benefits associated with reducing road users cost (vehicle operating costs and travel time costs) relative to a base case of the road user costs at minimum road agency costs.

Figure 2.20: Distribution of costs and benefits during the life cycle of a road option



Source: ARRB (2005).

Definitions of work costs, benefits, net present value (NPV) and marginal benefit-cost ratio

Maintenance works for unsealed roads are summarised in Table 2.8. The costs for these works should include the project costs associated with investigation, design, surveying, supervision, traffic management, environmental provisions and project procurement.

Table 2.8: Types of maintenance works

Category	Description	Example
Routine maintenance	Minor repairs in response to specific pavement defects	Repairs of potholes and ruts, shoulder grading, cleaning of surface drains and culverts
Periodic maintenance	Grading to maintain surface conditions (reduction in corrugations and ravelling and improve crossfall shape)	Light grading (gravel patch and patrol repairs), medium to heavy grading (with and without compaction and watering)
Resheeting	Addition of gravel to surface, compacting and grading to maintain surface condition and reinstate crossfall shape	Application of compacted gravel, or equivalent, to achieve design of wearing course thickness
Rehabilitation	Restores strength, and renews roughness and rutting to within the CLoS conditions	Ripping of pavement, re-compaction and possible stabilization and resheeting of the surface

Capital, or construction works, for investment pavement projects are summarised in Table 2.9. The costs for these works should include the project costs associated with investigation, design, surveying, supervision, traffic management, environmental provisions and project procurement.

Table 2.9: Types of capital or construction works

Category	Description	Example
New pavement	Construction of a new pavement to meet TLoS, including earthworks, and installation of off-pavement assets	Pavement base and surfacing, surface drainage works, and guide posts
Pavement realignment/widening	As above, usually involves a realignment of the pavement and possible increased lane and shoulder width	As above, with realignment and widening improving safety and travel speed
Reconstruction	Full rebuilding of the pavement structure; results in 'as new' condition along existing alignment	Reconstruction to cope with increased traffic
Sealing of unsealed road	Involves surface preparation prior to sealing and may involve strengthening of underlying pavement structure to suit expected traffic increase	Initiated to reduce maintenance costs and dust with increased traffic

Benefits

Benefits are usually in the form of reductions in the following costs relative to a base case of LoS delivery of minimum road agency costs:

- *road user costs (vehicle operating costs and travel time costs)*
- *crash costs (reduced incidence and severity of crashes)*
- *GHG emission costs associated with road users.*

Other quantifiable benefits can be the salvage value of the pavement at the end of the analysis period where investment options have different lives.

The costs and benefits cash-flow streams are each reduced to a present value (PV) of $s in today's terms using Equation 4, Equation 5 and Equation 6 (DIRD 2018).

$$PV_{cost} = \sum_{i=1}^{n} \frac{cost_i}{(1+r)^n} \quad (4)$$

$$PV_{benefit} = \sum_{i=1}^{n} \frac{benefit_i}{(1+r)^n} \quad (5)$$

$$Net\ present\ value\ (NPV) = PV_{benefit} - PV_{cost} \quad (6)$$

where

PV_{cost} = present value of the costs (sum of PV $cost_i$ in year 'i')

$PV_{benefit}$ = present value of the benefits (sum of PV $benefit_i$ in year 'i')

r = real discount rate (%), typically 7%, varies between 4–10% for sensitivity (DIRD 2018)

n = number of years in analysis

The investment/preservation option with the highest NPV is regarded as the most economic. The use of an NPV evaluation is particularly useful for the assessment of alternative investment/preservation options.

The costs shown in Figure 2.19 are the total PV of all costs (road agency and road user costs) expressed in terms of the annual costs for each road agency funding level.

The marginal benefit-cost ratio (MBCR) is used for ranking projects where there is a budget constraint and as a convenient way to express the economic worth of an initiative.

The MBCR is calculated using Equation 7, where any MBCR greater than one implies a positive NPV (DIRD 2018):

$$MBCR = \frac{PV\ net\ benefits}{PV\ net\ costs} = \frac{PV\ (benefits - operating\ costs)}{PV\ (additional\ investment\ costs)} \tag{7}$$

2.6 Implementing Works Programs

2.6.1 Network and Project Management Levels

Network management level

Network management level implies a top-down approach where the broad works for preservation/investment programs are more likely to define the preservation/investment strategies and other activities needed to achieve the TLoS and other network requirements rather than define detailed projects on specific lengths of each road in the network. The works program at a network level can provide the basis for scoping the work and provide options about how it could be packaged and delivered.

Alternatively, a bottom-up approach means the broad works program is defined by the aggregation of well-defined project level works. This approach may mean, as a consequence, that optimisation and prioritisation become more demanding in terms of data requirements and computing resources, although contemporary computer capacity is capable to achieve this.

Project management level

As implied above, project level management is concerned with managing specific details of maintenance treatments/investment works and other activities at clearly defined locations of the road network. Works programs at this level should be well defined so they can be accurately estimated for costs and completion programs that can potentially be implemented by means of a delivery package of project level works.

Consequently, there is a feedback cycle between network and project level management. The information collected at a network level and subsequently used in analyses to estimate annual budgets, preservation/investment strategies, condition and performance limits on strategic road links can be the basis for setting condition and performance limits and budgets at a project level.

2.6.2 Requirements for Successful Program Implementation

The requirements for successful implementation of the works program from program initiation to completion and handover are as follows (Austroads 2014):

- a well-defined brief for each package of the program which clearly states the objectives, scope, budget and major milestones

- a range of delivery strategies which impact on the scope of the program and how it is packaged and implemented
- a range of risk management strategies which also impacts on the delivery options
- adequate resources allocated for the program, which includes management resources
- ensure compliance with occupational health, safety and welfare laws (Austroads 2019a) and other statutory requirements in relation to environmental and community concerns
- managing and monitoring the project.

Project delivery strategies

The project delivery strategy adopted depends on the scale or scope of the project and the inherent risks associated with the project. Table 2.10 shows the range of delivery strategies available associated with the varying scale and potential risk of the project.

Table 2.10: Summary of project delivery strategies

Strategy	Suggested appropriate application
In-house	Minor works or maintenance
Design only, and subsequent construct only	Small to medium repetitive type e.g. standard bridge replacements
Hybrid, detail and construct (part design and construct)	Medium to large projects such as major maintenance/improvement works
Design, novate and construct (DN&C)	Transference of risks and benefits e.g. from client to a third party which replaces the original party as a party to the contract
Design and construct (D&C)	Contract delivery for large-scale works
Design, construct and maintain (DCM)	Multi-phase projects
Design development and construct (DD&C)	A single or series of contracts delivered

Source: Austroads (2018a).

In addition, the current state contestability, that is, the potential number of potential contractors/consultants competing for the project can influence project timing and its delivery arrangements.

The use of in-house resources are generally appropriate for small well-defined projects that are relatively low in risk. This approach may also be appropriate for high risk projects that are poorly defined but relatively small in scale.

2.6.3 Risk Management

Delivery of projects is a risk sharing arrangement. Risks need to be identified before commencing the project and tracked during progress of the project. Initial identification of risks can define the project delivery options.

When small-scale projects are undertaken in-house, all the risk is carried by the road agency. Conversely with large-scale projects that involve less prescriptive outcomes, the road agency can reduce their risk by packaging the project in such a way that the contractor carries all the risk by ultimately, in the extreme case, transferring ownership of the project to the contractor for a specified period of time.

There are usually commercial consequences associated with transferring risk to contractors as they will include a risk premium (cost) in their bid price to allow for risk. Where there is high contestability for the project, the premium for risk may be reduced by tenderers in order to secure the project. Consequently, contractual arrangements need to clearly define who is carrying/sharing the risk for the project so that completion of the project is secure and resort to litigation minimised. A detailed description of the various project delivery packaging options is documented in Austroads (2009a).

2.7 Audit and Review

2.7.1 Audit

The audit function involves monitoring the ongoing progress of the works program. This is also about ensuring that all the quantum of work listed in the works program is programmed and underway for completion within the specified program.

Audits

The audit can also include examining the following as part of the works program delivery:

- *The works program is on the way to achieving the specified outcomes.*
- *Any deficiencies in the outcomes are detected before program completion so they can be addressed and rectified before completion.*

2.7.2 Review

The review function involves monitoring the outcomes of the works program. This is not just about ensuring that all the quantum of work listed in the works program was completed, but that it was completed to the scope, standard and quality specified.

Reviews

The review can also include examining the following associated performance measures set by management as part of the works program delivery:

- *What is the financial performance of the works program?*
- *Were the expected improvements in condition and performance achieved and reflected by a customer survey post works program?*
- *Were the staff engagement, utilisation and productivity targets met?*

The results should be communicated to the wider organisation through meetings and forums to show the road agencies' performance in delivering works programs. The results should also feed back into the strategy development process for the next yearly asset management cycle.

3 Design

3.1 Road Planning and Development Overview

3.1.1 Overview

During the planning phase, an assessment of the proposed road aspects, such as class, pavement type, purpose, location, impacts, costs and potential alternatives is undertaken. This process may take place over several, increasingly detailed stages, such as those outlined in Table 3.1. The level of detail required for each of these stages can sometimes be less for unsealed roads than for sealed roads, however the main principals remain effectively the same.

Table 3.1: Example stages of road planning

Planning stage	Aspects to consider
Assess feasibility	• Current transport needs (e.g. of the public and freight industry). • Existing land use. • Current road and traffic conditions. • Potential need for cross-jurisdiction collaboration. • Timeline and cost forecasting. • Potential impacts (e.g. on the network, environment, future development). • Possible alternatives.
Define the scope	• Approximate location. • Road classification (Section 3.5.5. • Estimated traffic capacity. • Design life. • Level of service. • Proposed pavement structure.
Preliminary planning	• Connection to existing network. • Allowance for future network connections. • Traffic, safety and road engineering solutions. • Environmental impact assessment and design considerations (Section 3.2). • Climate and moisture considerations (Section 3.6.3). • Roadside considerations. • Construction and future maintenance considerations (Section 3.2.3). • Preliminary pavement design (including specific structural and drainage design, and pavement thickness – Section 3.6). • Cost estimate. • Target timeline. • Construction outline (e.g. short-term stages or long-term staged construction).
Final planning	• Precise location. • Geometric design of the road (Section 3.5). • Detailed traffic, safety, environmental impact, and road engineering solutions. • Site evaluation (e.g. assessing the in situ conditions – Section 3.6.4). • Detailed plan for the roadside. • Final pavement design (Section 3.6.7). • Refined cost estimate. • Construction plan including all required documents.

3.1.2 Staged Development

Depending on the availability of funds, traffic volumes, soil types and climatic conditions, roads may be constructed over a period of time. There can also be economic benefits in stage-developing a fit-for-purpose road. Section 2.5.4 deals with economic assessment methodology for when to upgrade or seal a road.

Staged development of roads can comprise the following steps (refer Figure 3.1):

1. Clear and make a trafficable track (unformed road).
2. Construct the roadway formation and rehabilitate disturbed areas of vegetation (formed road).
3. Provide pavement materials (formed and gravelled road).
4. Seal the pavement (sealed road).

The provision of drainage may also be staged, increasing the amount of drainage provided at each stage of development.

Figure 3.1: Staged development of roads

Unformed road

Formed road

Formed and gravelled road

Paved road with a sealed surface

The decision to undertake staged development is more likely to be taken in the case of low traffic volumes (i.e. AADT values of less than 25 vehicles per day), good soils and dry climate. Community disadvantages and benefits should be considered, e.g. delays resulting from lack of drainage or a suitable wearing course, or benefits to industry accruing from improved accessibility.

Another approach that maximises the effect of limited funds or resources is the use of a ‘spot improvement’ program or ‘differential improvement strategy’. An example of this approach is to provide a higher-quality surface or sealing a section of the road at a critical location; for example, on a tight bend where there is high wear and tear and poor safety, in areas where an unsealed surface provides poor traction and has high maintenance costs or at a weak section over low swampy areas. The higher cost of maintaining such a road section can often justify an initial higher cost treatment, although in some circumstances an all-weather unsealed or sealed solution can be cheaper. Spot improvement strategies can be evaluated based on the economic assessment methodology given in Section 2.5.4.

3.2 Managing the Environment and Cultural Heritage

Unsealed roads can have potentially more damaging impacts on the environment than sealed roads. These impacts are greatly influenced by the planning, design, construction and maintenance phases of road management.

Roadside reserves play an important conservation role in hosting a substantial proportion of Australia’s biodiversity; however, road management also poses significant threats to maintaining that biodiversity.

Many aspects of environmental management are covered by legislation. Road practitioners should be guided by environmental guidelines in their consideration of the impact of road planning, design, construction and maintenance activities.

In most cases new construction work will require the preparation of an environmental review (or impact study). The type and nature of the review may vary between States as will the magnitude of the impacts involved. This review may also extend to maintenance activities depending on the possible impacts. Road practitioners should consult the relevant regulations to determine the need for, and extent of, any environmental reviews.

3.2.1 Managing Cultural Heritage

Cultural considerations are important where there is the potential for disturbance to Aboriginal cultural heritage sites or other heritage sites.

Where a high-impact activity is planned in an area of cultural heritage sensitivity it may be State or Territory regulation that a cultural heritage management plan or similar be prepared. Obtaining such a plan prior to works starting usually involves an assessment of the impacts that may be associated with the proposed works area and the measures to be taken before, during and after the works.

As each State and Territory differs, appropriate cultural heritage management information can best be found directly from the relevant road agency.

3.2.2 Possible Environmental Impacts

Unsealed roads can affect different elements of the environment including waterways, the air, land and its biodiversity. Local roads are also used to transport many different types of hazardous material, for example fertilisers, pesticides or fuel, which can threaten water supplies and natural waterways if spills occur as a result of road accidents.

Air pollution from unsealed roads is caused by vehicle and dust emissions.

Degradation of the landscape surrounding the road can occur due to soil contamination by chemicals used during road use and maintenance activities, soil compaction by vehicles and machinery and by soil loss due to erosion from bare or disturbed areas of soil.

Road practitioners should therefore pay attention to the possible environmental impacts outlined in Table 3.2 when planning, designing, constructing and maintaining unsealed roads.

Table 3.2: Possible environmental impacts

Environmental impacts	Considerations
Erosion and sedimentation	• Erosion of material from the road surface, table drains and batters, with the possibility of material removal and concentrated damage (gullies, channels, etc). • From an ecological perspective, sediment is the most significant of all road run-off pollutants. Unsealed roads can generate large amounts of sediment which can cause serious environmental damage to waterways. • Where a road is poorly located and/or the surrounding drainage system is poorly designed, an unrestricted flow can yield up to 15 tonnes of sediment per km per year from a 10 m wide unsealed pavement (Norvill 1999). • Potential impacts of sediment include burying aquatic vegetation which leads to reduced water depths, smothering and killing of fish eggs/aquatic larvae, turbidity which reduces light and interferes with the respiration and feeding of aquatic animals/plant, and transmission of other pollutants such as heavy metals.
Local air impacts	• Unsealed roads can negatively impact the quality of air through dust and vehicle emissions. • Dust can impair visibility and safety for motorists, pose a health hazard and smother roadside vegetation.
Land degradation	• Vehicle traffic and maintenance activities along unsealed roads can damage soils and displace previously intact parts of the landscape. • Soil can become contaminated, compacted or eroded following road construction, usage and maintenance. • Weed spread caused by vehicles or maintenance activities. • Roads can modify catchment hydrology leading to increased erosion or increased recharge to ground water, as well changing local ground water and surface water flow. • Local watertables may be affected causing increased salinity of wetlands and streams.
Biodiversity	• Road corridors can have both positive and negative impacts on wildlife and native vegetation. • Road corridors can remove/reduce habitat, act as a barrier to wildlife movement and result in significant roadkill. • Road corridors can present difficulties for fish movement at culverts and road crossings. • High sedimentation of waterways can kill aquatic species. • Road corridors can facilitate the introduction of exotic flora and fauna due to soil and habitat disturbances.
Resource use and greenhouse gas emissions	• Unsealed road construction and maintenance activities utilises natural resources and energy. • Carbon dioxide (CO_2) emission are generated at an approximate rate of 2.7 kg CO_2/litre diesel fuel used during construction and maintenance activities (Transport Authorities Greenhouse Group (TAGG) 2013). • The growing scarcity of natural materials (including water) in some areas can increase the total cost of pavement construction and maintenance. • Using alternative materials, such as recycled and marginal (non-standards) materials can assist in making unsealed roads more sustainable. • Choosing materials with the lowest life-cycle costs are becoming increasingly important.

Note: The possible environmental impacts listed in this table may not necessarily be exhaustive and additional impacts may apply.

3.2.3 Planning, Design, Construction and Maintenance Considerations

The planning and design of unsealed roads should consider (as a minimum) the following environmental impacts:

- Road location – plan the road location to minimise adverse impacts on the surrounding environment (refer Appendix A.1.1).

- Design standards – select standards that will minimise the impact on the surrounding environment (refer Appendix A.1.2).
- Drainage design – design drainage structures to minimise flows rates and erosion (refer Appendix A.1.3).
- Stockpiles and waste storage sites – protect stockpiles from erosion, located away from roadsides with conservation value and in areas with effective drainage systems.
- Gravel borrow pits – should not be located within a road reserve of 200 m of a roadway or major watercourse.

Borrow pits and stockpiles sites can have a significant impact on the environment and guidelines for the sustainable management of these sites can be found in the ARRB Road Materials Best Practice Guide (ARRB 2020b).

Comprehensive guidance on minimising the environmental impacts of road design activities are provided in Appendix A.1 of this Guide.

Further guidance regarding environmental management requirements can also be found in the AUS-SPEC design work sections available for purchase through NATSPEC at www.natspec.com.au.

3.3 Safety in Planning and Design

It is important to understand what factors lead to the occurrence of crashes, and what measures may be undertaken to minimise them. This section provides guidance on practical and low-cost techniques for improving road safety and reducing potential litigation at the planning and design stages of a road project.

3.3.1 Duty of Care as a Road Agency and Liability

A road agency has a duty of care to all users of the road network that might be adversely affected by its acts or omissions.

The National Road Safety Action Plan (Transport and Infrastructure Council 2018) notes that up to 50% of serious casualty crashes occur on roads controlled by Local Governments and that Local Governments will need to support and apply cost-effective, innovative solutions in line with the Safe System approach.

In Australia, a series of court decisions established that road agencies have a duty of care towards road users. In practice, this means that they must do what is reasonable to be aware of deficiencies in the road system, to assess and priorities these deficiencies, and have a system for remedying them (Sarre 2003).

Note that the requirement of duty of care does not demand that there be no deficiencies in the road system – only that a road agency will do what is reasonable to monitor and remedy any deficiencies.

The court decisions recognised that the resources available to an organisation, including the availability of material, skilled labour and funding, may limit how quickly defects can be addressed. If this results in a delay to remedying a situation which is hazardous for road users, then the road agency should consider other alternatives such as using signs to alert road users of the hazard or, in extreme cases, closing the road. The minimum commitment to road safety is a process for identifying safety issues and prioritising them, a process for remedying these issues within a reasonable time frame and a process for managing unsafe situations until remedial works can be undertaken. Each of these processes must be defensible as 'reasonable'.

Case Study: Inadequate Guide Posts and Poor Superelevation on a Curve Causing a Fatality

In June 2001 while driving on Woodendale Road, an unsealed road in Toodyay, a vehicle skidded around a curve, left the road and crashed into a tree. The driver was injured, and the passenger was killed.

The driver was approaching a right-hand bend at about 60–80 km/h using the outside guide posts as a guide to negotiate a bend. Noticing that the vehicle was sliding off the road the driver adjusted the steering but lost control of the vehicle.

The Commissioner's findings were that the driver lost control of the vehicle due to the inadequacy of the guide posts spacings to adequately show the sharpness or radius of the curve. In addition, the flattening of the road crossfall and negative camber on the curve made it more difficult for the driver to regain control of the vehicle.

In the Commissioner's view the Shire was obliged to take reasonable steps to ascertain the existence of the dangers posed by imperfect camber and inadequate placement of the guide posts. He also cited that there was no evidence that any grader operator or staff members received training or instruction in what dangers to look out for and how to detect them.

The Commissioner concluded that the mishap was caused by the negligence of the Shire in the execution of its works and the Shire is liable.

Source: Shire of Toodyay v. Walton (2007) WASCA 76.

3.3.2 The Safe System Approach

Safe System Approach

Within the context of designing and maintaining roads, the following should be considered to align to Safe System principles:

- *Designing, constructing and maintaining a road system (roads, vehicles and operating requirements) so that forces on the human body generated in crashes are generally less than those resulting in fatal or debilitating injury.*
- *Improving roads and roadsides to reduce the risk of crashes and minimise harm: measures for high-speed roads include dividing traffic, designing 'forgiving' roadsides, and providing clear driver guidance.*
- *In areas with large numbers of vulnerable road users or substantial collision risk, speed management supplemented by road and roadside treatments is a key strategy for limiting crash forces.*
- *Advising, educating and encouraging road users to obey road rules and to be unimpaired, alert and responsive to potentially high-risk situations.*

The Safe System approach is built on three basic principles (Australian Transport Council 2011):

1. **People make mistakes** – humans will continue to make mistakes, and the transport system must accommodate these mistakes. The transport system should not result in death or serious injury as a consequence of errors on the roads.
2. **Human physical frailty** – there are known physical limits to the amount of force our bodies can take before we are injured or killed.
3. **A 'forgiving' road transport system** – a Safe System ensures that the forces in crashes do not exceed the limits of human tolerance. Speeds must be managed so that humans are not exposed to impact forces beyond their physical tolerance. System designers and operators need to consider the limits of the human body in designing and maintaining roads, vehicles and speeds.

'The Safe System approach focuses on creating safe roads, safe speeds, safe vehicles and safe road use' (Ministry of Transport 2010). The ultimate goal of a Safe System would be to achieve:

- **safe roads** – that are predictable and forgiving of mistakes; they are self-explaining in that their design encourages safe travel speeds
- **safe speeds** – travel speeds suit the function and level of safety of the road; people understand the road environment and drive to the conditions
- **safe vehicles** – that prevent crashes and protect road users, including pedestrians and cyclists, in the event of a crash
- **safe road use** – road users that are skilled and competent, alert and unimpaired; they comply with road rules, take steps to improve safety, and demand and expect safety improvements (Ministry of Transport 2010).

To achieve these goals, 'the human body's tolerance to crash forces will need to be the key design factor for the system. Crash forces would be managed so they do not exceed these limits' (Ministry of Transport 2010). Figure 3.2 illustrates the various components, the four key 'pillars', of the Safe System approach, i.e. Safe Roads, Safe Speeds, Safe Vehicles and Safe People.

Figure 3.2: Overview of road transport safe system

Source: Transport and Infrastructure Council (2018).

A fifth pillar – Post Crash Care – was introduced by the United Nations in 2011 (Austroads 2018f). This fifth pillar is yet to be reflected in many depictions of the Safe System: however, it can be a deciding factor on the survivability and severity outcomes of crashes. Some suggested treatments to reduce crash response time to a crash location and increase the chance of survivability are as follows:

- location marker signs for reference during communications with emergency services
- emergency phones in remote locations where most road users are unlikely to have reception (including tourists)
- airfields built into the road cross-section (Austroads 2015)
- censored guardrail that emits notification when struck
- camera monitoring at high-risk locations
- automatic crash notification in vehicle telematic systems (Lahausse et al. 2008).

'It can never be ethically acceptable that people are killed or seriously injured when moving with the road transport system.' – the origin of Safe System thinking

3.3.3 Crashes on Unsealed Roads

Crashes on Unsealed Roads

Factors that may contribute to the incidence and severity of crashes on unsealed roads include:

- *poor road surface conditions (loose materials, slippery when wet, dust emissions)*
- *poor geometric standards (tight curves, restricted sight distance, poor signage and delineation, poor vertical and horizontal coordination, roadside hazards)*
- *inconsistencies in the road conditions that can surprise an unsuspecting driver (e.g. sudden dip or an isolated sharp curve on an almost straight road)*
- *low traffic volumes which can encourage higher travel speeds*
- *traffic composition which may include a high proportion of heavy vehicles*
- *driver behaviour (excessive speed, lower levels of restraint use, failing to keep left)*
- *collisions with native animals*
- *driver impairment (alcohol, fatigue)*
- *driver inexperience*
- *low levels of enforcement*
- *longer emergency service response times due to rural and remote location of crashes.*

3.3.4 Typical Hazards on Unsealed Roads

The typical range of road and roadside hazards that can contribute to the incidence or severity of crashes on unsealed roads is presented in Table 3.3. These hazards should be considered at the design and planning stages, as well as when maintaining an unsealed road.

Table 3.3: Typical hazards found on unsealed roads

Loose material – loose material on the road surface reduces skid resistance and may contribute to loss of control type crashes. Loose stones may be picked up by wheels and flicked at other vehicles, resulting in broken windshields. Ways to minimise loose material are discussed in Section 5.1.3. It is in the nature of unsealed roads that as part of their normal wear and tear, loose stones will accumulate. Appropriate maintenance intervention levels need to be set to provide guidance for when action is to be taken.	 **Loose material on the road surface can lead to loss of control**
Superelevation – it is important to provide correct superelevation at horizontal curves. Loose material often builds up on the outside of curves, creating a potential safety hazard. Good superelevation will assist driver comfort and safety when travelling around curves and will minimise the build-up of loose material on the outside of a curve. The design of superelevation requirements is covered in Appendix C.3.1 and the maintenance of correct superelevation is discussed in Section 5.1.6.	 **Poor crossfall or superelevation may result in build-up of loose material on the outside of the curve, creating a potential safety hazard**

Drainage – is provided to protect and preserve the pavement. It is important that roadside drains do not create a hazard. Table drains should be constructed so that they are 'driveable' if a vehicle run off the road. Culverts can be installed such that end walls are not located immediately on the edge of the road, or driveable end walls can be installed. Drainage requirements are discussed in Section 5.1.6 and Appendix C.7.	 **Roadside drains should not pose a hazard**
Surface conditions – the surface of the road should be maintained to limit the development of surface hazards (such as rough surface, rutting, potholes, etc.). Regular grading to remove surface hazards and compaction of the pavement materials should be part of the ongoing maintenance schedule. Grading requirements are discussed in Section 5.1.6.	 **Potholes, and other surface hazards on the roadway, can create safety concerns**
Dust – excessive dust can limit visibility. Dust control measures and ways to minimise dust emissions are discussed in Appendix A.4.4.	 **Dusty conditions can result in reduced visibility for drivers**

Roadside hazards – can have a major impact on the severity of a crash. Hazards such as poles, steep embankments and trees close to the edge of the road can result in serious injuries or fatalities when vehicles run off the road. In some scenic locations, points of interest may cause visual distractions to drivers. The provision of an appropriate clear-zone, which allows errant vehicles space to recover is preferable at critical locations (such as near curves and intersections) where vehicles are more likely to run off the road. If a clear zone cannot be provided, then a safety barrier should be considered. Maintenance of the roadside environment is discussed in Appendix A.4.3.	 **Hazards located close to the carriageway can have a major impact on the severity of a crash**
Sight distance – it is important to provide adequate stopping sight distance so that drivers may safely navigate through the various road surface conditions, avoid hazards and see oncoming vehicles in time to take avoiding action. This is particularly important at critical locations such as at tight curves and intersections. Sight distance is influenced by road geometry and vegetation on the roadside. Safe stopping sight distances for unsealed roads are longer than those for sealed roads. It is important to take these longer safe stopping sight distances into account when considering sight distance requirements for unsealed roads, particularly when considering heavy vehicles. Sight distance requirements are discussed in Appendix C.2.	 **Drivers have restricted sight distance around this curve with no curve alignment markers or guide posts provided to delineate the tightness of the curve**
Intersections – it is important to provide adequate sight distance and/or signage to alert drivers that they are approaching an intersection. Intersections should be clearly visible to all approaching drivers and/or appropriate warning signs provided to alert drivers. The geometric design of intersections and appropriate intersecting angles, approach and safe intersection sight distances are discussed, is discussed in Appendix C.5.	 **Drivers may not be aware that just over the rise there is an intersection (see inset)**

Road signs – it is important that road signs are used appropriately when required to warn motorists of potential hazards. Make use of standard road signs to alert a driver to changing road features, or roadworks ahead to help motorists drive to conditions. Road signs are low-cost items and should be placed to remove potential 'surprise' situations. Do not use speed advisory signs on unsealed roads, as the surface conditions are too variable, and the safe curve speed is likely to change. A motorist should drive to conditions.	 **Speed advisory signs on unsealed roads where road surface conditions are variable should <u>not</u> be used**
Bridges – delineation on the approaches to a bridge is a critical safety requirement to prevent drivers hitting the bridge or missing it altogether. Bridge approaches should have sufficient sight distance and good delineation to guide a driver over the bridge which is often narrower than the approaching road. Safety barriers should be provided to protect vehicles from the bridge structure or a hazard adjacent to the bridge or behind the bridge (embankment, drop into creek bed etc.) and sometimes pedestrians, when warranted. The structural adequacy of bridges and related safety aspects are covered in Giummarra (2000) and the ARRB *Bridge Management Best Practice Guide* (ARRB 2020b).	 **Adequate signs and sight distances should be provided, and guardrails when warranted, on bridge approaches**
Causeways/floodways – crossings should consider safety requirements, particularly when water flows across the roadway. There should always be adequate signs and guide posts to indicate the alignment of the roadway over the causeway, as well as depth gauges and good sight distances on all approaches. Further guidance can be found in Austroads (2013a).	 **Example of a poor causeway with a lack of safety provisions, including causeway signs on approaches, guide posts and depth gauge**

Railway crossings – many railway crossings are on low volume roads. Some rail lines carry very few trains, and some may operate only for part of the year. This combination of few cars and trains can make road users complacent when approaching a railway crossing and not take the necessary care to watch out for possible trains approaching. Special measures may need to be taken to alert a road user of the railway crossing and any approaching trains.	 **Good sight distance on all approaches is required with adequate road signs at the rail crossing**

3.3.5 Safety Improvement Strategies

Developing a road safety strategy

All State jurisdictions in Australia have a formal road safety strategy which guides the efforts to reduce road deaths and injuries. Whilst many Local Governments have comprehensive strategies which are being actively pursued, many Local Governments may not have started to develop strategies (Austroads 2013b).

A road safety strategy should consider the following:

- **Vision:** 'an innovative description of the future traffic system, or a desired direction of road safety development' (OECD 2002, p. 20).
- **Strategy:** a coordinated set of actions designed to achieve a specific result or set of results in a specified period.
- **Plan:** an expression of the strategy over a shorter period, so that the fulfilment of successive plans, modified in the light of changing circumstances and outcomes achieved or not achieved, achieves the desired result of the strategy.
- **Target:** an outcome expressed in quantitative terms, e.g. number of fatalities, percentage reduction in fatalities, or fatality rate per population or per distance travelled.

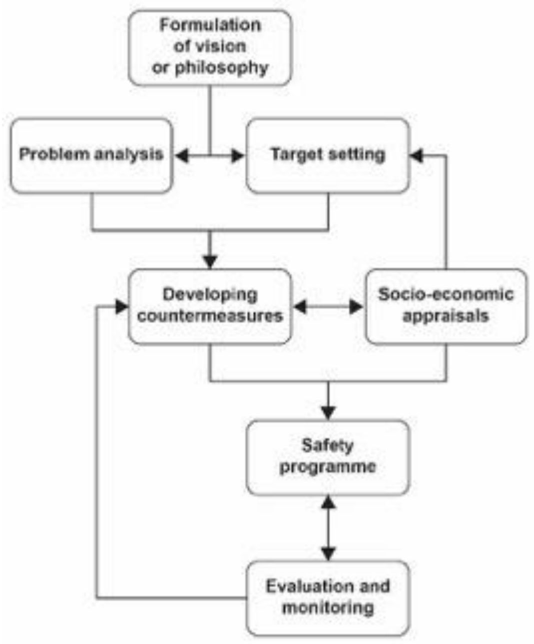
The development of strategies and their resultant shorter-term action plans is a continuing activity. Plans and strategies run their course and must be replaced by new plans and strategies. To be fully effective, the new strategies and plans must re-assess priorities in the light of what has been achieved in the previous strategies, changes in the population, economy and traffic system in the intervening years, and new developments in knowledge and practice (Austroads 2013b).

There is no single 'recipe' for developing a road safety strategy. The way in which a strategy is developed will inevitably depend on the jurisdiction's progress in terms of safe motorisation and road infrastructure, its previous history of road safety activity, the relations between the major stakeholder groups and between the individuals in leadership roles in different organisations (Austroads 2013b).

There are a number of different processes that must be gone through in developing a sound strategy. Figure 3.3 is taken from an OECD report on road safety strategies and may be used to illustrate a process. The figure illustrates a 'top down' approach, starting with a vision or philosophy. An alternative approach is to proceed 'bottom up', starting with an analysis of what can be achieved. An effective Road Safety Strategy will set targets that can be measured, these should be developed in consultation with all stakeholders (Figure 3.4).

For detailed information on developing a road safety strategy refer to the Austroads *Guide to Road Safety Part 2: Road Safety Strategy and Evaluation* (Austroads 2013b).

Figure 3.3: OECD strategy development process



Source: OECD (2002).

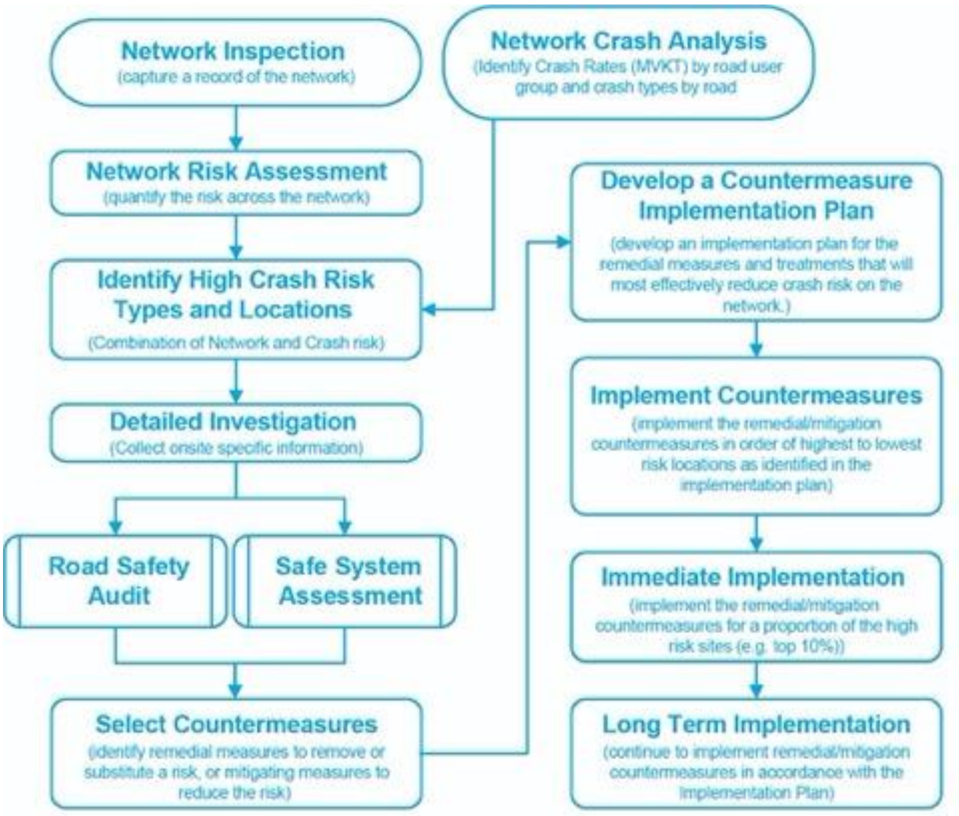
Figure 3.4: OECD stakeholder contribution to road safety

Source: Austroads (2013b).

Proactive road network level risk assessment and strategies

A key component of developing a road safety strategy is to proactively identify the safety risk on the network. A road network level risk assessment is designed to provide a road agency with a picture of high-risk sections across the network. The process is summarised in Figure 3.5 and the respective strategies and methods to provide, manage and improve safety during the design of new roads or management of existing roads are summarised in Table 3.4 and further explained below. Treatment and activity specific information is provided in Section 3.3.

Figure 3.5: Proactive road network level risk assessment process



Source: Adapted from Austroads (2006a).

Table 3.4: Strategies and methods to provide, manage and improve safety

Strategy/Method	Description
Provide a self-explaining road	• A self-explaining road is where the design of the road is such that drivers are able to readily interpret how they should act on the road. • For drivers to be able to drive to conditions, and thus adjust their driving behaviour to moderate risk, they need to be able to readily interpret what those conditions are. • Signage, delineation (Appendix B) and low-cost countermeasure treatments (Section 5.2.1) can assist in providing a self-explaining road, however ultimately this should be provided though good road design practices (Section 3.5).
Develop a road safety strategy	• Identify high risk crash types per user group and high-risk crash locations based on an analysis of historical crash rates and proactive crash risk scores. • Develop a strategy and implementation plan to reduce crash risk. A fundamental step in developing a road safety strategy is proactively identifying crash risk, prioritise treatment locations, develop and implement countermeasures.
Road network level inspections and surveys	Undertaken to identify locations by risk for various road users and crash types. Inspections and surveys may consider pavement condition (rutting, roughness, shape loss, skid resistance, texture loss), roadside hazards, signage or other local condition factors. The risk identification along a road or network can be used for several purposes. These include: • Select appropriate treatments. • Prevent fatal and serious injury crashes. • Calculate a BCR and NPV based on a reduction in crash costs. • Develop a safety strategy. • Identify locations for Road Safety Audits and Safe System Assessments.

Strategy/Method	Description
Road safety audit	Undertaken to identify and document detailed information about the road design, road condition, and roadside condition and features contributing to crash risk. This is achieved by an on-site inspection. A qualitative measure of risk is provided by the road safety auditor.
Safe System Assessment Framework	Undertaken to consider key crash types that lead to fatal and serious crash outcomes, as well as the risks associated with these crashes (exposure, likelihood and severity). Achieved by: • Considering each pillar of the Safe System. • Providing a treatment hierarchy to help identify the most effective treatments that might be used to minimise death and serious injury.
Identify and implement countermeasures	Undertaken to select countermeasures that are most effective in reducing crash risk for a given crash type and road user group. These include: • Low-cost measures that can be implemented in the short term to help the motorist to drive to conditions. • Higher cost treatments that can be implemented typically include improving the road geometrics and intersection layouts. • To strategically implement the countermeasure treatments through an implementation plan to incrementally reduce risk.
Monitoring and review	• The implementation and effectiveness of countermeasures should be monitored and reviewed. • The road safety strategy should be reviewed based on crash reduction performance. If required, the road safety strategy should be modified, and a new implementation plan developed.

Enable motorists to 'drive to conditions' – the 'self-explaining' road

While the number of crashes on the unsealed road network is low in comparison with the sealed road network the probability of having a crash on an unsealed road is at least double than on a sealed road (Willett 1992). Austroads (2010) found crash rates in Australia in some cases were considerably higher for rural unsealed roads compared to rural sealed roads. This is due to many factors, some of these are outlined in Section 3.3.3.

Geometric standards on unsealed roads are often poor (lower design domain values e.g. shorter stopping distances, smaller radius curves which increase side friction forces). As Moore (2005) notes, 'most unsealed roads were not designed or constructed to any standard,' rather, they 'evolved' along with the expansion of farming and mining activities. As such, the surface material, as well as the horizontal and vertical alignment of the road, is often poor. In addition, the variable nature of the road surface conditions, due to climatic factors, and lack of adequate resources to maintain the network contribute to a higher crash rate.

Improving safety on the unsealed road network poses a significant challenge for road agencies when there is often numerous roadworks needed to address the many potential hazardous situations within limited available budgets. The challenge is – how can a road agency demonstrate a duty of care across its entire road network, and show that the measures taken are reasonable with the limited resources available?

A suggested strategy to improving safety on the unsealed road network is to focus firstly on those safety actions that can help the motorist drive to conditions. For drivers to be able to drive to conditions, and thus adjust their driving behaviour to moderate risk, they need to be able to readily interpret what those conditions are. This is linked with the fundamental concept of providing a self-explaining road where the design of the road is such that drivers are able to readily interpret how they should act on the road. By creating a consistent, unambiguous, understandable and easily recognisable suite of treatments for locations of like levels of risk, drivers are able to create associations between the treatment types and the required driver behaviour (Jurewicz et al. 2014).

Many safety measures which warn motorists to drive to conditions and supplement providing a self-explaining road through high levels of design are low cost in nature (i.e. placement of signs, guide posts, improving sight distance, etc.) and sufficiently affordable to be applied across the whole network. This approach assists drivers to drive to the prevailing conditions.

One such example is at the urban/rural interface where often the sealed road ends abruptly and a gravel surface begins. Changed driving conditions are introduced and the default speed limit may be higher than the posted speed limit on the sealed road. Close assessment of these areas, within the available resources, is necessary to prevent potentially hazardous conditions from developing. In this case, placing the higher speed limit sign at the end of the sealed section of the road should be avoided. Locating the higher speed sign some distance along the unsealed road will first enable drivers to become accustomed to the changed road conditions.

Warning signs can be used to alert motorists of changing surface conditions and warning them to drive carefully (Figure 3.6). These signs are installed at strategic locations where a motorist is about to leave a sealed road environment to enter an unsealed road network.

Figure 3.6: Examples of special warning signs to alert motorists to drive to conditions on unsealed roads

DPTI SA W5-SA73 TMR QLD TC9607 TMR QLD TC1394

Identifying High Risk Locations at a Network Level

Assist motorists by identifying high risk locations, or sites with sudden changes in the driving environment ('surprises'). Safety at high-risk sites can be improved with good road design form, maintenance and low-cost treatments:

- *increasing sight distance to the hazard*
- *use of delineation and/or signage*
- *providing consistent road conditions and geometry*
- *upgrading road conditions where possible.*

Proactive road network level risk assessment

Road safety risk should be proactively identified at a network level and mitigation measures implemented with a strategic approach. This is a fundamental step in the development of developing a road safety strategy and a part of the Problem Analysis, Target Setting and then Developing Countermeasures. Proactively identified risk at a network level can be achieved with a road network level risk assessment.

A road network level risk assessment is designed to provide a road agency with a picture of high-risk sections across the network. The process is summarised in Figure 3.5 and presented in more detail below.

Network inspection procedures

Road agencies have a responsibility to maintain a good understanding of the ongoing condition of their road assets. This includes an assessment of the factors affecting safety.

Being aware of the condition of the road network helps authorities to develop programs to assist them in more effectively managing and maintaining their road assets, and in minimising potential litigation issues by demonstrating a duty of care.

Road safety audits provide a formal way to assess safety requirements of existing roads, but these are time consuming and require a high level of resources if the entire road network is to be assessed. Some road authorities undertake video surveys of their road network which serve as useful reference collecting road inventory information for the use in network safety assessments. Video surveys do not replace traditional road safety audit activities but can assist authorities to undertake network assessments which can assist in identifying and prioritising high-risk sites for detailed investigations through road safety audits.

Some road survey vehicles (such as the ARRB NSV shown in Figure 2.9) also collect additional data such as curvature, horizontal alignment, grade and pavement condition imaging and roughness and rutting data which can assist authorities manage their roads. The road survey video and data can be viewed and reviewed in a desktop environment (Figure 3.7).

Figure 3.7: ARRB survey and video data

Source: ARRB (2020).

Network risk assessment model

Network risk assessments are a key component in developing appropriate safety improvement strategies.

A typical network risk assessment process comprises of the following:

- identifying crash likelihoods and severity risks in 100 m segments along a road
- selecting road attributes for potential improvements
- evaluating and prioritising a number proactive road safety treatment, see their effect on the calculated risk score and establish estimate crash savings
- comparing benefits of potential road safety strategy programs and implementation plans
- quantifying incremental crash reductions based on incremental or periodic maintenance investment and measure progression towards Safe System performance.

The key benefits of a network level risk assessment are:

- If Local Government undertakes an assessment using the same method to quantify risk, then risk can be identified consistently over time. This assists in benchmarking to secure treatment funding and a review of the risk after implementation of countermeasures has begun.
- It is a simple, easy-to-use desktop assessment which places low demand on staff resources and there is no on-road inspection risk.
- It has the ability to assess low volume unsealed rural roads in a consistent way within both urban and rural town environments.
- The entire length of a road network can be inspected quickly and at low cost.
- It is based on engineering design features rather than routine maintenance issues.
- It is focused on problem road elements or sites.

The following are examples of isolated defects that, in combination with others, can lead to much higher risks. These are quantified in a risk assessment model and a total risk score provided which allows for prioritisation (highest to lowest score sites):

- fixed roadside hazards, which are defined as any objects or conditions located on or near the roadway and likely to create a hazard to any vehicle leaving the road
- sudden changes in geometric design standards
- road surface condition (including defects such as rock bars, wash outs, loose gravel, slippery surface, corrugations, excessive dust)
- poor sight distance on curves and at intersections
- carriageway width, which may be affected by encroaching vegetation.

The International Road Assessment Program (iRAP) star rating is a network risk assessment model used Internationally and in Australia. The Australian adaptation is the Australian Road Assessment Program (AusRAP). The AusRAP methodology is based on the iRAP protocol with an associated web-based processing tool, ViDA. ViDA uses road inspection data to review and capture road attributes via a desktop review to score roads (star ratings), generates countermeasures and Safer Roads Investment Plans.

The star ratings provide a measure of the safety performance of the road infrastructure. The star ratings are derived from a Star Rating Score (SRS) based on road safety inspection data and the extensive real-world relationships between road attributes and crash rates. The SRS concept provides an objective measure of the likelihood of a crash occurring and its severity. The aim of the SRS is to provide a star rating of the road network in a similar manner to the current 5-star rating scales for new car safety. A 5-star road will provide road users with the safest form of design standards regarding road cross-section, layout, roadside environment and intersection design and frequency and a 1-star rating represents a road with relatively poor road infrastructure design. The star rating bands are summarised in Table 3.5.

Table 3.5: Star rating bands and star rating scores (AusRAP)

Star rating	Star rating score				
	Vehicle occupants and motorcyclists	Bicyclists	Pedestrians		
			Total	Along	Crossing
5	0 to < 2.5	0 to < 5	0 to < 5	0 to < 0.2	0 to < 4.8
4	2.5 to < 5	5 to < 10	5 to < 15	0.2 to < 1	4.8 to < 14
3	5 to < 12.5	10 to < 30	15 to < 40	1 to < 7.5	14 to < 32.5
2	12.5 to < 22.5	30 to < 60	40 to < 90	7.5 to < 15	32.5 to < 75
1	22.5+	60+	90+	15+	75+

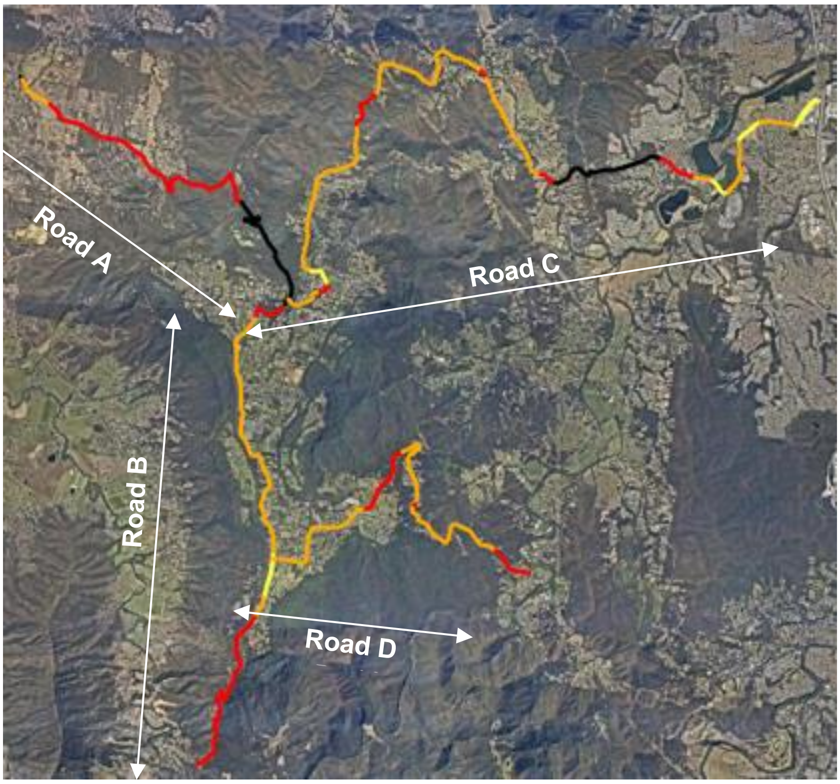
Source: iRAP (2015).

An example of the AusRAP star rating is presented in Figure 3.8 and Table 3.6.

The calculation of the Risk Score includes consideration of the design and condition of the following:

- road section type (e.g. rural intersection, sealed rural mid-block and unsealed rural mid-block)
- road elements impacting on crash probability (e.g. horizontal alignment, lane width, shoulder width, delineation, skid resistance/surface condition, sight distance, turning provision, pedestrian provision)
- road elements impacting on crash severity (speed, roadside environment, type of crash)
- consideration of historical crashes (if the crash data is available).

Figure 3.8: Example of mapped vehicle risk using AusRAP star ratings



Source: ARRB (2020).

Table 3.6: Example of distribution of vehicle risk by road using AusRAP star ratings

Road	Length (km)	Proportion in each star rating				
		1 Star	2 Stars	3 Stars	4 Stars	5 Stars
A	10.87	34%	57%	9%	0%	0%
B	13.33	0%	44%	49%	8%	0%
C	23.7	13%	13%	64%	11%	0%
D	10.9	0%	27%	73%	0%	0%

Note: 1 Star has the highest risk and 5 Star the lowest risk.

The AusRAP model considers more than 80 proven road improvement countermeasures to generate affordable and economically sound investment plans that will save lives. The countermeasures range from low-cost road delineation to higher-cost intersection upgrades and road surface upgrades. The road improvement countermeasures can be activated or deactivated based on the road agency's available funding. The development of the plans follows three key steps:

- Using the Star Ratings and traffic volume data, the estimated numbers of deaths and serious injuries are distributed throughout the road network.
- For each 100 m section of road, countermeasure options are tested for their potential to reduce deaths and injuries.
- Each countermeasure option is assessed against affordability and economic effectiveness criteria. The economic benefit of a countermeasure (measured in terms of the economic benefit of the deaths and serious injuries prevented) must, at a minimum, exceed the cost of its construction and maintenance. That is, it must have a BCR greater than one. In many circumstances, the 'threshold' BCR for a plan is lifted above one, which has the effect of reducing the overall cost of the plan. This ensures that a plan that is affordable for a location while still representing a positive investment return and responsible use of public money can be generated.

Road safety audit

The process of a Road Safety Audit (RSA) aims to identify potential safety problems and to ensure that measures to eliminate or reduce the problems are fully considered. It is a proactive measure to prevent crashes from occurring rather than reacting to crashes when they have occurred.

In order to ensure that a road agency is aware of the conditions of its roads, particularly in relation to road safety, it is essential that, as part of the performance evaluation and management of the road network, road safety audits be conducted.

A RSA is a formal examination of the road safety risks associated with road transport projects or existing roads, in which an independent, qualified audit team reports on all hazards identified for all road users (Austroads 2019c). Recent updates to the RSA process see renewed emphasis on the Safe System approach to road safety particularly around the types of crashes that may occur, their relative impact speeds and the ability of the human body to tolerate these impact speeds.

Conducting RSAs on unsealed roads will assist a road agency to identify and prioritise safety improvements and, subject to the resources available, address locations requiring attention. Conducting RSAs will not necessarily eliminate a council's or road agency's legal liabilities, as it will still be held liable for any defect in the road that causes an injury. Nevertheless, a road agency that has undertaken safety audits will have at least demonstrated a duty of care by undertaking remedial treatments within its available resources. In order to ensure that a road agency is aware of the condition of its roads, particularly in relation to road safety, it is essential that, as part of the performance evaluation and management of the road network, safety checks (audits) be conducted.

RSA procedures and practices are detailed in the Austroads *Guide to Road Safety, Part 6: Road Safety Audit* (2019c). The main points are summarised below:

- An audit can help identify road safety issues before crashes occur – prevention is better than a cure.
- A prudent road agency should adopt road safety audits as a method for identifying risks and reducing potential liabilities.
- A road safety audit is a formal examination of existing or future and future roads in which an independent, qualified team reports on the road's crash potential and safety performance.
- Road safety audits should ideally be conducted during design stages. Auditing during early stages of a project can identify issues sooner when it is easier (and cheaper) to amend designs to address issues.

While the Austroads *Guide to Road Safety, Part 6: Road Safety Audit* (Austroads 2019c) provides advice on the audit of existing roads, it does not provide guidance specifically relating to unsealed roads. For all road safety audits, practitioners are advised that checklists can serve as a useful prompt when undertaking audits, but these may not address all safety issues. For this reason, audit team members should have adequate experience of the type of audit being undertaken and should be mindful of other road safety issues that may not be covered in the checklists used. The guide's checklist prompts auditors to consider primarily sealed road surface issues. This is often not applicable for unsealed roads, but auditors should consider similar issues relating to the unsealed road surface.

Table 3.7 presents topics from Austroads (2019c) (Checklist 6 – Existing Roads) that relate to unsealed roads (note that topics that generally do not apply to unsealed roads have been omitted from this list). Consideration should also be given to other potential hazards (such as those listed in Table 3.3) that may be found on unsealed roads.

Table 3.7: Unsealed roads: road safety audit considerations

Existing unsealed roads: additional road safety audit considerations

- Road alignment and cross-section
  - Visibility; sight distance
  - Design speed
  - Default speeds/operating speeds
  - Overtaking
  - Readability by drivers
  - Widths
  - Shoulders
  - Crossfalls
  - Batter slopes
  - Drains
  - Driveway access points
- Intersections
  - Location
  - Visibility; sight distance
  - Controls and delineation
  - Layout
  - Miscellaneous
- Signs and lighting
  - Lighting
  - General signs issues
  - Sign legibility
  - Sign supports
- Crash barriers and clear zones
  - Clear zones
  - Crash barriers
  - End treatments
  - Fences
  - Visibility of barriers and fences
- Bridges and culverts
  - Design features
  - Crash barriers
  - Miscellaneous
- Pavement
  - Pavement defects
  - Skid resistance
  - Ponding
  - Loose stones/material
- Floodways and causeways
  - Ponding, flooding
  - Safety of devices
- Miscellaneous
  - Landscaping
  - Temporary works
  - Headlight glare

Existing unsealed roads: additional road safety audit considerations

- Markings and delineation
  - General issues
  - Guide posts and reflectors
  - Curve warning and delineation
  - Roadside activities
  - Errant vehicles
  - Rest areas
  - Animals
  - Other safety issues

Further information on undertaking RSAs, and RSAs generally, can be found in Austroads (2019c).

Safe System Assessment Framework

The Safe System Assessment (SSA) Framework considers key crash types that lead to fatal and serious crash outcomes, as well as the risks associated with these crashes (exposure, likelihood and severity). It provides prompts to ensure each pillar of the Safe System are considered. A treatment hierarchy is also provided to help identify the most effective treatments that might be used to minimise death and serious injury (Austroads 2016b).

SSA is a tool that considers the alignment of a design with Safe System principles and seeks to minimise death and serious injury (Austroads 2019c). SSAs consider the three components of risk; the *exposure* road users have to a crash, the *likelihood* of the crash occurring and – in the event the crash does occur – the severity of the crash outcome.

More information of SSAs can be found in Austroads (2016b).

Identify countermeasures

Selecting countermeasures that most effectively reduce crash risk for a given crash type and road user group must be undertaken. These treatments generally fall into the following two classifications:

- Low-cost measures that can be implemented in the short term to help the motorist to drive to conditions such as increased maintenance activities or low-cost measures as per Section 5.2.1 these cover the provision of appropriate signs, roadside delineation (Appendix B), management of roadside hazards (Section 3.3.4) and improving or providing the required horizontal and vertical sight distances at critical locations to avoid surprises (Appendix C.2). These mitigate the risk and provide an incremental reduction of risk however do not remove the risk.
- Higher cost treatments that can be implemented typically include improving the road geometrics and intersection layouts (Appendix C). These typically reduce the risk more than low cost treatments, and in some cases substitute an existing risk with a far lower risk. These treatments may also contribute more to enabling motorists to ‘drive to conditions’ by providing a ‘self-explaining’ road as improvements in road geometrics may improve sight lines and provide more consistent horizontal and vertical alignments.

Implement countermeasures

The implementation strategy for countermeasure treatments should align with the vision, strategy, plan and road safety targets outlined in the road safety strategy. The implementation plan should include countermeasures for:

- Immediate implementation: Implement the remedial/mitigation measures for a proportion (e.g. top 10%) of the high-risk sites. This can be actioned whilst a safety strategy is being developed however should also be a key action in an existing safety strategy.
- Long-term implementation: Continue to provide remedial/mitigation measures in accordance with the Implementation Plan. Typically, implementation is in order of highest to lowest risk locations.

Monitor and review

The implementation and effectiveness of countermeasures should be monitored and reviewed. The road safety strategy should be reviewed based on crash reduction performance. If required road safety strategy should be modified and a new implementation plan developed.

3.3.6 Signs and Delineation

It is recommended that reference is made to the relevant Australian Standard AS1742.1 Manual of Uniform Traffic Control Devices series and relevant State Road Agency code of practice document for further guidance.

Road signs and delineation can provide a low-cost measure to inform drivers of changing road geometric features or to reinforce the need to take care at a particular location. It is particularly important to alert drivers (using signs and delineation) to hazards they might not ordinarily expect (for instance, due to sudden changes in conditions).

Typical signs and delineations used for unsealed roads include:

- delineation through guide posts and reflectors
- hazard markers and sight boards
- road signs.

This is not an exhaustive list of suitable signs. Detailed guidance on the use of road signs and delineation markers to improve the safety of unsealed roads are provided in Appendix B.

3.4 Transport Infrastructure Product Evaluation Scheme

There are numerous materials and products available in the market that can be used in the construction and maintenance of road assets. It can be difficult to ascertain whether these materials and products are suitable for your project purely based on the information and data provided by the suppliers. A way to determine their suitability is to utilise independent assessment and certification schemes such as the Australian Paint Approval Scheme (APAS) or the Transport Infrastructure Product Evaluation Scheme (TIPES).

The Transport Infrastructure Product Evaluation Scheme (TIPES) is a process aimed at providing an independent fit-for-purpose assessment of innovative road construction products. TIPES is intended for the evaluation products that fall outside the scope of established standards and specifications.

Understanding how well a proprietary product will perform for pavement applications reduces risk and can also provide cost-saving design options or construction techniques.

TIPES is a national scheme endorsed by all Australian State and Territory road agencies as well as IPWEA (QLD), the Queensland Local Roads Alliance and the Western Australia Local Government Association (WALGA).

3.4.1 Process of Obtaining TIPES Certification

Products are assessed by an expert panel (inclusive of road agency representatives), who determine what is required to substantiate the proponent’s claims for a product. This involves products being evaluated through a gating process where products need to pass each stage to move to the next phase of evaluation.

The stages of a TIPES production evaluation are:

4. Stage 1: Evaluation
    a. An evaluation of available product information by the expert panel.

5. Stage 2: Test
    b. An independent series of laboratory tests recommended by the expert panel based on the product application and claims.
6. Stage 3: Trial
    c. Field trials to assess real-world performance. These are often incorporated into existing road agency and Local Government projects.
7. Stage 4: Certification
    d. Final assessment of results and certification of product.

Figure 3.9: TIPES certification

3.5 Geometric Design

3.5.1 Overview

Many unsealed roads have developed over the years with little or no attention given to applying appropriate geometric design requirements to suit current vehicle requirements and drivers' expectations. As a result, there are numerous geometric design deficiencies on existing roads, including narrow width, tight curves, poor drainage provisions and limited sight distances that can lead to higher maintenance costs and poor safety outcomes.

In order to improve the geometric design features of many existing unsealed roads, within the limited resources available, attention should be given to rectifying, as a matter of priority, those sections of road where there are significant design inconsistencies. These should be considered in a comprehensive gap analysis as highlighted in Section 2.4.5.

Unsealed roads with geometric design inconsistencies are a priority because if a driver can readily identify a road as being sub-standard, they can moderate their driving behaviour accordingly to help manage the risk. Accordingly, inconsistencies that can 'surprise' the driver pose a particularly high risk. This is included in the broader concept of the 'self-explaining road' which is discussed in more detail in Section 3.3.5.

The purpose of this section is to cover briefly the main aspects relating to the geometric design of road upgrades or new road construction and to highlight those features which are of particular relevance to unsealed roads. This section can also be used to help in identifying those parts of an unsealed road which do not conform to appropriate geometric and safety requirements. Further information on the important safety considerations for the design and operation of unsealed roads are provided in Section 3.3 and Section 5.2 respectively.

More comprehensive guidance for the geometric design of unsealed roads are provided in Appendix C of this Guide.

3.5.2 Approach to Geometric Design

The amount of known research dealing specifically with unsealed road design, both in Australia and overseas, is limited.

Overseas work (AASHTO 2001) provides valuable guidelines for the geometric design of very low volume roads (average daily traffic (ADT) < 400 vpd). The geometric design of unsealed roads presents a unique challenge because very low traffic volumes and reduced number of crashes make the design standards normally applied to higher volume roads less cost-effective. The design philosophy adopted for low volume roads indicates that because of their unique characteristics design guidelines can be less stringent than those used for higher volume roads. Whilst the number of crashes on unsealed roads are typically less than on sealed roads the crash rates (based on usage) are typically higher, whilst reduced design values can be applied to unsealed roads it is critical to consider the safety implications as identified in Section 3.3.

The fundamental characteristics of low volume roads that distinguish them from other types of road are:

- Low traffic volumes mean that encounters between vehicles that represent opportunities for multi-vehicle crashes to occur are rare events and that multiple-vehicle collisions of any kind are rare.
- The local nature of the road means that most motorists using the road have typically travelled it before and are perhaps familiar with any safety risk locations along the road and may modify their driving. Users who do not frequent the road, such as season or tourist traffic, would not be aware of the risk locations, this should be considered in the design. Heavy vehicles have their own safety risk and should be considered before this is adopted.

When applying lower order design values on an unsealed road there should be a recognition that safety is inherently compromised. The research undertaken by AASHTO concluded that the risk assessment on which its normal road design guidelines are based shows that less restricted design criteria can be applied on low volume roads without compromising safety. The guidelines infer a consistent driving experience should be provided and discourages widening of lanes and shoulders, changes in horizontal and vertical alignment and roadside improvements except in situations where such improvements are likely to provide substantial safety benefits.

The approach that should be taken in the geometric design of an unsealed road differs from that used for sealed roads because of the highly variable nature of unsealed road surfaces in terms of material properties, climate, and maintenance practices. These factors can have a significant effect on changing road surface friction values and directly influence the design parameters of stopping sight distance and horizontal curve radius. Because of the variability in surface conditions, higher geometric design standards are often necessary to compensate for often lower surface friction values.

The geometric design of an unsealed road should be the result of a careful balance between the purpose of the road, traffic volumes, terrain, design standards, costs and the standard of maintenance to be adopted.

The purpose of the road will have a significant influence on the design standards to be used. For example, there is little point in undertaking a detailed geometric design for an access road to private property. Conversely, the design standard chosen can affect how a road will be used. As an illustration of this, traffic speeds on a particular section of road will depend to a large extent on the geometric standards adopted and road surface conditions at that time. Other factors also requiring consideration include:

- Economics – consideration should be given to the expenditure required to produce a given design standard. These costs may well rule out the use of the typical standards, when the type and volume of the traffic and the importance of the road are considered.

- Design life – a road, which will remain unsealed, should be designed accordingly. Design standards for unsealed roads should be greater than sealed roads because the lower surface friction values will require larger radius curves, longer sight distances etc. compared with a sealed road. However, a road which is to be sealed at a later date should still be designed initially with a higher standard of alignment required for when it is sealed as it is best to set the alignment at the beginning of a road's life rather than later.
- Maintenance – the designer should be aware of the likely maintenance standards to be adopted and design the road in keeping with the maintenance level envisaged. Since the maintenance of the road can lead to an effective rebuilding of it (e.g. resheeting), supervisors should be briefed as to the purpose of various design features of the road. One of the more obvious design features which requires attention throughout the life of the road is the provision of 4–6% crossfall on straight sections.

3.5.3 Evaluation of Geometry Requirements

It is important to select geometric design parameters on the basis of a balanced consideration of construction, maintenance, safety, desired operating speed and vehicle operating costs, as well as the level of service required for the volume, type and importance of the road.

The geometric design standards for a road are governed by the function of the road, traffic volumes, vehicle type, terrain, environmental issues and cost considerations. Ideally a compatible cross-section, horizontal and vertical alignment will provide road users with an adequate quality of service in terms of ride comfort, convenience and safety.

The geometric design of low volume roads presents special challenges requiring the application of common road engineering practices to a lower cost facility that serves only a small number of vehicles, often in sensitive environmental conditions and with constrained budgets. The design has to provide a road which can cater for large vehicles, recognise the safety of all road users and must be accomplished at minimal costs. This requires a unique and flexible approach, without overturning the principles of roadway engineering.

Guidelines for geometric design standards for each road class are given in `Table 3.10. The standards are based on the main design components for varying terrain types, namely, flat, rolling and mountainous. It should be noted that they are based on roadway engineering principles with applied engineering judgment to arrive at practical and reasonable standards relating to a range of low volume roads. In determining a geometric design standard for (say) horizontal radius, it has been necessary to select an appropriate value for the coefficient of friction for the road surface, and response times from a range of values. Details of the engineering principles applied are found in the references listed.

In the case of tracks, these are not engineered roads and design guidelines listed are not generally applicable. However, special consideration needs to be given to their location in relation to topography to avoid steep grades causing erosion (Figure 3.10). What is essential is that adequate width is provided for the passage of required vehicles (minimum 3 m) and natural surface crossfalls both across and along the road are less than 6%. Tracks should desirably follow land contours to minimise the concentration of water flows and the severe erosion that can occur particularly in very weak soils. For existing tracks it is desirable that these roads are 'gripped' by rolling the grades and rotating the pavement along the centreline so that surface water is allowed to run off the road from the high to low side to avoid the use of side drains (refer to Appendix A.1.3). Where this is not possible particular drainage measures may have to be taken to minimise future maintenance requirements. Details are provided in Section 5.1.6.

Figure 3.10: Poor location of a track on a steep grade leading to major erosion

Source: ARRB (2009).

3.5.4 Main Geometric Considerations

A number of key geometric aspects relating to the geometric design of unsealed roads are summarised in Table 3.8. A detailed discussion of each of these aspects are also provided in Appendix C of this Guide.

Table 3.8: Main aspects relating to the geometric design of unsealed roads

Design aspect	Technical considerations
Route location	• Most new roadworks are confined to existing road reserves. • May require evaluation of several alternative routes based on social, environmental and economic considerations. • Where a new alignment is selected, adopt appropriate geometric design standards and safety measures. • Meet control points or match to existing roads as required. • Keep to the ridge line or high ground to avoid low-lying areas and minimise drainage requirements. • Follow land contours as far as practical to reduce the extent of cut and fill. • Avoid impacts to cultural heritage sites where practical. • Avoid or minimise impacts on the environment.
Road classification	• The primary purpose of a road hierarchy is to ensure appropriate management and standards are applied. • Allows more efficient use of limited resources by allocating funding to higher priority roads. • A functional road classification should be established in each road agency which outlines design standards, performance criteria and maintenance intervention levels for each road class. • Functional road classification systems allow for consistent treatment of all roads on the network in terms of driver expectations and the provision of a safe and economical road network.

Design aspect	Technical considerations
Approach to geometric design	• Unsealed roads present a unique challenge because low traffic volumes and reduced number of crashes make conventional design standards less cost-effective. • Design standards can be less stringent than for higher volume roads. • Whilst reduced standards can be considered, it is critical to consider safety implications • A consistent driving experience should be provided to avoid any surprises. • Design should be a balance between road purpose, traffic volumes, terrain, safety, standards, costs and the standard of maintenance to be adopted. • Need to cater for large vehicles, safety of all road users and at minimal costs. • Must consider coefficient of friction for varying road surfaces and response times. • Unsealed tracks are not engineered, and design guidelines are not generally applicable.
Safety	• Appropriate horizontal and vertical alignment standards should be used for prevailing speeds. • Key geometric features that influence safety include road alignment, stopping sight distance, road widths, intersection layouts and road crossfall/superelevation. • Drivers should receive a consistent message about safety travelling speeds from the road geometry.
Design criteria	• Parameters that influence the geometric design of unsealed roads include: – manoeuvre sight distance (MSD) – operating speed – traffic volumes – vehicle composition – vehicle grades – driver characteristics – longitudinal deceleration – coefficient of side friction – driver reaction time.

3.5.5 Road Hierarchy

The primary purpose of a road hierarchy is to ensure that appropriate management, engineering design, construction standards and maintenance practices are applied to a road based on its function. It also enables more efficient use of limited resources by allocating funding to those roads of higher functional importance, where the greatest return on investment is to be expected.

In developing a road hierarchy system, the following guiding principles should be considered:

- The classification system should link and be consistent with other adjoining road authorities and Local Government standards.
- The classification system should be functionally based. Traffic volumes and vehicle type should not affect the road classification.
- The width of a road, or whether it is sealed, is not necessarily a criterion that influences a classification.
- Special purpose roads, i.e. quarry, logging or tourist roads should be made to fit existing classifications rather than establish a separate classification.
- Unused road reserves, or ‘paper’ roads, should be ignored, and used only for mapping purposes.

A system of road classification based on functional use allows for a consistent treatment of all roads in a network, both in terms of the driver’s expectations and the provision of a safe and economical network.

The functional classification of a roadway identifies the relative importance of the mobility and access functions of that roadway. This should not be confused with the various forms of unsealed road construction types, i.e. formed and gravelled, formed and unformed roads.

The functional classification system suggested in this guide has been adapted from the Austroads classification system (Giummarra 2001). The Austroads functional classification of rural 'Class 4' roads (Austroads 2019a) has been further subdivided into four categories as listed in Table 3.9 and shown in Figure 3.11.

Table 3.9: Unsealed roads classification system

Road class	Class type	Service function description	Road type description
4A	Main road > 150 ADT	This type of road is used for major movements between population centres and connection to adjacent areas. High traffic volumes occur, and the road can carry large vehicles.	• All weather road, predominantly two-lane and unsealed. Can be sealed if economically justified. • Operating speed standard of 50–80 km/h according to terrain. • Minimum carriageway width is 7 m.
4B	Minor road 50–150 ADT	This type of road is used for connection between local centres of population and links to the primary network. Roads may or may not be sealed depending on the importance and function of the road.	• All-weather two-lane road formed and gravelled or single-lane sealed road with gravel shoulders. • Operating speed standard of 30–70 km/h according to terrain. • Minimum carriageway width is 5.5 m.
4C	Access road 10–50 ADT	Provides access to low use areas or individual rural property sites and forest areas. Caters for low travel speed and a range of vehicles and may be seasonally closed.	• Substantially a single lane two-way, generally dry weather, formed road. • Operating speeds standard of < 20–40 km/h according to terrain. • Minimum carriageway width is 4 m. • May be restricted to four-wheel drive vehicles.
4D	Tracks < 10 ADT	Mainly used for fire protection purposes, management access and limited recreational activities.	• Predominantly a single-lane two-way earth track (unformed) at or near the natural surface level. • Predominantly not conforming to any geometric design standards. • Minimum cleared width is 3 m. • Primarily for four-wheel drive vehicles.

Figure 3.11: Typical examples for each road classification

Class 4A – Main road

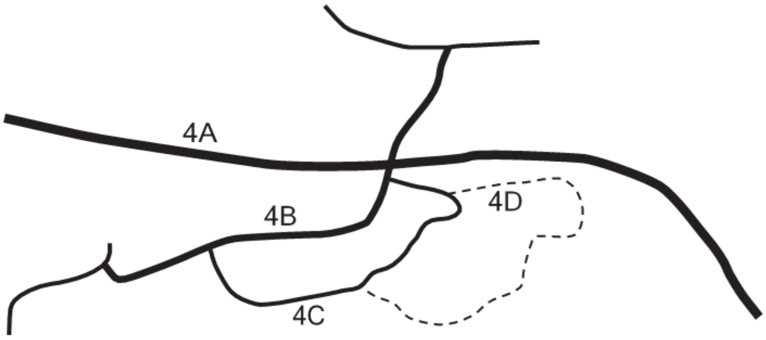
Class 4B – Minor road

Class 4C – Access road

Class 4D – Tracks

A schematic diagram of the various road classifications for unsealed roads is illustrated in Figure 3.12. The intent of the diagram is to depict the relative function of the road classifications in terms of the main road through an area and the various collector/distributor roads. This is a generic diagram and should be adapted to suit local requirements.

Figure 3.12: Schematic diagram of unsealed roads classification system



Source: ARRB (2009).

3.5.6 Geometric Design Criteria

Guidelines for desirable standards for each unsealed road class are given in `Table 3.10. These desirable standards are based on the main design components for varying terrain types, namely, flat, rolling and mountainous. It should be noted that they are based on roadway engineering principles with applied engineering judgment to arrive at practical and reasonable standards relating to a range of low volume roads. In determining a geometric design standard for (say) horizontal radius, it was necessary to select an appropriate value for the coefficient of friction for the road surface, and response times from a range of values.

`Table 3.10: Guidelines for the main geometric design standards for unsealed roads

Road classification	4A Main			4B Minor			4C Access			4D Tracks			Comments
Terrain type	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous	
Main geometric characteristic *based on safety, costs and environmental considerations*													
Operating speed value (km/h)	80	70	50	70	50	30	60	40	20	N/A	N/A	N/A	Based on 85th percentile speed
Cross-section elements													
Number of traffic lanes	2	2	2	2	2	2	1	1	1	1	1	1	Unsealed lanes
Minimum cross fall (%)	5	5	5	5	5	5	5	5	5	4	4	4	Min. of 4% to drain rainfall off tracks
Maximum superelevation (%)[1]	6	7	8	6	8	10	6	8	10	N/A	N/A	N/A	
Minimum traffic lane width (m)[2]	3.5	3	3	3	3	3	3	3	3	3	3	3	
Minimum shoulder width (m)	1	1	0.5	0.5	0.5	0.5	1.5	1	0.5	0	0	0	
Minimum carriageway width (lanes + shoulder) (m)	9	8	7	7	7	7	6	5	4	3	3	3	
Minimum formation width (including verges) (m)[3]	11	10	9	9	9	9	8	7	6	3	3	3	
Horizontal geometry													
Minimum curve radius (m)[4]	320	250	140	250	100	35	170	60	15	N/A	N/A	N/A	

Road classification	4A Main			4B Minor			4C Access			4D Tracks			Comments
Terrain type	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous	
Minimum stopping sight distance (m)[5]	150	120	70	120	70	30	90	50	30	N/A	N/A	N/A	
Minimum meeting sight distance (m)[6]	290	230	130	230	130	60	180	100	60	N/A	N/A	N/A	
Vertical geometry													
Maximum vertical grade (%)[7]	6	8	12	6	8	12	6	8	12	N/A	N/A	N/A	Avoid steep grades to reduce soil erosion along tracks
Minimum crest vertical curve (K value)[8]	50	30	10	30	10	5	19	8	2	N/A	N/A	N/A	
Minimum sag vertical curve (K value)[9]	11	8	4	8	4	3	6	3	2	N/A	N/A	N/A	

1 *The maximum superelevation value will need to consider the number of loaded heavy vehicles, speed and curve radii.*
2 *In cases where there are a high percentage of heavy vehicles (> 20%) minimum lane widths can be increased by 0.5 m.*
3 *Allows for 1 m verge/table drain width. This must be reviewed based on actual locations where for drainage reasons greater widths may be required.*
4 *Values rounded up. For minimum radius curves, widening on the inside of a curve may be necessary to accommodate longer vehicles.*
5 *Based on a reaction time of 2 seconds and surface coefficients relating to unsealed surfaces. Values rounded up. Values based on flat grades and allowances will need to be made for up and down grades.*
6 *This is mainly a requirement for single lane two-way roads. Values rounded up.*
7 *In some cases, higher grades of up to 20% can be allowed for short sections (about 150 m). Keep grades on unsealed roads lower due to ravelling and scouring of surface.*
8 *Calculation of these values is to be based on information contained in Austroads (2016c). The length of the vertical curve (L) is based on the product of K multiplied by the algebraic difference in grades percentage A (i.e. L = K × A).*
9 *Sag values are based on comfort control criteria.*

3.5.7 Detailed Geometric Design

The geometric design of unsealed roads is a complex process that should be undertaken by experienced road designers. The geometric design should consider a variety of aspects, including:

- design criteria, including operating speed, traffic volumes vehicle composition, vertical grades, driver characteristics, vehicle deceleration and surface friction (Appendix C.1)
- sight distance (Appendix C.2)
- horizontal alignment (Appendix C.3) and vertical alignment (Appendix C.4)
- intersection location and layout (Appendix C.5)
- road cross-section (Appendix C.6)
- drainage (Appendix C.7)
- floodways (Appendix C.8)
- roadside vegetation (Appendix C.9).

Comprehensive guidelines for the geometric design of unsealed roads in Australia (based on the above-mentioned aspects) are provided in Appendix C of this Guide.

3.5.8 Safety in Design

When designing an unsealed road, it is desirable that the appropriate horizontal and vertical alignment standards are used for the prevailing speed of travel on the roadway. It is preferable to be on the generous side of the geometric standards outlined in this chapter to compensate for the variable surface conditions and the lower friction values found on unsealed roads.

Key geometric features that will influence safety are:

- horizontal and vertical alignment, particularly at curves
- stopping sight distances
- road widths and extra widening on sharp curves
- geometric layout of intersections
- road crossfalls and superelevation requirements.

The driver should receive a consistent message about safe travelling speeds from the various aspects of the road's design.

For example, a good quality pavement will tend to produce higher speeds and, in order to provide a safe travelling environment, the pavement design standard should be matched with a geometric design of the same standard. A wide pavement and shoulders will also produce high speeds and these conditions need to be matched with a high-quality pavement surface and good sight distance.

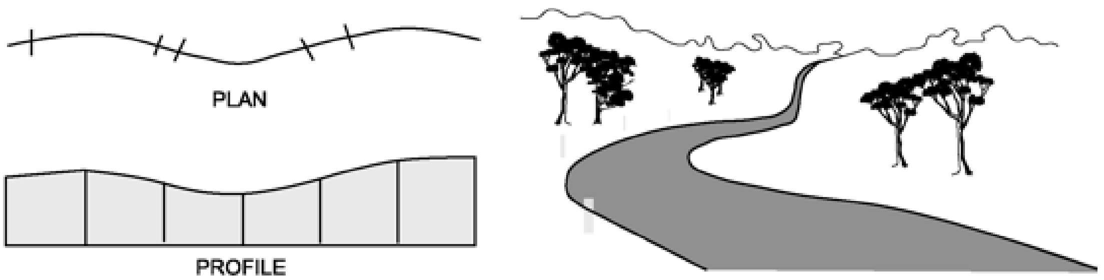
An unsealed road should desirably be of consistent standard throughout its length. Sudden changes in the driving environment, which can cause 'surprises' to the driver, can result in accidents. Approaches to dips in the road, bridges and culverts should contain gradual grade changes rather than sudden changes.

Pavement width and sight distance should desirably be constant throughout the length of the road, but where this is not possible then a ‘transition’ zone of gradual change should be introduced. Steep descents followed by sharp horizontal curves may cause vehicles to fail to adjust their operating speed appropriately resulting in single vehicle crashes.

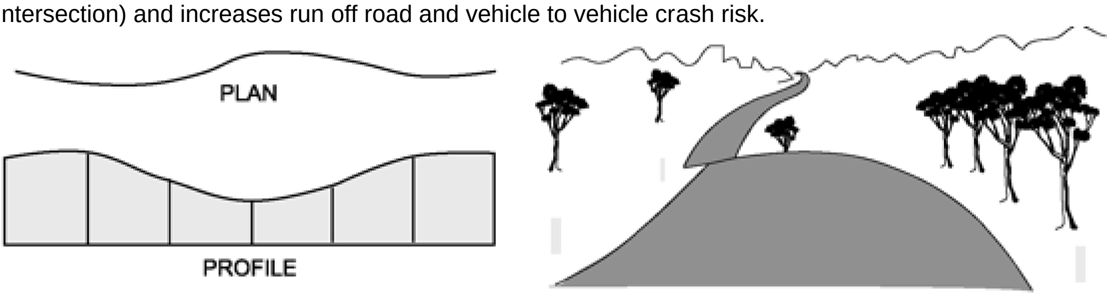
Designing a road where horizontal and vertical curves are coordinated can result in greater safety and better road appearance (Austroads 2016c), as illustrated in Figure 3.13.

Figure 3.13: Coordination of horizontal and vertical alignment

Ideal coordination. A smooth flowing appearance results when the vertical and horizontal curves coincide. Ideally horizontal curves should slightly overlap the vertical.



Poor coordination. The summit vertical curve restricts the drivers view of the start of the horizontal curve (or an intersection) and increases run off road and vehicle to vehicle crash risk.



Source: Austroads (2016c).

The main reasons why this is important in road design are:

- Co-ordination of horizontal and vertical alignments is a basic geometric design principle and a key safety factor which ensures horizontal curvature is not hidden.
- Drivers react to horizontal curvature, and often will not react and reduce speed when sight distance is restricted by vertical curvature.
- When a horizontal curve is combined with a crest vertical curve, the horizontal curve must start before the vertical curve, to allow drivers to perceive the horizontal curve and make the appropriate speed adjustment.

A road safety audit and safe system assessment should be undertaken during both the planning and design stages to ensure that no safety problems are present before the road is constructed. More details on designing safe unsealed roads are provided in Appendix C of this Guide.

3.6 Pavement Design

3.6.1 Overview

The basic function of a pavement is to withstand the traffic loading, protect the subgrade, and at the same time provide a smooth and safe ride for road users.

Roads that are poorly maintained and do not have the required pavement strength or thickness can have a significant economic impact on the operating cost of vehicles, particularly heavy vehicles on haulage and freight routes.

The surface condition and rolling resistance of an unsealed road surface can have a significant impact on vehicle operating costs and road user costs. The aim of the design process is to minimise such negative effects as if unaddressed they can substantially reduce the lives of vehicle components and increase vehicle operating costs and reduce overall fleet productivity reflected in reduced travel time and freight delay. Design solutions will need to be tailored to different conditions with this being important in minimising overall costs and making best use of available resources.

Pavement Performance

For a given traffic of known volume and load, a pavement's ability to perform is dependent on three main factors:

- *pavement material strength and performance*
- *the presence of excess moisture in the pavement layers or subgrade*
- *subgrade strength and support stiffness.*

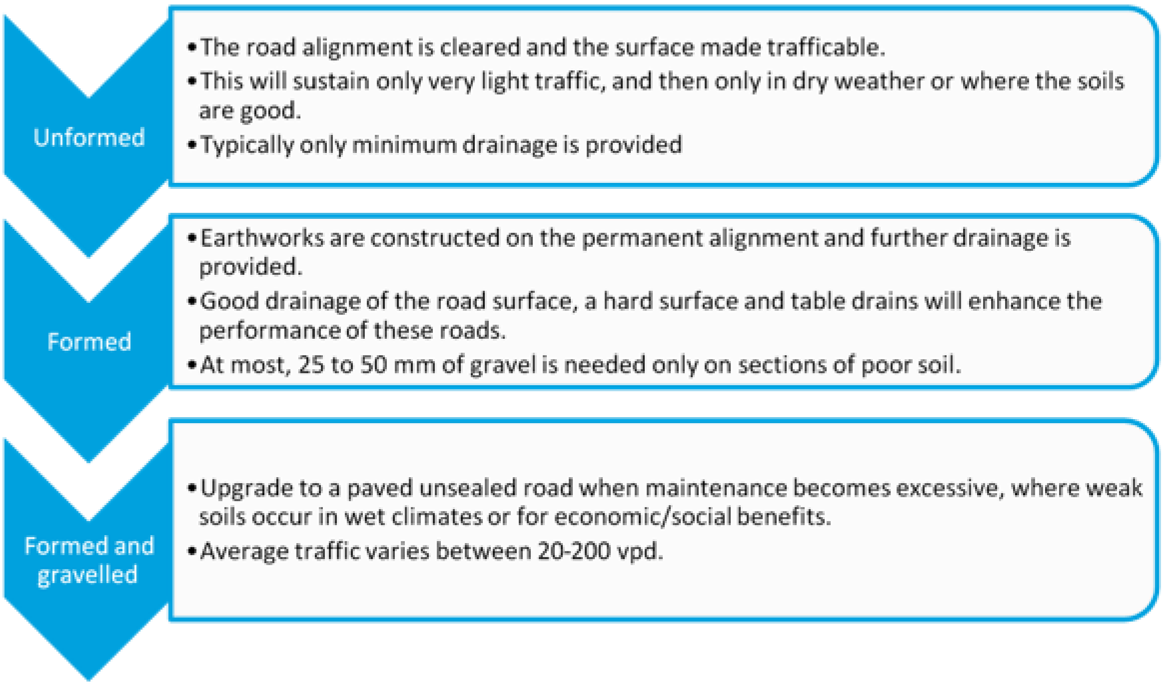
3.6.2 Staged Pavement Development

Since traffic intensities and benefits derived from unsealed roads are usually lower than those for sealed roads, the level of service required for unsealed roads are typically lower than for sealed roads.

Additional pavement material can readily be added to an unsealed road at future stages, as required. Also, the surface of an unsealed pavement can be maintained by routine grading and periodic reshaping or resheeting.

Attention should also be given to managing surface shape as poor shape leads to accelerated deterioration and ultimately high road user costs, as well as poor access quality. Staged development of unsealed pavements is widely practised as shown in Figure 3.14.

Figure 3.14: Stages in the development of unsealed pavements



The first consideration in the design of an unsealed pavement is deciding the stage to which the pavement will be constructed initially, e.g. unformed, formed, formed with minimum paving, partially paved, or fully paved.

The design thickness of the pavement can be provided initially, but more often only part is provided as a first stage of pavement construction; the remainder being provided at a later date (e.g. at the time of sealing). Also, the high cost or lack of pavement materials may favour providing a single course, followed by a full pavement structure and possible sealing in the next stage.

Staged Pavement Thickness

There are two approaches which have been adopted in deciding the first stage pavement thickness:

- *Provide a nominal single basecourse (e.g. 100 to 150 mm thick).*
- *Provide a designed pavement thickness 50 to 100 mm less than what would be required for a sealed road. A minimum pavement thickness of 100 to 150 mm should be provided.*

The first approach, (i.e. a single course of nominal thickness) can be considered when most of the following conditions apply:

- dry climatic conditions and good drainage
- low traffic volumes
- traffic consisting predominantly of light vehicles

- the road is regularly graded and readily repaired
- the risk of overloaded vehicles is low
- the paving materials are suitable.

A nominal pavement thickness of up to 150 mm will usually be suitable (particularly in dry climatic conditions with good drainage) on roads with low traffic volumes of predominantly light vehicles, and where risks of overloading are low.

The second approach (i.e. the provision of 50 mm to 100 mm less pavement thickness than what would be required for a sealed pavement) is more appropriate when the following conditions prevail:

- wet climatic conditions and/or poor drainage
- higher traffic volumes
- traffic mix contains a significant number of heavy vehicles
- the road carries through truck traffic
- the road is likely to be used in times of high subgrade moisture
- the risk of overloaded vehicles is high.

In wet climatic conditions, or where poor drainage conditions exist, and where the road is likely to be used frequently by truck traffic, an unsealed pavement of 50–100 mm less in total thickness than what would be required for a sealed pavement is typically required.

It should be recognised that where the first stage of a pavement is provided (i.e. a reduced pavement thickness), the ongoing maintenance requirements are expected to be higher compared to thicker pavement structures.

Prior to sealing the road at a later stage, the residual pavement depth will be required to be built up to full depth in accordance with the design standards.

Ultimately, however, an economic analysis of the options is preferred in order to inform appropriate strategies. This should include the application of appropriate road deterioration and works effects models as described in Section 2.4 and Section 2.5.

3.6.3 Environmental Factors Influencing Pavement Design

The performance of low traffic volume roads is often more affected by environmental factors than the nature and level of traffic loading encountered over their design life. The main environmental factors affecting pavement performance are moisture and temperature (Austroads 2019b).

Moisture environment

The moisture regime associated with a pavement has a major influence on its performance. The stiffness, strength and susceptibility to permanent deformation of unbound materials and subgrades are heavily dependent on the in-service moisture content of these materials.

Factors influencing the moisture regime within a pavement include:

- rainfall and evaporation pattern of the locality

- permeability of the wearing surface, pavement layers, subgrade and adjacent surfaces and drains
- effectiveness and proximity of drainage (table drains, culverts)
- depth to the watertable and movement of ground water
- roadside vegetation, particularly overhanging trees shading the pavement
- local geology – specifically the presence of open jointed or fractured rock materials which frequently have permeable layers which may allow in high seepage flow
- pavement construction type (boxed or full width).

Most pavements contain measures to control the ingress of water into the pavement structure. The provision and maintenance of a sufficiently high crossfall, (4–6%), a wearing surface that is tightly bound, table drains, cross-drains and, if necessary, sub-surface drainage (or moisture barriers) will reduce the influence of water on pavement performance. These effects may be more significant adjacent to the edge of the pavement, the critical area of the pavement in respect to moisture effects.

Pavements constructed on expansive subgrades may experience ongoing movement, with seasonal moisture changes causing loss of shape, affecting trees in close proximity to the roadway and reducing ride quality.

Temperature environment

The temperature environment can have a major influence on pavement performance. At high temperatures the pavement surface can become dry and dusty and may crack. At low temperatures, usually associated with periods of precipitation, moisture can remain within the pavement layers and subgrade for considerable amounts of time, potentially softening the materials and weakening the structure. Freeze and thaw cycles can also cause large surface movements and unevenness.

3.6.4 Subgrade Support

Subgrade support is the primary factor influencing pavement thickness design and is in many respects beyond the control of either the designer or constructor.

Drainage, however, does have a significant influence on material strength and subgrade support and drainage improvements should be given high priority where relevant.

Table 3.11 *clearly show the influence of drainage on the strength of subgrade materials, with as much as a 100% increase in strength for some soil types where good drainage is provided.*

The purpose of subgrade evaluation is to estimate the support that the subgrade will provide to the pavement during its lifetime. The support will be dependent on material strength, its moisture content and degree of compaction. Although the material at the top of the subgrade may be uniform along the project, the moisture variations that will occur in this material, both along the road (due to topography, drainage, underlying soil profile etc.) and cyclically with time (annual wetting and drying cycles), should be considered in assessing the support provided.

For the pavement design procedure presented in this Guide, the subgrade support is characterised by the material's California Bearing Ratio (CBR). The CBR can be determined by field and/or laboratory testing, or by experience using presumptive values.

The CBR of the subgrade soil is affected by moisture. For pavement design purposes, four different subgrade CBRs can be defined by moisture content:

- CBR at equilibrium moisture content (EMC) noting that in many locations unsealed roads may not maintain an EMC due to direct exposure to the effects of weather and flood events.
- CBR at the in situ moisture content which is dependent on the time of the year the CBR is measured. This may be wetter than EMC if the drainage is not yet constructed.
- CBR at the optimum moisture content (OMC) of the material and under unsoaked conditions.
- CBR at a four-day soaked conditions, as commonly used in Australia for sealed pavements.

Unsealed roads are typically more permeable than sealed roads and the majority of pavement damage occurs when the pavement layers and subgrade are in a higher moisture state (e.g. following significant rain events).

It is therefore often desirable to determine the subgrade CBR at a four-day soaked moisture content when compacted at OMC in the laboratory.

Site specific subgrade evaluations

If the pavement designer is not experienced in subgrade evaluations, it is strongly recommended that specialist advice be sought. A detailed subgrade evaluation procedure is presented in Austroads (2019a).

Subgrade Evaluation

Suggested approach to subgrade evaluations:

- *Minimum test spacing of 120 m for urban projects, to a minimum of 300 m for longer rural projects.*
- *Not less than three sites should be tested in any one project to enable confirmation of the design CBR value.*
- *Where there is variation along a project, at least three test sites should be selected in each subgrade, topography and drainage combination.*
- *Subdivide the project into sections, which are deemed to be homogeneous, with at least three test sites in each uniform section.*
- *A design subgrade CBR is determined for each section taking the 10th percentile low value of the CBR values determined for each uniform section.*

The subgrade CBR can determined in situ using the dynamic cone penetrometer (DCP), (Figure 3.15), or in the laboratory using disturbed samples from the site. The ARRB *Road Materials Best Practice Guide* (ARRB 2020b) contains detailed information regarding use of the DCP to determine an equivalent CBR value and laboratory CBR tests.

Figure 3.15: Use of a dynamic cone penetrometer

Source: ARRB (2020).

Soil Strength

The soil composition (gravel, sand, silt, and clay) and the degree of moisture present can also give a quick and simple indication of the soil strength:

- *Dry materials will generally have a higher strength than wet materials.*
- *Coarser-grained and well-graded mixtures will generally be stronger than fine-grained or uniform sands or clays.*
- *In a dry environment, clays can be very strong but will rapidly lose strength when wetted.*
- *A small amount of moisture in a sandy material can improve the cohesive strength of the material.*
- *The visual appearance, the feel of the material in hand and local knowledge provide valuable additional information when assessing materials.*
- *The field moisture content, particle size distribution and Atterberg Limits of the subgrade materials can also be determined using field-based equipment or in the laboratory.*

Presumptive CBR values

Presumptive CBR values are typically only used for planning purposes to give a high-level indication of pavement thickness required. It is recommended that more detailed evaluations (such as field investigations or laboratory testing) be undertaken if more certainty regarding construction costs, material quantities and performance is required.

Presumptive values can be sourced from a number of publications available both in Australia and internationally, with some typical values provided in in Table 3.11 (Austroads 2019b). Care should be taken when using these values, given the inherent variability in naturally occurring materials, whilst also noting that site investigations using DCP methods should be timed to ensure design values represent the likely conditions during road operation.

Table 3.11: Typical presumptive design CBR values

Description of subgrade		Typical CBR values (%)	
Material type	Unified soil classification	Excellent to good drainage	Fair to poor drainage
Highly plastic clay	CH	5	2–3
Silt	ML	4	2
Silty clay, sandy-clay	CL	5–6	3–4
Sand	SW, SP	10–18	10–18

Source: Austroads (2019b).

The effects of drainage on soil strength is also clearly illustrated in the table above.

3.6.5 Design Traffic

Light vehicles (such as cars and motorcycles) contribute very little to the structural deterioration of pavements and only heavy vehicles (also known as commercial vehicles) are therefore considered in pavement design. A heavy vehicle (HV), for the purposes of this Guide, is defined as class 3–12 (refer Table 3.12) vehicles in accordance with the Austroads Vehicle Classification system (Austroads 2019b).

Table 3.12: Austroads vehicle classification system

Length (indicative)	Axles and axle groups		Vehicle type	Austroads classification
Type	Axles	Groups	Description	Class
Light vehicles				
Short Up to 5.5 m	2	1 or 2	Short Sedan, wagon, 4WD, utility, light van, bicycle, motorcycle, etc.	1
	3, 4, or 5	3	Short – towing Trailer, caravan, boat, etc.	2
Heavy vehicles				
Medium 5.5 – 14.5 m	2	2	Two axles truck or bus	3
	3	2	Three axles truck or bus	4
	4	2 or 3	Four axles truck	5

Length (indicative)	Axles and axle groups		Vehicle type	Austroads classification
Type	**Axles**	**Groups**	**Description**	**Class**
Long 11.5 – 19.0 m	3	3	Three axles articulated Three axles articulated vehicle, or rigid vehicle and trailer	6
	4	> 2	Four axles articulated Four axle articulated vehicle, or rigid vehicle and trailer	7
	5	> 2	Five axles articulated Five axle articulated vehicle, or rigid vehicle and trailer	8
	6 > 6	> 2 3	Six axles articulated Six (or more) axle articulated vehicle, or rigid vehicle and trailer	9
Medium combination 17.5 – 36.5 m	> 6	4	B Double B double, or heavy truck and trailer	10
	> 6	5 or 6	Double road train Double road train, or heavy truck and two trailers	11
Long combination Over 33.0 m	> 6	> 6	Triple road train Triple road train, or heavy truck and three trailers	12

Source: Austroads (2019b).

Design traffic loading is commonly described in terms of the number of Equivalent Standard Axles (ESAs) that are expected to traverse the pavement over its design life. An ESA is defined as the number of repetitions of a standard axle which causes the same amount of damage as a single pass of a loaded axle group. The standard axle in Australia is defined as a single axle with dual tyres (SADT) applying a load of 80 kN to the pavement (Austroads 2019b).

Traffic volumes in terms of the number and type of heavy vehicles are needed to convert the traffic spectrum on a road into ESAs for pavement design purposes. It is also important to consider the potential growth expected in the number of HVs along the road when estimating the pavement design traffic.

Manual or automatic traffic counts can be undertaken to provide estimates of the number of HVs along a particular section of road.

Estimating Design Traffic

A recommended approach to estimate the design traffic for pavement design purposes is as follows:

1. *Select a design period/life – this is usually about 10 years for unsealed roads, however a longer period (of at least 20 years) should be considered when undertaking a whole- of-life based evaluation of options, including possible sealing.*
2. *Determine the existing HV traffic or % of AADT. Where AADT is not available, the average daily traffic (ADT) can be used based on the maximum daily traffic per annum.*
3. *Estimate the expected heavy vehicle growth over the design period and any significant changes anticipated due to development (including resource development/mineral extraction etc).*
4. *Estimate the ESA/HV factor for the heavy vehicles using the road. Use should be made of the ATAP values (DIRD 2016) or based on locally available data as values can vary significantly.*
5. *Estimate the cumulative heavy vehicle loading over the design life expressed in terms of ESAs (Equation 8).*

The design number of ESAs for pavement design purposes can be determined using Equation 8.

$$DESA = \left(AADT * DF * \frac{\%HV}{100} * LDF * CGF * 365\right) * \left(\frac{ESA}{HV}\right) \qquad 8$$

where

$DESA$	=	design number of ESAs
$AADT$	=	annual average daily traffic in vehicles per day in the first year
DF	=	direction factor
$\%HV$	=	average percentage heavy vehicles
LDF	=	lane distribution factor
CGF	=	cumulative growth factor ($CGF = \frac{((1+0.01*R)^P-1)}{0.01*R}$ $for\ R > 0, CGF = P\ for\ R = 0$)
R	=	annual growth rate (%)
P	=	design period (years)
$\frac{ESA}{HV}$	=	average number of ESAs per HV

Designers are encouraged to establish the design traffic for a given road based on site specific traffic information. However, if there is a lack of readily available traffic information or for initial planning purposes, Table 3.13 provides a general guide based on likely traffic volumes and estimated ESA for various road classifications.

Table 3.13: Indicative design traffic volumes for various road classes (based on 10 year design life)

Road class[1]	ADT[2]	% HV[3]	% HV growth (%)	ESA/HV[4]	Cumulative design traffic (ESA)[5]
4A – main road	> 150	10	0	0.5	$3.7*10^4$
		20		3.9	$5.7*10^5$
		10	2	0.5	$4.0*10^4$
		20		3.9	$6.2*10^5$
4B – minor road	50–150	10	0	0.5	$1.8*10^4$
		20		3.9	$2.8*10^5$
		10	2	0.5	$2.0*10^4$
		20		3.9	$3.1*10^5$
4C – access road	10–50	10	0	0.5	$5.5*10^3$
			2		$6.0*10^3$
4D – track	< 10	10	0	0.5	$1.8*10^3$
			2		$2.0*10^3$

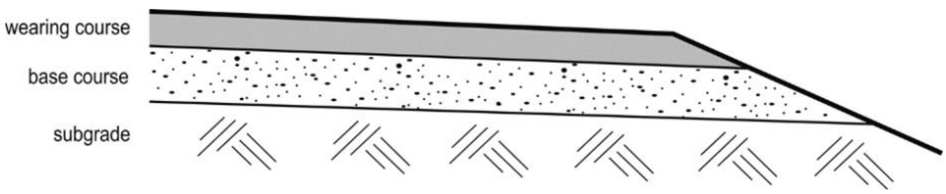
1 *Road class details are provided in Section 3.5.5.*
2 *Maximum daily traffic in a year (ADT).*
3 *Higher value to be used for heavy freight routes.*
4 *Higher ratio to be used for industrial areas or haulage routes.*
5 *Rounded up values.*

Note: Lane distribution factor is assumed as 1.0 because for unsealed roads trafficking generally straddles the centreline.

3.6.6 Pavement Layers and Materials

A formed and gravelled road pavement generally consists of distinct layers as shown in Figure 3.16. The preferred pavement make-up consists of a separate basecourse and wearing course. In some cases where the pavement thickness required is greater than 150 mm, a subbase course may also be used. However, a pavement type commonly used in Australia and internationally consists of a single combined basecourse and wearing course. In this case the basecourse must also perform the function of a wearing course.

Figure 3.16: Preferred layers associated with an unsealed road



Note: It is common in many jurisdictions to combine the wearing course and basecourse using the same materials.

Source: ARRB (2009).

Unsealed Pavement Layers

A formed and gravelled road is desirably made up of three layers, i.e. the subgrade, basecourse and a wearing course:

- *The subgrade provides the foundation to a pavement.*
- *The basecourse spreads the heavy wheel loads to the subgrade.*
- *The wearing course provides a durable surface to withstand the abrasive actions of vehicle tyres, minimise water penetration and dust emissions (i.e. a de facto seal).*
- *A suitable wearing course on the basecourse may avoid the loss of basecourse material.*
- *Where a wearing course is not provided, the basecourse needs to perform both roles. This will require a higher fines content and PI that will better bind the granular material whilst not becoming too soft and slippery when wet.*

Materials for unsealed road pavements are usually selected on the basis of availability, material properties, cost, and environmental factors. Appropriate material selection is critical to the performance of unsealed roads. A brief summary of important materials properties is given in the following sections and comprehensive guidance is provided in the ARRB *Road Materials Best Practice Guide* (ARRB 2020b).

Wearing Course Material

The wearing course material is considered critical in the performance of unsealed roads and should be durable and of consistent quality to ensure it wears away evenly. The suitability of an unsealed wearing course materials can be assessed by understanding its key properties, such as particle size distribution (grading) and plasticity characteristics.

Wearing Course Properties

The desirable characteristics of a wearing course for unsealed roads are:

- *adequate skid resistance*
- *smooth riding characteristics*
- *well-graded with a maximum size of 19 mm*
- *cohesive properties*
- *easy to grade and compact*
- *resistance to ravelling and scouring*
- *wet and dry stability*
- *low permeability*
- *load spreading ability.*

The ideal unsealed wearing course material is a well-graded gravel-sand mixture with a sufficient proportion of clayey fines, whereas less ideal wearing course materials include fine-graded silts and silty-sands lacking gravel-sized particles (i.e. silts and silty sands) or gravel and sands that are low in fines.

Wearing/Basecourse Materials

Many unsealed roads in Australia do not have a separate wearing course and the basecourse is required to perform both the structural function of supporting the wheel loads, as well as providing a tight road surface to resist ravelling and water entry.

This can be particularly challenging (especially on heavier-trafficked roads) given that the basecourse will need to have a higher PI to bind the pavement material to withstand the abrasive action of vehicles. This in turn which can make the basecourse more susceptible to moisture being retained and reduce the shear strength of the material (which may lead to rutting or other load associated distress).

Basecourse Materials

The base and subbase course layers determine the structural capacity of the pavement. These layers support the unsealed wearing course and protect the subgrade from deformation. The principal performance attributes of these pavement layer materials are no different to those required of conventional unbound pavement materials for bituminous sealed pavements. However, specification requirements for unsealed road basecourse materials are generally broader than for sealed roads.

Basecourse Properties

The desirable characteristics of a basecourse for unsealed roads are:

- *An appropriate particle size distribution to ensure adequate strength is achieved through particle interlock and the maximum density principle applies.*
- *The shape of the stone is important to achieve good compaction. Ideally the stones shape should be cubical with rugged edges to assist in mechanical interlocking. Sharp edges should be avoided to prevent vehicle tyres being cut.*
- *Sufficient plasticity to ensure the fine material contributes to densification of the aggregate through the reduction of interlock when wet and the provision of a cohesive strength to hold the aggregate in place when dry.*
- *Sufficient aggregate hardness to resist breakdown under compaction and trafficking.*

For base and subbase materials, greater emphasis is placed on material availability/cost and assessment in terms of performance, with a soaked CBR value of greater than 40% generally suitable.

3.6.7 Pavement Thickness Design

A gravel pavement structure is generally warranted when maintenance costs for formed roads become unacceptable, or when economic, safety or social benefits justify it. Undertaking a pavement design is then recommended to ensure adequate pavement depth is provided.

Sometimes the granular pavement thickness is not designed. Normally, a minimum thickness of granular material is used based on experience, ranging from 100 to 300 mm. It is important to note that this practice can result in more frequent pavement repairs.

The design of an unsealed road pavement requires the determination of the granular base (and subbase if present) thickness. The total pavement thickness required depends on the subgrade support and design traffic loading as discussed in Section 3.6.5.

In theory the pavement structure of a sealed or unsealed road is the same as both are required to support the traffic load over a given subgrade. In practice, however, the material specifications for unsealed roads are typically of a lower standard than for sealed roads due to limited funding and the extensive coverage in the road network.

Figure 3.17 provides pavement thickness design curves for unsealed roads constructed with granular materials (Austroads 2019b). The empirical design curves are based on a probability level of 80% (i.e. 20% risk of rehabilitation of the pavement being required before the end of the design life).

Because unsealed roads can be periodically reshaped or resheeted, these 80% probability curves would provide a reasonable estimate of the full thickness of pavement for unsealed roads, considering the design traffic, subgrade support and moisture conditions.

The curves apply to the design of flexible pavements if the design traffic is in the range of 10^3 to 5×10^5 ESAs. For very large and heavy mine haul vehicles a different design approach should be applied, including the use mechanistic pavement design procedures (Austroads 2019b).

Pavement Design Procedure

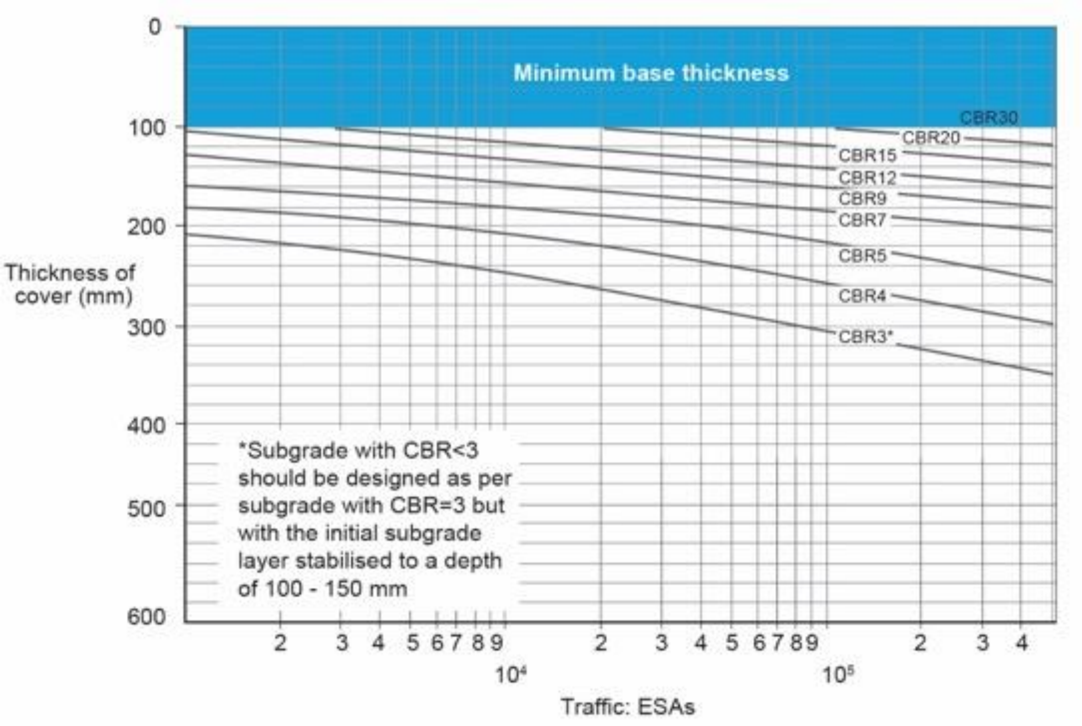
A suggested pavement design procedure is as follows:

- *determine the support conditions (refer Section 3.6.4)*
- *determine the pavement design traffic (refer Section 3.6.5)*
- *determine the total pavement thickness (i.e. thickness of cover) required using Figure* 3.17.

Some important pavement thickness considerations are:

- *Where a separate wearing course is applied this is an additional layer above the total thickness determined using Figure* 3.17.
- *The minimum depth of wearing course should take into consideration the likely loss of material during the resheeting cycle and is usually of the order of 75–100 mm.*
- *Where a separate wearing course is not specified, an additional allowance in pavement thickness should be made to allow for gravel loss over time and ensure the minimum gravel depth is not less than 50 mm prior to resheeting to limit punching into lower layers and to avoid rapid deterioration.*

Figure 3.17: Design chart for granular pavements (80% confidence)



Source: APRG (1998).

Thickness design example

With an estimate of the design CBR of the subgrade and the design traffic volume expressed in cumulative ESAs, these values are used together with Figure 3.17 to determine the total pavement thickness required.

Pavement Design Example

An unsealed pavement is to be designed for confidence limit of 80% with the following parameters with the assumption that traffic is channelised and lane distribution is not appropriate:

- *Subgrade strength = design CBR 5%*
- *Design traffic = 100 vehicles per day (ADT), 10% HV (average over 10 years)*
- *Growth rate = 1% (cumulative growth factor (CGF) = 10.5)*
- *Lane distribution factor (LDF) = 1.0*
- *ESA/HV = 2.2 based on a mix of medium rigids and articulated trucks*
- *Design period (P) = 10 years.*

Design traffic:

- *Design traffic = 365 * ADT * %HV/100 * CGF * DF * ESA/HV*
- *Design traffic = 365 * 100 * 0.1 * 10.5 * 1.0 * 2.2*
- *Design traffic = 84012 ESAs = 8.4 x 10^4 ESAs (rounded up).*

***Design** thickness (Figure* 3.17*):*

- *Thickness = 220 mm (excluding wearing course).*

Note: Allow for construction tolerance additional to design thickness (approx. +20 mm).

3.7 Drainage Design

This section covers design aspects of surface and subsurface drainage applicable to unsealed roads. In some instances, the road drainage system may be part of the local drainage system and it must be compatible with the requirements of the local drainage authority.

The objectives of a road drainage system are to (Giummarra 2005):

- contribute to a safe driving surface in all weather conditions within some economic constraints
- dispose of runoff in a safe and responsible manner without causing downstream problems
- maintain the pavement formation such that the strength and durability are not adversely affected by moisture ingress.

Some key drainage design considerations are summarised in Table 3.14.

Table 3.14: Road user and design considerations when choosing road drainage

Design aspect	Drainage considerations
Road user considerations	• Reduction in visibility due to spray. • Aquaplaning (more relevant to sealed roads). • Reduced availability of roadway during flood events. • Loss of stability for vehicles in floodways. • Spray and splashes from vehicles affecting cyclists and pedestrians. • Velocities in drainage channels are not excessive. • The safety of workers and the road users around them during maintenance activities. • Safe access to inlets and outlets of underground facilities.
Design considerations	• Roadway grading with respect to flood levels and tidal influence. • Flow across superelevation. • Calculation of storm discharge and rainfall intensity. • Development of a catchment area – homogenous or mixed in nature. • Acceptable flow widths. • Channel capacity. • Minimum pipe and box sizes. • Pit sizes and head losses. • Outlet condition. • Subsurface drainage.

Drainage systems are an important part of the moisture control system for a pavement and the surrounding materials. Austroads (2013c; Austroads 2017a; Austroads 2019a) provide comprehensive guidance to the design of surface, subsurface drainage systems in addition to culverts and pipes.

3.7.1 Types of Drainage

Most pavements contain measures to control the ingress of water into the pavement structure. The provision of a low permeability wearing course, side drains, and in some circumstance's subsurface drainage (or moisture barriers) will reduce the effect of water on pavement performance.

Drainage systems for pavements can fall under the following categories:

- surface drainage
- subsurface drainage
- cross-drainage including pipes and culverts.

Surface drainage

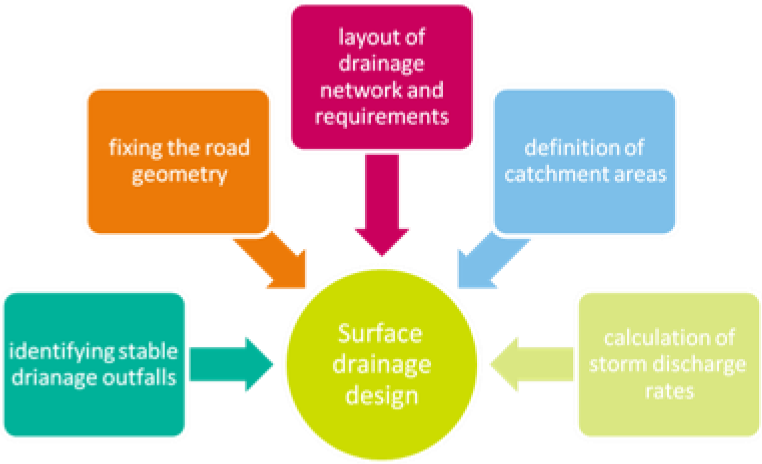
Surface drainage relates to the management of water which has fallen on the pavement surface or water which may flow onto the pavement from the surrounding environment.

The basis for the provision of surfaces drainage is to:

- cater for the safety and convenience of road users
- protect adjacent properties from damage due to uncontrolled surface runoff
- protect the road pavement by reducing water ingress
- provide protection for erosion sensitive areas during construction.

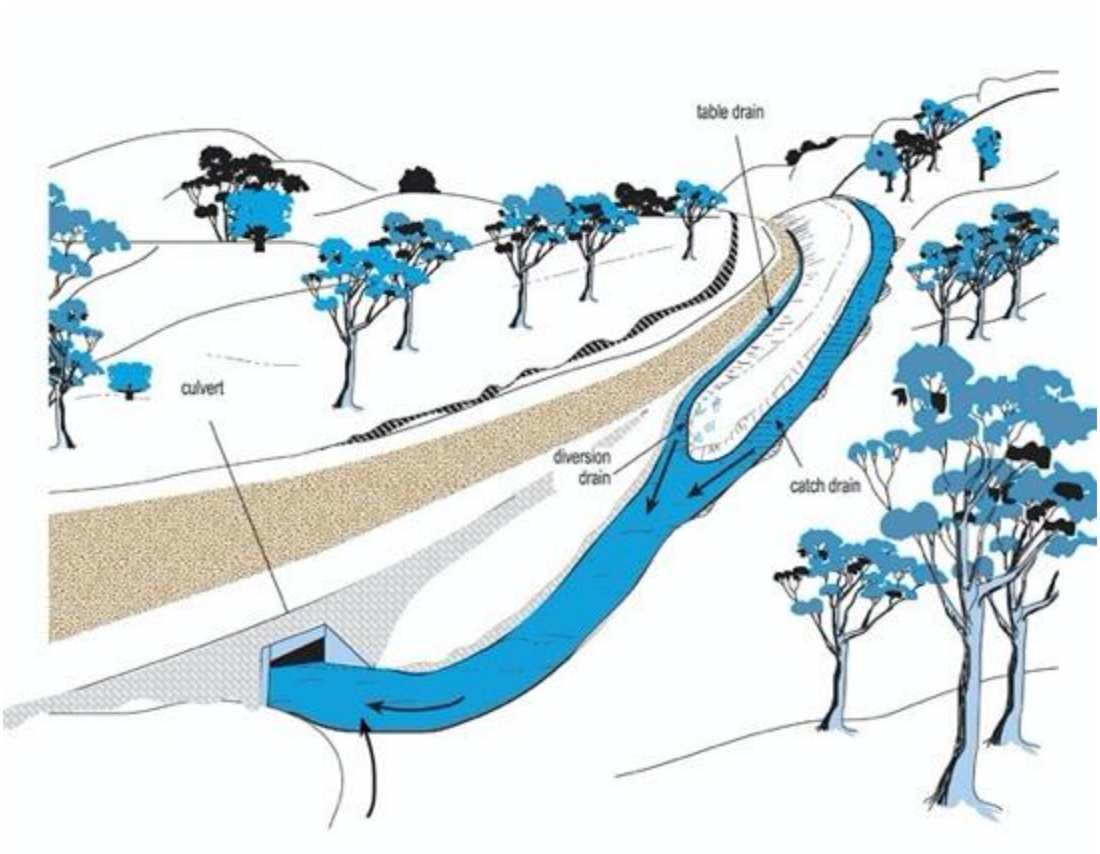
The key elements and components of surface drainage are shown in Figure 3.18 and Figure 3.19, respectively.

Figure 3.18: Elements of surface drainage design



Source: Adapted from Austroads (2013c).

Figure 3.19: Typical urban and rural road surface drainage components



Source: ARRB (2009).

A summary of the various surface drainage types applicable to unsealed roads is presented in Table 3.15.

Table 3.15: Various surface drainage types

Surface drainage	Suitability and use	Design considerations
Crossfall	• Part of the geometry of a pavement surface. • Direct surface flow towards table drains.	• 4–6% crossfall required. • Road user safety. • Shoulder materials. • Road operating speed
Table drains (longitudinal drains)	• Catch and convey water from: – road formation runoff. – overland flows toward the roadway. – flows from culverts or outlets. • Essential for roads within cuttings or flat terrain. • Run parallel to the pavement alignment. • Minimum slopes to avoid silting: – 1:200 (0.5%) for unlined ditch. – 1:300 (0.33%) for concrete or asphalt lined. • Maximum slope to avoid erosion: – 1:20 (5%) for unlined ditch. – if slope is greater than 5% provisions to prevent erosion. • Depth at least 150 mm below subgrade level but preferably > 500 mm.	• Hydraulic efficiency. • Structural soundness. • Erosion resistance. • Cross-section. • Provide cross drain culverts to reduce soil erosion.
Catch drains	• Intercept and drain water flowing towards the road from higher surrounding areas. • Often used at the top of deep cuts. • Prevent erosion of cut batters. • Reduce load on table drains. • The longitudinal slope of the catch drain should be: – greater than 1% to prevent pooling of water – less than 5% to prevent scouring.	• Hydraulic efficiency. • Structural soundness. • Erosion resistance. • Cross-section.

Subsurface drainage

Subsurface drainage is related to the removal and management of water which is located under a pavement structure. This water may be the result of a high watertable or through infiltration of moisture through the pavement shoulder or surrounding environment.

The basic objectives of subsurface drainage are to minimise the costs of moisture control by:

- minimising opportunities for groundwater to enter the pavement
- collecting and conveying infiltrated surface water to an outlet
- protecting the subgrade.

The use of subsurface drainage is crucial in areas where subsurface soils are not free draining, as the infiltration of water into a pavement system is highly likely to cause premature failure.

Subsurface Drainage Types

The common types of subsurface drains are:

- *pavement drains (both longitudinal land transverse):*
  - *placed just below the top of the subgrade to collect water infiltrating the pavement*
- *formation drains:*
  - *placed in deep trenches to intercept underground flows and lower the watertable*
- *combined stormwater/pavement drains:*
  - *useful where both are required but space is limited, and outlet levels are critical.*

Location of subsurface drainage

Choosing the correct location of subsurface drainage structures will ensure efficient and appropriate removal of water from the pavement system. The location of subsurface drains will depend on:

- permeability of pavement materials and the surrounding soils
- pavement superelevation and geometry
- pavement profile depth
- watertable depth
- surrounding environment
- pavement importance and level of service requirements.

Table 3.16 summarises the types of subsurface drainage and their suitable locations.

Table 3.16: Suitable locations of subsurface drainage

Subsurface drainage type	Suitable location
Pavement drain – longitudinal	• The low sides of a pavement. • Both sides of the pavement near any cut-to-fill line. • Both sides of a kerbed pavement. • Both sides of the pavement where the crossfall is less than 0.02 m/m. • High side of the pavement where seepage is evident, or where water may enter from batters, full width pavement, service trenches or abutting properties. • Along the joins between an existing pavement and a pavement widening where pavement depths or different materials permeabilities could create a moisture trap.
Pavement drain – transverse	• Approximately 5 m upstream of cut-to-fill lines. • Along changes of pavement depth or material permeability. • Both ends of bridge approach slabs. • At superelevation changes, to limit the length of the longest drainage path within the pavement to about 50 m.

Subsurface drainage type	Suitable location
Formation drain	• Along both sides of cuts where the road is known to be below the watertable, or where seepage is encountered during construction, or expected in wet weather. • Transversely at any seepage areas, and further downgrade if required.
Combination of stormwater and pavement	• Where the road is below the watertable for most of the year, and flows are expected to exceed the capacity of the standard size subsurface drain. • It can prove economical to lay slotted pipes in deep trenches to cater for both groundwater and stormwater flows.

Source: (Austroads 2013c).

Subsurface Drainage Design Considerations

Subsurface drainage placement:

- *Pavement layers should preferably not be surrounded by materials of lower permeability.*
- *The flow path to the subsurface drain should preferably proceed through materials of increasing permeability.*
- *the capacity of the subsurface drainage system should be adequate to dispose of estimated quantities of water from surface infiltration or other sources.*

Subsurface drainage in expansive materials:

- *Locate the subsurface drains at least 600 mm from the back of the kerb (if present), and not greater than 250 mm below the subgrade level.*
- *Introduce an impermeable membrane on the pavement side of the drainage trench when it is decided to place the subsurface drain within 300 mm of the back of the kerb (if present).*

Cross-drainage – pipes and culverts

Pipes and culverts direct surface flow under a pavement and allow flow from one side of a pavement to the other. The selection and design of a culvert structure or pipe is critical as failure of these structures can cause damage to the overlying pavement structure if overtopped by flood water or damaged through high velocity flows.

The following design considerations are critical to the correct function of a culvert or pipe system:

- location, orientation and grade (erosion or siltation avoidance)
- hydraulic efficiency
- structural soundness
- self-cleaning capability
- local practices and component availability.

As a rule of thumb, the suggested spacing of cross drains to reduce erosion is presented in Equation 9 (ARRB 2009).

$$spacing(m) = \frac{300}{\%\ grade\ of\ longitudinal\ drain} \tag{9}$$

Alternatively, Table 3.17 provides suggested spacing criteria originally developed for forest roads.

Table 3.17: Maximum spacing between cross drains

Road grade	Soil erodibility class		
	Low to moderate – high (m)	High (m)	Very high (m)
1–5%	150	120	70
6–10%	120	90	40
11–15%	95	70	30
16–20%	50	35	30

Source: Forestry Commission Tasmania (1993).

The most common type of culvert used in road construction is precast reinforced concrete pipes and box culverts. For smaller sizes the trend is towards using precast concrete end walls and pits which are made to match and are easily fitted on site. In all cases a stable and uniform foundation is required for the satisfactory performance of any culvert.

3.7.2 Calculation of Design Parameters

Rational method for storm discharge calculation

A commonly used method for calculation of storm discharge from a road catchment is the rational method which considers rainfall intensity and catchment characteristics such as runoff and area. It is used to design stormwater drainage systems, spillways and culverts. The estimated maximum discharge may be calculated using Equation 10 (Austroads 2013d).

$$Q = \frac{(C_Y \times I \times A)}{360} \tag{10}$$

where

Q	=	estimated maximum discharge for the selected design storm (in m^3/s)
C_Y	=	coefficient of runoff, dependent on the density of buildings, area of pavement, soil type, slope of catchment, vegetation cover, and storage or other delay producing characteristics
I	=	rainfall intensity (in mm/h), for the chosen average recurrence interval and storm duration
A	=	catchment area (in ha).

Time of concentration

The time of concentration is defined as the time taken for water to flow from the most time-remote part of the catchment to the outlet being designed.

For road surface drainage the time of concentration is generally made up of:

- time of flow from road surface areas and adjacent roadside areas
- time of flow in gutters and surface channels
- time of flow in pipes.

Urban catchments

Various methods are available for determining overland flow time. This is typically dependent on the length of flow and the average surface slope. An iterative approach is required because the rainfall intensity alters as the time of concentration alters. The equation should be limited to overland surface flows on pervious areas of less than 200 m. Generally, sheet flows will enter some form of channel within 200 m and the flows are then calculated using Manning's Equation for open channel flow as presented in Equation 11.

$$t_c = 6.94 \times \frac{(Ln)^{0.6}}{I^{0.6} S^{0.3}} \qquad (11)$$

where

t_c	=	time of concentration (minutes)
L	=	overland flow path length (m
n	=	Manning's roughness coefficient
I	=	rainfall intensity (mm/h)
S	=	slope of overland flow path (m/m)

Rural catchments

For rural areas where large catchment areas may be involved, the time of concentration is calculated differently within each State. However, Equation 12 equation will provide a reasonable estimation of the time of concentration for long overland flows.

$$t_c = 91 \times \frac{L}{A^{0.1} \times S^{0.2}} \qquad (12)$$

where

t_c	=	time of concentration (minutes)
L	=	overland flow path length (m
A	=	catchment area (in ha).

S = slope of overland flow path (m/m)

Rainfall intensity (I)

The rainfall intensity for a particular design storm is a function of both the time of concentration and the average recurrence interval (ARI), for the design storm intensity. The critical storm duration is usually taken as the time of concentration.

Rainfall/intensity/duration diagrams covering a range of ARIs for a specific location are available from the Bureau of Meteorology for locations specified by latitude and longitude. Designing a minor stormwater management network to cater for the basic ARI values is given in Table 3.18.

Table 3.18: Recommended minimum ARI to minor road drainage system elements

Item	Average recurrence Interval (years)
Cross drainage for National highways and arterials (typically roads with > 2000 vehicles per day)	100
Cross drainage on roads other than national highways or arterials (typically roads ≤ 2000 vehicles per day)	50
Longitudinal surface drainage (including intersections and bridge decks)(1,2)	10
Flows over the trafficable surfaces	
Permanent sedimentation basins Temporary sedimentation basins	2 0.5
Wide flat pavements	1
Water quality basins	1
Urban road surface drainage	See section 6.4.1 of Austroads (2006b)
Temporary work sites(3)	1

1 If the road is sited in a town center, the ARI should be increased to 20 years.
2 Local Government policies and the local drainage authority should be consulted for the design of minor rural road drainage schemes, since these can vary across Australia.
3 A contractor shall provide adequate drainage to side-track including off road drainage in order to prevent ponding of water. Culverts shall be installed at creeks and streams.

Note: For minor/convenience systems the above values are ONLY applicable where an integrated major drainage system is planned and designed for a 100-year ARI.

Source: ARRB (2005).

3.7.3 Environmentally Sensitive Drainage Design

The design and operation of a road's drainage system can be a major source of degradation to the environment. The planning and design phase of a new road project offers the best opportunity to minimise the environmental impacts of road runoff and drainage. The route selection process should also consider potential impacts on roadside vegetation and aquatic biodiversity in adjacent waterways.

Road crossings can affect catchment hydrology, potentially exacerbating localised salinity problems. Particularly in lowland agricultural areas, floodwaters tend to pond behind roadways with either silted or undersized culverts, damaging the land upstream of the crossing.

Environmental Considerations in Drainage

Many of the environmental considerations relevant to road drainage design are discussed in Austroads (2001). The principal objectives of this document are:

- *Identify and quantify the potential impacts of runoff and road drainage on ecosystems.*
- *Identify the source of those impacts.*
- *Identify remedial measures and best practice approaches to reduce impacts.*
- *Identify priority areas requiring further research and understanding.*

4 Construction

Effective and efficient road construction relies on a combination of good forward planning, technical knowledge and practical experience in the field (Figure 4.1). This requires the collective effort of the supervising engineer/administrator, the job supervisor, contractor (and any subcontractors), as well as the plant operators. It also necessitates having a good understanding of construction theory and techniques. An important consideration of any new construction is the requirement for close consultation with adjacent landowners and affected road users. In most cases, environmental and cultural heritage considerations will also need to be considered.

Figure 4.1: New road construction site

This section covers the basics of new road construction, be it for a new road alignment, a road deviation or road upgrade. The same principles and practices apply irrespective of the scale of construction.

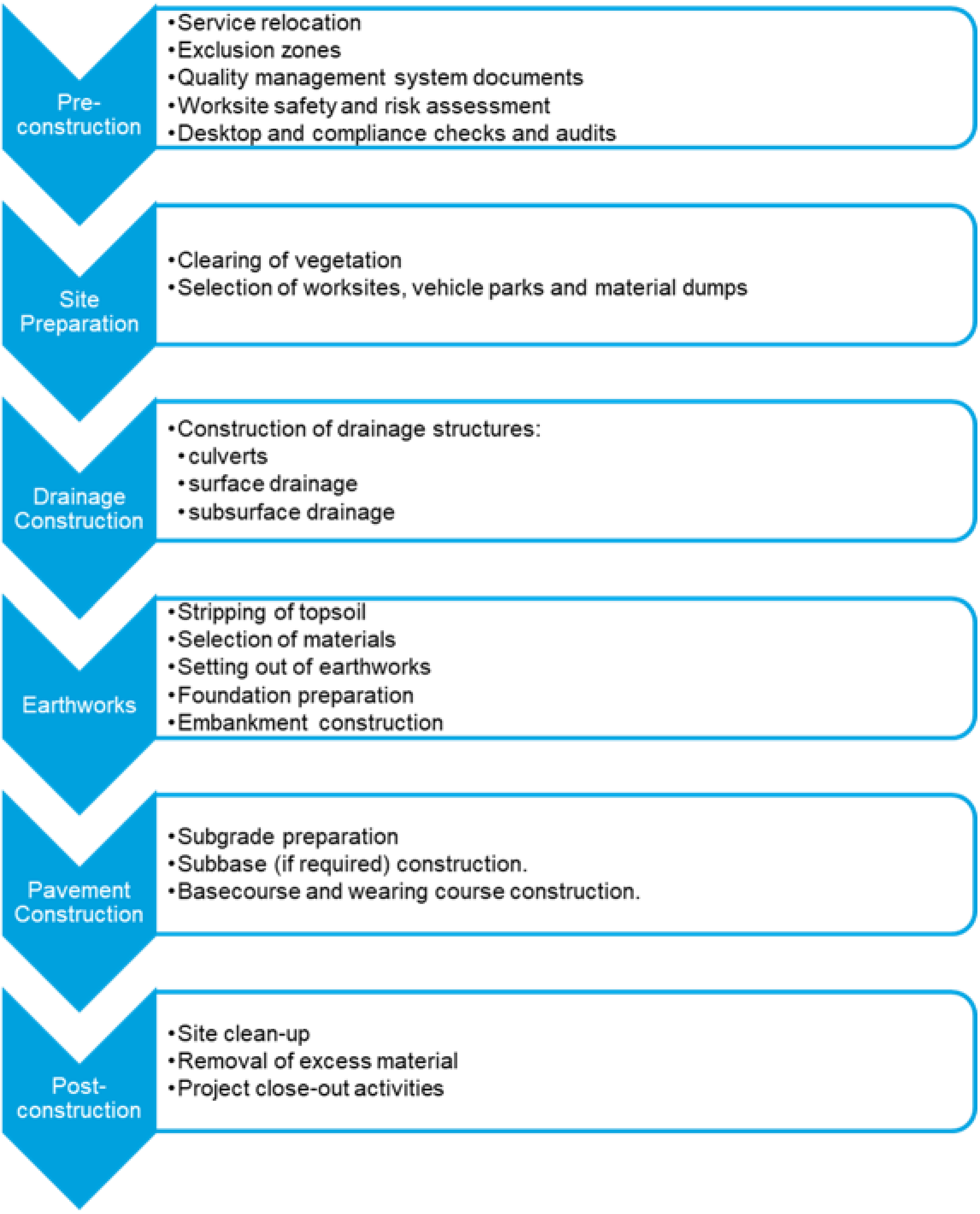
As for all forms of roadworks, construction operations must be carried out in strict conformity with the relevant state laws, local laws and bylaws, regulations and codes for safety and environmental protection.

While the occupational health and safety requirements and environmental requirements are similar between states or districts, these may be changed over time and reference should always be made to the latest requirements for a particular locality.

4.1 Construction Sequence

The usual sequence of operations for the construction of a new unsealed road is summarised in Figure 4.2. Further details of each operation are provided in Section 4.6 to Section 4.14.

Figure 4.2: Sequence of operations for the construction of a new unsealed road



4.2 Quality Management in Construction

4.2.1 Quality Management System

Most Local Governments have embraced the principles of quality management system (QMS) requirements as set out in Australian standard AS/NZS ISO 9001: 2016. QMS is now extensively specified in contracts as a requirement for road construction.

A QMS provides management requirements which supplement requirements for product quality. It provides confidence to internal management and to customers that the requirements for quality are being fulfilled or will be achieved in the delivered product.

4.2.2 Quality Control and Quality Assurance

Quality control (QC) *refers to inspection and test procedures which are applicable to control of quality of product characteristics during the construction process.*

Quality assurance (QA) *refers to inspection and test procedures which are required for the verification of the quality of end-product characteristics relative to specified requirements, whether the end-product is a purchased product for use in the process (incoming product, e.g. aggregates) or a product of the process (outgoing product, e.g. sprayed sealed road).*

For example, in the compaction process, QC would refer to inspection and test (I&T) procedures for control of moisture content, grading, levels, thickness of pavement and compaction. QA, on the other hand, would refer to I&T procedures for the verification of compliance with the specified requirements for aggregate properties and compaction.

QA also relies on the collation of all documentation leading to acceptance of work or remedial action required to satisfy non-conformances.

4.2.3 Quality System Documents

A quality system typically consists of several documents, details of which are summarised in Table 4.1.

Table 4.1: Quality system documents

Document type	Purpose
Quality manual	The primary document which describes the full scope of an organisation's quality system. It contains all the relevant organisational policies relating to quality.
Project quality plan	Details the contractor's specific quality system for a particular project. Each new project has a new quality plan; however, once the base plan is set up, only minor changes may be required to meet the particulars of a similar project.
System or quality procedures	Details how specific administrative processes are to be carried out, e.g. tender reviews.
System instructions	Detailed instruction on how to carry out a particular task within an administrative process, e.g. document numbering
Technical procedures/method statements	Details how particular construction processes are to be planned and controlled, e.g. flexible pavement construction.

Document type	Purpose
Technical instructions/work instructions	Detailed instruction on how to carry out a particular task within a construction process, e.g. supply and placement of pavement material.
Inspections and test plans (ITPs)	Details the inspections and tests to be carried out for a particular construction process. As a minimum they should include all those inspections and tests set out in the project specification; however, the contractor may elect to carry out additional tests if so wished.
Non-conformance report	Records the detail of a non-conformance and subsequent actions taken to address the deficiency, sometimes known as a 'disposition' or 'corrective action'.
Checklists	Shows all the steps required to perform the process in accordance with the technical procedures.
Audit reports	Identifies issues and procedures required to achieve compliance.
Corrective action reports	Records the details of a deficiency and the subsequent corrective action taken to prevent its recurrence.
Documents register	Provides a record for particular types or groups of documents.
As constructed drawings	Drawings of as constructed road structure, particularly if there were any deviations from the design/standard drawings.

4.2.4 Project Quality Plan

Prior to commencing construction on a project, a Project quality plan (PQP) should be prepared based on, and using the general format of, the organisation's Quality Manual. A typical quality plan for a road construction project would contain the following details:

- contents of plan
- organisation quality policy
- project specific quality policy
- project specific quality objectives
- estimated contract duration and proposed dates
- audits and surveillance proposed
- project organisation chart
- project organisational responsibilities
- training and qualifications of all personnel, including the site-specific induction
- principal operations
- procedures schedule
- list of hold points and witness points
- inspection and test plans
- subcontractors' quality plans
- site safety plan.

4.2.5 Technical Procedures

Technical procedures are an important part of the PQP as they describe in detail the purpose and scope of a construction process, what is to be done by whom and when, where and how. They should be prepared for each phase of the construction process, e.g. clearing, drainage, earthworks etc. Each technical procedure should detail:

- responsibilities
- sequence of operations
- work methods
- characteristics and tolerances to be met
- types of equipment to be used and their testing calibration requirements
- materials including their source
- safety requirements
- reference documents
- records produced.

4.2.6 Surveillance

Surveillance is the continual observation of the work and analysis of the records generated by the contractor, to gain assurance that the specified quality is being delivered. The project owner will generally nominate a person responsible for surveillance on behalf of the road agency on the project.

Surveillance may also include ensuring that traffic, safety, environmental and cultural heritage activities are being managed appropriately during construction. For example, a surveillance officer could periodically check sites during non-working hours to ensure the signage and cones etc. are still upright and providing clear guidance and that the site is safe.

Hold points are introduced at critical stages throughout the specification to give the project owner an opportunity to review an activity before proceeding further.

Witness points are used to indicate when testing or recording of current status is required prior to proceeding.

4.2.7 Quality Audits

A quality audit is an activity aimed at verifying that the system, procedure or process complies with the relevant requirements. Audits may be either a system audit, i.e. an audit to verify the effectiveness of the overall quality system, or a compliance audit, which verifies whether the procedures which are in place have been complied with.

Audits may be either internal – undertaken by the contractor to check their own quality system, or external – undertaken by the project owner. In both cases the audit should be undertaken by a person who is not directly associated with the project but has appropriate qualifications and experience.

It is recommended that at least one internal and one external audit be undertaken on a project, especially on larger or more significant projects.

4.3 Safety in Construction

4.3.1 Workplace Health and Safety

It is of the utmost importance that all construction operations are carried out safely, and that road users and adjoining landholders can pass safely through or around the roadworks.

It is generally a requirement of a road agency that the management of occupational health and safety be incorporated into the PQP. As a minimum, those sections of the relevant state legislation relating to the duties of employers should be complied with. This will include the development of a roadworks safety plan.

Roadworks Safety Plan

A Roadworks Safety Plan should as a minimum address the following:

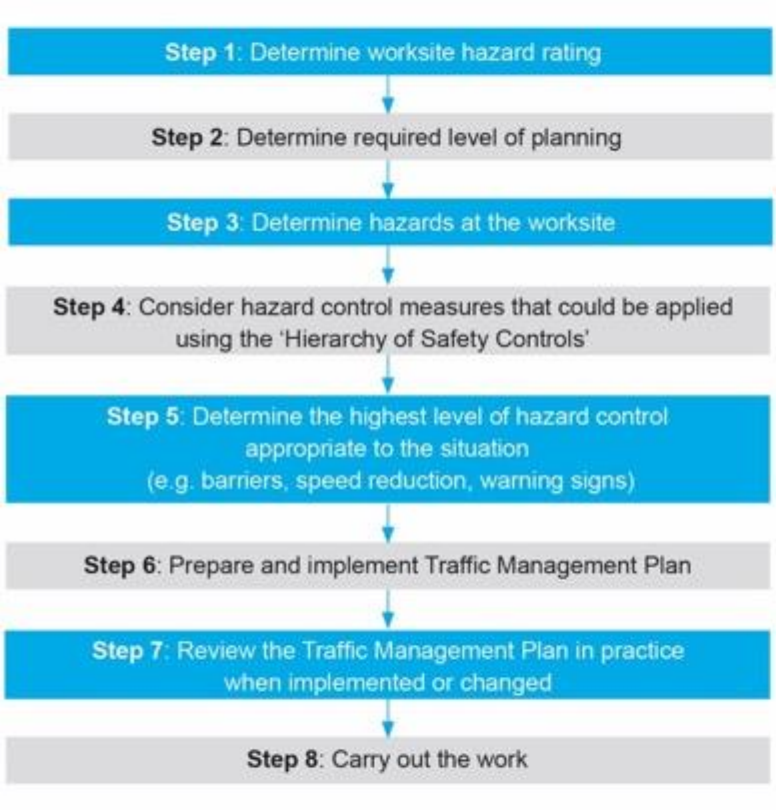
- *plant maintenance, including records, inspections, fault reporting and operator training programs*
- *systems of work, including safe operating procedures, safety instructions etc.*
- *dangerous goods and chemicals and emergency procedures*
- *workplace hazard identification and risk control measures*
- *full details of safety training and induction procedures, training records etc.*
- *management of subcontractors*
- *names and addresses of all persons to provide expert occupational health and safety advice*
- *reporting procedures for incidents, ill health, injuries or near misses.*

All construction work must be carried out in accordance with the relevant laws of the state or district in which the work is undertaken. All staff must be given appropriate training and be made fully aware of their responsibilities. All plant and its operation must comply with the appropriate laws, regulations and codes. Materials must be stored and handled in a safe manner.

Arrangements must be made for regular safety inspections. Should any unsafe situation arise, immediate steps must be taken to rectify the situation.

A systematic approach is necessary to identify areas of hazard, to prioritise the critical risks from lesser risks, and to identify effective ways of reducing hazards that may have an undesired or unexpected outcome. A methodology for a risk-based assessment of worksite conditions is given in (Victoria Government 2010) and summarised in Figure 4.3. Readers may wish to use this as a guide to set up their own risk assessment system, using a more interactive process, with likelihood and severity considerations.

Figure 4.3: Safety and traffic risk assessment methodology



Source: Victoria Government (2010).

4.3.2 Provision for Traffic

A Traffic Management Plan (TMP) should be prepared for road construction works which provides procedures for traffic control and safe movement of traffic through the work zone for both road users and works staff. Traffic Guidance Schemes (TGS) are developed for various work scenarios and work site locations. These schemes demonstrate the arrangement of temporary signs and devices to warn traffic and guide it through, or past a work area or temporary hazard.

All signs and traffic control devices within the TGS necessary for the warning, guidance and protection of the public, workers and other on-site personnel must be provided. Such signs and devices must conform to the relevant jurisdictional requirements. The installation of the signs and devices must also comply with the Australian Standards Manual of Uniform Traffic Control Devices (AS1742.3), or any other relevant state or Local Government supplement to AS1742.3.

The risk of travelling on or through a work site or hazard is not necessarily reduced on lower volume roads. Whilst the exposure and likelihood may be reduced due to lower traffic volumes, the severity of any accidents is still high. It is therefore important that a TGS is designed and installed correctly as:

- a road user may not be anticipating work crews or a hazard
- lower volume roads typically have reduced sightlines due to the horizontal and vertical geometry and this highlights the importance of providing a TGS that adequately warns road users of upcoming work zones, and personnel on the road or roadside.

The warnings signs and devices used must be maintained in an effective and clean condition while being used. Regular inspections should be made of the installed signs and devices, and prompt action taken to remedy any deficiency. Damaged or worn signs which are ineffective must be removed and replaced. It may be desirable to keep up-to-date records and photographs of signage to assist in any court cases should an accident occur on-site.

Persons involved in managing traffic at construction sites should be appropriately trained and certified.

Any necessary detours and side-tracks should be constructed and maintained to an appropriate standard to ensure the safety of road users.

When the construction works are completed all roadwork signs should be removed and the site left in a safe and clean condition. This will assist in compliance, as roadwork signs that are left at sites where personal or a hazard is not present diminishes the effects of the same signage where there is an active worksite or a hazard.

Further guidance regarding traffic management practices are also provided in the Austroads *Guide to Traffic Management* (Austroads 2019d).

4.4 Environmental Management

Road construction sites have the potential to significantly affect the local environment. Their management needs to take into consideration the local native vegetation and its potential as wildlife habitat, the proximity of nearby creeks and rivers and the aesthetic appeal for motorists who will use the road.

The construction of unsealed roads should consider (as a minimum) the following environmental impacts:

- Clearing and site preparation – ensure that site establishment has minimal impacts on the environment (refer Appendix A.3.1).
- Erosion and sediment control during construction – construction erosion control measures before commencing road construction operation (refer Appendix A.3.2).
- Drainage construction – divert flows from entering the site and reduce sediment leaving the construction site (refer Appendix A.3.3).
- Excavation and embankment construction – revegetate disturbed areas progressively during construction (refer Appendix A.3.4).
- Pavement construction – cover loads during transportation and compact material at the end of all workdays to minimise erosion (refer Appendix A.3.5).
- Machine selection – choose plant that minimise impact and keep the work area as small as possible (refer Appendix A.3.6).
- Aesthetic and landscape construction – remove excess material and reuse where possible (refer Appendix A.3.7).

Environmental guidelines, as outlined in a construction site-specific environmental management plan (EMP) or roadside management plans, will require consideration during road construction activities. To assist in the development of a suitable EMP, a Site EMP Kit is available on the Clearwater website at /www.clearwatervic.com.au

Further guidance regarding environmental management requirements can also be found in the AUS-SPEC construction work sections available for purchase through NATSPEC at www.natspec.com.au.

4.5 Plant Selection and Usage

The various types of plant typically used in the construction of unsealed roads include tractors, dozers, rippers, scarifiers, excavators, graders, loaders, backhoes, screening/crushing plants, trucks, earthmoving plant and compactors are summarised in Table 4.2.

All plant should be well maintained and in a serviceable condition to ensure that the works are undertaken in a safe, efficient and effective manner.

Table 4.2: Summary of main equipment and plant types

Main equipment and plant types		
 **Truck dozer –** a dozer blade is fitted to the front of a tractor to push material forward or cast it to one side.	 **Grader –** designed primarily for the work of trimming, mixing, shapign and finishing in road cosntruction.	 **Excavator –** generally used for bulk earthworks, loading from stockpiles, table drain maintenance, trimming an shaping batters, trenching and removing soft areas on site.
 **Front end loader and dump truck –** versatile pneumatic-tyred or tracked loaders for moving or loading materials.	 **Water truck –** a water cart fitted with a spray bar should be used to add additional moisture to the pavement, assisting in achieving desired compaction.	 **Screening/crushing plant –** small mobile screens, screening plants or screening and crushing plants may be employed to remove or crush oversized material in paving gravel.
 **Scraper –** used to rip hard ground and reduce loading time.	 **Rock breaker –** designed to break oversized rocks into smaller rocks.	 **Steel drum roller –** applies static or vibratory pressure to the material for compacting the pavement.

Main equipment and plant types		
 **Multi-wheeled roller –** applies pressure to knead and compact the material, useful for materials with low cohesion.	 **Grid roller –** used to break up soft rock and force large rocks below the surface through impact force.	 **Padfoot roller –** produce high contact pressure with low mass, tamping the soil and are most useful for compacting clay.

It is important to select the type and number of construction equipment based on what is needed to carry out the task safely, efficiently and effectively.

4.6 Pre-construction Considerations

4.6.1 Service Relocations

For works in rural areas the common services encountered are communication facilities such as underground lines and junction boxes, power authorities' assets such as poles, sub-stations etc., high pressure gas mains, and facilities for irrigation distribution such as channels, narrow road culverts and underground property service pipes.

Confirm the location of all underground services with the appropriate service authorities and field testing before digging commences. Also consider any overhead services that may be impacted by the works.

The identification and relocation of services is normally the first phase of any construction and the works program should allow adequate time for this to be carried out. This early identification of services will enable the most appropriate road alignment and design being chosen to allow for construction to be clear of services in order to avoid:

- damages to services
- injury to workers
- costly repairs
- delay of works
- disruption of services to the general public.

Underground services are located either by probing, electronic location and marking or exposing for easy recognition. Generally, due to the specialist nature of the facilities they are relocated by the owner or responsible authority, or by its contractors. Refer to individual state and territory codes of practice for utility management requirements.

Location of Services – 'Dial Before You Dig'

'Dial before you dig' is a free national service that provides information on buried utility infrastructure directly from the asset owners of the utility services. Lodging an enquiry can be done via:

- *their website @ www.1100.com.au/*
- *mobile app*
- *phone on 1100 (within business hours).*

Prior to dialling 1100, check the location details at the worksite (i.e. GPS coordinates) to accurately locate the information sought. It should be noted that not all utilities or councils may subscribe to 'Dial before you dig'. In such cases construction staff should contact their local council to determine the location of any services.

Further information can be found on the 'dial before you dig' website @ www.1100.com.au/.

Any services that remain in the works area after relocation, e.g. lowering of a water main or a service should be clearly marked by pegs to avoid accidental disturbance during the subsequent works. Many service authorities also have exclusion zones. The exclusion zone requirements will vary between states, possibly between regions and may vary according to a particular service.

4.6.2 Stakeholder Notifications and Communication

Consideration should be given in the planning phase to ensure that the required public notifications are issued, and permits received. Police and motoring associations and any affected property owners should also be advised.

Examples of notifications include:

- letter drops to surrounding residents and businesses
- signage such as variable messaging systems displaying dates and timing of construction works
- media advertisements/news releases in accordance with the road agency's standing arrangements for such releases.

4.7 Site Preparation

Site preparation primarily involves clearing, including the removal of all vegetation, refuse and artificial features from the area to be occupied by the earthworks. This is generally the whole width between the outside edge of batters plus up to 3 m, but not beyond the road reserve boundary or, where catch drains are required, to the edges of catch drains.

It is important to clearly identify and mark the boundary of earthworks and check the environmental plan for any 'no go' areas. Aim to remove as little as possible of the existing vegetation on roadsides to minimise the revegetation of the area and exposure to soil erosion.

Prior to commencing clearing, all permits or resource consents (including native title clearance and cultural heritage concerns) required for removal of native vegetation should be obtained and any special conditions noted.

Prior to excavating material for use in embankments, all surface vegetation should be stripped from the area to be excavated. The surface on which the embankments are to be constructed should also be stripped of vegetable matter.

The vegetation to be removed should be clearly marked to avoid accidental removal or damage to vegetation that is to be retained. Special attention should be paid to any special conditions or mitigation measures specified relating to seed collection, the avoidance of the spread of noxious weeds and the possible pollution of waterways. If working over native vegetation is unavoidable, squash down the vegetation in preference to scraping it off.

Tree roots are usually removed to 300 mm below the ground surface.

4.8 Water Sources and Quality

Care should be taken regarding the quality of water used for construction to ensure it is free of deleterious materials. A large amount of fines may be sucked up while water is being drawn from a dam or creek bed, and this can adversely affect the pavement materials used in construction.

For unsealed roads the effect of soluble salts is not so critical as for unsealed roads. This may even be beneficial, as the salts will attach to the moisture and minimise dust emissions.

Filling trucks and carting water to an unsealed road construction site can often be the most critical factor in terms of the rate of construction. Therefore, it is beneficial to consider short hauls and adequately sized pumps and plumbing.

In addition, the amount of water required for compaction at OMC can be reduced by selecting or blending materials to produce a material with a lower OMC. Reductions in OMC can also be achieved by applying heavier rollers to achieve the required density. Keeping the water spraying equipment close to the ground will also assist with minimising wind drift and evaporation.

With the scarcity of water in many regions across Australia greater attention is being given to the use of marginal, non-potable or recycled water on road construction instead of potable water sources.

4.9 Drainage Construction

The installation of adequate drainage during construction is a key factor influencing the ongoing performance of unsealed roads, as well as limiting rain delays during construction.

4.9.1 Subsurface Drainage

The subsurface drains, most frequently used to intercept and remove groundwater, are narrow trenches cut with a backhoe, excavator or a trenching machine, and filled either wholly or partially with a porous material. A perforated pipe, normally with a sock or filter medium, is provided in the lower part of the trench to remove the water collected.

The perforated pipes used may be of corrugated or rigid smooth walled plastic, corrugated galvanised steel or fibre reinforced pipes. Diameters vary from 40 mm to 150 mm, however, the most common size is 100 mm.

The porous backfill material must act as a filter to retain the surrounding soil particles but allow the water to drain into the pipes. The backfill material must also be coarse enough not to enter the pipes and block them.

The typical steps in subsurface drainage construction include:

1. trenching – the base may be shaped like a ‘v’ so water does not pond
2. placement and compaction of first stage filter material or geotextile
3. placement and compaction of second stage granular filter material
4. laying of pipes (Figure 4.4)
5. placement of granular filter material on top of pipes
6. saturate and compact filter material
7. flushing of pipes until discharge water runs clean.

Once constructed and flushed, pipe openings and outlets should be blocked to stop foreign matter entering the pipe before completion of pavement construction.

All subsurface drains should be marked at the outlet with marker posts to assist with maintenance and have inspection pits at least every 150 meters.

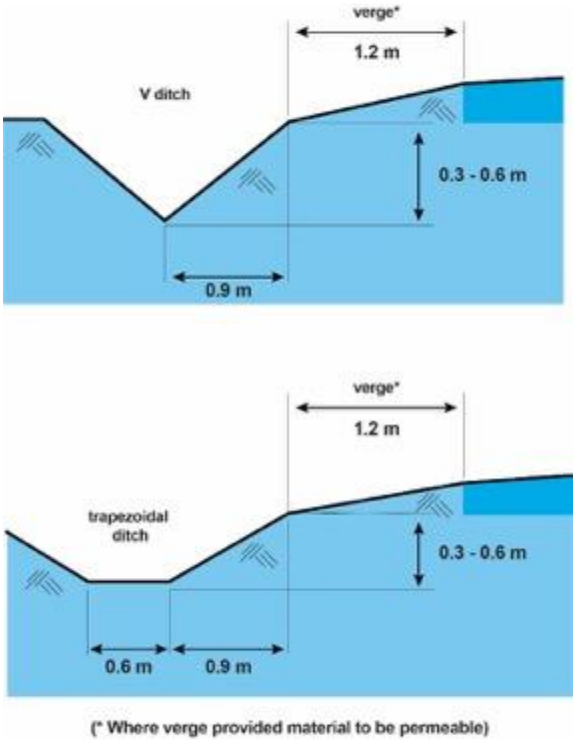
Figure 4.4: Strip subsoil drain installation

Source: ARRB (2009).

4.9.2 Table Drains

Table drains are usually constructed into the natural material on site adjacent to the road. They can be in the shape of a ‘v’, trapezoid, or parabola, although a flatter base will reduce the risk of erosion. During construction, the levels must be carefully controlled, and table drains should be graded to the nearest outfall. Figure 4.5 shows the shape of typical table drains.

Figure 4.5: Typical table drains



Source: ARRB (2009).

4.9.3 Culverts

Proper placement and construction of culverts is critical during construction as it is a potential for early road failures. The typical steps involved in culvert installation and construction include:

1. Confirm the position and invert levels of every culvert.
2. Check the load class of each culvert for each location as per the design.
3. Excavate the trench for installation.
4. Install and compact the bedding material along the bottom of the trench.
5. Install the culvert structure.
6. Confirm the as-constructed levels and grade of the culvert.
7. Install and compact the backfill materials.

4.10 Soil Compaction

Adequate material compaction is essential to the long-term performance of unsealed roads. Key benefits of compaction include:

- reduces permeability
- reduces consolidation
- provides greater material strength/stiffness
- minimises permanent deformation under traffic loads
- minimises loss of shape under traffic loads

- reduces erosion and gravel loss of wearing course materials.

There is a wide choice of compaction equipment used in roadworks. Most equipment is available in several sizes (generally between 5–25 tonnes) based on dead weight. Compactors can be self-propelled or drawn by a tractor.

Static rollers, which rely on their own deadweight and can be used for compacting all types of soils such as gravels, sands and clay. Rollers with vibrating devices impose pulsating stresses in the soil. This reduces the friction between the soil particles and results in a highly effective and deep compaction, particularly in sand and gravel.

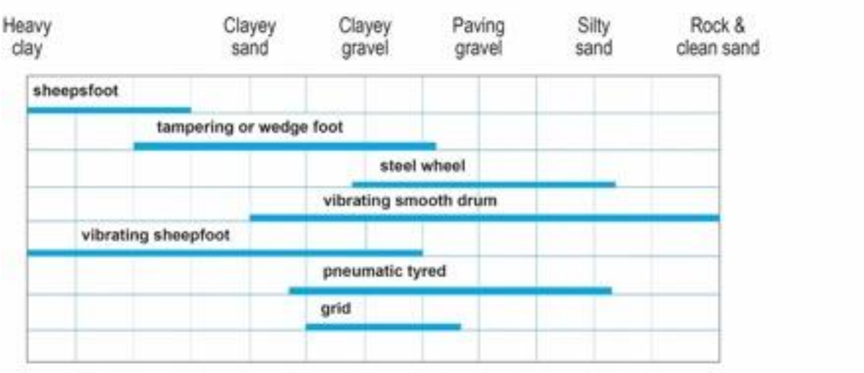
For compaction of free draining cohesionless soil (i.e. sand) the best results are obtained using a relatively low frequency (25–30 Hz) and high amplitude (1.5–2.0 mm) vibration.

For compaction of road base gravels high frequencies (33–50 Hz) and low amplitudes (0.4–0.8 mm) are best (Bowler 1999). Similarly, fine plastic gravels and loams are best compacted with a heavy, high frequency, low amplitude vibrating roller (Skinner 1989).

It is possible to compact a soil to a higher density and to a greater depth by increasing the loading per unit width of the roller. The loading must not, however, exceed a certain limit depending on soil type. If the roller produces shear stresses exceeding the shear strength of the soil, the soil will be remoulded and loosen or become spongy.

Typical compaction equipment used in roadworks are summarised in Table 4.2. The range of soil which can normally be compacted economically with each type of roller is shown in Figure 4.6.

Figure 4.6: Economic use of rollers



Source: RCA (1986).

The uniformity of compaction on a site can be determined in various ways, including the use of:

- the sand replacement method to determine the in situ density of the soil
- a nuclear density gauge to determine the in situ density of the soil
- a Clegg Hammer, DCP or light weight falling deflectometer
- a pick handle and the noise emanating when the pavement is struck or bouncing a golf ball on the surface – considerable skill is required to detect adequate compaction levels
- a loaded truck (typically a water truck) to see if any wheel ruts or visible deflections form, also known as a 'proof roll'

- a steel drum roller: if there is no further ‘sinking’ of the roller into the material or the roller ‘bounces’ then this can indicate that compaction is complete for the roller used.

Most of these methods are subjective and low-cost and do not provide a direct measure of the level of compaction (except for the sand replacement method and nuclear density gauge); however, it is desirable that a quantitative, reliable and repeatable compaction measure is used to ensure good results.

Good Practice Compaction

- *Pavement material should be compacted in lifts not exceeding 250 mm loose thickness, unless it can be demonstrated that a heavier roller will be able to achieve compaction over the full depth of the layer.*
- *The minimum loose layer thickness of material to be compacted is 2½ the nominal stone size. This enables two nominal stones to be compacted in one layer (i.e. for a 40 mm nominal size stone the minimum loose layer thickness should be 100 mm).*
- *Rolling should generally commence at the outer (lower) edge of the pavement and progress towards the centreline (or lower edge, if superelevated). Rolling with passes progressing towards the lower edge can cause material to move downhill and result in loss of shape.*
- *A forward and reverse pass is made over the same section of pavement before moving to the adjacent section. It is important to check that this is done at the edges of the pavement. When changing direction, the roller should be located on the previously compacted section.*
- *Ensure that the pavement is compacted evenly across the whole width by checking that the roller passes are not all concentrated in one path at a time.*
- *Each pass of the roller should overlap the previous pass by up to 500 mm or 30% of roller width, whichever is the greater, to ensure complete coverage.*
- *Where the outside edge of the pavement is unsupported and squeezes out excessively, rolling should commence 200 to 300 mm from the edge and the 200 to 300 mm strip rolled later.*
- *Vibrating rollers should have the vibrator turned off when the machine is stopping or manoeuvring.*
- *All rollers should be slowly reversed without jolting. Sharp turns of the roller or sudden changes in direction should also be avoided. Such practices can cause surface roughness.*
- *Static drum rollers should have the drive wheels leading on the initial pass to avoid pushing material ahead of the drum.*
- *The number of passes required to achieve a particular level of compaction depends on the roller, the layer thickness and the material (including moisture content). Bowler (1999) found that on basecourse gravels, after eight passes the density gain achieved was only minor. If four to eight passes do not achieve the required result, then change is required, i.e. either layer thickness, roller type or moisture content.*
- *The best roller speed is usually at a brisk walking pace, which is 4–6 km/h.*
- *When using vibrating rollers, a sequence consisting of a non-vibrating initial pass, followed by several high amplitude passes, and finishing with low amplitude passes, has been found to achieve good compaction and surface evenness.*
- *Depending on weather conditions, light sprinkling of the surface with water may also be necessary during compaction.*
- *For wearing courses, a multi-wheeled pneumatic tyred roller is preferred to provide a tightly bound surface finish.*

Further details of soil compaction and appropriate test methods are provided in the ARRB *Road Materials Best Practice Guide* (ARRB 2020b).

4.11 Earthworks

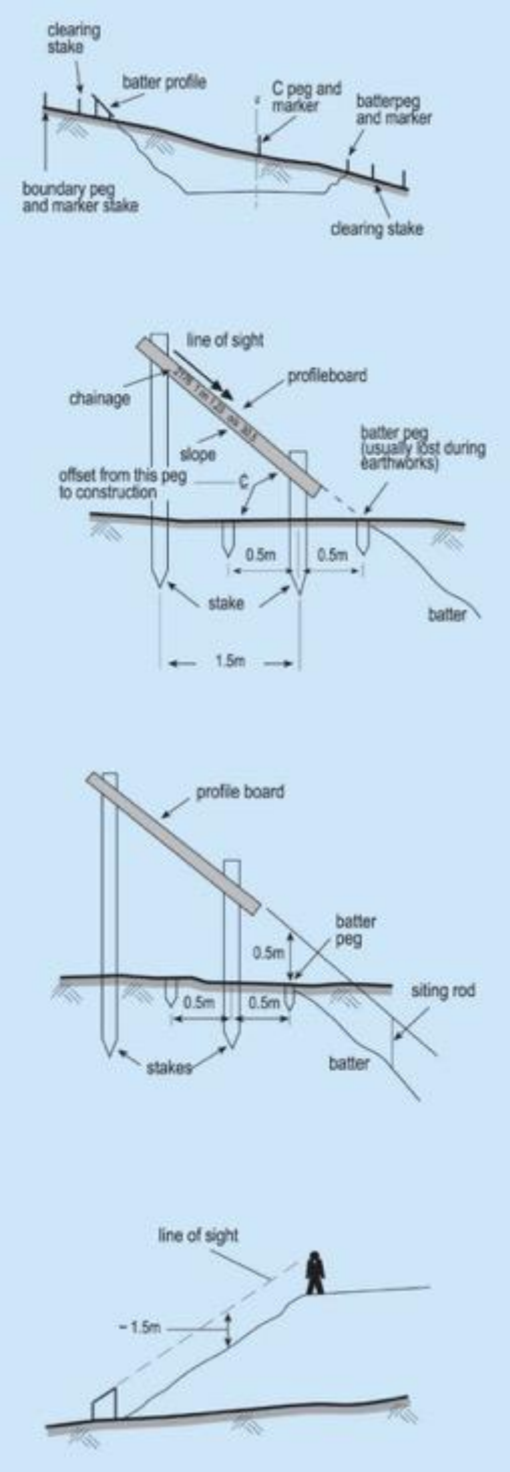
Earthworks form the foundation of unsealed roads. Table 4.3 summarises the key steps and considerations when conducting earthworks.

Table 4.3: Key steps and considerations for earthworks

Key steps	Considerations
Pre-construction	• Locate the following: – vegetation to be avoided – positioning of stockpiles – vehicle parking areas – cleaning locations. • Pedestrian movements around site. • Proximity to community areas (e.g. schools). • Access restrictions to adjoining properties.
Stripping of topsoil	• The work site should be stripped of all topsoil. • Stripped material should be stockpiled ready for use as batter or embankment re-vegetation material. Refer to Appendix A.3.1 for stockpile considerations. • Stripping should take place in all cut and fill areas between the limits of the batters as defined by the pegged batter and toe line. • The depth of stripping will depend on depth of topsoil, but generally is about 150 mm.
Selection and processing of earthwork materials (if not already detailed in design)	• Careful selection of embankment materials is important if the embankment is to retain shape and stability. • Earthwork materials such as cuttings, soil gravel pits, riverbeds and rock quarries must be inspected, tested and evaluated prior to use to determine if the material is suitable in its natural state or will need processing to meet specification requirements, such as grading or compaction. • Ensure sufficient quantities of materials are available to meet project requirements. • Detailed information on the selection, processing and delivery of earthwork materials can be found in the ARRB *Road Materials Best Practice Guide* (ARRB 2020b), Austroads *Guide to Pavement Technology Part 8: Pavement Construction* (Austroads 2019e) and *Austroads Guide to Pavement Technology Part 4L: Earthworks Materials* (Austroads 2009b).
Setting out earthworks	• Setting out of earthworks can be completed using various methods: – Manually using pegs and/or stringlines that are set with laser measurements. This method is suitable for small- to medium-sized construction projects. – Automatically using modern electronic equipment, such as Global Positioning Systems (GPS), stringline and sensor or laser levels that are installed on earth moving equipment. • Peg references should be located along the centreline of each cross section, at least 500 mm clear of the works. • The reference stake should show the chainage, offset to centreline and level, either above or below the finished centreline level. • Peg reference the batters at each cross-section. Figure 4.7 illustrates methods for setting out roadworks in cuttings or fills and one of these markers is shown in Figure 4.8.

Key steps	Considerations
Preparation of foundation	• Backfill holes or depressions that were a result of clearing. These holes should be compacted in layers no greater than 150 mm thick. • Tyne and compact foundations to a depth of 150 mm to set design standards. • Soil may need to be dried or moisture added to be at OMC for the material to be compacted. • If the soil has a high plasticity it may need to be removed and replaced with a non-plastic material or stabilised. • Horizontal benches may need to be prepared to prevent slipping of material in longitudinal cut/fill zones where slopes are steeper than a 1 in 4 grade. Refer to local standard drawings. • The surface may need to be made rough or 'ripped' to allow for wet soils to dry and for dry soils to open up so water can be absorbed easily. This is usually done with a scarifier or ripper attached to a grader. • All oversized rocks and boulders should be removed to a nominal depth of 150 mm below the subgrade level. Any depressions created should be filled with in situ material, reworked and compacted to the specified compaction. • The spreading of fill material is shown in Figure 4.9.
Embankment construction	• The surface of each layer should generally be kept parallel to the level of the design subgrade cross-section to ensure uniform thickness. • To prevent water from washing over the edges of the embankment and causing scouring in areas of high rainfall, the outer edges of the embankment should generally be kept higher than the remainder of the embankment. • Provision for drainage should be made by cutting drains at the ends of the embankment to ensure any discharge is over undisturbed ground. • Conversely, the centreline should be kept higher than the edges to allow construction equipment to work right up to the batter toe and for drainage to be facilitated along the edges. • Where scouring is not likely to be a problem, the profile of the cut should be kept as near as possible parallel to the design subgrade level. • The density of compacted layers should be tested to ensure the specification limit is achieved. Refer to ARRB *Road Materials Best Practice Guide* (ARRB 2020b) for information on density measurements and testing.
Compaction	• All embankment fill material should be placed and spread in uniform layers and compacted to the specified limit. • The subgrade layer of embankments is compacted usually to a higher standard than for the deeper part of the embankment, as it provides the foundation upon which the pavement will be placed. • Care should be taken at the end of each day's work to ensure that all embankment material has been compacted to a tight finish, to prevent the entry of moisture in case of overnight rainfall occurring.
Proof rolling	• Proof rolling, using an approved roller, should be undertaken as defined in the specification or as directed by the supervising engineer on all layers of fill within 150 mm of the finished subgrade level in cuts.
Levelling and trimming	• Levelling and trimming of earthworks are usually undertaken with a grader. • Profile and levels should be checked regularly using a straight level, camber board, laser level or GPS. • Turning of the grader should be kept at a minimum as to not disturb the earthwork surface. • The trimmed material should be removed, and the surface given a final compaction.

Figure 4.7: Diagram showing setting out roadworks in cuttings and on fills

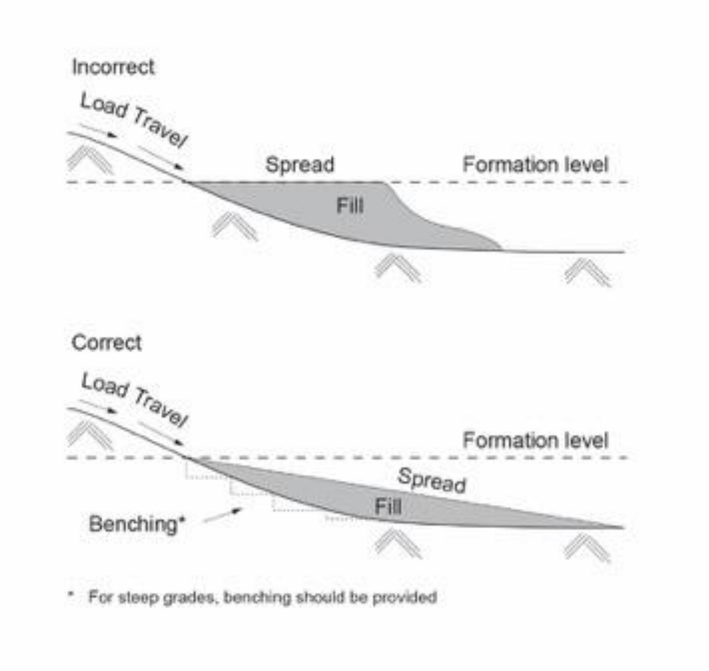


Source: ARRB (2009).

Figure 4.8: Setting out roadworks in cuttings and on fills

Source: ARRB (2009).

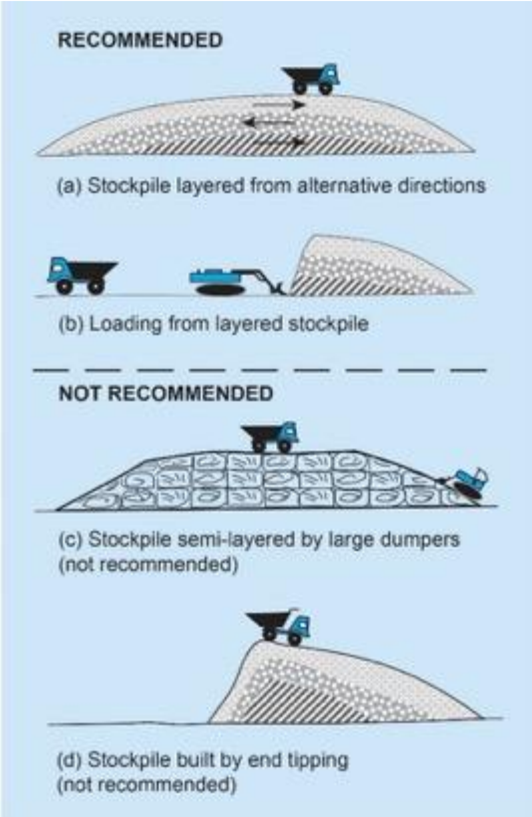
Figure 4.9: Spreading of fill material



Source: ARRB (2009).

Figure 4.10 illustrates the recommended method to stockpile material and those methods not recommended. The aim is to ensure that in the process of stockpiling and later use the materials are mixed and blended as part of the process so as to minimise later mixing on-site by plant operators.

Figure 4.10: Methods of stockpiling material



Source: Bartley and Cornwell (1993).

4.12 Pavement Construction

4.12.1 Subgrade Preparation

So as to provide a suitable foundation for the pavement, the subgrade layer of embankments is compacted usually to a higher standard than that for the deeper part of the embankment. Subgrades in cuttings are treated similarly to provide a suitable foundation for the pavement.

Subgrades should be trimmed to the same tolerances as those specified for pavements and shaped to the same final crossfall to ensure uniform pavement course thickness. Making up deficiencies in the subgrade with pavement material can be expensive.

In low-lying or swampy areas where subgrades are weak (i.e. < CBR 3%), the use of a geosynthetic reinforcement between the subgrade and subbase has proven to be a very cost-effective way to provide a firm base for the pavement (Austroads 2009c). Alternatively, the poorer material can be replaced by better quality material to a nominal thickness (typically between 150 mm and 450 mm thick) that will provide a stable platform for the overlying pavement layers.

4.12.2 Winning Pavement Materials

Pavement materials can be purchased from commercial sources or won from gravel pits, cuttings or other deposits in the field.

Obtaining suitable road pavement material for the effective construction and maintenance of the unsealed road network is an ongoing challenge for local practitioners, as the better quality materials are becoming increasingly scarce or less accessible.

Increased use of readily available local materials, often of marginal quality, will be required to enhance the efficiency and effectiveness of the construction and maintenance of unsealed roads.

More detailed information for locating, evaluating and winning pavement materials are provided in the ARRB *Road Materials Best Practice Guide* (ARRB 2020b).

Loading and hauling

Material loading and hauling is often a substantial part of constructing and maintaining unsealed roads. The haulage capacity target should be linked to the amount that can be compacted by the machinery on-site. This is to avoid excess being stockpiled on the road that can affect traffic operations and safety, or machinery waiting around while material is being delivered.

Close scrutiny of outputs achieved, and distances travelled by trucks is required to monitor the efficiency of operations. Causes of haulage delays should be determined and the delays eliminated or minimised.

Plan the route for loaded trucks to travel on the newly paved road sections rather than on the prepared subgrade to avoid damage.

In some cases, it may be necessary to water road sections to minimise dust nuisance.

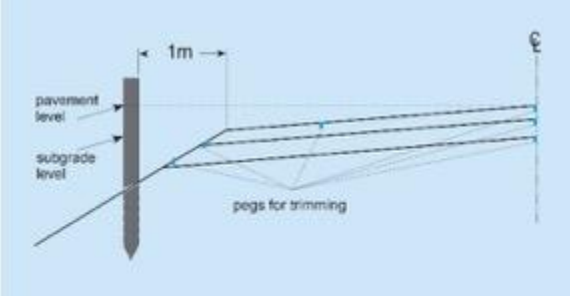
Most material loading is carried out using front-end loaders. For maximum efficiency of loading, the following points should be observed:

- Balance the capacity of trucks and loader to minimise down time.
- Keep the working floor clean, level and smooth for both loader and trucks.
- Have a supervisor position the trucks and truck drivers to be alert to the needs of the loader.
- Avoid working under an overhang.
- Work wherever possible with the wind at the back of the loader operator.
- Position the trucks so that loader turning, and travel is reduced to a minimum.
- Position the trucks alternately on each side of the loader, so that one truck can manoeuvre into position while the other is being loaded.
- Avoid sharp turns with a loaded bucket. The bucket should be carried low when travelling and raised when approaching the truck.
- When the loader is parked, the bucket should always be lowered to the ground for safety reasons.

4.12.3 Setting Out Subgrades and Pavement Layers

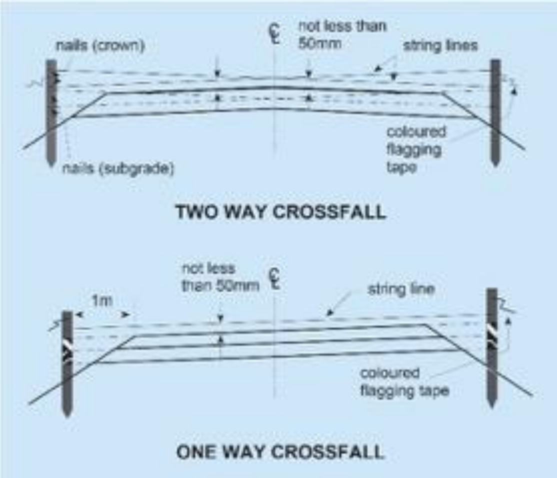
The methods of setting out and level control which are suitable for rural road construction using conventional grader construction are illustrated in Figure 4.11 and Figure 4.12. Modern techniques utilise laser and GPS technology to set levels.

Figure 4.11: Pegging of subgrade and pavement



Source: ARRB (2009).

Figure 4.12: Control of subgrade and pavement with stringlines



Source: ARRB (2009).

Temporary pegging along the centreline can assist in locating the crown in the correct position.

There is always a tendency for the finished level of pavements to vary more from the desired level between control pegs than opposite these pegs. Consequently, it is essential that checks be made between pegs. On straight grades, these checks may readily be made by sighting across boning rods. The extent this is done will depend on the level of accuracy required.

Confirmation of actual crossfalls achieved can be accurately done with a 'smart' spirit level as it provides a digital readout either in percentages or degrees (Figure 4.13).

Figure 4.13: Use of a smart level with digital readout of crossfall

Source: ARRB (2009).

4.12.4 Pavement Layer Works Construction

After the subgrade has been prepared, the pavement material can be brought in and spread (Figure 4.14). However, before spreading these materials, the subgrade should be tested and inspected for soft spots, rock bars, etc., and its levels and crossfall checked.

Figure 4.14: Tipping of pavement basecourse material

Source: ARRB (2020).

When delivering pavement material to the work site, ensure that the loaded trucks travel on the section of roadway already constructed rather than on the newly formed subgrade to avoid premature failure of the subgrade.

For staged construction, when only a thin layer is to be placed, it will be necessary to lightly tyne the previous pavement (or subgrade) layer in order to assist bonding between layers and prevent surface laminations.

When spreading the material by grader, the first stage of the operation consists of blading the tipped material into a uniform windrow parallel to the centreline of the road. If the material is not windrowed in this manner, it is much more difficult to obtain a uniform thickness of spread material. Windrowing also facilitates remixing any material segregated during handling.

The grader then spreads the material over part-width of the road by cutting into the edge of the windrow with the blade raised 50 to 60 mm. As the grader moves along the windrow, the material cut from it moves along the blade and drops under it (Figure 4.15). The flow of material along and under the blade is controlled by the pitch of the blade (top set slightly forward of vertical), the angle of the blade to the centreline of the road and the width of cut into the windrow. Care should be taken to avoid segregation in this operation. A slower grader speed and a squarer blade will assist in this regard.

Figure 4.15: Grader spreading pavement material

Source: ARRB (2020).

If two materials are required to be mixed on the road, the required quantities per 100 m can be spread to a uniform thickness, one on top of the other. The two materials are then mixed by the grader, by cutting to the full depth of material, turning it over and spreading it across the balance of the road.

The additional water required for compaction is added at this stage. A water tanker equipped with a spray bar follows the grader through and uniformly applies water to the thin layer of material spread by the grader (Figure 4.16). The grader on the return trip picks up the layer, turns it over, and deposits it in a windrow outside the edge of the blade, normally in the centre of the road.

Figure 4.16: Water tanker with spray bar

Source: ARRB (2020).

It is important that the pavement material to be compacted has been well mixed with the required moisture content before it is compacted.

The objective in adding water is to assist in the compaction process by lubricating soil particles, allowing them to rearrange into a denser state. Depending on the material it is usual to have the moisture content slightly above the OMC for the roller when compaction commences so that, as the material dries, it passes through the OMC while rolling is in progress.

When the material is thoroughly mixed, it is spread in layers of about 150–250 mm loose to the full pavement width and shape. The spreading should be carried out so that the coarse material does not segregate and 'run' along the grader blade to the edge of the pavement. Compaction equipment is introduced at this stage to firm the material only enough to carry the weight of the grader. While the material is in this state, it is trimmed to its final shape, preferably not later than the day following initial spreading.

It is much easier to trim a pavement at this stage than when it is fully compacted. The damp, lightly compacted material can be easily cut by the grader blade, and the cut material, when used to raise low spots, will bond into the material below, thus avoiding weakly bonded layers.

As the final trimming progresses, levels and crossfalls should be continually checked and the surface maintained in a damp state by sprinkling.

Only after the top layer has been shaped and trimmed is the compaction completed.

Compacting Pavement Materials

The prime objective of compacting pavement materials and subgrades is to limit and if possible, prevent loss of shape and rutting from further compaction by traffic after construction.

Use of normal road traffic is not an effective way to adequately compact pavement materials.

The desired level of compaction can either be specified through the number of passes required by a specific class of roller (subjective specification), or by specifying the level of in situ density required against a reference density determined in the laboratory (quantitative specification).

The material to be compacted should typically be at or near OMC to achieve maximum compaction. performance.

Control the moisture content as close as possible to OMC for the material and compaction equipment employed.

The moisture content of the material can be assessed using the 'hand squeeze test' as described below.

Hand Squeeze Test

- *This is a simple and practical field measurement to assess whether the moisture content is close to OMC.*
- *Take a handful of pavement material from the works site and squeeze it in the hand.*
- *If the material oozes out of the hand the moisture content is too high.*
- *If it is too dry when the hand is opened, the ball of material will not stick together.*
- *However, if the material remains in a ball, then the moisture content is close to OMC (Figure* 4.17*).*

Figure 4.17: Simple field test for moisture content

Source: ARRB (2009).

In arid areas, where water is likely to be scarce and possibly insufficient to achieve OMC, it may be better to compact the soil in a dryer state and use heavier rollers. The UK Transport Research Laboratory (TRL) (1993) has shown from research carried out in sub-Saharan Africa that adequate densities can be achieved at lower moisture contents using conventional compaction equipment.

4.13 Shoulders

Shoulder construction should involve placement of layers as an integral part of the pavement with the material carried out for the full road width. In previous editions of this guide 'boxed construction' with shoulder materials that are less permeable than the pavement wearing course were acknowledged as a possibility, although not recommended. Such practices can lead to considerable performance problems and also require additional features, such as pavement drains to facilitate drainage from the pavement. The associated risks and costs are unwarranted and such practices should be avoided.

4.14 Post-construction

Cleaning up and removal of excess material should be an integral part of each construction operation. On completion of the job, the whole site should be left in a clean and tidy state.

Some of the more important post-construction activities include:

- The site should be cleaned of all surplus material and rubbish.
- All culverts should be checked and cleaned of debris (such as gravel) and clearly marked with guideposts.
- Any existing signs should be re-erected at the correct locations and cleaned.
- Revegetate disturbed areas progressively during the construction operation.
- Windrows around posts, trees and other fixtures should be removed and the area left clean and tidy.
- Tree butts, survey stakes, and other construction waste should be picked up and disposed of at an approved location.
- All drains should be left clean and ready for use.
- Where appropriate, the zone within the construction area should be graded level with great care being taken to not disturb native vegetation.
- Remove any roadwork signs.

5 Operations and Maintenance

5.1 Road Maintenance

The exposed nature of unsealed road surfaces makes these roads susceptible to rapid deterioration as a result of heavy traffic movements, loss of wearing course material and damage from water. A major task that therefore face practitioners responsible for unsealed roads is ongoing maintenance (usually on a limited budget) to ensure the network remains safe and serviceable.

Unsealed road deterioration cannot be prevented, but good maintenance practices should aim to slow down the rate of deterioration by ensuring that the key elements listed in Figure 5.1 *are adequately managed.*

Effective maintenance practices rely on sound technical experience and good design and construction practices.

Maintenance can be defined as those activities that are intended to maintain the serviceability of a road, due to the deterioration caused by traffic and climate. However, as most unsealed roads have developed over time, from probably horse and cart tracks, with very little technical input to suit current vehicles, it is not surprising that maintaining roads to original conditions is not always possible. Instead, maintenance works programs should make use of some of the funding available for more substantial works to correct significant design and construction deficiencies that will over time reduce future maintenance demands.

Therefore, in order to address the many maintenance requirements of unsealed roads it is important to recognise that the maintenance needs are often a direct consequence of the inadequacy of the many components that make up a road. A road with poor geometric design, use of lower quality local materials, inadequate drainage and construction methods will result in much greater maintenance demands than one designed and built in accordance with good practices.

It is essential that deficiencies causing the problems are identified and remedied as resources become available so that over time greater value is obtained from the available funding. Figure 5.1 illustrates the key factors contributing to maintenance of unsealed roads.

Figure 5.1: Maintenance components

Source: ARRB (2009).

The importance of a holistic approach to maintenance can be demonstrated through the repair of a pothole.

Common practice would involve bringing in material to fill the pothole as and when it appears. A better approach would be to find out why potholes are being formed, (normally insufficient crossfall) and to correct the underlying cause so that the problem is overcome, rather than spending good money continuously filling in potholes. This approach may cost more to fix the problem in the short term, but in the longer term provides much higher savings.

The main objectives of maintaining unsealed roads are to:

- provide a good riding surface
- carry heavy traffic loads in a safe and efficient manner
- meet community expectations
- minimise safety hazards to vehicular traffic
- provide a free draining surface to the formation.

5.1.1 Types of Maintenance

Maintenance can vary from on-demand (reactive) maintenance to correct immediate defects to preventative (proactive) maintenance to reduce the occurrence or frequency of defects in future.

The approach adopted will depend on the importance of the road link in the network, available resources and knowledge of the performance of each road link.

On-demand vs Preventative Maintenance

On-demand (reactive) maintenance:

- *necessary for unforeseen events such as floods*
- *impacts on road safety or serviceability*
- *may result in higher vehicle operating costs for road users*
- *if defects remain uncorrected for any length of time, it can contribute to more severe pavement deterioration*
- *reduces the overall efficiency of maintenance resources.*

Preventive (proactive) maintenance:

- *routine or periodic maintenance*
- *predict defects in advance and aim to eliminate or reduce the occurrence or frequency of the defect*
- *primarily concerned with maintaining adequate ride quality and repairs to the drainage system*
- *involves regular grading of the pavement surface to remove corrugations, potholes, rutting and removing loose materials*
- *often associated with major reshaping of the road and resheeting operations*
- *although initial costs are higher, there is the potential longer service life of a pavement, reduced vehicle operating costs, increased safety for road users, increased community satisfaction and more efficient use of maintenance resources.*

5.1.2 Factors Influencing Maintenance Requirements

Maintenance on unsealed roads generally consists of reshaping pavement cross-sections, replacing lost wearing course material (resheeting), adding material where pavement weaknesses show up, cleaning and extending roadside drainage, and repairing surface defects.

Deterioration of Unsealed Roads

The factors that influence the deterioration of unsealed roads and subsequent maintenance requirements include:

- *traffic type and numbers, particularly heavy vehicles*
- *climatic conditions*
- *pavement materials, depth and standard of construction*
- *condition of subgrade*
- *drainage considerations*
- *community level of service expectations*
- *level of service/intervention level requirements.*

Using materials that meet the desirable specifications can significantly reduce maintenance compared with pavements constructed from materials outside of the specification limits.

5.1.3 Road Defects and Maintenance Options

Defects are usually the result of interactions between pavement materials, traffic, climatic conditions and construction methods. When assessing defects and the necessary actions to repair the road, it is the level or quality of service that is critical in determining the maintenance effort required.

Classification of defects into 'surface' and 'structural' provides a basis upon which to analyse the causes and remedies, and to distinguish between superficial and deep-seated issues.

Surface defects are confined to the upper pavement layers and primarily impact on the safety and comfort of road users.

Structural defects are caused through over-stressing the pavement and/or subgrade which causes failure of the pavement.

The recognition and identification of pavement defects is a pre-requisite to developing economical treatment solutions.

Generally, surface defects can be attributed to a variety of factors including traffic, climatic conditions, inappropriate maintenance, poor availability of suitable material, inappropriate grading, poor compaction or any combination of these factors.

Structural defects are generally characterised by large area settlements, heaving or rutting and require investigation into the causes. Causes can be a lack of drainage, poor compaction and the use of inappropriate or insufficient material to carry the axle loads.

The most common defects are presented in Table 5.1, along with possible causes and remedial options. A more detailed discussion on defects, possible causes and remedial options is also provided in Appendix D.

Table 5.1: Defects and typical maintenance treatments

Defect	Issue	Causes	Maintenance options
Surface Defects			
Loss of surface material (gravel loss)[1] 	• Aggregate replacement costs may be as high as 60% of total maintenance costs. • Environmental concerns, including dust and, loss of natural materials. • Increased roughness and poor ride quality. • Increased vehicle operating costs. • Increased safety risk.	• Vehicles, rainfall and lack of strength/cohesion in materials.	• Improved compaction (refer Section 4.10). • Appropriate wearing course material selection (refer Section 3.6.6).
Loose material[1] 	• Increased safety risk. • Damage to vehicles. • Increased vehicle operating costs. • Windrows can impede lateral drainage. • Poor ride quality due to stoniness (percentage of material larger than the recommended maximum size).	• Lack or loss of plastic fines (binder) in surface material. • Wind or water transport materials onto or, away from the roadway. • High traffic usage. • Ravelling due to excessively dry materials. • Poor compaction.	• Appropriate wearing course material selection (refer Section 3.6.6). • Improved compaction (refer Section 4.10). • Replace lost fines and compact to optimum moisture content. • Import new material and compact at optimum moisture content. • Grade loose materials to side and respread at a later date when sufficient moisture and materials are available. Limit windrow height to 75 mm. • Routine smoothing operations provide very little benefit (refer Appendix D.1).

Defect	Issue	Causes	Maintenance options
Coarse texture [1] 	• Increased roughness and poor ride quality. • Increased vehicle operating costs.	• Attrition or erosion of fines from coarse pavement materials. • Exposure of rocky subgrade. • Use of oversize basecourse materials.	• Use of a rock breaker to provide a well-graded material. • Improved drainage of road surface (refer Appendix C.7). • Addition of a wearing course layer with well-graded materials and binder (refer Section 3.6.6).
Corrugations [2] 	• Increased roughness and poor ride quality. • Increased safety risk. • Increased vehicle operating costs.	• Inadequate quality material for prevailing climatic conditions. • Loose surface material combined with dynamic traffic impacts. • Absence of tight surface combined with high proportions of coarse sandy materials. • Poor grading practices (inappropriate operating speed or damaged blades).	• Cutting to depth of corrugation and respreading materials (refer Appendix D.2). • Adequate compaction at optimum moisture content. • Appropriate wearing course material selection (refer Section 3.6.6). • Improved grading practices (refer Appendix E). • Low cost 'drags' (only a short-term solution and not very effective). • Import and blend better quality materials. • Sealing of sections where corrugations persists. • Improved road alignment.
Potholes [2] 	• Increased roughness and poor ride quality. • Increased safety risk. • Increased vehicle operating costs. • Damage to vehicles (when 250–1500 mm diameter and > 50–75 mm depth).	• Ponding of water due to inadequate crossfall (bridge approaches, alignment changes, superelevation etc). • Excessive weakening of pavement by moisture. • Inadequate compaction. • Variable quality of pavement materials.	• Increase crossfalls to 4–6% to allow adequate surface drainage (refer Appendix C.6). • Improved compaction of pavement materials (refer Section 4.10). • Appropriate surface material selection (refer Section 3.6.6). • Patching (refer Appendix D.3).

Defect	Issue	Causes	Maintenance options
Rutting [2] 	• Retain water that can cause pavement damage. • Safety hazard due to loose material between ruts and loss of steering. • Increased vehicle operating costs.	• Dry season rutting caused by non-cohesive materials displaced sideways. • Wet season rutting caused by inadequate wet strength. • Insufficient pavement depth. • Poor surface drainage. • Poor material grading. • Lack of maintenance. • Vehicle tracking. • Traffic compaction of pavement or subgrade.	• Improved material properties to increase strength (refer Section 4.12 and the ARRB *Road Materials Best Practice Guide* (ARRB 2020b)). • Improved compaction of pavement materials (refer Section 4.10). • Provide crossfall (4–6%) to minimise water penetrating pavement (refer Appendix C.6). • Improved drainage (refer Appendix C.7). • Routine blading. • Stabilisation or modification of basecourse materials (refer to ARRB *Road Materials Best Practice Guide* (ARRB 2020b)).
Slippery surface [2] 	• Increased safety risk. • Increased vehicle operating costs.	• Inadequate road crossfall to shed water off the road surface. • Excessive fines or plastic materials. • Loose stones with traffic forming deep wheel tracks.	• Place clean well-graded gravel on the surface to increase grip. • Increase crossfalls to 4–6% to allow adequate surface drainage (refer Appendix C.6). • Remove and replace affected areas with suitable wearing course material (refer Section 4.12 and the ARRB *Road Materials Best Practice Guide* (ARRB 2020b)).
Surface scour [3] 	• Increased roughness and poor ride quality. • Increased safety risk. • Possible damage to underlying pavement layers and subgrade. • Increased vehicle operating costs.	• Poor drainage allowing concentration of water flows. • Erodible surface material. • Lack of adequate compaction. • Excessive crossfalls or longitudinal grades.	• Provide adequate table drainages on high side to divert water away from the road (refer Appendix C.7). • Provide the required road crossfalls and longitudinal grades (refer Appendix C.6). • Improve the surface materials properties to better withstand scour (refer Appendix D.6). • Slow down rate of water flow. • Stabilise or modify materials (refer to ARRB *Road Materials Best Practice Guide* (ARRB 2020b)). • Sealing of road surface.

Defect	Issue	Causes	Maintenance options
			• Use of rollover drains (refer Appendix D.6).
Soft surfaces (2) 	• Increased roughness and poor ride quality. • Increased safety risk. • Increased vehicle operating costs.	• Lack of pavement compaction. • Water entering the pavement. • Materials containing a high percentage of fines or clays.	• Improved compaction (refer Section 4.10). • Installing appropriate drainage (refer Appendix C.7). • Replace with suitable quality material (refer to the ARRB *Road Materials Best Practice Guide* (ARRB 2020b)). • Material stabilisation or modification (refer to the ARRB *Road Materials Best Practice Guide* (ARRB 2020b)).
Ice formation on surface (2) 	• Reduced skid resistance leading to increased safety risks. • Increased vehicle operating costs.	• Cold temperatures.	• Application of 3–5 mm grit spread at a nominal rate of 0.2 – 0.6 kg/m^2. • Removal of trees to allow sun onto the pavement. • Application of chemicals (calcium chloride or sodium chloride (salt)) to lower freezing point of water. • Sealing localised areas using a large aggregate. • Install warning signs (refer Section 5.2.2).
Frost heave (4) 	• Increased roughness and poor ride quality. • Increased safety risk. • Increased vehicle operating costs.	• Expansion of freezing water in the pavement causes heaves.	• Use materials with low permeability. • Use of industrial waste materials or thermal insulated materials less prone to frost heave. • Improved drainage (refer Appendix C.7). • Use of reinforcing fabrics and geogrids. • Stabilisation or modification of materials (refer to ARRB *Road Materials Best Practice Guide* (ARRB 2020b)). • Reduce the silt content of wearing course material.

Defect	Issue	Causes	Maintenance options
Structural Defects			
Heaving (5) 	• Increased roughness and poor ride quality. • Increased safety risk. • Increased vehicle operating costs.	• Plastic deformation of pavement or subgrade. • Material weakened by water. • Use of inadequate quality materials. • Underlying spring wetting subgrade/pavement materials.	• Remove and replace existing material to a depth were sound/relatively firm material is encountered. • Install subsurface drains if required (refer Appendix C.7). • Provide the required pavement thickness to support traffic loads (refer Section 3.6). • Good drainage of the surface and side drains (refer Appendix C.7).
Settlement (2) 	• Increased roughness and poor ride quality. • Increased safety risk. • Reduced embankment stability.	• Consolidation of the pavement as a result of moisture being forced out of underlying material. • Inadequate embankment construction.	• Periodically build up the surface to match the design profile and longitudinal grade.
Subgrade intrusion (6) 	• Contamination of pavement materials. • Increased roughness and poor ride quality.	• Overloading of the subgrade, causing the subgrade and overlying materials to mix.	• Install geotextiles between subgrade and basecourse. • Place additional pavement material over the subgrade. • Place large coarse stones over the road foundation.

Image source:
1 Local Government and Municipal (LGAM) knowledge base (n.d.).
2 ARRB (2009).

3 Austroads (2009d).
4 Wikimedia Commons (2012).
5 Roadex Network (n.d.)
6 Mwaipungu & Allopi (2015).

5.1.4 Scheduling Maintenance Operations

The severity and frequency of defects such as corrugations, potholes, rutting and loss of crossfall, coupled with service levels and available resources, should set the maintenance requirements for the road network.

Intervention thresholds will depend on the category of the road section and available funding. Threshold levels should be determined using local criteria. These may be based on the number or severity of defects and/or safe speeds of travel over a road section.

Intervention (maintenance) threshold levels can be set to trigger when maintenance operations should be carried out. Values for these thresholds will vary between climatic regions, with traffic levels and with overall quality standards. Moreover, specific defects will trigger a particular action in each case. Further details on performance measures are provided in Section 2.4.1.

Priorities in scheduling maintenance must be determined based on local needs.

Defects that affect normal vehicle use and road safety should have priority over structural or cosmetic defects.

The volume and nature of traffic on the network should be known, to facilitate priority setting for frequency of grading, resheeting and routine minor maintenance, and for intervention levels to be determined or modified if a balanced maintenance program is to be obtained.

Despite the best planning and scheduling of maintenance, restoration works are inevitable after damage caused by flooding or accidents occur. While preventive maintenance relies on predetermined scheduling of maintenance tasks, on-demand maintenance is based on taking action after the event. Scheduling of preventive work has the advantage of reducing on-demand claims for resources and allows the network to meet serviceability needs more consistently.

A road agency should determine the relevant threshold or intervention level(s) for any defect. Intervention thresholds can be classified as:

- **Warning/urgent threshold** – the level indicating a need to monitor the condition of the road with a view to determining an appropriate remedial treatment.
- **Optimum threshold** – the level at which maintenance activities will minimise total costs.
- **Public acceptability threshold** – the minimum level that is compatible with road user demands, which may change over time, as community perceptions change.

The relative position of the last two thresholds will vary from road to road and with traffic. The unformed track in a dry arid region possibly requires no intervention levels because closure naturally occurs in adverse weather, traffic speeds are low and areas of distress are bypassed by the traffic, creating a new track.

Appropriate intervention thresholds should consider:

- *the importance of a particular road section; for example, a major road carrying large numbers of heavy, high-speed vehicles will have different intervention thresholds compared to a low-volume unformed track*
- *local conditions pertaining to the particular section of road*
- *safety risks*
- *community expectations and whole-of-life costs*
- *current practices and local resources.*

Based on surveys conducted relating to road quality, rideability (roughness) was the highest ranked factor above other related factors such as rutting, edge wear and road surface (texture). The latter factors are important to those who maintain the roads, but the survey suggests that road users are primarily interested in how comfortable the roads are to drive on (Martin, Thoresen & Ai 2016).

Various threshold values have been cited in publications. However, these should only be used as a guide to assist a road agency to develop its criteria for triggering maintenance activities.

The Queensland Department of Transport and Main Roads (TMR) *Routine Maintenance Guidelines* (TMR 2017a) considers uniform intervention levels and response times across the network as being unsustainable. From a road management perspective, the same defect is considered to represent a higher risk on high traffic road compared to a low traffic road. Therefore, higher maintenance standards are applied to road sections where traffic volumes are high.

Table 5.2 presents intervention levels, based on visual assessment. Road agencies can use this as a guide for the development of criteria based on local needs.

Table 5.2: Guide to intervention levels for unsealed roads

Defect	Level to intervene	Extent	AADT	Urgent maintenance required	Typical action
Windrows, channels, corrugations, soft slippery areas, coarse surface texture, loose material, roughness	Safe travelling speed of less than 85% of environmental speed	20% of road	Any	Safe travelling speed of less than 70% of environmental speed	Grade or resheet
Loss of pavement/running surface[1]	Depth left of 50 mm	> 20% of sub-length	Any	Depth of cover remaining of 0 mm over > 10% of sub-section length	Resheet
Wheel ruts, shoves and potholes[2]	Depth of 75 mm	Any	Any	Defect depth of 150 mm	Grade/repair
Coarse texture/ride quality[3]	IRI > 9.8 (AADT < 100) IRI > 7.6 (AADT > 100) or safe travelling speed of less than 60% of environmental speed	> 50%	See Column 2	IRI > 9.8 (AADT < 100) IRI > 7.6 (AADT > 100) or safe travelling speed of less than 50% of environmental speed	Heavy grading and reshaping

Defect	Level to intervene	Extent	AADT	Urgent maintenance required	Typical action
Insufficient crossfall	Crossfall of 4% or less	Any	Any	Crossfall of 2% or less	Grade
Excessive crossfall	Crossfall of 6% or steeper	> 20% of sub-length	Any	Crossfall of 8% or steeper	Grade
Insufficient formation height above natural surface	In rolling country – natural ground level. In flat terrain – 100 mm. In flood plain areas – 0 mm.	> 20% of sub-length	Any	Water ponds, and formation is lower than natural ground (level measured at the shoulder point)	Heavy grade and import fill
Insufficient formation width	Width of 8 m	> 20% of sub-length	Any	Width of 6.5 m or 8 m when visibility is restricted	Formation widening or realignment

Note: environmental speed for a road is based on elements of the road and traffic environment that collectively influence a road user's determination of the appropriate travel speed.

Source: Adapted from Department of Transport, Queensland (1992) with revisions and additional criteria based on the following:

1. *TRL (2003).*
2. *VicRoads (2014).*
3. *Austroads (2020a).*

Inspection frequencies and response times

A road agency has a duty to inspect, maintain and repair public roads for which it is responsible. This requires that inspection and response times be set for the various road classes based on available resources, budget cycles and at times weather events.

An example of inspection frequencies and response time codes for unsealed roads when the intervention levels are exceeded is given in Table 5.3. In many cases there may be more work generated by the inspections and response times set. In such cases a maintenance prioritisation procedure should be established to ensure that high risk sites are dealt with first.

Table 5.3: Inspection and response frequencies codes

Road type	Inspection frequency	Response time(1)
Main (Class 4A)	Three months	Within one week to one month of notification or inspection
Minor (Class 4B)	Twice per year	Within one week to three months of notification or inspection
Access (Class 4C)	Once per year	Within one month to six months of notification or inspection
Track (Class 4D)	Two years	Within twelve months of notification or inspection

1. *Short response times recommended where the hazard poses an immediate safety risk or is likely to impact road operation or require road closure. The higher response time relates to hazards which pose a lower risk.*

Source: Department of Environment, Land, Water and Planning (2019) with revisions and additional criteria based on VicRoads (2014) and typical Local Government practices.

Typical intervention policy

A maintenance intervention policy is necessary to achieve the objectives set out in Section 5.1.4, and also to form a basis for preparing a schedule of works in a prescriptive tender and defining a level of service in a performance tender for maintaining unsealed roads.

Ride quality or rideability is considered to be one of the more important requirements for road users (Martin et al. 2016). Details on how to measure ride quality are provided in Section 2.4.1. Alternatively, a subjective assessment can be made based on travel speed values able to be comfortably achieved on a given road section.

The frequency of restoring ride quality on any particular road will be influenced by the road agency's policy for:

- available funding
- acceptable ride quality
- importance of the road to the local economy (its function or classification).

5.1.5 Appropriate Maintenance Plant and Equipment

The number and type of maintenance plant and equipment will depend on the maintenance organisation and whether work is partly or wholly contracted, the length of road to be maintained, and the desired serviceability of the network.

The most important aspect in the selection of maintenance plant and equipment is choosing what is best for local conditions.

For example, multi-wheeled rollers are appropriate for finishing surfaces containing well-graded material with high fines content yet are inappropriate for large-aggregate material low in fines. A smooth steel drum static or vibrating roller, depending on the task being performed, may be more appropriate in these circumstances.

Typically, routine (patrol) maintenance will require light grader(s), rubber-tyred roller(s), water cart(s), tractor/front-end loader(s), and light patrol truck(s). Routine maintenance may be enhanced by using grader blade systems incorporating adaptors which scarify and break surface material, making grading operations easier and allowing maintenance grading to continue in periods of relatively dry weather. The system can also give longer operational life to grader blades and better riding surfaces with minimal disturbance of the gravel pavement.

Periodic maintenance can be either undertaken using contract or day labour or a combination of both, depending on the extent of work required, haulage distances, and availability of plant.

Table 5.4 sets out, as a guide, a summary of maintenance tasks and plant required for an operation to be successfully completed.

Table 5.4: Summary of maintenance tasks and recommended equipment

Activity/task	Labour-based methods	Plant methods
Levelling and smoothing	–	Motor grader, towed planer, pavement drag
Load, haul and spread gravel up to 100 m, 100–500 m	–	Small tip truck and front-end loader Large tip truck loaded with trailer, front-end loader, scraper or bottom dump semi-trailer
Excavate soil or rock	–	Tracked or wheeled excavator with rock breaker, dozer, ripper, scraper, excavator
Compact soil and gravel	Land rammer, plate vibrator	Powered or towed roller
Blend and mix aggregate or stabilising material in situ	–	Motor grader, rotary hoe
Blend and mix aggregate away from site	–	Pugmill, batch plant, front-end loader
Clean drains	–	Tracked hydraulic excavator, motor grader, specialised ditching plant
Trim vegetation	Slashers, knapsack, sprayers, line trimmer	Hydraulic power saw, mechanical sprayer, shaft or hydraulic powered circular/rotary mower, boom-mounted mulcher

Source: Adapted from Ferry (1986).

Typically, a team comprising one grader (125+ hp), one roller, one water cart (with close water supply), three 10 m^3 trucks and one 1.25 m^3 loader can process in excess of 500 m^3 per day on a 5 km lead.

A road requiring 100 mm compacted thickness of material 7.5 m wide will require approximately 950 m^3 loose material delivered to the site for each kilometre constructed. The actual amount will depend upon 'bulking' of the material and consequent reduction in volume as a result of compactive effort achieved.

5.1.6 Unsealed Road Maintenance Activities

There are several key maintenance activities that are typically undertaken on unsealed roads. These activities are briefly discussed in the paragraphs below.

Shaping the formation

Loss of shape is often caused by improper grading practices, loss of material, settlement, poor construction, or inadequate drainage.

Light grading will provide a smooth surface, however heavy grading is necessary to reshape and restore the surface to its correct profile.

The frequency with which either light or heavy grading is required will depend on traffic, materials, the skill of the operator, and the available resources of the road agency.

Moisture conditions greatly influence the effectiveness of grading operations, with best results obtained when the surface is reasonably firm and when there is enough moisture retained to facilitate cutting, moving and compacting the materials. Maintenance grading should, when carried out on a dry pavement, have water added to it. It is however recognised that this may not always be possible.

Retaining superelevation on curves is as important as retaining the crown on straight road sections as it allows surface water to drain from the pavement and improves driver comfort and safety.

Figure 5.2 shows a typical situation found on many curves on unsealed roads. Most drivers drive on the inside of the curve to maintain operating speeds and in doing so the inside of the curve has double the wear, which causes lowering of the inside edge below the table drain, with the superelevation only provided on the inside of the curve. This leads to drainage problems and poor safety, weakening of the pavement and potholes where there is not adequate crossfall provided on the higher side.

Figure 5.2: Result of poor maintenance practices on curves

Source: ARRB (2009).

Grading operations

Grading a road, on an 'as required' basis, will maintain ride quality and minimise surface defects. This, however, must be balanced with available resources and maintenance levels adopted.

Unsealed roads require regular grader maintenance of the running surface and drainage systems because of the effects of passing traffic and climate on an exposed aggregate surface. Grading, irrespective of the task being undertaken, is the single most important function in maintaining an unsealed road network. It achieves the standard set by the maintenance policy.

The three most commonly use grading activities are:

- Light grading (patrol grading) – refer to Appendix E.1 for detailed guidance.
- Medium grading – refer to Appendix E.2 for detailed guidance.
- Heavy grading – refer to Appendix E.3 for detailed guidance.

Light or routine maintenance grading consists of light grading of the running surface to keep the road surface in a good riding condition (Figure 5.3).

Figure 5.3: Light grading activities

Source: ARRB (2020).

It is preferably carried out when the aggregate and fines are moist. Smoothing can be conducted in the dry weather, to redistribute the loose gravel across the road, but the blade should not cut deep enough to disturb the hard crust. This operation may also include spot gravelling or patching to fill potholes or surface depressions. In such cases, patching materials should preferably be the same as the surface gravel, moistened and properly compacted. Part of this operation should include the cleaning out of the table drains and any cut-off or mitre drains to retain the required drainage system. This operation may not be necessary on every light grade but 'as and when' required. Maintenance of table drains and cut-off drains should not be ignored.

Medium and heavy grading normally forms part of periodic maintenance to restore the shape of the road and is sometimes combined with resheeting operations. Reshaping of the road involves more than just smoothing the surface. After periods of heavy traffic and wet weather, traffic can scatter the aggregate, flatten the crown, form potholes and ruts in the road. These conditions cannot be corrected by just smoothing the surface (light grading) and will require reshaping the gravel base using medium grading.

Reshaping often involves scarifying the road surface and remixing the aggregate base to get a proper blend of fines and different sizes of aggregate and blading this blended material into a properly crowned road surface with the required moisture content and compaction.

Wet vs Dry Blading

Wet blading is when water is added to the surface material and compacted. Dry blading is undertaken without any form of additional moisture applied. In areas where there is no water available or in extremely low rainfall climates this method may have to apply.

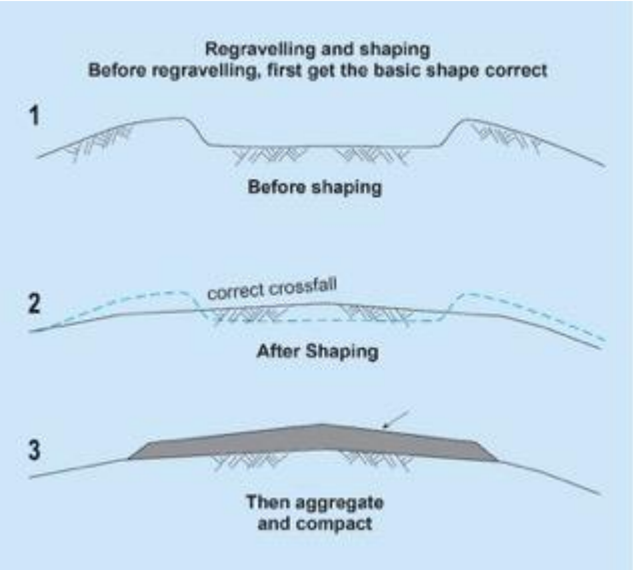
Experience has shown that too often maintenance is undertaken without the use of a water cart and roller and, while obtaining short-term cost savings, this practice is not overall the most cost-effective when water is readily available.

Resheeting

As part of periodic maintenance activities gravel roads will require the replacement of lost pavement materials (known as resheeting or regravelling (Figure 5.4). Resheeting is necessary due to loss of pavement material resulting from:

- degradation of stone
- climatic conditions, i.e. wind and rain
- scouring and erosion
- traffic abrasion
- maintenance practices
- inappropriate pavement material selection.

Figure 5.4: Shaping and resheeting



Source: ARRB (2009).

Typically, about 100–150 mm is added in overall thickness over the entire length or substantial parts of a road (Figure 5.5). It is an expensive maintenance procedure and it is critical that the material properties are suitable, and the appropriate thickness is applied (Section 3.6.7) to take the estimated traffic loading. Resheeting should take place well before the subgrade is exposed in order to avoid loss of pavement strength and deformation of the road formation occurs.

Figure 5.5: Resheeting operations

Source: ARRB (2009).

If the loss of material is excessive, then an analysis of the material used for the pavement should be undertaken. Materials meeting the requirements set out in the ARRB *Road Materials Best Practice Guide* (ARRB 2020b) should be used for resurfacing. If these requirements cannot be achieved using local materials, then modification of the materials may be necessary.

The rate of gravel loss is not constant over the life of the pavement. The rates of gravel loss are approximately constant for the first two to three years only following resurfacing and vary with vehicle speed, residual pavement thickness, climatic conditions and grading practices.

Also, geometric conditions such as tight curves or steep grades may result in more rapid gravel loss compared to other parts of the road and therefore a detailed knowledge of how the roadway wears is required in resheeting operations.

Gravel loss prediction models for Australian conditions are provided in Section 2.5.

As the thickness of the wearing and basecourse reduces, other developments such as the formation of ruts can also affect the loss of pavement material. Although gravel loss can be seen as a loss of the upper surfacing layer, any inherent weaknesses or strengths due to varying depth of the wearing and basecourse can also influence the resistance of the road to deformation (Jones 1984).

Ways to estimate gravel loss can be done by:

- taking auger levels of gravel depth over time
- taking spot levels on various representative sections of roads to measure annual wear loss
- applying a formula, calibrated to local conditions to estimate gravel loss (Section 2.5)
- using GPR to measure existing gravel depth.

Drainage repairs

Water penetrating the pavement weakens the structure, making the pavement more susceptible to damage by traffic. The objective of the drainage system is to prevent the pavement layers from becoming saturated in the zone between the surface and a level approximately one metre below the surface.

Maintaining a good drainage system that protects the pavement surface from rainfall, ground water and high ground is critical to minimise pavement deterioration.

As mentioned previously in Section 5.1.3, a lack of adequate crossfall (and associated ponding of water) can lead to potholes and rutting on the roadway (Figure 5.6). Maintaining adequate crossfall is therefore one of the principal maintenance activities associated with unsealed roads. The crossfall of unsealed roads should preferably be between 4% and 6% to reduce the adverse impact of water falling on the roadway. While this practice is most desirable, it is recognised that in some cases, due to a lack of resources, this may not always be possible. When crossfall requires attention, this is best achieved by scarifying the surface, adding material, mixing and shaping the surface to form a crown and finally compacting at the optimum moisture content for the material.

The road should also be raised above the level of the local watertable to prevent soaking by ground water (i.e. typically > 500 mm where possible) and provision should be made where on the high side of batters to place cut-off mounds to divert the water away from the road.

Figure 5.6: Potholes and rutting due to low crossfalls

Source: ARRB (2009).

Regular grading to eliminate surface defects, maintain crossfalls, and restore drainage profiles should reduce the effects of surface water. If table drains are not regularly maintained as part of routine maintenance activities, they will over time become filled with debris and vegetation (which may even include small trees). This will make it more difficult to restore the drain at a later stage (Figure 5.7).

Figure 5.7: Poorly maintained table drain

Source: ARRB (2009).

The effects of sub-surface water can be overcome by improving the drainage through installation of sub-surface drains where possible, and clearing table drains of debris.

Drains formed in the shape of a ‘V’ or wide flat-bottomed drains can be mechanically cleared and maintained with a grader or slashed if surfaced with grass (Figure 5.8). While these works address drainage requirements, consideration should also be given to any safety hazards that may be created by having a deep side drain close to the traffic lane. In such cases, guideposts (particularly on curves) should be provided to better delineate the road edge.

Table drains which are graded to a V shape can produce excessive siltation and can degrade the water quality downstream. It is much better to provide a wide grassed V drain where possible so that the drain can be maintained by mowing.

Figure 5.8: Well maintained drains but needing guide posts to delineate roadway edge

Source: ARRB (2009).

Other drain profiles, such as a semi-circular profile, can be formed and maintained using a hydraulically operated and driven circular cutting edge attachment mounted on maintenance or construction equipment, providing there are not large loose stones in the table drains. Drains inaccessible to mechanical equipment require manual maintenance with hand tools and approved non-sterilant herbicides.

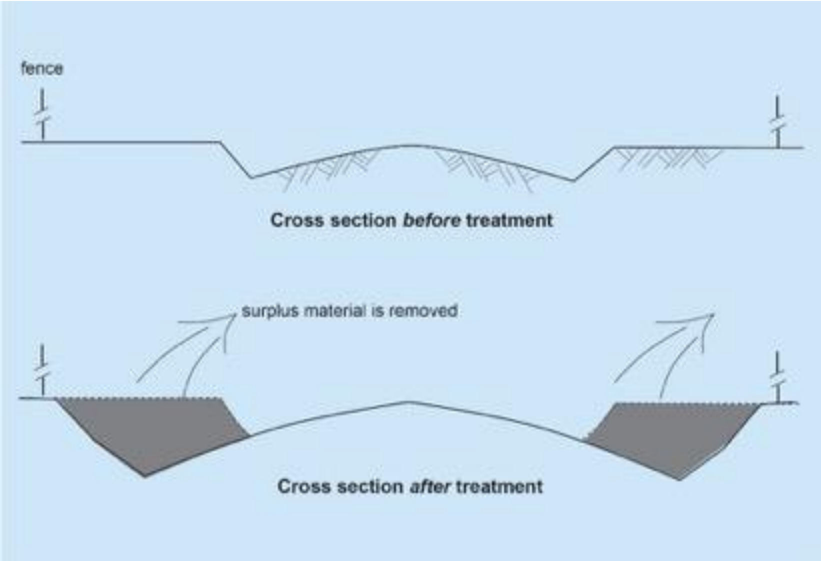
In low lying areas, where there is limited fall for the discharge of water from table drains, excess water can remain on the pavement edge weakening the pavement (refer Figure 5.9).

Figure 5.9: Excess water on the roadway

Source: ARRB (2009).

In such cases, consideration should be given to either raising the road formation or ‘flanking’ activities (as shown in Figure 5.10) to reduce the amount of water on the road.

Figure 5.10: Flanking activity



Source: Ferry and Major (1997).

At culverts, pipes or pits, the main maintenance task is the removal of any silt and debris which would significantly impede the flow of water, particularly after a heavy storm (Figure 5.11). Culverts and pipes should be checked on a routine basis for structural defects and subsidence, which should be noted for further investigation (refer to the ARRB *Bridge Management Best Practice Guide* (ARRB 2020a) for further guidance).

Figure 5.11: Debris collected at culvert after heavy rainfall

Source: ARRB (2009).

Floodways

The maintenance of floodways and fords, as outlined by Austroads (2009a), can be divided into three types:

- **During dry weather –** the pavement, batters and supplementary culverts require routine maintenance similar to that of a normal road. Warning signs and depth indicators need special attention, the former because they warn of a dip in the pavement during dry weather as well as indicating the possible presence of water over the pavement in wet weather, and the latter because they must be easily read at a distance when there is water over the floodway.
- **During flooding –** regular inspection is desirable to ensure that the floodway is safe for traffic, having regard to the fact that deep holes and washed out batters may not be apparent to all drivers.
- **After flooding** – high priority must be given to the repair of any physical damage so that the floodway is safe for traffic and is not further damaged by subsequent floods. Debris that may collect on the floodway should be removed and holes under the water filled with rock pending permanent repair when the water has receded. Also, debris should be cleared from the upstream channels leading to the floodway and culvert. Markers and signs should receive attention to ensure they are sound. It is also important to ensure the designed crossfall on the pavement through the floodway is reinstated, where necessary.

Many dry watercourses contain loose debris, sand and gravel which may be deposited on the floodway or causeway in sufficient thickness to prevent the passage of vehicles or at least create hazardous conditions for them (Figure 5.12). The removal of this loose material is generally the most urgent restoration work after floods. In some cases, it may also be desirable to raise the pavement level of the floodway to inhibit the further deposition of sand when the watercourse next carries water, provided this does not cause damage upstream by afflux or lead to downstream scour due to increased velocity.

Figure 5.12: Causeway blocked with flood debris

Source: ARRB (2009).

Cattle grids

Maintenance may be required to cattle grids, which are sometimes provided on unsealed roads where the property boundaries are not fenced. This usually consists of the removal of dirt and debris from beneath the structure and repair or rewelding of loose grid bars. Before undertaking maintenance, a check should be made as to whether or not the landholder is responsible for such work. Poorly maintained cattle grids, (Figure 5.13) can also be a safety hazard. It is desirable to seal the approaches to cattle grids to eliminate maintenance problems associated with potholes on approaches, gravel being deposited into the grid and damage to the cattle grid itself.

Figure 5.13: Poorly maintained cattle grid

Source: ARRB (2009).

Road closures

Significant damage can be caused to roads if they are opened prematurely to traffic after periods of heavy rainfall or flooding. On the other hand, if the period of road closure is excessively conservative then the connectivity of the road network is compromised, communities are isolated, and social and economic interactions are inhibited. Optimising the timing of the opening of a road to traffic without causing undue pavement damage is an issue of critical importance to network managers, transport operators and the communities operating in the northern areas of Australia (the 'top end') where inundation of roads is a yearly occurrence.

Unsealed roads may therefore have weight limits placed on them or may need to be temporarily closed to traffic when they are unsafe for use, or may experience extensive damage by the passage of vehicles due to excessive rainfall (Figure 5.14).

Figure 5.14: Damage due to vehicle traffic when pavement is too wet

Source: ARRB (2009).

When closure of the road is the only option available, all legal requirements, as applicable in each state or territory, must be observed. In most cases where the action of a driver in illegally entering a closed section of road results in damage to the road, the cost of repairing the damage may be recovered from the owner of the vehicle or alternatively the driver. Obtaining evidence to prosecute offenders successfully can, however, be difficult unless witnesses to the breach of a legal road closure are available. Small cameras with motion detectors taking photographs every 2 to 3 seconds have been used in New South Wales to successfully prosecute offenders.

If it is proposed to close a road for any purpose then appropriate advance warning signs, similar to those shown in Figure 5.15, are necessary to warn motorists well in advance of the closure. This will enable them to select an alternative route, if available. Similarly, appropriate signs and barriers are necessary at the section of road to be closed to prevent the passage of vehicles (refer Figure 5.16).

Figure 5.15: Typical advance warning signs

Source: ARRB (2009).

Figure 5.16: Typical barriers for road closure

Source: ARRB (2009).

The use of facilities such as radio and telephone to advise about road conditions are important to the travelling public when flooding or excessive rainfall results in road closures.

5.1.7 Environmentally Sensitive Maintenance

Care should be taken to ensure maintenance operations do not degrade the conservation value of the roadside and the surrounding environment. Environmental requirements, included in roadside management plans, should be adhered to during road maintenance activities. Some key environmental considerations for maintenance activities are summarised in Table 5.5. The list below is by no means exhaustive and practitioners should also refer to local legislative and organisational requirements.

Table 5.5: Environmental considerations for maintenance

Environmental maintenance	Considerations
Routine maintenance (refer Appendix A.4.1)	• Important environmental aspects of routine maintenance include grading, maintaining drainage structures, batter slope maintenance and vegetation management. • Roadside vegetation should be pruned in a manner that minimises the impact on the biodiversity of the area.
Protecting stream water quality (refer Appendix A.4.2)	• Avoid directing table drains and cut-off drains discharging directly into waterways and clean only when necessary as the rough texture will slow water flow and trap sediment. • Shape table drains to a shallow, flat-based profile, minimise the area of disturbance and keep well clear of roadside vegetation when grading. • A well compacted road surface with a crossfall of 4–6% will facilitate drainage.
Assessing roads for sediment risk (refer Appendix A.2)	• Identify stream crossings along unsealed roads, assess each site and prioritise corrective actions. • Follow-up actions include maintaining the road surface, slowing drainage water flows, treating run-off prior to discharge and improving overall drain maintenance practice.
Periodic maintenance (refer Appendix A.4.3)	• Perform grading operations regularly to maintain a surface that will minimise erosion and avoid widening the pavement during grading. • Resheeting unsealed roads has similar potential environmental impacts as construction, and an appropriate environmental approach should therefore be adopted.
Dust control (refer Appendix A.4.4)	• Chemical dust suppressants are often a shorter-term solution to the loss of fine particles from the road surface. • Be aware of potential water quality impacts associated with some dust suppressants.

5.1.8 Maintenance Contracts and Specifications

Funds maintaining unsealed roads are normally limited, and the lengths to be maintained are often considerable. The objectives of maintenance contracts are to:

- maintain riding surfaces to provide a degree of safe and convenient travel commensurate with the volume and type of traffic on the road
- preserve the pavement by careful use of often marginal local gravels
- work within overall budgets in the most cost-effective way.

Maintenance contracts and specifications should there allow for timely maintenance to occur and the flexibility to adjust to unusual weather, natural disasters and other abnormal events.

Timely maintenance

Cost-effective maintenance should be carried out at appropriate times, taking advantage of increased moisture as the weather changes at the close of a dry season, and of suitable fine weather just after a prolonged wet spell. During prolonged dry periods, undue disturbance of the pavement should be avoided to minimise gravel loss through dust and whip-off.

At the start of the wet season, an appropriate road crossfall and crown is very important to enable water to drain quickly from the pavement and reduce damage caused by trafficking during rain.

Potholes can occur on flat surfaces after rain and ponded water on a pavement can cause these potholes to become deeper with the passage of heavy vehicles. Carting gravel over weak roads in adverse weather may damage a longer length of road than the section being improved by the resheeting and carting may have to be prohibited during certain months of the year and at unexpectedly wet times as stipulated in the contract.

Flexibility

Unsealed roads are more subject to sudden changes in surface condition compared to sealed roads. Any program of works should have the flexibility to adjust to unusual weather, natural disasters and other abnormal events. Traditionally, direct labour intervention by a portion of a larger workforce has been responsive to emergencies and is capable of choosing appropriate times for various works. Contracted works should be similarly responsive and flexible.

It is not feasible to provide a single generic specification to adequately cover the wide variation in soils, gravels, climates, locality of towns, traffic types, available funds and methods employed which apply to the vast lengths of unsealed roads in Australia. However, two generic specifications are provided in Appendix F of this Guide to assist road agencies and practitioners with preparing maintenance contracts.

The first generic specification provided is a '**prescriptive**' specification based on a schedule of rates contract for maintenance works, where the works are prescribed and carried out to a set program in a specified manner.

The second generic specification is a '**performance**' specification based on a lump sum contract. The end result is specified and generally includes ride quality and the preservation the assets to a given level of performance for the duration of the contract.

Generic specifications are provided as a guide only and ARRB takes no responsibility for their use. Users of these generic specifications should apply their own skill, experience and judgement.

Default values are shown in italics, and while these are often considered to be appropriate, they should be changed where other values are known from experience, or more recent research, to be better applicable to a specific area.

Earth formation roads and tracks are not included in the generic specifications.

AUS-Spec also developed technical specifications for the construction and maintenance of unsealed roads which is available to purchase through NATSPEC at www.natspec.com.au.

Prescriptive specifications

Prescriptive specifications can be used for a schedule of rates contract for:

- routine maintenance and light formation grading
- periodic medium and heavy formation grading and resheeting.

In this type of contract, the road agency predetermines the program, selects materials, approves work quality and provides customary service together with preserving network integrity. Contractor input to programming is limited.

There are three schedules, so that some of the works (e.g. patrol maintenance) could be done by direct labour and the others by contract maintenance. The three schedules are for:

- patrol maintenance
- light formation grading and periodic grading
- resheeting.

During the course of a long-term prescriptive contract, the contractor often quickly gains knowledge of the network, and this knowledge should be used to assist in better selection of interventions for maintenance, and also to make suggestions for capital improvements where maintenance is considered to be excessively frequent or costly.

An advantage of prescriptive contracts is that total expenditure can be controlled by deleting or postponing works, although the level of service to users and degree of asset preservation may not be as high as desired.

Performance specifications

In a performance contract, the maintenance program is not predetermined, but rather responds to intervention levels (triggers) and local conditions, with the contractor having a major ongoing role in programming maintenance works.

The level of service is linked more closely to road user requirements which are to be fulfilled for the duration of the contract. At the same time, the asset value of the road network, generally measured by the overall thickness of the gravel course and overall shape quality, is not allowed to fall below a specified limit.

At the conclusion of the contract, the road network must be handed back to the road agency in a condition at least equal to the ‘as received’ condition. While fair wear and tear is the contractor’s responsibility, the cost of abnormal events (e.g. bushfires, floods) is borne by the road agency.

In a performance contract, timely and successful interventions may lead to:

- less frequent intervention treatments
- less costly treatments
- less patrol maintenance
- better earnings for the contractor and benefits to the road agency.

Experiences with the long-term performance-based network contracts have been mixed, with efficiency gains and indicative cost savings of up to 20% (Robinson 2008). These contracts have not been without their challenges, and some road agencies may feel that they were becoming too detached from operations and are losing control of the strategic management of their networks to an unacceptable extent.

A number of resulting developments have seen the general nature of these contracts begin to change from an almost completely outsourced mode of delivery, driven by adherence to a suite of prescribed outcomes monitored by adherence to key performance indicators, to a much more sustainable and transparent model where the road agency and private sector personnel work together in an integrated and collaborative alliance based approach.

Advantages and Disadvantages of Performance Contracts

Typical advantages include:

- *Ride quality commensurate with the volume and type of traffic is maintained more consistently across the entire road network.*
- *Asset preservation of pavement thickness and shape of the entire road network is consciously maintained.*
- *The contractor has an incentive to make timely and successful interventions which benefit the contractor, road agency and the road user.*

Typical disadvantages include:

- *The intervention criteria specified may not necessarily be the most economic treatment, because the root cause is a geometric or operating deficiency.*
- *Road agency personnel may become too detached from the operations and strategic management of the network.*
- *Road agencies could lose their local knowledge and experience of the road network.*
- *Unsealed road conditions do not remain constant.*

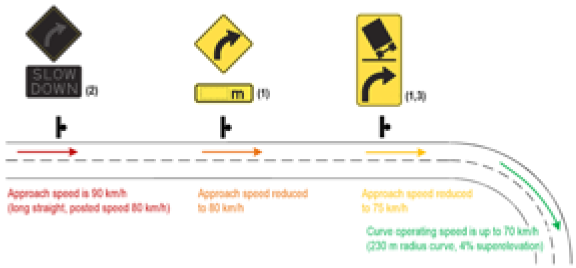
5.2 Safety and Maintenance Works

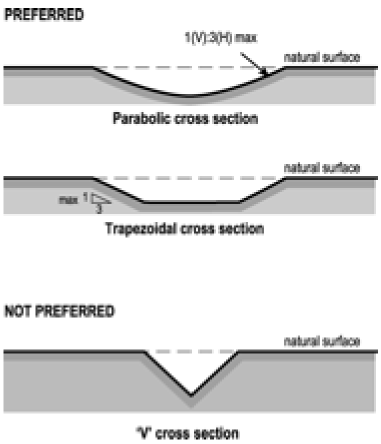
It is important to take into consideration the ongoing wear and tear on roads and changing surface conditions as these can be contributing factors leading to the occurrence of crashes. This section provides guidance on practical and low-cost techniques for improving road safety and reducing potential litigation. In the management of its road network a prudent road agency will be able to demonstrate a duty of care, and that it has acted reasonably in addressing road safety issues.

5.2.1 Low Cost Safety Improvement Measures

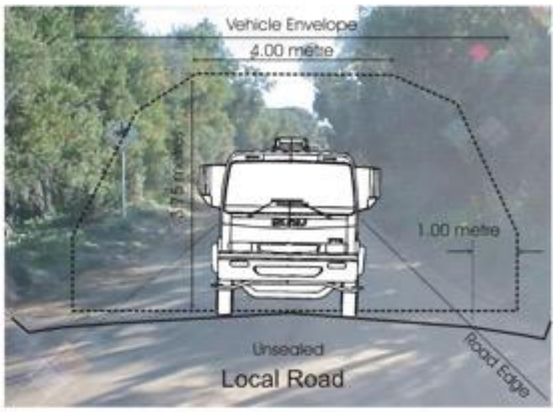
Table 5.6 illustrates some low-cost measures that can be considered to address safety concerns for the hazardous locations identified in Table 3.3. These are generally aimed at assisting motorists to drive to the conditions. These measures are not exhaustive and may not always be appropriate for all given situations. Sound engineering judgement needs to be employed when considering measures to address hazards on the road network.

Table 5.6: Low cost safety improvement measures

Issues	Possible countermeasures	Desired outcomes – examples
Tight horizontal curves A large majority of crashes occur on curves because of one or more of the following: • most are well below the minimum radius for the prevailing operating speed • inappropriate superelevation • loose surface materials • inadequate sight distance. On rural low volume roads drivers often cut into the inside of a curve to help increase the radius of the curve and thereby maintain the desired speed. In such cases providing adequate horizontal sight distance is critical.	Place curve warning signs on all approaches to high risk sites. A list of standard signs is provided in Appendix B. Avoid the use of speed advisory signs as the surface conditions cannot always be guaranteed. Where a reduction in operating speed is required to safely navigate the curve (i.e. the curve is substandard (Appendix C.3.6) vehicle activated warning signs and if appropriate heavy vehicle rollover signage should also be provided. including vehicle activated signs. Provide guide posts and/or roadside vegetation around the outside of a curve to assist the driver to gauge the sharpness of the curve. Provide the required horizontal sight distance by removing or slashing roadside vegetation within prescribed limits. In some cases, batters may need to be cut back to provide sight lines.	 **Place signs and guide posts to guide motorist around a curve**  **Vehicle activated curve warning and slow down signs**  **Improved horizontal sight distance**

Issues	Possible countermeasures	Desired outcomes – examples
Sharp crests/sag curves Many unsealed roads do not have the required vertical sight distance over a crest or sag to enable a driver to see and stop should there be a hazardous object on the road. Crests on single-lane two-way roads where drivers have little warning of an oncoming vehicle are particularly critical locations.	Place standard crest road signs at critical locations where lowering the grade to provide the required sight distance are cost prohibitive. Seal the road surface over the high-risk crest only and place double barrier lines to ensure drivers remain on the left side of the road. For single-lane two-way roads widen the roadway over the crest to provide a driver with greater manoeuvring space in case of encountering an oncoming vehicle.	 **Install a crest sign on approaches to sharp vertical curves**  **Widen road over a crest curve when sight distance is limited**
Roadside hazards Roadside hazards on unsealed roads often include table drains and roadside vegetation consisting of large trees with diameters > 100 mm. Light poles or other utilities can pose a hazard if they are placed too close to the traffic lane. The aim is to provide a forgiving roadside environment that can reduce crashes, or their severity, particularly at potentially high-risk locations (such as on the outside of curves).	Check the clear zone clearance requirements for the road given the traffic volumes and operating speed. Appendix C.6. In some cases, removal of environmentally significant vegetation may not be possible and other measures may need to be considered, such as the provision of a safety barrier. Drainage ditches should aim to have flatter slopes and rounded inverts to reduce the chance of rollover if a vehicle traverses them. Provide adequate guide posts where there are deep table drains close to the roadway to provide better delineation of the roadside edge.	 **Provide a desired clear zone where possible**  **Side/table drain options**

Issues	Possible countermeasures	Desired outcomes – examples
Sudden surprises Avoid sudden surprises or inconsistencies along a road that may catch drivers off-guard. These include features such as sudden dips, causeways, and a sharp curve at the bottom of a down grade or at the end of a long straight. Changes to road surface conditions or operations such as water on the road, loose gravel after grading or gravel testing trials sites etc. need to be known to a driver if it may affect driver behaviour or route choice.	Measures that can be readily applied include installing appropriate warning signs to alert drivers to changing road conditions (including vehicle activated signs). Where a road suddenly narrows, these locations need to be clearly delineated to ensure drivers adjust to the road situation in time. Often the placement of road advisory signs may be necessary to alert drivers to changing conditions.	 **Sign advises drivers of a dip in the road**  **Drivers may be better prepared for changing conditions**
Intersections Intersections can be high risk locations because drivers may have a low expectation of meeting other vehicles and so tend not to slow down or look carefully for other vehicles when approaching an intersection. There are many intersections on unsealed roads that do not have the required sight distances and road signs to indicate an approaching intersection. These intersections need to be carefully reviewed and critical locations given preference to apply the appropriate improvement measures.	Ensure that the required sight distances and necessary road signs (including vehicle activated signs) are provided on approaches including advance warning if there is inadequate sight distance. In some cases, it is desirable to eliminate a crossroad by providing two staggered T-intersections to encourage drivers to slow down when approaching the intersection. These can often be constructed within the existing road reserve at little cost. Ensure that the intersecting angle is > 70° at T-intersections.	 **Placement of appropriate road signs**  **Staggered T-intersections in place of a crossroad**

Issues	Possible countermeasures	Desired outcomes – examples
Bridges/Causeways Road widths on bridges and causeways are often much narrower than the approaches which can lead to a hazardous situation unless appropriately signed. The road alignment leading to a bridge/causeway can often be inconsistent with the preceding road standards and may surprise drivers. This can also be compounded by poor sight distances when approaching a bridge/causeway. Lack of the necessary signs to alert drivers to the approaching bridge/causeway can lead to driver difficulties in negotiating the crossing.	Ensure that on all narrower bridges/causeways there are appropriate road signs to indicate a narrowing roadway and who has precedence if it is a one-lane two-way bridge. Ensure that there are adequate bridge barriers and guardrails where warranted. Good sight distances need to be provided on both bridge/causeway approaches to enable a driver to adjust to road alignment conditions. Particular attention is required at causeways/floodways so that the roadside edge has guide posts and, when necessary, a depth gauge for crossing the road.	 **Informative signage on bridge approaches**  **Guardrails provided**
Road surface hazards • some typical road surface hazards that can occur on unsealed roads include foreign materials on the road such as fallen trees, dead animals, etc. • loose or slippery roads surface • deformations in the road such as potholes, corrugations, rutting • overgrown vegetation overhead restricting vertical clearances • vegetation on the side of a road restricting driver sight lines around curves • missing or damaged road signs, guardrails, guide poles, safety barriers • loose gravel not adequately compacted during maintenance grading.	The various road surface hazards can be managed through routine and periodic maintenance programs. As part of a road agency's asset management plan, regular road inspections should be undertaken to assess road conditions and identify safety hazards. Reports from the public on road conditions should also be considered as they provide a valuable and ongoing way of monitoring network conditions. Intervention levels should be set for each road condition/hazard depending on the road classification and available resources. A suggested list of the items that should be assessed and intervention levels is given in Section 5.1.4. The list of works required should be prioritised and a maintenance program prepared based on the available resources. During grading operations ensure the appropriate 'grader ahead' signs are placed or other signs when roadworks are being carried out. If loose gravel is left on the road an appropriate sign	 **Maintenance grading to improve road surface conditions**  **A suggested vegetation clearance envelope**

Issues	Possible countermeasures	Desired outcomes – examples
	should be placed on the road sections where this occurs.	

5.2.2 Signs and Delineation

Roadworks Signage

During maintenance and roadwork operations, all traffic control devices necessary for warning, guiding and protecting the public and maintenance staff are essential.

- *It is important to have good and consistent signage.*
- *It is important to ensure guide posts (delineators on the posts) are maintained in a good condition as this is often the only delineation provided for road users.*
- *Immediately following completion of the works, all temporary signs and safety devices must be removed from the site.*

Table 5.7 outlines typical activities and considerations for the inspections and maintenance of road signs, line markings and delineating road furniture. Table 5.7 does not provide in-depth instructions on any maintenance activities that may need to be carried out but is aimed at giving a general overview of some aspects and to be considered in planning and carrying out maintenance on these road features.

Table 5.7: Maintenance activities and considerations for road signs and delineators

Road feature	Maintenance activities and considerations

Signs	• Inspect regularly and maintain signs to ensure visibility and legibility
	  – Inspect reflective signs at nights for legibility.
	• Prune any plants/branches obscuring visibility of the sign.
	• Straighten signs and sign supports if required.
	• Clean signs
	  – Flush dirt/abrasive particles from the sign with water before further cleaning.
	  – Avoid excessive rubbing as it can damage any reflective coatings.
	• Repair or replace damaged signs (e.g. when illegible due to fading or are damaged by accidents or vandals).
	• Location, height and orientation of signs should be checked against the requirements of AS 1742.3 Manual of uniform traffic control devices for general use (Standards Australia 2009), or against relevant state/territory manuals.
	• Some minor damage to signs can be repaired in field:
	  – Holes in metal signs can have pressure-sensitive adhesive sheeting applied or filled with plastic filler.
	  – Holes in timber signs may be plugged with putty or wood filler.
	  – Dents may be removed by beating, using a hammer and dolly (or rubber mallet for reflective signs).
	• Temporary signs must be removed when they are no longer needed e.g. warning signs once a road has been treated.

Road furniture	• Road edge guideposts should be inspected regularly and straightened, cleaned, repainted, and/or replaced as required.
	• Delineators should be cleaned or renewed as required.
	• Periodic night-time inspection of delineators to check reflectivity is desirable.
	• Maintenance of fencing (including safety barriers) should include:
	  – repainting (if fencing is painted), and
	  – replacement (if damaged from an accident).

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Appendix A Environmental Considerations

A.1 Planning and Design

A.1.1 Road Location

The location of a new road is a critical step to reduce the impact it will have on the surrounding environment. Careful consideration needs to be given to the effect that the existing environment may have on a road that is constructed in a certain location, and the impact the road may have on that environment. The construction costs of a road increase as the length increases; however, the shortest possible distance between two points is rarely the best option as it may involve large cuts/fills or affect significant vegetation or properties. Locating a road so that it follows the land contours, all else being equal, will minimise the extent of earthworks cuts and fills required and reduce drainage requirements (Figure A 1).

Figure A 1: Road alignment following land contours

Source: ARRB (2009).

There are many environmental factors to consider in the planning of a new road location, including:

- soil type
- topography
- proximity to existing vegetation
- specially dedicated land
- proximity to natural waterways
- drainage line crossings
- drainage discharge points
- scenic value and aesthetic appeal
- existing road reserves.

New road reserves

Some of the most important factors in relation to the planning of a new road location are summarised in Table A 1.

Table A 1: Factors to be considered when planning a new road

Factor	Notes
Soil type	• Relevant information about the area's soils, geology and land capability should be gathered during planning of the route and used as a guide to identifying potential problem areas. • Road building should be avoided on soil types prone to landslips, particularly if they are on steep hills. The native vegetation is sometimes a good indicator of these soils because vegetation growing on an angle or the occurrence of benches may indicate prior landslips which should be investigated before the area is approved as a new road location. • Road construction on erosion prone soils will increase the impact on the environment and increase construction costs through the need to install permanent erosion control measures. • Road construction sites should be assessed for the potential existence of acid sulphate soils (ASS) prior to works commencing. Lands typically subject to ASS are low-lying swampy areas. If these areas cannot be avoided, mitigation of the effects of ASS should be addressed in the environmental review and implemented through the environmental management plan (EMP).
Topography	• Roads should be located, where possible, to follow the natural contours and maintain the road at a manageable grade. • Design of road locations should avoid steep hill slopes which will require large amounts of cut and fill in the construction process. Cut and fill areas have higher landslip and erosion risks than natural land surfaces. • Roads can significantly alter the natural drainage pattern of the area, particularly on low-lying land or where drainage is essentially uncoordinated or allows sheet flows across vast areas. This can lead to increased flow in designated drainage channels, which may become prone to erosion and bank instability. • Siting roads along ridges is sometimes desirable to minimise earthworks and drainage problems.
Proximity to existing vegetation	• Road alignments should minimise the need to remove existing vegetation. • If the design allows, locate roads on the north side of existing vegetation to avoid shading and allow for drying of wet roads. • Substantial trees could be dangerous to motorists in run-off-road incidents and so roads should be kept well clear of them.
Specially dedicated land	• Vegetated areas that contain endangered plant species, or are significant wildlife habitats, should be avoided. Destruction of this type of vegetation will lead to the extinction of species and reduced biodiversity of the area. • Sites of cultural significance, either of Aboriginal or European origin, should also be avoided or included in the roadside reserve to allow for their protection.

Factor	Notes
Proximity to natural waterways	• The number of waterway crossings should be minimised because this will reduce the chances of adversely affecting stream quality and lessen the likelihood of sedimentation problems and impeded fish movement. • A stream should be crossed at right angles wherever possible. • Roads can disturb local drainage conditions and cause increased frequency, size and duration of peak discharge events, leading to stream bed and bank erosion and sediment transport. • Unsealed roads can generate high sediment loads, particularly when poorly maintained. • Run-off needs to be discharged off the road before erosion velocities are generated. • It is also prudent to locate roads away from waterways allowing undisturbed vegetation to act as a buffer zone between the road and the waterway. Buffer zones of at least 20 m are desirable. • Avoid locating a road parallel and too close to a waterway, especially in narrow stream valleys. Locate the road high enough in the landscape to avoid the toe of the fill impacting on the waterway. • Avoid locating roads in the creek lines even though the grades may be less severe as they will form a drainage line in wet conditions.
Scenic value and aesthetic appeal	• Scenic quality is important to motorists, and it can contribute to driver alertness and thus to road safety. • Most tourist trips in Australia and New Zealand are undertaken by car. Encouraging tourists into an area, through the scenic value of a road, can have economic benefits to the local community. Tourist drives and scenic roads are a relatively cheap way for local councils to encourage tourists to their area.
Existing road reserves	• Many Local Governments are restricted in the location of new roads to existing designated road reserves. The location of the road within an existing road reserve should try to minimise the environmental impact, through the careful design of the road. • For other road agencies, such as forestry or parks organisations, where there may be less restrictions on maintaining an existing alignment, further consideration should be given to relocating poor road sections to minimise any adverse impacts for the long-term.

A.1.2 Design Standards

Different design standards of roads can have varying impacts on the surrounding environment. The aim in selecting the design standards for an area is to choose the design which will have the least impact on the environment but will maintain user comfort and safety as well as minimising costs.

Environmental factors to consider when choosing an appropriate geometric design standard include the following:

- width of road carriageway
- crossfall
- grade
- curves
- terrain
- use of low formation roads.

Width of road carriageway

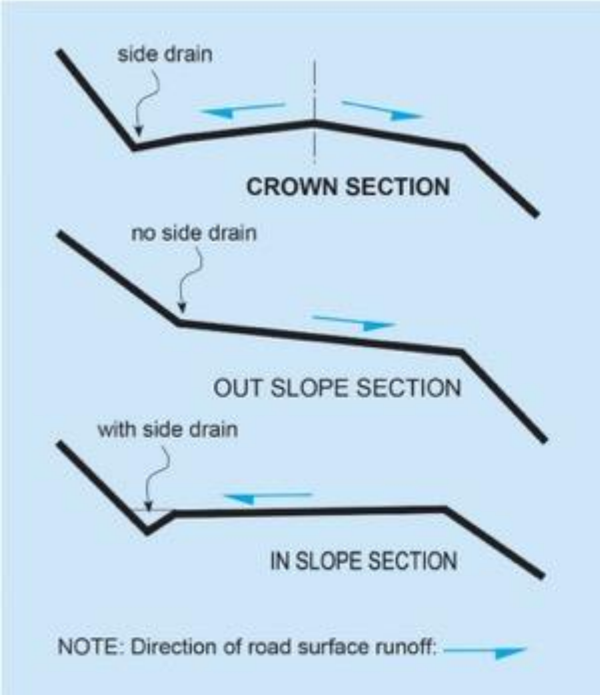
The width of an unsealed road pavement can vary from 4 m to 8.5 m. Both engineering and environmental considerations encourage narrower widths to reduce costs and adverse impacts, as long as the intended use and the traffic considerations are covered. When two cars are forced to pass on a single-lane two-way road, they may disturb the roadside verge. If this is frequently occurring, it can cause detrimental impacts to the surrounding environment. Consideration of the long-term traffic predictions is important in the choice of road width.

Crossfall

There are three main types of crossfalls, shown in Figure A 2, which are used to drain surface water off unsealed roads:

- **Crown** – Crowned roads are the most common crossfall for unsealed roads along straight sections. They are a combination of in-slope and out-slope crossfalls and therefore have similar potential environmental impacts as both. Where the vertical road grade is < 8% either an out-sloped or in-sloped crossfall can be used.
- **Out-slope** – Commonly used on single-lane two-way roads. This crossfall requires less engineering works than other designs and have minimal environmental impact if they are well constructed. The big advantage of this type of road is that it does not concentrate water from the road surface, allowing diffuse drainage (i.e. sheet flow) into the surrounding environment. A catch drain/bank is essential above the top embankment to protect the batter slope and this design is only appropriate where fill slopes are stable. Out-sloped crossfalls are restricted to roads with a straight alignment (or to low speed roads less than 40 km/h) as their construction on curves may be restricted due to comfort and safety considerations. An out-sloped road is the least expensive type of road to construct and maintain and will have the least impact on the environment (Keller et al. 1995).
- **In-slope** – In-sloped roads with an inside table drain are used in erosive areas, where the drainage requires tight control to prevent water from accessing unstable fill slopes. In-sloped roads are more expensive to construct and require more maintenance than out-sloped roads. In-sloped crossfalls are restricted to roads with a straight alignment (or to low speed roads less than 40 km/h) as their construction on curves may be restricted due to comfort and safety considerations.

Figure A 2: Crossfalls and drainage

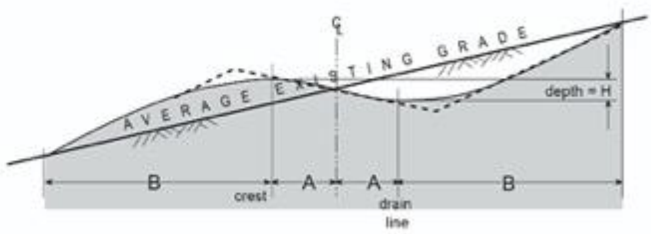


Source: Moll (1993).

Grade

Unsealed roads with steeper grades (> 8%) are more subject to longitudinal scours than roads of flatter grades. Scouring of unsealed roads may lead to sediment build up in table drains, which increases the risk of sediment transport into surrounding waterways. Where steep grades cannot be avoided in the design, construct surface drains across the road, such as water bars or rolling grades (Figure A 3), to facilitate the flow of water off the road surface.

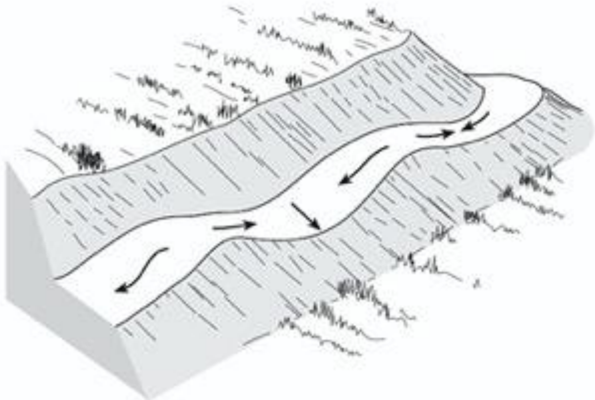
Figure A 3: Rolling grades and dips constructed with an out-slope on the downside of the road



Notes

- The slope of the road shall be maintained through the dip.
- Taper lengths shall be within ± 10% of listed lengths. The skew of drain line shall be 5° to 25° in the direction of water flow.
- For dips on average surfaced roads reduce depth by 60mm.

% grade of road	Length (m)		Depth (h) (m)	
	A	B	Outside edge	Inside edge
0 to 4	14	30	1.0	0.6
5 to 8	14	45	1.0	0.6
9 to 12	13	56	0.8	0.4
13 & over	12	70	0.6	0.4



Source: Keller et al. (1995) (top), Garden (1983) (bottom).

Curves

Horizontal curves on unsealed roads will require superelevation to maintain driver comfort and safety for travel speeds > 40 km/h. Superelevated roads have high crossfalls, which increase the potential erosion risk. Careful management of superelevated roads will reduce their impact. Surface drainage and sediment traps in table drains are important, as well as the use of good quality pavement material to minimise erosion around the curve.

Terrain

In flat terrain, consider drainage lines that may not be obvious during dry periods of the year. This is of particular interest in tropical areas which have long dry spells and then heavy rainstorms. During flood situations a road can cause water to collect on the upstream side of the road. Construction of many cross drains under the road will assist to maintain the natural drainage pattern of the area. In steep country, there needs to be careful consideration of drainage structures, as the steep slopes will facilitate fast water movement, increasing water velocity and potential risks from erosion. Catch drains/banks above the cut batter are critical to remove surface water before it reaches the road. Protection of batter slopes, using either vegetation or geotextiles in special cases, will reduce the erosion risk of exposed soil surfaces. Frequent cross drains under the road will reduce concentrations of water in table drains and reduce the erosion risk.

Use of low formation roads

Low formation roads have a reduced level of the road surface of a maximum of typically 300 mm above the natural surface level (NSL), while high or standard formations have a reduced level of the road centreline of up to 1 m or more above NSL. These rolling low cost roads are typically 'draped' over the landscape, formed and then paved with 100–150 mm of 'gravel' or friable rock such as limestone, and may or may not be sealed (Foley 1997) (Figure A 4).

Figure A 4: Low formation road

Source: ARRB (2009).

There is considerable scope for making low volume roads 'low-impact' by choosing the most suitable positioning of the road in the landscape. Location is an important factor in the ultimate performance and impacts of a new road – well located roads minimise environmental impact. Good location coupled with designing a road to minimise disruption to the natural surface hydrology are essential elements for the successful construction of low-impact roads in rural environments.

The following features of low formation road design can have environmental benefits:

- **rolling grades** – close to the natural terrain minimise any modification of existing drainage patterns and facilitate the shedding of water and prevent ponding upstream of the road formation
- **minimum earthworks** – reduce cuts and fills and the number of borrow pits which lessens the overall disturbance of soils and reduces their exposure to erosion
- **floodways** – used rather than culverts, which have a greater potential for erosion and scour
- **careful culvert design (location, orientation and grade)** – to avoid scour, use low, wide/multiple culverts installed only where necessary, and piped outlets designed so that outflow is spread rather than concentrating flows.

These drainage features will allow floodwaters to flow quickly over the road formation, with only a small head of water and reduced periods (if any) of inundation adjacent to the road. These factors help to preserve the stability and strength of the formation and road pavement materials, as well as cause minimal disruption to the naturally occurring surface hydrology (Austroads 2001).

A.1.3 Drainage Design

Drainage is often described as the most important aspect of design and construction of any road, including unsealed roads. Drainage of unsealed roads can be of even greater concern because they are typically constructed with lower quality materials and thus, water is able to enter the pavement more easily. Poor drainage will reduce the life of the pavement and have serious environmental impacts if left unchecked.

The key environmental consequence of poor drainage design is large hydrologic changes and erosion and sedimentation of natural waterways. There are many approaches to reducing erosion of exposed surfaces associated with unsealed roads, such as table drains and batter slopes.

In many cases, there will be limited options for reducing sediment generation from the unsealed road surface itself, so it will be necessary to consider all available options for treatment of road run-off before it reaches natural watercourses. In the first instance, desired drainage flow needs to be calculated and drainage structures designed with adequate capacity and armouring of discharge outlets to safely pass designated flows.

Important aspects of drainage design for unsealed road applications include the following:

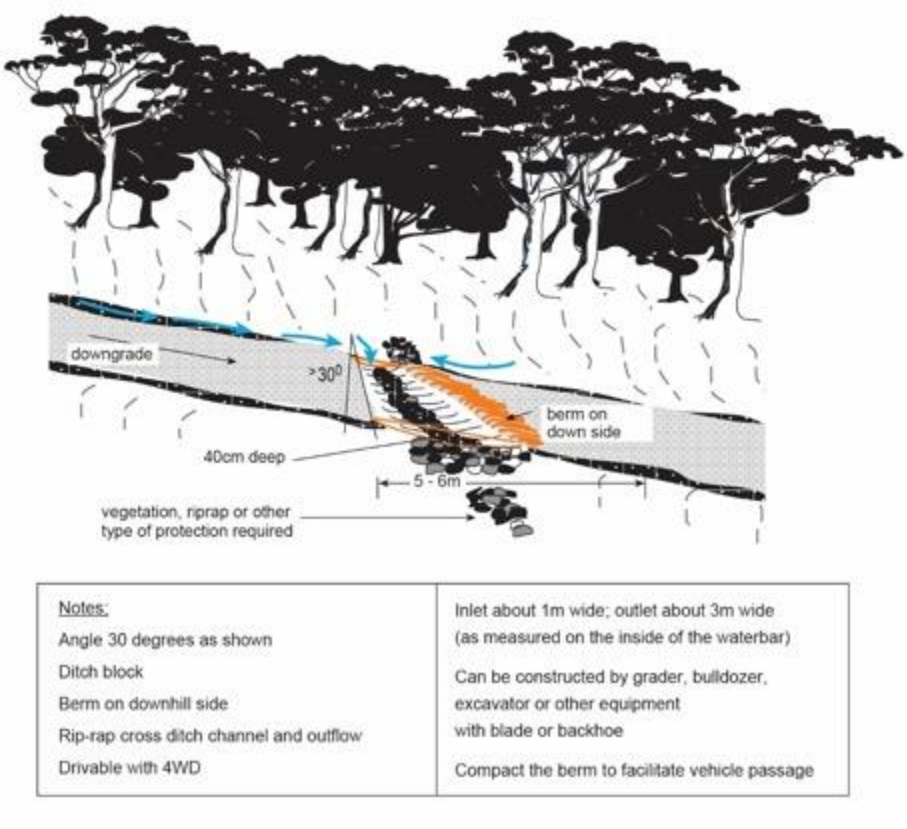
- pavement surface drainage
- table drains
- catch drains and batter slopes
- culverts and pipes
- creeks and drainage line crossings
- road drainage in areas with high watertables
- road drainage in semi-arid and arid areas
- road drainage in wet tropics.

The important aspects of drainage design and the various unsealed road applications are described as follows:

Pavement surface drainage

- Design adequate crossfalls, whether in-sloping, out-sloping or crowned, to facilitate water movement off the road surface. Crossfalls between 4% and 6% are recommended for unsealed roads.
- Applying a surface with well-compacted and bound gravel wearing course offers less erosion and better scour protection.
- Maximum run-off velocities can be estimated for various soil materials to avoid erosion.
- The preferred method of draining some minor roads in relatively flat terrain is by ‘rolling grades’, where gently rolling dips are constructed into the surface. Consider also the use of these ‘driveable’ rolling dips on moderate speed roads with grades greater than about 8%, to facilitate water movement off the road surface. Rolling dips, as shown in Figure A 3, should be spaced frequently depending on the soil type and road grade. Where erosion potential is moderate and the vertical grade is between 5–10%, dips might need to be spaced at 50 m intervals (Keller et al. 1995).
- Cross drains in a rolling grade road can be constructed into the road pavement surface using a grader, bulldozer or excavator for very low volume roads. They should be angled at 30° from the road in the direction of the water flow. The inlet should be about 1 m in width and the outlet around 3 m. Vegetation or riprap protection may be required at the outlet and crushed rock or stone placed in the drain itself. A typical surface cross drain is shown in Figure A 5. For steep vertical grades other forms of treatment are provided in Section 3.3.4.

Figure A 5: Typical cross ditch constructed into a road in moderately steep terrain



Source: ARRB (2009).

Table drains

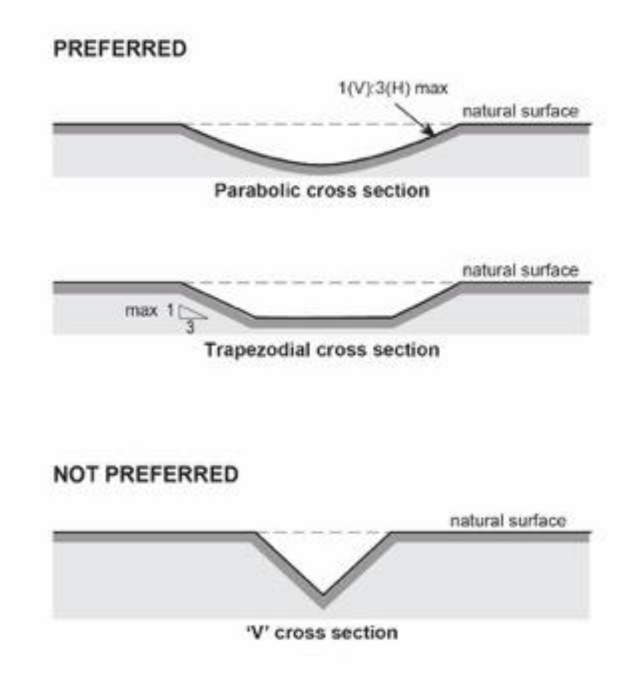
- Table drains collect run-off from road surfaces, overland flow, cut batters and ground water where the drain invert has intercepted the watertable. Excessive flows may initiate scouring within the drain or at the outlet of the drain.
- The success of the table drain will depend on its ability to carry run-off water without initiating scour. Scouring will occur when water velocity causes flow stresses which exceed the strength of the drain surface.
- There is limited scope to alter the grade of the table drain as this follows the slope of the road and the natural surface.
- Careful design can keep the flow velocity within an acceptable range through manipulating three factors: the total area contributing to the drain (or catchment area), spacing between cross drain outlets (or cut-off drains) and its cross-sectional shape.
- Provide regular cut-off drains to slow flow velocities and minimise the potential for erosion of road edges. Intervals between cut-offs should be shortened with increasing steepness of terrain.
- Turn out table drains into surrounding stable country, such as a heavily vegetated area as frequently as possible (Figure A 6). This minimises the amount of water collected in a drain, the amount of water discharging to private property and reduces the water velocity.

Figure A 6: Typical turn-out into a stable vegetation area

Source: ARRB (2009).

- Avoid discharging road drainage at points with direct access to natural drainage lines and streams. Turn out table drains at least 50 m before a creek or waterway crossing to prevent sediment entering directly into the waterway. It is desirable that run-off is spread so that sediment is dropped well before the waterway. This distance will be dependent on the grade of the road, soil infiltration rates, flow release velocities and the erosion potential of the soil.
- U-shaped or trapezoidal drains can have lower water velocities compared to V-shaped drains, hence reducing the risk from erosion.
- Table drains should be between 0.6–1.0 m width at the base with the side batters graded to a 3 (horizontal) to 1 (vertical) ratio. Figure A 7 shows the table drain cross-sections.

Figure A 7: Typical table drain cross-section



Source: Giumarra (2009).

- The armouring of drains may need to be considered for drains with grades over 5% on erosive soils and on grades over 10% on normal soils (Keller et al. 1995). An armour is a layer of material placed on the soil surface to protect it from erosion. This material may include rock, concrete, geotextile, gabions or turf. Care must be taken in the placement of material because if it is poorly done it may add to turbulence.
- For steep table drain grades a preferred way is to add at regular intervals check dams as they have the effect of slowing down the water velocity and still enable at a later stage the winning back of fines that end up in the table drain (Figure A 8).

Figure A 8: Check dams in table drains

Source: ARRB (2009).

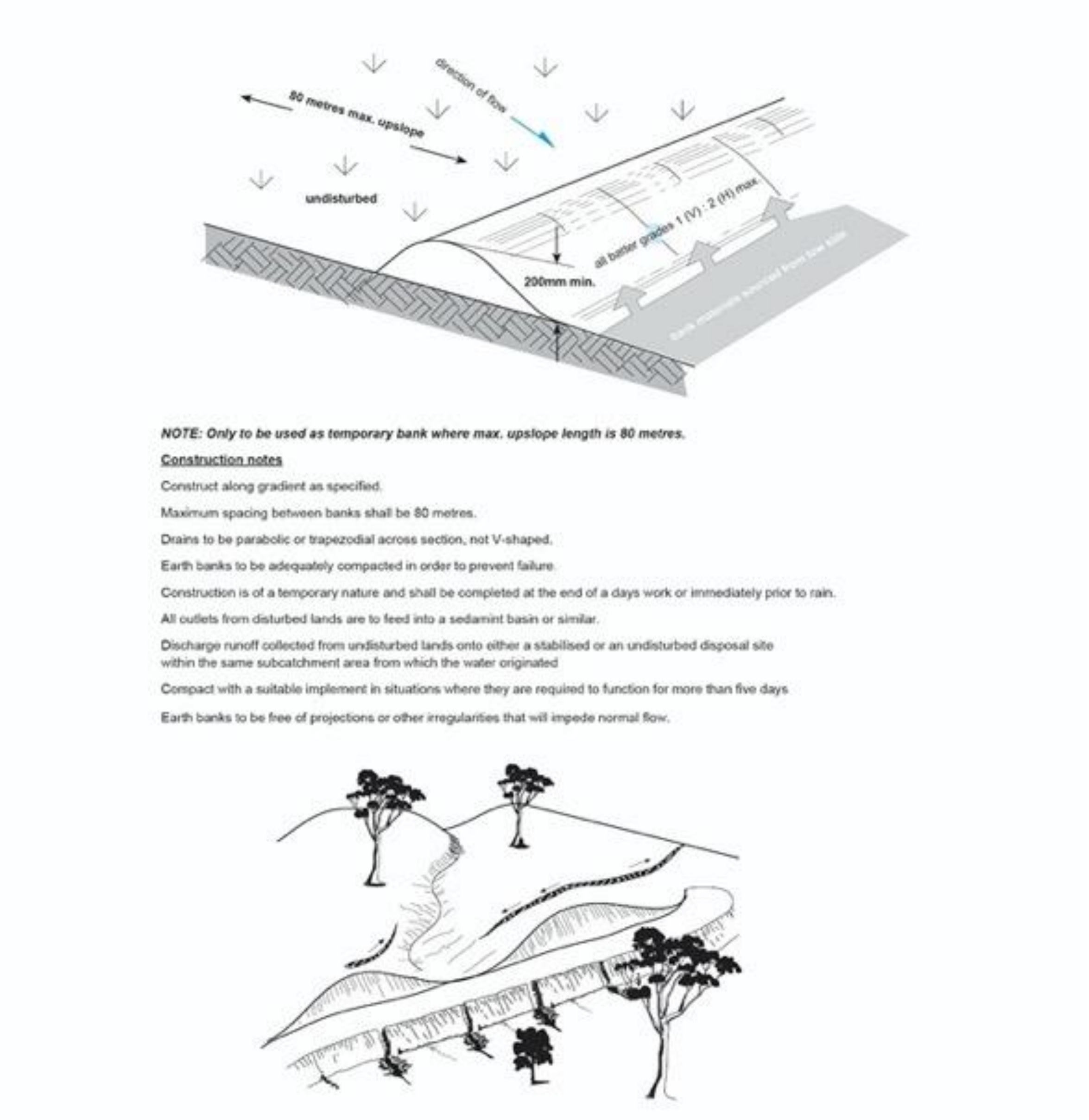
- More frequent cross drains will prevent water accumulating in table drains, reduce the potential for scour and may allow table drains to remain unarmoured. This will allow fine material that collects in the table drain to be reused on the road in the future.
- Where feasible, avoid discharging concentrated run-off from the road reserve directly onto adjacent private property or into areas of high conservation value indigenous vegetation.
- In a side cutting, construct the table drain on the high side of the road only, whereas in general table drains will be necessary on both sides of the formation in cuttings to provide adequate drainage.
- Always investigate the suitability of other drainage structures before installing table drains. Under some conditions, grassy swales can be more suitable and highly beneficial in terms of sediment removal, preventing the concentration of run-off and thereby reducing peak flows.

Catch drains/banks and batter slopes

- Catch drains/banks are located above the road embankment to prevent water entering the road from uphill and can safely discharge collected water at each end of the cut or carry water down fill slopes if necessary, as shown in Figure A 9.

- Use small and properly graded diversion banks, also shown in Figure A 9, rather than a trenched ditch as a catch drain, as this reduces the potential erosion risk. Water collected should be carried to each end of the batter and discharged safely onto the natural surface, as shown in Figure A 9. This may not be possible on steeper slopes.

Figure A 9: Catch bank design and diversion drain



Source: NSW DPIE (2004) (top), Garden (1983) (bottom).

- Constructed earth batters should not exceed the following grades according to mass movement hazard (NSW DPIE 2004):
  - cut slopes (horizontal:vertical):
    - 2:1 if low hazard
    - 3:1 if moderate hazard
    - 4:1 if high hazard
  - fill slopes:

  - 2.5:1 if low hazard
  - 3.5:1 if moderate hazard
  - 4.5:1 if high hazard.
- Batter stabilisation other than by routine vegetative means should be considered for all constructed slopes exceeding a 2:1 gradient.

Culverts and pipes

- Culverts and pipes are to be used for natural waterway crossings and for cross drains to remove run-off from table drains.
- Stream realignment works associated with culvert or bridge placement should be avoided; however, where deemed necessary, advice about environmental considerations should be sought.
- Where culverts are placed, flood flows are constricted and velocities increase, leading to a higher than normal erosion potential at that site. The culvert size, location and grade will be important design considerations, to determine erosion risk.
- Erosion and scour at culvert crossings are common, damaging road embankments, the structure itself or the natural channel bed at the discharge outlet.
- Culverts should be designed so that their entrance and exit points conform to the slope of the natural waterway or desired drain slope, where possible.
- The estimated outlet velocity will determine where there is potential for erosion at the exit point. Refer to local drainage design manuals for information on maximum permissible velocity of water for various soil types before erosion begins (such as Garvin, Knight & Richmond 1979, Alderson 2006 or VicRoads 2013).
- Locate culverts and pipes exactly in the middle of waterways. Use multiple pipes in wide channels, so that water is not channelled through one, fast-flowing culvert. This allows the energy associated with moving water to dissipate over a larger area (Figure A 10).

Figure A 10: Multiple culverts to adequately transfer creek flow

Source: ARRB (2009).

- Protect entrance and exit points of pipes and culverts with armouring (Norvill 1999) where high water velocities and erosion are anticipated. Energy dissipaters such as ripraps or silting basins will help spread the flow and prevent scouring and sedimentation. The armouring or dissipation structures must coincide with existing channel grade to avoid the creation of an overfill (Figure A 11).

Figure A 11: Typical low box culvert used on low volume sealed roads

Source: ARRB (2009).

- Minimise the length and slope of culverts and pipes because long, steep pipes increase water velocity, which increases the erosion risk at the exit point.
- Adopt the use of a culvert 'sock' in locations with steep outfalls to help dissipate the water velocity to minimise downstream scouring (Figure A 12).

Figure A 12: Culvert sock

Source: ARRB (2009).

- Use debris collectors upstream of culvert and pipe entrances to prevent debris obstructing the entrance and preventing the correct function of the structure. Consider using an oversized pipe to assist against blockages or construction of a bridge structure or ford, where costs allow.
- Fish habitat is almost always present in permanent waterways. Consider the impact of the structure on fish habitats and the movement of fish and consult with local natural resource managers. Where fish are present, use open bottom culverts, arches or bridges, which maintain the natural stream channel bottom. Culverts with a roughened base installed below the natural stream bed can minimise fish impacts. Further details are provided in this Appendix.

Creeks and drainage line crossings

- Road location design should try to minimise the number of creek crossings, since each crossing site has significant impact on the environment.

- When a road must cross a natural waterway, it is important to consider the impact it may cause. Locate waterway crossings perpendicular to the bank and in areas where the bank is most stable.
- Preferred watercourse crossing types to maintain fish passage are listed below in order of preference (NSW Fisheries 1999):
  - Bridges and culverts designed so that the cross-sectional area of a stream is not altered are the most favourable.
  - Arch and box culverts designed to retain the natural morphological features of the stream such as width, bed slope and cross-sectional area, e.g. a series of large culvert cells is preferred to a single cell.
  - Low level crossings such as fords and causeways designed to have an invert level the same as the stream bed can overcome a potential weir effect.
  - Pipe culverts and pipe causeways can create most problems for fish passage as they reduce the width of the stream; they tend to scour on the downstream side thereby creating a drop or 'waterfall' effect. Where they are used, a series of pipes is preferred to maximise the cross-sectional area.
- Protect the banks near creek and river crossing structures. Erosion and scouring near structures will cause sedimentation of the waterway and undermine the stability of the structure.
- In some very sensitive or relatively undisturbed environs, bridge deck drainage may need to be collected and taken to detention ponds for sediment to settle before release into the waterway.

Road drainage in areas with high watertables

Where possible, it is prudent to avoid road placement in areas affected by a high watertable and salinity. However, this is not always possible and as watertables in some catchments rise, more and more formerly arable and stable land is becoming saturated.

A separation and drainage layer of a coarse-grained material such as sand, for instance, can be constructed to isolate the pavement from the underlying saturated soils. An embankment can be constructed using coarse-grained materials. However, this will tend to disrupt natural surface flows and pond catchment water on the upstream side of the road. This is particularly undesirable in areas where watertables are already high and can exacerbate local salinity problems. Existing granular pavement materials can be stabilised by various means (typically using lime and or cementitious materials), followed by a resheet of say 100 mm of new gravel. This would then require the normal maintenance grading and periodic topping up with gravel.

If the road is likely to be subject to heavy traffic volumes and/or axle loads, then sealing the section traversing the waterlogged zone may be the best option as shown in Figure A 13. In general, however, expect higher maintenance costs following sealing, because regular shape repair, patching and reinstatement of the surface will be required in areas with a high watertable.

Figure A 13: A paved ford crossing with scour protection on downstream edge

Source: ARRB (2009).

In some situations, it may be necessary to introduce improved surface or sub-surface drainage to prevent the road from continually breaking down.

Good drain performance depends on (McRobert & Foley 1999):

- Sufficient surface grades to keep water draining to a suitable discharge point – grades < 0.5% (1:200) will usually present difficulties.
- Control of water from surrounding catchments – this will improve the effectiveness of localised drainage systems; can also improve surface water control by working with adjacent landholders to install grade banks on surrounding slopes.
- Acceptable discharge outlets being available.

Disposal of saline ground water and/or surface drainage from salt-affected sites raises several issues:

- By increasing downstream soil and stream salinities, further pressure will be placed on already declining ecosystems in salt-affected catchments.
- Additional water will change the hydrology of nearby streams, wetlands and other sensitive environments.
- Regulations exist in some states under various Soil and Water Conservation Acts which require parties to give notification of their intent to undertake drainage works in saline catchments.

A suitable consultation process might involve:

- Establishing contacts with local catchment coordinating groups and adjacent landholders.
- Incorporation of existing or proposed community revegetation or drainage works into designs.
- Seeking advice from relevant government agencies and authorities regarding ground water disposal obligations.

Road drainage in semi-arid and arid areas

The road drainage system associated with most unsealed roads is fairly simple. However, design problems in some land types have led to erosion and scour. Past road drainage practice in some semi-arid to arid landforms have led to extensive erosion. Drainage structures such as table drains and catch drains can be unstable when highly erodible soil profiles are exposed, leading to deepening and considerable lateral extension of drains.

Specific road drainage problems associated with the gibber plain land type in the north-eastern regions of South Australia have been investigated and have been described as follows (Woodburn Associates 1999):

- **Scouring along table drains or behind windrows** – grading practices render the road formation below the natural surface providing a preferred route for channelled water flow.
- **Scouring of diversion drains** – again, grading practices cause the road formation to deepen so diversion drains become longer and begin to scour.
- **Cut-off or catch drains** – also tend to transfer the problem as they collect and concentrate the flow into exposed soil areas which can lead to scour (Figure A 14).

Figure A 14: A typical catch drain in an unstable arid environment

Source: ARRB (2009).

Good practice for road design of new and existing unsealed roads in arid areas includes the following methods (Woodburn Associates 1999):

For new roads:

- The broad recommendation is to adopt the principles of low formation roads as discussed in Appendix C.7.2.
- Choose the highest elevation and most stable country for positioning the road, wherever possible.
- Allow the road to track the highest contour, following the natural inundations of the land using minimal straight sections, and lessening the chances of crossing of drainage channels.
- Sensitive positioning should lead to minimal cutting of the ground surface and very few floodways.
- Where unavoidable, construct low, wide and rectangular culverts, or a series of small diameter pipes.
- Construct roads on fill to a depth between 0.3 – 0.5 m (and no greater) above the natural surface.
- Do not construct table drains or diversion drains.

Rehabilitation of existing roads

- Minimise any additional disturbance and exposure of highly erodible soils by limiting the use of earthmoving machinery.
- Backfill scours by end-dumping material from trucks, working back along the scour.
- Fill scours to above the natural plain level to allow for some settlement, and cover with stones for protection.
- Where scouring has occurred, the road has effectively obstructed natural drainage flows; attempt to reinstate natural drainage flows, where possible, to avoid re-scouring.
- Minimisation of scouring can only be achieved by following the principles outlined in the guidelines for new roads (above).

Road drainage in wet tropics

In wet, tropical regions of north-eastern Australia, where annual rainfall is in excess of 1200 mm, there is a need for additional consideration of the potential for erosion once native vegetation has been disturbed.

In the design stage of any new road or roadworks there is an even greater need for planning to minimise disturbance to native vegetation as well as the use of temporary erosion and sedimentation controls and timely revegetation of these areas. There is also an enhanced requirement for effective drainage systems which remove water from the road as quickly as possible and the adoption of special techniques to ensure its safe discharge to the environment.

Good practice for drainage design of unsealed roads in wet tropics includes the following methods (Main Roads Queensland 1997):

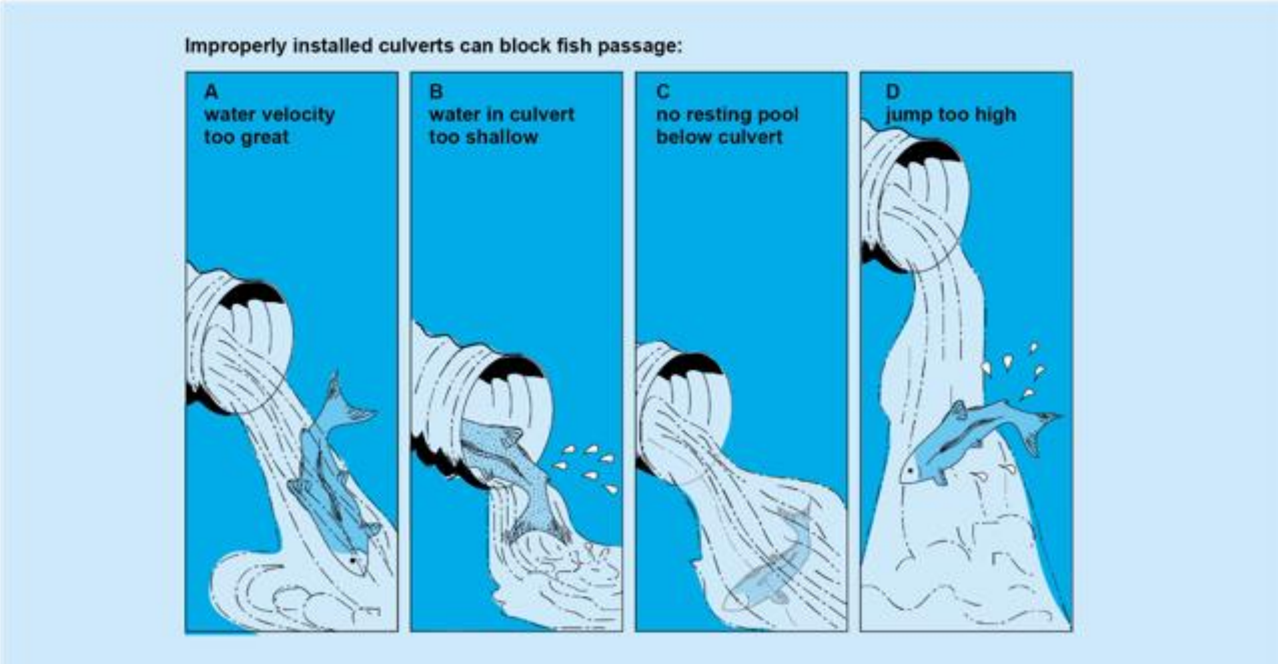
- Identify areas where there is extreme erosion hazard and avoid construction where possible.
- Where practicable, plan to construct roads during only the dry season.
- Design road corridors which utilise the natural slope of the land to minimise requirement for cuts and embankments.
- Use pavement crossfall design to drain water to the downslope of the road rather than concentrating flow in table drains; this will minimise water collection points.
- Suitably spaced cross drains should be constructed into the pavement to channel water away and to be discharged into stable areas.
- Take particular care to remove water from drains as often as possible (using pipes or cut-off drains) so as to minimise water concentration and volume.
- Maintain grass in table drains and canopy cover of roads wherever possible.
- Special care is required to design culverts and drains with sufficient capacity to allow design flows to pass without unduly concentrating flows and increasing velocities.
- Design for protection at culvert outlets (such as rock riprap) where there is potential for erosion of the natural stream bed.

Fish passage design requirements for culverts

Many species of fish must migrate as part of their life cycle. In-stream barriers to fish such as unsuitably designed culverts have the potential to affect all aquatic fauna to varying degrees. The most obvious and dramatic impact is the direct exclusion of migratory fish moving to or from habitat areas essential for completion of their life cycle, such as spawning grounds in estuaries or headwaters (O'Brien 1999).

This section provides design considerations for minimising the impact of culvert installation on migratory native fish in small waterways (Figure A 15). The information has been adapted from an information sheet developed by the Department of Natural Resources and Environment in Victoria (O'Brien 1999).

Figure A 15: Examples of poor culvert outlets for fish passage



Source: O'Brien (1999).

Protection of fish habitat is necessary for steam crossings where fisheries exist. The choice of crossing type is important in terms of both sedimentation effects and fish passage. For fish passage, preferred locations are those that do not cause large increases in velocity and have no abrupt changes in gradient or alignment of the channel. Sections of a stream with uniform, gentle gradients are easier to cross with provision for fish passage.

Although the standard corrugated round pipe culvert is often used, it is the least desirable for fish passage. The width constriction from stream channel to culvert is usually severe, and the gradient of the pipe should be less than 2% to keep the water velocities within an acceptable range for fish passage. This type of culvert is also the most likely to be installed with its outlet elevated above the tail water level, producing an outfall barrier (Figure A 15). Elevated outfalls must be avoided or mitigated.

Installations for larger waterways will require site-specific biological advice as to the most appropriate method of providing for fish migration. General guidelines are listed below.

- Bottomless culverts should be used where practical as these most closely maintain natural substrate conditions (Figure A 16). Of the other culvert designs, corrugated pipes are next preferred as they provide some degree of roughness while concrete box culverts are the least preferred as they offer little shelter for migrating fish.

Figure A 16: Arch culvert maintaining natural river bed

Source: ARRB (2009).

- Where fully enclosed culverts are used, inverts should be installed below the existing stream bed to a depth adequate for maintaining a natural substrate within the culvert as smooth surfaces within the culvert may lead to impassable areas of high water velocity. The depth required will vary with substrate type and gradient. However, 0.3–0.6 m should suffice for culverts < 3.0 m in diameter; larger culverts should be installed with 20% of the culvert diameter below the stream bed. Natural materials such as rock, gravel or logs should be introduced and allowed to accumulate within the culvert as these provide more opportunities for fish movement by breaking up flow and allowing fish to rest between the swimming bursts used to negotiate areas of high water velocity.
- If smooth-based culverts must be installed, the maximum velocity at discharges below the design flow should not exceed 1.0 m/second as this will impede fish movement. This velocity criterion is especially important in situations where there is little variation in velocity due to the culvert's smoothness when compared with the wide range of velocities that occur across a stream in natural situations.
- Culverts should be installed in areas of minimal gradient at a slope as close as possible to the existing stream bed. Perching (scouring at the outlet resulting in a vertical drop) of culverts must be avoided. Most native fish are unable to leap over even small structures.
- Provision for fish movement past culverts when they are completely inundated is considered impractical; it is therefore important that the culverts be designed to operate below capacity at flows that are exceeded no more than 5% of the time.
- The potential impact of erosion should be considered, and appropriate protection provided to prevent perching. Even small (> 0.15 m) vertical or steep drops must be avoided as many native fish are unable to leap in-stream barriers.
- Flow-through culverts must maintain adequate water depth for fish passage. Where low flows are likely to spread out over a wide area and become impassable to fish, (particularly in large single box or pipe culverts that are not installed below the stream bed), it is desirable to concentrate the flow by installing culverts at different heights. In some cases, it may be appropriate to design one culvert for fish passage during low flows and others to cope with flood events and provide fish passage during high flow periods. A minimum depth of 0.20 m is required for culverts installed on small waterways.
- The impact of changes to bed profile should be minimised and the wetted perimeter should be maintained as close as possible to natural conditions to minimise increases in water velocity and the loss of rest areas within the culvert. In cases where existing average water velocities are less than 0.50 m per second some narrowing of the existing channel may be acceptable. These should not result in greater than a 15% reduction of total wetted perimeter at the design flow as the resulting velocity increases may make the culvert impassable to fish.
- Vertical concrete walls remove the slower, sheltered bank areas used by many fish to negotiate areas of high water velocity. These should be made irregular and roughened, for example by embedding or attaching rock onto them.

Approximately 50% of the stream bed should be covered with jutting, irregular shaped and sized rocks for a short distance (2.0 m) immediately upstream and downstream of the culvert. This provides shelter and rest areas for fish entering and exiting the culvert.

A.2 Assessing Roads for Sediment Risk

Unsealed roads can be a significant source of sediment to waterways in a particular catchment. Assessing unsealed roads for sediment risk is a strategic management approach to minimising water quality impacts on receiving waters. A suitable approach to sediment risk assessment has been adapted from work undertaken as part of the Victorian Stormwater Action Program (Kemp 2004).

Most sediment impacts occur where road drainage water directly enters streams (Figure A 17). Sediment management measures should therefore be focussed on stream crossings and the maintenance of drainage conditions approximately 100 m either side of each crossing. The assessment can be undertaken at the network level or by road segment.

The main steps in the sediment risk assessment are:

1. Identify stream crossings along unsealed roads.
2. Assess each site using a survey checklist.
3. Prioritise each site using the survey score and then rank accordingly.

Figure A 17: Sediment laden water entering waterway from table drain

Source: ARRB (2009).

Risk assessment criteria are outlined in the sample assessment sheet shown in Figure A 18. These criteria are based on the likelihood of the road section transporting sediment from the road to a nearby stream. The criteria include:

- Drainage outlets – their linkage to nearby streams.
- Drainage area of the stream crossing – in lineal metres.
- The presence of erosion – level of stability in relation to terrain and soils.
- Roadside vegetation – condition and significance.
- Receiving waters type – temporary or permanent stream or wetland.

- Conservation status of the catchment – degree of disturbance or naturalness.
- Vehicle traffic – rated as low, medium or heavy.
- Road gradient – steepness of terrain.
- Road surface condition – rated as poor, fair or good.

Follow-up actions at identified high-risk sites include:

- Maintain the road surface in good condition.
- Slow drainage water flows, and disperse early and often, rather than concentrate flow.
- If necessary, treat run-off prior to discharge to waterways.
- Improve overall drain maintenance practice.

Figure A 18: Sediment risk assessment sheet

Date:		Road section from:	
Assessor:		Road section to:	
Road name:		Distance to nearest intersection:	

				Weight	Score
Drainage Outlets:	0- No linkage to stream	1- Partial linkage to stream	2- Direct discharge to stream	5	
Drainage Area ofStream Crossing:	0- 0-50 lineal metres	1- 50-100 lineal metres	2- > 100 lineal metres	3	
Presence of Erosion:	0- Stable	1- Relatively Stable	2- Unstable	3	
Roadside Vegetation:	0- Good	1- Fair	2- Poor	2	
Stream Type:	0- Temporary	1- Permanent	2- Wetland	2	
Conservation Status of Catchment:	0- Highly disturbed	1- Slightly or moderately disturbed	2- High conservation value	2	
Vehicle Traffic:	0- Low	1- Medium	2- High	1	
Road Gradient	0- Flat	1- Moderate Slope	2- Steep	1	
Road Surface Condition:	0- Good	1- Fair	2- Poor	1	
				Overall Score:	

Photos: 1. 2.

Source: Kemp (2004).

The assessment in Figure A 18 provides a hypothetical example of a high risk unsealed road section comprising between 50–100 lineal metres in drainage area, supporting average quality roadside vegetation, on unstable soils, with medium traffic volumes and a fair road surface condition of moderate slope, directly draining into a permanent stream. The overall score is calculated as 28 which is deemed a high sediment risk road segment.

Sites can be ranked accordingly into high, medium and low risk categories, as listed in Table A 2.

Table A 2: Method to rank risk categories

Category	Score
Low	0–9
Medium	10–24
High	25–40

A.3 Construction

A.3.1 Clearing and Site Preparation

Clearing of vegetation

The importance of roadside vegetation should not be overlooked, as it aids in many different aspects of the road. In many cases the road reserves provide the only remnant of native vegetation of rural Australia.

Some of the contributions made by roadside vegetation to the road system and the environment are:

- provides a scenic view and also increases driver alertness by creating a changing and interesting surrounding to the road
- assists in delineation of the roadway, particularly around sharp curves
- holds soil in place and reduces erosion, landslips and silt run-offs into drains
- reduces the velocity of surface run-off, thus reducing scour and erosion of batters and embankments
- stabilises ground water leading to a reduction in the likelihood of landslips
- can lower the watertable level
- prevents the establishment and spread of weeds
- preserves indigenous plants by providing an area free from grazing and clearing
- helps support the local ecosystem by providing a source of shelter and food for animals.

It is important to clear only what is necessary. Over-clearing increases the impact of the road on the environment, as well as increasing the construction costs and future maintenance costs. Under-clearing can choke drainage lines, culvert inlets and can result in overtopping, scouring and erosion downstream and restrict sight distances.

The extent of clearing should also consider roadside safety requirements so that a clear zone is established free of hazards (e.g. trees) so as to make the roadside more forgiving for errant vehicles. The extent of such clearing is dependent on the traffic being carried, importance of the road and vegetation.

Before any vegetation clearing begins, ensure peg lines are placed correctly and that machinery operators know where pegs are. Mark any significant vegetation, before clearing starts, to ensure it is not accidentally destroyed. Figure A 19 shows an example of temporary markers.

Figure A 19: Marking of significant vegetation

Source: ARRB (2009).

Road agencies should also consider the use of permanent markers to indicate the location of threatened flora and fauna sites. Permanent makers should also be considered to indicate cultural and heritage sites to ensure that the sites can be easily identified by maintenance staff.

Unnecessary removal of vegetation can lead to:

- loss or reduction of vegetation that may be of significant conservation value
- reduction in the conservation value of wildlife habitat
- increased potential erosion and weed invasion risks due to exposed or disturbed soil.

Some beneficial practices to consider when clearing vegetation include:

- Thorough vegetation surveys where soil-borne diseases (such as dieback) may exist to identify such diseases and locations and to establish suitable measures to prevent their spread.
- Where feasible, prior to vegetation removal, collect seeds and cuttings from indigenous plants suitable for use in revegetation activities.
- Once vegetation has been cleared, stack the vegetation in an open area, away from remaining vegetation. This helps to prevent the harbouring of pests amongst stacked vegetation.
- Re-use as much of the vegetation as possible by mulching on-site (Figure A 20) and spreading over exposed soil surfaces. This reduces the risk of erosion from bare soil and helps to spread local seeds.
- Vegetation that cannot be chipped and re-used as mulch should either be burnt on-site (if allowed) or removed from the construction site. When burning vegetation, keep the fire clear of existing native vegetation. If the vegetation is to be removed from the site to an authorised disposal depot, cover the vegetation during transportation to prevent any weed seeds being spread to other areas.

Figure A 20: Stockpiled mulch of a road construction site

Source: ARRB (2009).

Topsoil management

Topsoil is vital for healthy vegetation as it can contain large amounts of organic matter, the majority of a tree's surface roots and the seeds of local native vegetation. However, topsoil can also contain weed seeds in areas where weeds have established, and this should be considered when reusing topsoil.

Appropriate topsoil management practices include:

- Grade off topsoil from work sites and stockpile for rehabilitation operations.
- Topsoil should not be moved from an area where weeds exist to areas of significant conservation value.
- Topsoil should not be stockpiled higher than 1 m or for more than 12 months, to ensure the survival of local native seeds, which will germinate when the soil is spread (Western Australian Roadside Conservation Committee 1998).

- If topsoil is to be spread as part of rehabilitation work, ensure it is not mixed with poorer quality subsoil. The depth of topsoil to be graded will depend on the depth to the subsoil. Topsoil is generally graded to a depth of between 100 and 200 mm (Western Australian Roadside Conservation Committee 1998).
- Stockpiled topsoil can be temporarily re-sowed with sterile grasses to maintain soil structure and organic matter, reduce weed invasion and prevent erosion.

A.3.2 Erosion and Sediment Control during Construction

Once a site has been disturbed for road construction, it becomes susceptible to erosion and sediment run-off. The adoption of erosion control measures is therefore an important consideration when planning construction works. Erosion control involves a pro-active approach and should always be the first line of defence taken, followed by sediment controls where necessary.

Important aspects of erosion and sediment control during road construction include:

- **Revegetation** – vegetative erosion control methods use living plants to reduce the effects of raindrop impact, slow down the velocity of surface run-off, draw moisture out of the soil and increase the soil strength by allowing plant roots to bind the soil and help resist soil movement.
- **Sediment control structures** – structures that control the movement of water are designed to direct water away from erosive areas or to disperse water before it can become concentrated.
- **Drainage (catch drains, table drains, culverts and pipes, sediment traps)** – the best way to reduce erosion from a construction site is to prevent foreign water entering the site from the surrounding landscape

Important factors to consider when managing erosion include (EPA 2004):

- Limit the time that areas are left exposed on-site.
- Strip vegetation and topsoil only as necessary and undertake progressive rehabilitation.
- Minimise the size of areas left exposed.
- Schedule high-risk activities for drier times of the year.

Minimising Erosion

The erosive effects of run-off on a construction site can be minimised by following a few broad principles:

- *Divert flows from upslope catchment areas away from the road formation and reduce slope length.*
- *Keep gradients as low as possible to reduce flow velocities.*
- *Encourage infiltration wherever possible through progressive revegetation of exposed surfaces such as batters and stockpiles (if a longer-term site).*
- *Stabilise any protected exposed surfaces as soon as possible.*

One of the most important considerations when planning for construction is to stage works so as to minimise the impacts of erosion and sedimentation. The main factors include (EPA 2004):

- Limit the time that areas are left exposed on-site.
- Strip vegetation and topsoil only as necessary and undertake progressive rehabilitation.

- Minimise the size of areas left exposed.
- Schedule high-risk works for the drier time of the year.

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- Keep gradients as low as possible to reduce flow velocities.
- Encourage infiltration wherever possible through progressive revegetation of exposed surfaces such as batters and stockpiles (if a longer-term site).
- Stabilise any protected surfaces as soon as possible.

Important aspects of erosion and sediment control during road construction include:

- revegetation
- physical control measures
- drainage construction: catch drains, table drains, culverts and pipes, sediment traps
- quality control.

The important aspects of erosion and sediment control are described below.

Revegetation

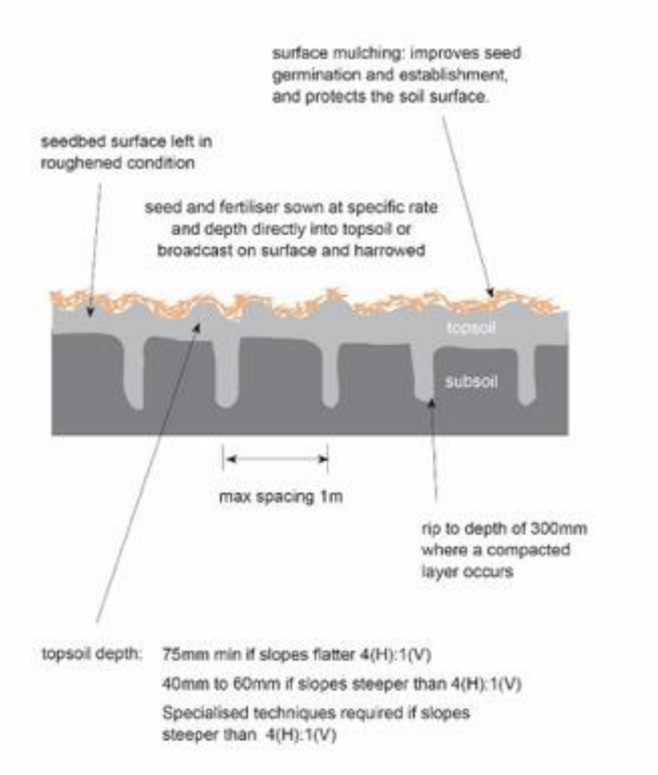
Vegetative erosion control methods use living plants to reduce the effects of raindrop impact, slow down the velocity of surface run-off, draw moisture out of the soil and increase the soil strength by allowing plant roots to bind the soil and help resist soil movement.

A protective cover of vegetation is the ultimate in erosion control (Main Roads Western Australia 2004) because plants and their roots can:

- bind the soil
- use excess water and allow enhanced infiltration
- slow wind speed over the soil surface
- prevent moisture loss
- trap airborne dust, seed and organic matter.

To increase the chances of success, any exposed surfaces to be revegetated should have a rough and loose surface free of compaction, as shown in Figure A 21. This will provide a favourable seed bed by facilitating moisture retention, providing protection for the seed and a good medium for rapid plant growth (NSW DPIE 2004).

Figure A 21: A suitable seed bed to assist rapid revegetation



Source: NSW DPIE (2004).

Grass can cover a large area in a short period of time and produce a dense mat of vegetation. Consideration should be given to the use of native versus non-native grasses, and the potential for exotic grasses to become weeds. A cover crop such as rye corn is useful to hold soil while other vegetation becomes established. This crop is non-invasive and poses little weed risk. Sowing rates of between 50–150 kg/ha are recommended, applying the higher rate where soils are less fertile and more fragile.

Hydro mulching and/or bitumen mulching can also be effective as a short-term means of stabilising loose soils. A suspension of water and paper, straw pulp or bitumen can be used, applied as a slurry to exposed surfaces and will effectively cover and bind the top layer of soil. The mulch can include seed, which can hasten revegetation.

Environmental management during construction needs to be dynamic as risks can change from day to day, depending on the nature of work being undertaken and the occurrence of unforeseen events such as heavy rainfall. As a result, contingency planning is a difficult element of the implementation of any environmental management plan. Scheduling certain parts of the construction job during periods of lower rainfall is possible, but weather patterns are not sufficiently consistent in many parts of Australia.

Revegetation of batters as soon as possible after earthworks are completed is recommended rather than waiting till all roadworks are completed. This will minimise the potential for soil erosion and additional sediment in drainage channels (Figure A 22).

Figure A 22: Rapid reseeding of fill batter reduces potential for erosion

Source: ARRB (2009).

Trees and shrubs have similar effects to grasses but take longer to provide the same protection. Consideration of the type and source of trees and shrubs should include the use of local indigenous species, the form of planting, for example seeds, cuttings or transplanting, the preparation of the planting site and after-planting care, such as watering. It is essential to consider local conditions and the needs of local plant species to ensure success. Consult local guides on appropriate revegetation techniques.

Non-vegetation erosion and sediment control structures

Structures that control the movement of water are designed to direct water away from erosive areas or to disperse water before it can become concentrated.

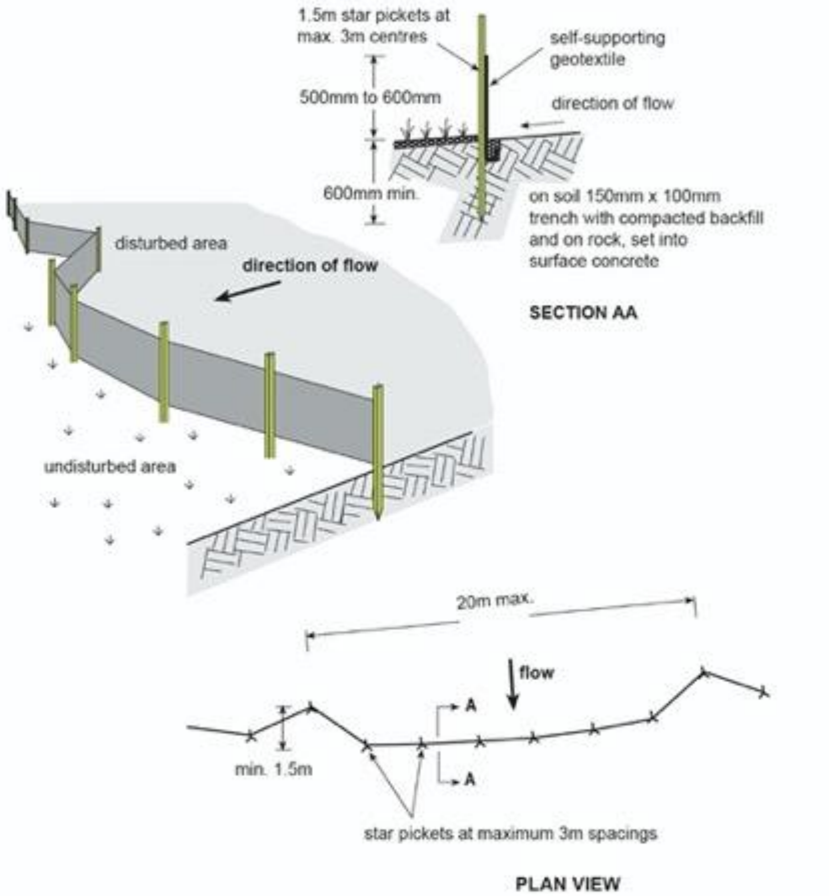
Physical control measures are structures, materials and methods, which are built to control the movement of water, to provide surface protection or to modify the soil surface. These include:

- catch drains or diversion banks to transport water for safe disposal e.g. lined batter drains, culverts, cross drains
- sediment traps such as hay bales and geotextile sediment fences which can be effective in protecting construction activities and give insurance for that period of time when vegetative stabilisation is establishing
- detention basins for settling out sediment (and other pollutants) before drainage water leaves the construction site
- energy dissipaters which slow the velocity and spread of water (e.g. box culverts, riprap at exit points)
- soil protectors e.g. mulches such as straw, woodchips, gravel and netting.

Even if erosion control measures are put in place, some sediment will eventually be washed from earthworks. Sediment traps are temporary measures which can be very effective in mitigating sediment pollution of downslope areas (particularly waterways) if properly installed and maintained. They will contain the coarser sediment fractions and should be positioned to keep sediment as close to its source as possible.

Install sediment traps as near as possible to the source of the sediment. Their catchment area should not exceed 900 m^2 and they need to be able to hold up during the design storm event. Sediment fence design and construction is presented in Figure A 23 and depicted in Figure A 24 while Figure A 25 provides details on the design and construction of a straw bale filter, which is shown in Figure A 26 (NSW DPIE 2004). They can be made from straw bales, woven geotextiles or aggregated rock material.

Figure A 23: Sediment fence design



Construction Notes

Construct sediment fence as close as possible to parallel the contours of the site.

Drive 1.5 metre long star pickets into ground, 3 metres apart.

Dig a 150mm deep trench along the upslope line of the fence for the bottom of the fabric to be entrenched

Backfill trench over base fabric

Fix self-supporting geotextile to unslope side of posts with wire ties or as recommended by geotextile manufacturer

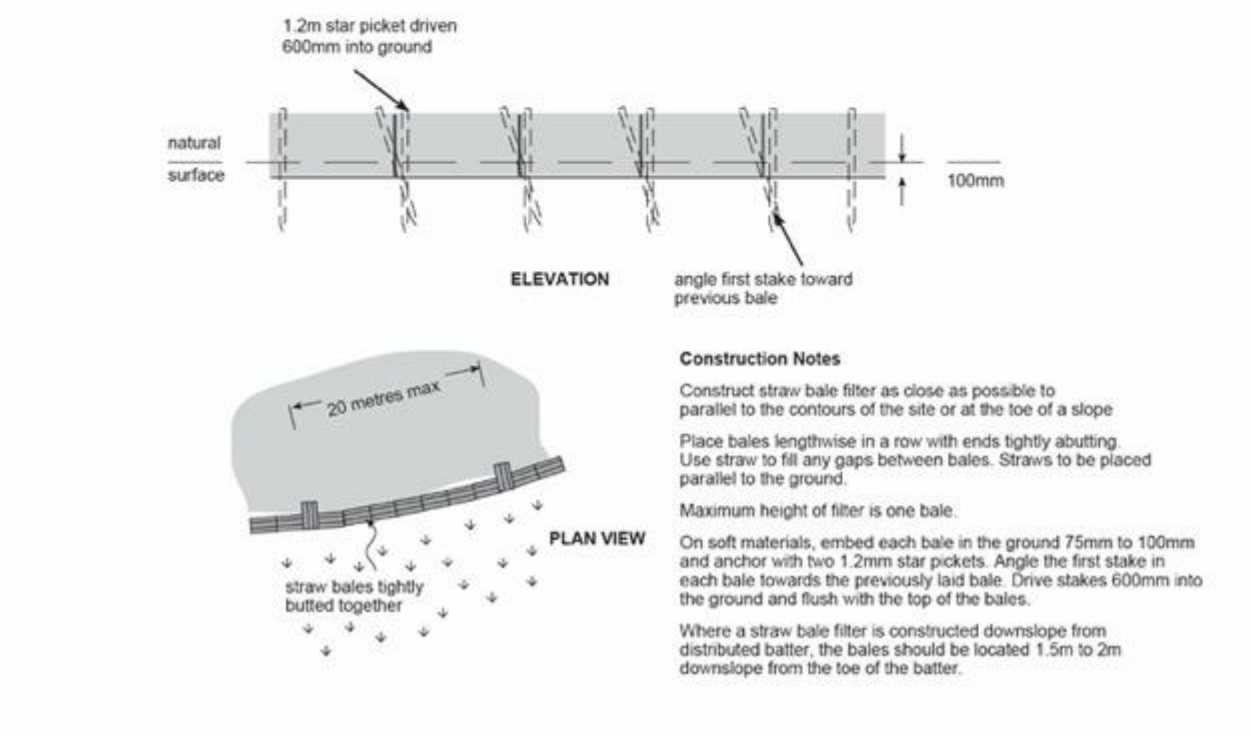
Join sections of fabric at a support post with 150mm overlap

Source: NSW DPIE (2004).

Figure A 24: Sediment fences are effective during road construction

Source: ARRB (2009).

Figure A 25: Straw bale filter design



Source: NSW DPIE (2004).

Figure A 26: Straw bales used as sediment traps

Source: ARRB (2009).

Other measures that provide surface protection against erosion are generally temporary structures that are used until the surface can be stabilised, usually through revegetation. Other methods which can modify the soil surface include soil compaction which improves a soil's resistance to particle movement, and soil stabilisation and sealant products, which cement or promote densification of the soil to achieve a non-erosive surface (Keller et al. 1995).

Sediment basins, as shown in Figure A 27, are used on larger construction projects and are designed to intercept sediment laden run-off and then settle out the suspended sediment prior to release to the natural discharge point. Basins are designed according to the type of soils involved and their relative 'residence time' required to settle. Coarser-grained fractions will settle more quickly than finer material. Various stormwater management manuals provide design guidelines for sizing sediment basins (such as NSW DPIE 2004 or Victoria Stormwater Committee 1999).

Figure A 27: Sediment basins intercept sediment laden run-off prior to release into waterways

Source: ARRB (2009).

A.3.3 Drainage Construction

Catch drains/banks

The best way to reduce erosion from a construction site is to prevent foreign water entering the site from the surrounding landscape. This can be achieved in the following ways:

- Construct stable diversion drains/banks to divert water around and away from exposed areas of soil or loose material (Figure A 28).

- Diversion banks should be built with a gradient no steeper than 5%, unless they are stabilised prior to the occurrence of a rainstorm.
- Good soil bonding between the bank and the natural surface is important to prevent the bank from being undermined or subject to rill or tunnel erosion.
- Compact and revegetate as soon as the bank is constructed to assist in stabilisation.

Figure A 28: Catch drain/bank should be established as soon as possible to divert water from the road construction area

Source: ARRB (2009).

Table drains

- Minimise the steepness of drain batters. Table drains with steep batters are prone to erosion.
- Where table drains are prone to erosion, such as drains on steep roads, construct cut-off drains at more frequent intervals.

Culverts and pipes

Undermining of pipes can have significant impacts on water quality and stability of road embankments. There are several ways to reduce this including:

- Place culverts and pipes on well-compacted material and compact backfill to ensure erosion from around or underneath the structure does not occur at a later date.
- Pay special attention to exits and entrances of new culverts and pipes to protect against the increased flow which will pass through the area.
- Install energy dissipation and water-spreading devices such as riprap and geotextiles where there is risk of erosion occurring.
- Ensure entrance and exit elevations are close to the natural ground surface, or the desired elevation of the drain.

A.3.4 Excavation and Embankment Construction

There are several key factors that affect the environmental impacts of earthworks during construction. These are outlined below.

Cut and fill batters

- Construct catch drains/banks above the cut before works proceed.

- Undertake contour cultivation of the batter face to assist with holding the topsoil and the establishment of vegetation. Figure A 29 shows an unstabilised and eroding batter slope.
- Stabilise fill batters as soon as possible after construction, especially if located on the outside of an out-sloped or crown crossfall, where water will flow down the batter.
- Ensure proper toe drainage is installed as soon as the cut is made, as shown in Figure A 29.
- Round the top and toe of the batter to help reduce water velocity and control soil erosion.
- Consider batter protection banks and catch drains as insurance against erosion before vegetation has established.

Figure A 29: Unprotected batter slope

Source: ARRB (2009).

Staggered earthworks

Wherever practical, work a small road section at a time. This reduces the amount of soil that is exposed at any one time, which reduces the risk of erosion from sudden rainstorms and strong winds.

Revegetation

Revegetate exposed soil surfaces such as batter slopes as soon as possible after construction of each road section. Avoid leaving all the revegetation works until the end of the construction process. Progressive revegetation helps to reduce erosion and sediment loss as well as increasing the aesthetic appeal of the work once it has been completed.

A.3.5 Pavement Construction

Key considerations in reducing the environmental impacts of pavement construction works include:

- Cover loads during transportation of dry materials, except over a short distance (< 2 km). Covering loads prevents material being blown out of the trucks, especially if the material contains fine soil particles.
- Consider adding water to material before removal from the stockpile or borrow pits, especially if water is required for compaction at the construction site. Dampened material is less likely to lose fines out of a truck.
- Do not overwater pavement material on a construction site, especially if the site is on a steep grade and run-off is likely.

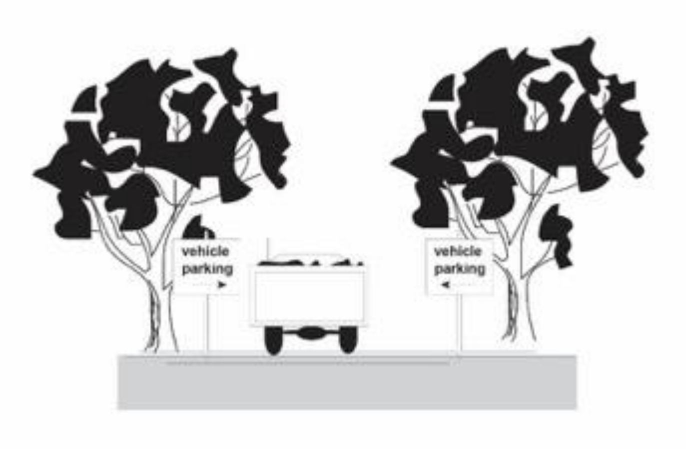
- Compact material at the end of all workdays, even if it will require ripping the following morning. This will reduce the risk of erosion if a rainstorm passes overnight.

A.3.6 Construction Equipment and Movements

Key considerations in reducing the environmental impacts of machinery used in construction include:

- Vehicle and machinery parking areas should be designed and allocated before commencement of works, as shown in Figure A 30. Parking areas should be clear of vegetation, well drained, have low erosion risk, be away from tree drip lines and, where feasible, not be visible from the road.

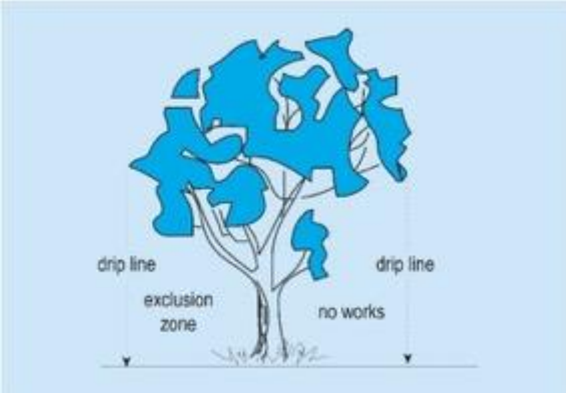
Figure A 30: Parking of machinery and vehicles in designated areas



Source: ARRB (2009).

- Avoid vehicle and machinery movement in vegetated areas and on undisturbed soils as it leads to:
  - disturbance of surface cover, surface soil structure and undergrowth (this can lead to loss of habitat for native animals and promotes the invasion of weeds)
  - direct damage to trees by nicking of roots or trunks, or by tearing off of limbs (this increases the tree's susceptibility to disease)
  - soil compaction which may prevent air and water reaching roots and increases the velocity of surface run-off, leading to increased erosion and sedimentation of the surrounding environment.
- Work should be avoided between the drip line, shown in Figure A 31 and the trunk of a tree. Most a tree's surface roots are located in the top 300 mm of soil in this zone and are the main source of water, air and nutrients to the tree. Therefore, any works that cause soil compaction, deposits of material or the removal of the topsoil from this area will have a detrimental effect on roadside vegetation.

Figure A 31: The drip lines of a tree



Source: ARRB (2009).

- Where practical, operate vehicles and machinery from cleared areas such as the road carriageways, stockpile sites or cleared private land.
- Maintain vehicle exhaust systems to minimise air and noise pollution.
- The servicing of vehicles on roadside reserves should be avoided wherever possible. Moving vehicles to another location, such as a works depot, is preferable to servicing on site. If servicing on site must occur, the selection of an area of low conservation value and use of pollution prevention techniques against spillage of machinery fluids, will reduce its impact on the environment.
- All vehicles and machinery should be cleaned before being moved to new work sites. Cleaning should involve the scraping and brushing off of soil and vegetation matter and then washing down with a high-pressure water device. Washing of vehicles and machinery should use as little water as possible, because contaminated water can flow into nearby waterways. The incorporation of vehicle hygiene procedures will minimise the spread of weeds and soil-borne diseases.

A.3.7 Aesthetic and Landscape Considerations

There are also aesthetic and landscape considerations during the construction phase.

Dust control

Dust can be a major problem on road construction sites and can become a nuisance to the public, and a safety and environmental hazard. Dust can be minimised using one or more of the following techniques:

- Establish vegetation as soon as possible.
- If an area is required to be left with exposed soil, rough the soil surface through cultivation or ripping. This reduces the air velocity at the soil surface and minimises the amount of fine particles removed from the surface.
- Cover exposed soil surfaces with straw, gravel, woodchips, mulch or netting wherever feasible.
- Where practical, cover exposed construction material with tarpaulins or woven mesh.
- Water the exposed soil surface frequently to dampen the surface, which reduces dust and particle movement, as shown in Figure A 32.
- Install semi-permeable windbreaks.
- Apply dust suppressant products on exposed areas.

Figure A 32: Watering of road to reduce dust emissions

Source: ARRB (2009).

Tidying up

The condition in which a site is left after construction can also have a significant environmental and aesthetic impact on the area. It is there recommended that the following should be considered when tidying a site:

- Remove all excess material that has the potential to be eroded or to harbour pest and weeds if left on site.
- Avoid tidying up around vegetation, other than to remove exotic material. Shrubs, logs, old or dead trees and small native plants are valuable for wildlife and should be retained, unless they are a threat to safety.

A.4 Maintenance

A.4.1 Routine Maintenance

Important environmental aspects of routine maintenance of unsealed roads include the following:

- grading of road pavements
- maintenance of drainage structures
- clearing of table drains, culverts and pipes
- batter slope maintenance
- vegetation management.

The important aspects of routine maintenance are described below.

Grading of road pavement

- Grading of unsealed roads is important in order to maintain the desired crossfall and to remove surface defects. If the road is not graded regularly, it will become prone to scouring and erosion, leading to increased sediment entering the surrounding environment.
- Avoid increasing the pavement width when grading unsealed roads.
- Grading is best undertaken after some rain, when the surface material is damp which aids compaction.

Maintenance of drainage structures

- Drains require regular clearing to remove deposited material which reduces their capacity and function.
- Avoid reshaping drains during clearing operations.
- Turn-off drains will need to be re-opened if blocked by road surface grading.
- Avoid windrowing drain material into roadside vegetation. Direct drain spoil towards the road pavement for collection.
- Where drain spoil cannot be re-used on the road pavement, dispose of it in a designated area or disposal depot.
- Avoid damaging or removing vegetation that is growing outside the function area of table drains.

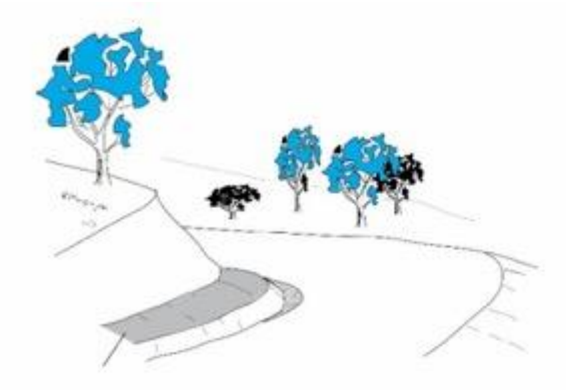
Drain spoil being directed to pavement

- Clear debris from the entrance points to culverts and pipes, ensuring that the ground surface is not disturbed in the process, as this will cause increased erosion.
- Confine machinery to the formal road, where practical. If machinery is required to be located on the roadside reserve, avoid damage to tree roots, trunks and limbs and understorey vegetation.
- Ensure all debris and excess material are removed at the end of a job and not left on roadside reserves to harbour animal pests.

Batter slope maintenance

- Maintain vegetation on the batter slope. If necessary, revegetate batters regularly to ensure protection from erosion.
- Maintain catch drains above the batter slope to minimise surface water flowing down the embankment.
- Avoid cutting into the toe of cut batter slopes during table drain maintenance operations, as this will reduce their stability and may lead to the bank collapsing (Figure A 33).
- Reshape batter slopes only as a last resort when other maintenance operation cannot prevent erosion. Cut slopes on as flat a grade as possible, to prevent erosion in the future. Rip along the contour of the slope and revegetate as soon as possible to increase slope stability. For very weak soils an almost vertical face is preferable to minimise soil erosion.

Figure A 33: Possible slumping of cut batter following removal of batter toe during grading



Source: Garden (1983).

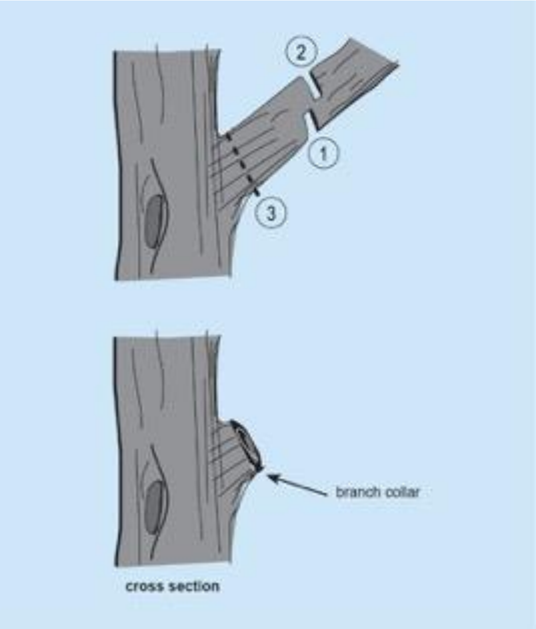
Vegetation management

Vegetation growing along roadside reserves will inevitably grow over the road carriageway in a way that may make the road unsafe for motorists. Vegetation requires continual pruning to maintain it within safe boundaries, using the following approaches:

- Pruning should always maintain the aesthetics of an area.
- A general guideline for pruning of branches is for a vertical clearance of up to 5 m above the road and between the back of table drains or road verge.
- The careful pruning of overhanging branches above roads can often reduce the need for the removal of the entire tree.
- Always use the target pruning method, as it assists the tree in wound healing and provides a protective barrier against disease attack. The target pruning method requires a three stage cut for all but the smallest of branches, as shown in Figure A 34 (Coder 2008); it involves:

4. the under cut
5. the upper cut, to remove the branch
6. the final trim: cut close to, but not flush with, the tree-trunk and on the outside of the branch collar. (The branch collar is where the timber grains interlock; when pruning retain the interlocked area but remove the limb.)

Figure A 34: Target pruning



Source: Coder (2008).

- Do not burn or dump unchipped material along roadside reserves. It reduces the aesthetics of the area and a pile of vegetation is a haven for pest animals. Chip vegetation and add it to road reserves as mulch or stockpile it at a works depot for use in landscaping projects.
- In areas where trees have Mallee roots, it may be preferable to trim the tree back to its base.

Slashing and spraying are an essential part of fire prevention operations and to maintain the safety of roads. It is a common practice along many roadsides, as it is relatively cheap and effective. It is proposed that the following guidelines be considered:

- Mow only what is necessary for road safety and fire prevention and control. In many circumstances, this is only to the back of the table drain.
- Minimise soil disturbance by ensuring the ground is dry enough to support machinery and that slasher blades are set high enough to provide adequate ground clearance.
- Avoid mowing native vegetation wherever possible. When mowing is required, mow native grasses and wildflowers after seeding or flowering. In most cases, this is Autumn, but check with someone who knows the local vegetation, such as a botanist or ecologist.
- Avoid mowing over regenerating trees and shrubs. Stakes can be used to protect young trees when mowing, as shown in Figure A 35.

Figure A 35: Protection of young regenerating trees

Source: ARRB (2009).

- Time slashing to encourage growth and spread of indigenous species rather than exotic grasses and weed species.
- The chemical control of weeds in the vicinity of waterways is undesirable due to the vulnerability of frogs, fish and invertebrates.

A.4.2 Protecting Stream Water Quality

The eight steps to achieve best practice drainage maintenance of unsealed roads are (Kemp (2004)):

1. Divert stormwater away from waterways:
   - Avoid directing table drains and cut-off drains discharging directly into waterways to prevent easy access of sediment into streams and rivers.
   - Where necessary, trap sediment before it reaches the stream using cut-off drains, sediment traps and filters (Figure A 36).

Figure A 36: Sediment filter preventing sediment from entering stream

Source: ARRB (2009).

2. Clean table drains only when necessary:
    - Keeping drains rough and irregular shaped (at the same time retaining adequate capacity) will slow water flow and trap sediment, whereas smooth surfaces will mean more erosion and more sediment production.
3. Shape table drains to a shallow flat-based profile:
    - Avoid using a grader if it is possible to form and clean out drains, rather use an excavator or backhoe to get better results.
    - Aim for a flat-based profile.
4. Minimise the area of disturbance:
    - Keep work area as small as possible and avoid widening the road or producing windrows on the roadside.
5. Ensure cut-off drains are adequately spaced:
    - Cut-offs reduce the volume and speed of stormwater in the table drain, thereby reducing erosion and sediment transport.
    - As rule-of-thumb, place cut-offs about 100 m apart, on gentle slopes that will not cause erosion at the outlet.
6. Always protect roadside vegetation:
    - Keep well clear of roadside vegetation when grading and drain cleaning as vegetation plays a key role in maintaining roadside stormwater quality.
7. Maintain a good quality road surface:
    - When a road surface deteriorates it produces more sediment. To maintain a good quality surface aim for a crossfall of 4–6% to facilitate drainage, a well compacted surface using water whenever possible, adequate gravel thickness, minimal rills and corrugations, and good quality road material with a well-graded mix of stone sizes.
8. Assess risks prior to applying dust suppression products:
    - Be aware of potential water quality impacts associated with the application of some dust suppressants, as they may become unstable when wet.

A.4.3 Periodic Maintenance

Additions of pavement material

Adding extra pavement material to unsealed roads, as a replacement for surface material lost over time, has similar potential environmental impacts as the original laying of the material. Therefore, follow the guidelines under Section 4.4.

A.4.4 Dust Control

The economic, health and environmental implications of road dust on adjacent land use can be significant, in addition to the problems resulting in loss of material from the road surface.

Dust also has safety consequences that require addressing. The adoption of a road dust control program for a specific road depends upon an evaluation taking into consideration the:

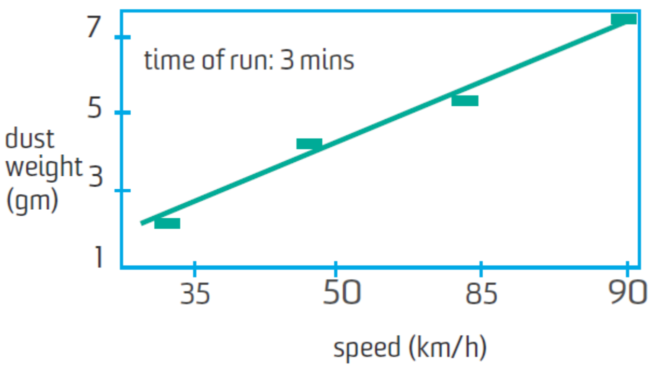
- degree of social and environmental impact
- average daily traffic
- road safety needs.

Dust is caused both by the loss of fine particles (less than 0.075 mm) from road surfaces arising from loosening of the pavement materials, and disturbance of the wearing surface caused by the action of traffic and climatic conditions.

The effect of the loss of fines is to increase the permeability of the surface, resulting in early pavement deterioration and accelerating the need for resurfacing. Loss of fines also exposes a coarser textured surface, creating higher levels of irregularities which, in turn, increase vehicle operating costs. Loss of fines incurs replacement costs of pavement material, with subsequent social and economic costs. As the proportion of fines increases in the pavement so does the potential loss. Maintenance plays a major role in controlling fines loss by dust and erosion.

The amount of dust generated from a pavement surface depends on various factors relating to wind speed at the road surface caused by vehicles (as illustrated in Figure A 37), number and type of vehicles, grading and restraint of fines and climatic conditions.

Figure A 37: Dust generation as a function of speed



Source: Addo and Sanders (1995).

Short-term or seasonal dust suppression may be affected by the application of dust palliatives to the road surface. Longer-term solutions involve either sealing of the pavement or using materials with optimum plasticity limits, to achieve cohesion in the wearing course material without affecting its strength and resistance to skidding.

The remedies for dust emission problems can be expensive; nevertheless, dust palliatives may provide an alternative short-term solution to sealing the road. Where dust is the principal cause of accidents or degradation of primary produce, the use of dust palliatives may be justified in terms of the benefits occurring from the reduction in accidents and loss in value of primary produce. Any long-term improvement to the dust problem, however, is likely to come from either sealing of the pavement or, alternatively, upgrading the gravel surfacing materials to the specifications discussed in Section 3.6.6.

Dust palliatives

Numerous proprietary chemical stabilisers are currently on the market, suggesting a wide range of benefits associated with reducing gravel loss and maintenance requirements, reducing dust and erosion potential and even providing structural improvement of roads. These can be separated into those that only retain surface fines (dust palliatives) and those that chemically treat and strengthen the wearing course materials.

Details regarding the selection and use of dust palliatives can be found in the ARRB *Road Materials Best Practice Guide* (ARRB 2020b).

Appendix B Signs and Delineation for Unsealed Roads

Signs for alerting drivers of potential hazards on unsealed roads are outlined in the following sections. It is particularly important to alert drivers to hazards they might not ordinarily expect (for instance, due to sudden changes in conditions). This is not an exhaustive list of suitable signs. Refer to the relevant Australian and New Zealand Standards and road design manuals for further guidance. Information for signs and delineation in the following is based on *AS 1742.1 Manual of Uniform Traffic Control Devices* series.

Drivers rely on visual information when operating their vehicle. Poor visual information is a major factor in the incidence and severity of single vehicle run-off-road crashes. It is therefore imperative that roads provide sufficient visual information to allow drivers to travel safely whether it is an unsealed access road or a high standard sealed road.

The application of appropriate visual information on unsealed access roads may be provided in a number of ways, namely, by guide posts, warning and directional signs. Visual information (signage, guide posts etc.) should only be installed where a risk assessment has identified that a hazardous situation exits. For very low volume tracks there should be signage at least at the commencement of the route with only hazard warning signage at critical locations, i.e. where there are surprises (e.g. steep descent, road ends, sharp curve, etc.).

B.1 Delineation

Delineation of a road is used to (Freeman et al. 1988):

- control the positioning and travel of vehicles by providing visual information to the driver that identifies the safe and legal limits of the travelled path
- regulate travel direction, lane changing and overtaking
- improve lane discipline, particularly during night-time
- assist in identifying potentially hazardous situations (e.g. hazardous obstacles)
- highlight changes in horizontal and vertical alignment.

Delineation can be more difficult for unsealed roads than sealed roads, as pavement markers and raised reflective pavement markers (RRPMs) cannot be used. Therefore, it is important to ensure adequate delineation through provision of guide posts and reflectors.

Consider whether hazards change during different driving conditions. For instance, a horizontal curve that may be visible during daylight conditions may be difficult for drivers to detect during night-time (Figure B 1). The same considerations need to be given to intersection visibility.

It is important to ensure guide posts (delineators on the posts) are maintained in a good condition as this is often the only delineation provided for road users.

Figure B 1: Contrast between daylight and night-time conditions

Daytime view **Night-time view**

Delineation is crucial to the safe and efficient operation of a road. Drivers use visual cues to position their vehicles within a roadway (short-range delineation), to drive at an appropriate speed (short to long-range delineation) and to make navigation and control decisions (long-range delineation). Long-range delineation, which allows a driver to plan the route to be travelled ahead needs to be consistent and continuous. An outline of roadside delineation hardware follows.

B.2 Guide Posts

Guide posts and post-mounted delineators. Guide posts are light in weight, 0.9 m to 1.2 m high and are placed 1.5 m to 3.0 m from the edge of the outside lane (i.e. on the outside of the shoulder). Guide posts are inexpensive to buy, install and replace. They are resistant to extreme weather, and generally do not pose a risk to road users. Guide posts may be manufactured in a variety of materials such as timber, fibreglass, aluminium and plastic. The posts can be used at specific locations to mark the location of a culvert, along a short section of road to highlight the presence of a curve or be provided along hazardous sections of road such as across a causeway. Where provided along a continuous road section the driver should be able to see at a minimum two guide posts (AS 1742.2).

The posts generally have reflective markers fixed to their upper end to face oncoming traffic. The reflective markers may be either corner cube delineators or retro-reflective sheeting (AS/NZS 1906.2; AS 1742.2). They should be at a height (i.e. 1.2 m) that minimises the degree to which soil spray or dust obscures the reflective markers. The posts should be positioned at a consistent offset from the edge of the road shoulder, taking account of superelevation and unevenness of the shoulder and be installed in pairs (i.e. either side of the road).

The colours of the markers should be as follows:

- white: on the right-hand side of the carriageway
- red: on the left side of the carriageway.

Desirably on straight sections of road guide posts should be spaced at 150 m intervals while on curves they should be spaced as shown in Table B 1. As a minimum it is considered that guide posts should be placed at each road culvert crossing, approaches to causeways/floodways and bridges and on very tight curves < 200 m. Spacings should be reduced to 60 m in fog prone areas.

Table B 1: Guide post spacing

Curve radius (metres)	Spacing (metres)	
	On outside of curve	On inside of curve
< 100	6	12
100–199	10	20
200–299	15	30
300–399	20	40
400–599	30	60
600–799	40	60
800–1999	60	60
1200–2000	90	90
2000 (incl. straights)	150	150

Source: AS 1742.2.

B.3 Hazard Markers and Sight Boards

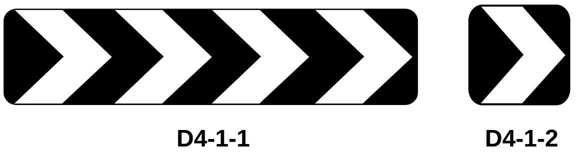
Hazard markers are signs that consist of diagonal black and white stripes which are used to indicate the presence of an obstacle or hazard, or a changed direction of travel at an intersection. A description of these signs follows.

B.3.1 One-way Hazard Markers

One-way hazard markers are used to alert approaching traffic (Figure B 2):

- to the presence of an abrupt road narrowing or where there is a lateral shift
- to an obstruction in the road where all traffic is required to pass to one side
- to vehicle paths at intersections.

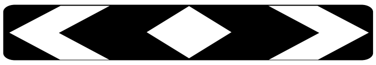
Figure B 2: One-way hazard markers



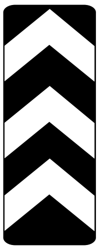
B.3.2 Two-way Hazard Markers

Two-way markers are used where it is necessary to delineate an exposed obstacle at which traffic may pass on either side (Figure B 3).

Figure B 3: Two-way hazard markers



D4-2-1

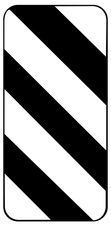


D4-2-2

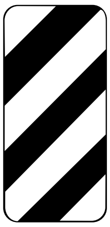
B.3.3 Width Markers

Width markers are generally installed in pairs and are used to highlight the width at narrow points in a road which may occur as a result of a bridge, a rail crossing or an underpass pier (Figure B 4). The D4-3 (L) sign is used on the left-hand side while the D4-3 (R) sign is used on the right-hand side.

Figure B 4: Width markers



D4-3(L)

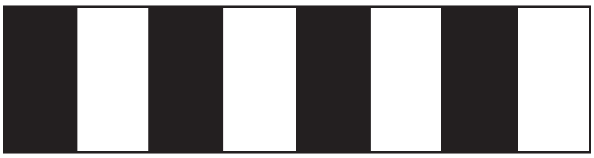


D4-3(R)

B.3.4 Obstruction Markers

Obstruction markers are used to delineate obstructions within or above a road (Figure B 5). Typically, they are used to highlight a road closure or to show the vertical clearance above a road where there are height restrictions.

Figure B 5: Obstruction markers



D4-5

B.3.5 Curve Alignment Markers (CAMs)

CAMs should be used to augment the delineation of substandard curves and in conjunction with post delineators (Figure B 6). The recommended spacings of CAMs are provided in Table B 2. A minimum of three markers should be used on any one curve, while a minimum of two markers should be visible to approaching vehicles. To meet these requirements, it may be necessary to vary the recommended spacings.

Figure B 6: Curve alignment markers (CAMs)

D4-6

Table B 2: Recommended spacing for curve alignment markers

Curve radius (metres)	Spacing (metres)
< 50	6
50–99	8
100–149	12
150–199	16
200–249	20
250–300	24
> 300	26

CAMs are installed on the outside of curves at a height of about 1.5 m and should be placed out from the carriageway at between 1.5 m and 3.0 m. The signs should also be angled to face approaching traffic.

B.4 Road Signs

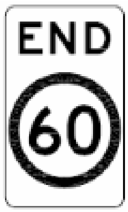
Road signs inform drivers of:

- legal or regulatory requirements (i.e. stop or give way signs)
- a potential hazard ahead (e.g. concealed road, steep descent)
- directions to take to reach a destination.

Figure B 7 illustrates typical regulatory signs while Figure B 8 and Figure B 9 provide examples of hazard and directional signs. AS 1742.1 and AS 1742.2 provide a comprehensive range of hazard signs and additional examples of guide or directional signs. Avoid the use of advisory speed signs on unsealed roads, as the road surface conditions cannot always be guaranteed to enable a driver to travel safely at the advised speed. Better practice is to advise drivers of potential hazards (e.g. curve warning signs where appropriate) and allow drivers to determine appropriate driving speed based on the prevailing conditions (Figure B 10).

Table B 3 provides guidance on the use of posts and signs for various road classifications.

Figure B 7: Examples of regulatory signs

		
 Speed zone	 End speed zone (reverts to default speed limit)	 Speed de-restriction (reverts to default speed limit)

Note: AS1742 advises that ‘speed limits other than the default or default rural limit shall not be applied to unsealed roads’, this indicates that regulatory speed signs should not be on unsealed roads. Should a road manager chose to use a regulatory speed sign to reduce speeds below the default speed limits, to for example, mitigate safety risks, the decisions leading to the use of a regulatory speed sign should be documented.

Figure B 8: Examples of hazard signs

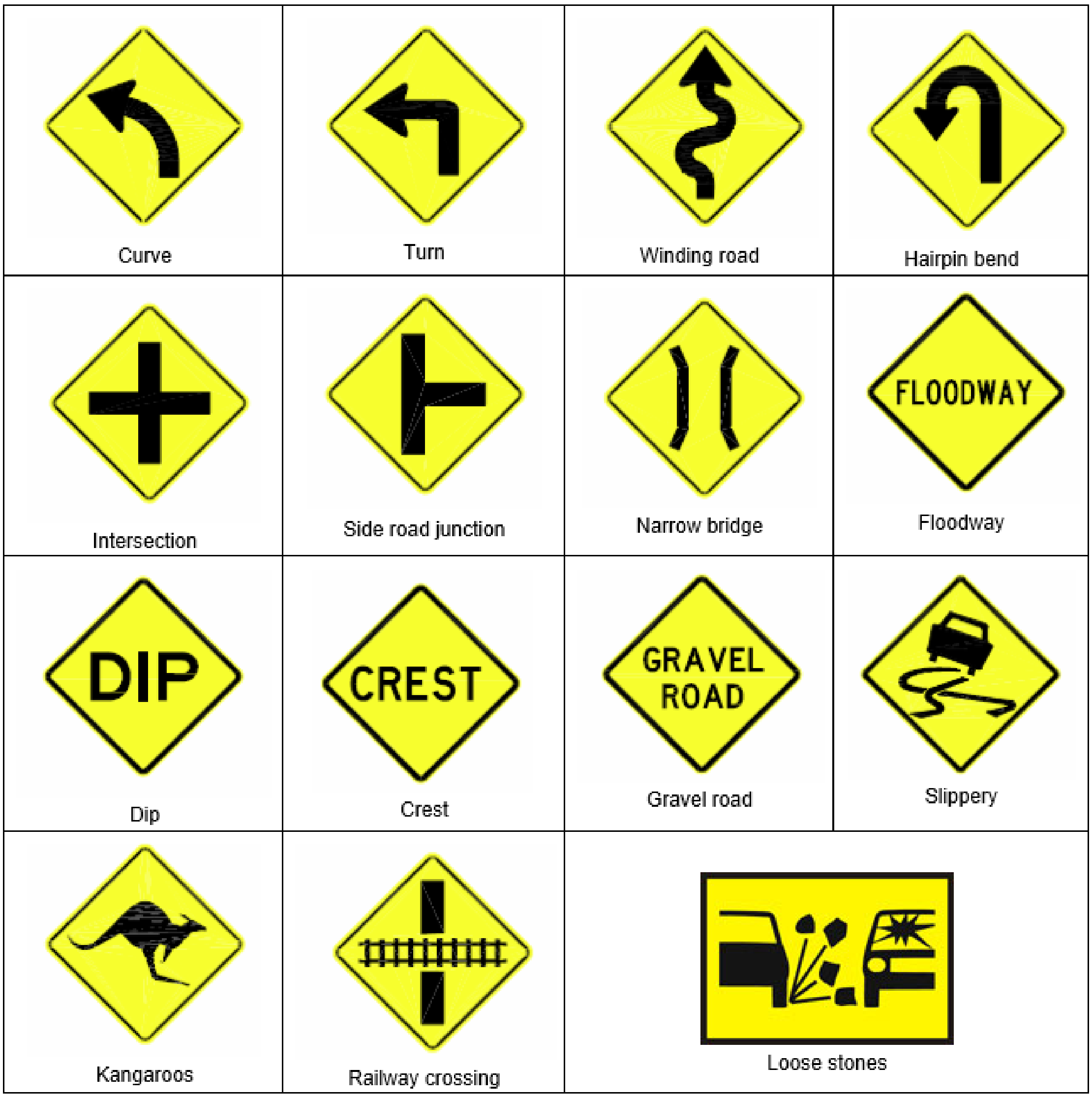


Figure B 9: Examples of guide signs

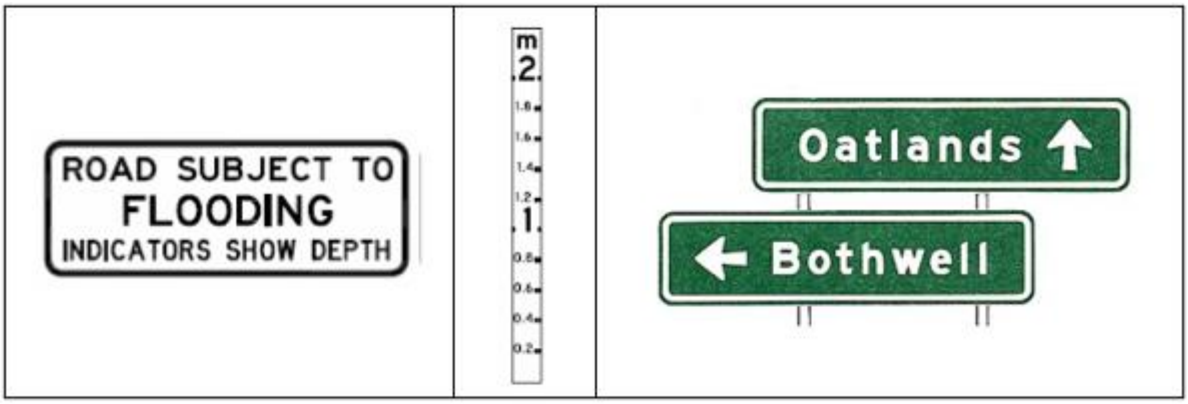


Figure B 10: Examples of non-standard warning signs for unsealed roads that can provide more specific guidance and/or advice for drivers than existing standard signs.

Table B 3: Recommended use of guide posts and signs based on road classification

Road classification	4A Main road	4B Minor road	4C Access road	4D Tracks
Guide posts	Yes	Yes	Yes	No
Hazard markers and sight boards	Yes	Yes	Possibly	No
Curve alignment markers	Yes	Possibly	No	No
Road signs – guidance	Yes	Possibly	Possible	Possibly
Road signs – hazards	Yes	Possibly	Possibly	Possibly
Road signs – regulatory	Yes	Possibly	Possibly	Possibly

Source: Giummarra and Blanksby (2006).

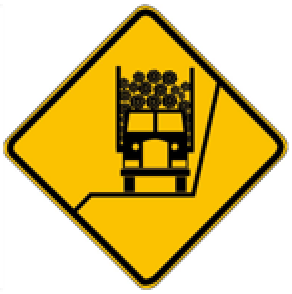
Signage for roads with heavy vehicles

The vehicle composition of road or route should be considered. On a route where there is a high proportion of heavy vehicles, or where drivers on a route may be likely to be tourists, vehicles towing caravans, or drivers not familiar with the area and inexperienced in encountering heavy vehicles, the possible safety risk to other road users' needs to be considered. Appropriate signage advising motorists of heavy vehicle operations should be provided, some examples are provided in Figure B 11.

Figure B 11: Examples of heavy vehicle route signage

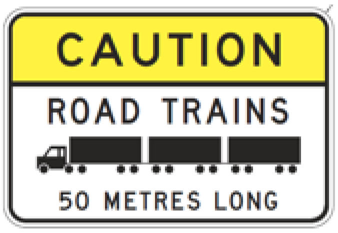
TC1210-1

TC1210-4

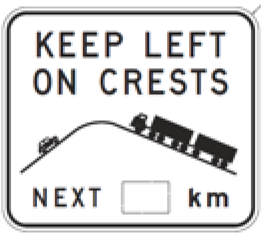


Signs for logging route

Signs for logging route



TC9927



TC9491

TC9466

TC1506 (seasonal)

Note: Installed as per AS 1742.2 (2009), TC signage as per TMR traffic control (TC) signage.

Source: NACoE (2019).

Appendix C Detailed Geometric and Drainage Design

The purpose of this Appendix is to cover the main aspects relating to the geometric design of major road upgrades or new road construction and to highlight those features which are of particular relevance to unsealed roads. The Appendix can also be used to help in identifying those parts of an unsealed road which do not conform to appropriate geometric and safety requirements.

C.1 Geometric Design Criteria

The following sections give a guide to the various parameters which influence the geometric design of an unsealed road.

C.1.1 Operating Speed Considerations

Drivers in general travel at a speed which they feel to be safe, and at a level of risk which they are prepared to accept. Speed is often based on the quality of ride on unsealed road surfaces, the radius of horizontal curves, road environment and visibility. However, drivers may not have a good appreciation of roadside hazards and their consequences.

For unsealed roads travel speeds can vary significantly from day to day based on the prevailing road surface conditions at the time. During a wet period, travel speeds will be much lower than in dry conditions. Drivers are therefore encouraged to drive to the road conditions and not to the highest possible speed as per the default (or posted) speed limit.

The 'operating speed' is defined as the speed of the 85th percentile driver, (i.e. 85% of drivers are travelling at that speed or less). When operating speed is cited, it means that a vehicle can travel at that speed without being exposed to hazards arising from curtailed sight distance, inappropriate superelevated curves, severe grades or pavements that are too narrow.

Usually, the higher the operating speed, the higher is the cost of construction and ongoing maintenance. The type of road, traffic volume and terrain influence the choice of operating speed. General operating speeds for unsealed roads for particular terrains are given in Section 3.5.8.

C.1.2 Traffic Volumes

A road should be designed so that it will accommodate the estimated number of vehicles using it towards the end of its design life. This number is referred to as the 'design traffic volume'.

In estimating the design traffic volume, a minimum life of 15 years is normally adopted and, where possible, the traffic volumes are based on the AADT. Where an unsealed road is exposed to high seasonal variations i.e. a popular route to the beach in summer the peak average daily traffic (ADT) volume may be more appropriate to determine the number of lanes required.

The number of vehicles and type using a road determines the number of traffic lanes, the lane width, and the time at which it may be necessary to widen a single-lane two-way road to two lanes. High traffic volumes can also justify when an unsealed road should be sealed. Details on how to undertake an economic evaluation of when to seal a road are provided in Section 2.5.4.

C.1.3 Vehicle Composition

Consideration needs to be given to the types of vehicles that are likely to be using the unsealed road network. In general, road traffic is a mixture of passenger cars and commercial vehicles with varying performance characteristics.

Figure C 1 shows the range of vehicles that may use the unsealed road network. In general, road traffic is a mixture of passenger cars and commercial vehicles with varying performance characteristics. The composition of traffic is a factor in the determination of the width of traffic lanes and the maximum vertical grade adopted for the road.

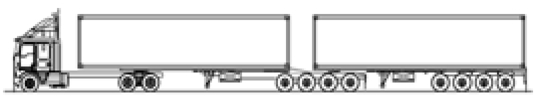
The presence of heavy vehicles on a road should be considered. Dependent on the size of a vehicle the design requirements may be based entirely on ensuring that the road can cater for that vehicle, that is that a lower order of design values may not be sufficient for the width, grade and horizontal alignment requirements for a heavy vehicle. Safety considerations should also be considered, although traffic volumes may be low the specific needs of heavy vehicles should be considered to provide safe access. A heavy vehicle is defined in legislation as a vehicle with a gross vehicle mass (GVM) exceeding 4.5t, including trailers. The National Heavy Vehicle Regulator (NHVR) regulates all vehicles of this time, including administration of the Heavy Vehicle National Law (HVNL). HVNL divides all heavy vehicles on the network into three classes, each with their own performance characteristics (NACOE 2019):

- Class 1 vehicles include special purpose vehicles, agricultural vehicles and over size over mass (OSOM) vehicles.
- Class 2 vehicles are freight vehicles longer than 19m that require specific networks that are capable of accommodating vehicles of this size. This class includes B-doubles to Road Trains.
- Class 3 vehicles are those that, together with their load, do not comply with prescribed mass or dimension requirements and are not a class 1 vehicle. This may include a B-double transporting a load wider than 2.5 m.

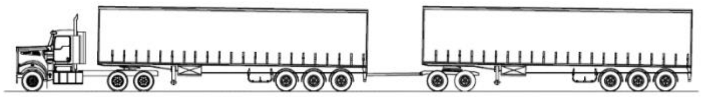
Class 2 vehicles (Figure C 2) are most likely to frequent unsealed roads, which may include the following combinations: rigid truck, rigid truck and trailer, semi-trailer, B-Double, Type 1 road trains, and Type 2 road trains. If the current vehicle composition or a future vehicle composition is likely to include these vehicles, then a Performance Based Standard (PBS) equivalent consideration should be given. Comprehensive guidance for assessing a road to provide heavy vehicle access is provided in NACOE (2019). This should be considered the minimum requirements for design purposes.

Figure C 1: Multi-combination vehicles that may require last mile access

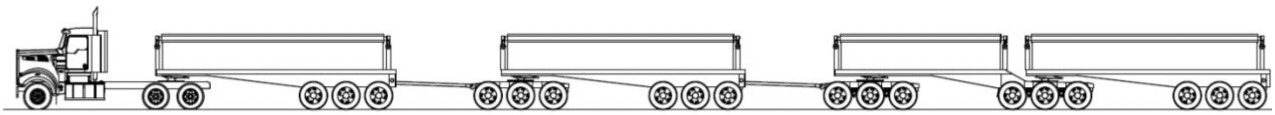
General freight 30 m B-double (PBS combination)



General freight 36.5 m A-double (Type 1 Road Train)



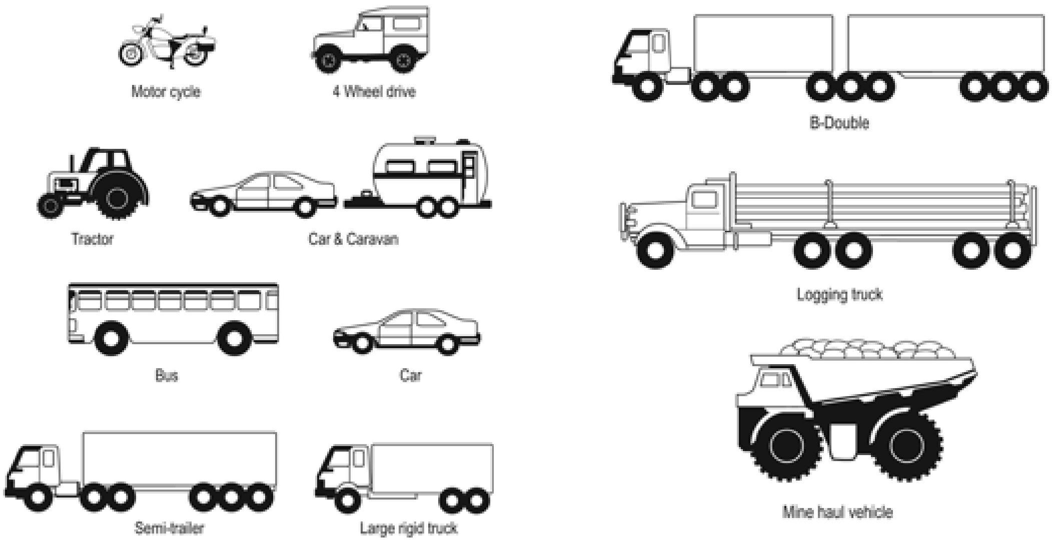
48-metre side tipping AAB-quad (Type 2 Road Train)



Source: NACoE (2019).

For logging and mine haul routes special design considerations are required and details are provided in Appendix C.6.2.

Figure C 2: Typical vehicles on unsealed roads



Source: NACoE (2019).

C.1.4 Vehicles on Grades

Although it is rare to construct roads with grades sufficient to enable all vehicles to operate at the same speed, there are nevertheless limits to the magnitude and length of grade sections. The grade limit chosen will depend on the types of vehicles using the road, the terrain and road costs.

Four aspects which influence the selection of grades in difficult terrain are:

- Grades must be able to be negotiated by heavy vehicles with low power ranges.
- Grades lead to speed variations, braking and gear changes. In the case of haulage roads, a flatter grade will enable a more constant speed, demand less of both vehicle and driver and generally lower vehicle operating costs.
- Steeper grades will cause increased wear and tear of the road surface due to extra acceleration, gear changes and braking.
- Grades create speed disparities between vehicle types. This can lead to queuing and overtaking requirements.

The maximum grade that a heavy vehicle can negotiate on a sealed road is 15%. However, this figure is dependent on the power to weight ratio of the vehicle and is therefore not fixed for all vehicles (Austroads 2003). Evidence exists that, due to insufficient traction, travel on earth or gravel roads is difficult for grades greater than 8% (Nyasulu 1989).

The following situations may, however, justify the use of grades steeper than would normally be used (Austroads 2003):

- comparatively short sections of steeper grade
- difficult terrain where the maximum grade limit is impossible to achieve
- generally low numbers of heavy vehicles
- roads of low importance where the cost of achieving lower grades cannot be justified in economic terms.

Typical grades for forest roads in New Zealand can be as high as 12% on arterial type roads and up to 18% on minor offshoots.

It should also be noted that steeper grades of > 6% will cause water run-off to flow mainly down the pavement and could cause longitudinal scouring of the surface. Further details are provided in Appendix C.7.

C.1.5 Driver Characteristics

Design parameters for determining sight distance are based on driver reaction times, vehicle types and driving conditions. The following values characteristics should be considered (Austroads 2016b):

- Driver eye height
  - passenger car 1.1 m
  - commercial vehicle 2.4 m
- Object cut-off height above the road
  - top of vehicle 1.25 m
  - stationary object on road 0.2 m
- Driver reaction time
  - Reaction time is the time for a driver to perceive and react to a particular stimulus and take appropriate action. This time depends on the alertness of the driver, recognition of the hazard and the complexity of the decision or task involved. Table C 1 outlines typical reaction times. Typically, a reaction time 2.5 seconds is appropriate; however, a reaction time of 2.0 seconds may be considered in sections of tight geometry that requires high levels of concentration.

Table C 1: Driver reaction times

Reaction time (seconds)	Typical road conditions	Typical use
2.5	High-speed roads with long distances between towns	Absolute minimum value for high speed roads with unalerted driving conditions, such as an isolated intersection on an otherwise straight and uninterrupted section of road.
2.0	Alerted driving situations in rural areas	Absolute minimum for this road type, general minimum for other road types.

Source: Adapted from Austroads (2016b).

C.1.6 Longitudinal Deceleration

Unsealed road surfaces are highly variable and very little research has been undertaken to quantify friction coefficients under various climatic conditions (Austroads 2016b). On unsealed roads, the friction factor may vary between 0.05 and 0.40, with the former applying on smooth wet surfaces and the latter on gravelly dry surfaces. As it is not practical to design for the lowest friction factors, designers may consider use of the longitudinal friction factor for unsealed roads, as shown in Table C 2. Consideration of the quality of the road surface, gravel type, local drainage, impacts of atmospheric conditions and average annual rainfall should be made. Designers should take particular care with the location of intersections to ensure that adequate stopping sight distances are available on the approaches.

Table C 2: Coefficient of deceleration for cars on unsealed roads

Speed (km/h)	Coefficient of longitudinal deceleration* (d)
30	0.27
40	0.27
50	0.27
60	0.27
70	0.26
80	0.25
90	0.24

** Values from Department of Transport, South Africa (1994) for gravel or unsurfaced pavements (with interpolation).*

As shown in Table C 3, the coefficient of deceleration for trucks on sealed roads is lower (slower) than for cars on unsealed road. This indicates that heavy vehicle stopping distances will be longer on a sealed road and even longer on an unsealed road. To calculate heavy vehicle stopping distances on unsealed roads a gravel correction factor is applied, as an additional reaction time to allow for brake lag (NACoE 2019).

Table C 3: Coefficient of deceleration for trucks on sealed roads

Vehicle class	Coefficient of longitudinal deceleration (d)
Trucks	0.29
B-double	0.24
Road Train Type 1	0.22
Road Train Type 2	0.20

Source: NACoE (2019).

For design purposes, it is important to choose values for friction coefficients which will not lead to loss of vehicle control during braking or cornering, and yet will lead to acceptable sight distances and horizontal curvature. The use of ABS braking may be of limited value on unsealed roads because of the roll-over effect of the wheels using ABS braking. It such cases switching off the ABS braking, if this is possible, should be considered.

C.1.7 Coefficient of Side Friction

Coefficients of side friction (f) for gravel or unsurfaced pavements, adopted by the Road Construction Authority (RCA) (1983), are also shown in Table C 4.

Table C 4: Coefficient of side friction on unsealed roads

Speed (km/h)	Coefficient of side friction* (f)
50	0.12
60	0.11
70	0.10
80	0.10
90	0.09
100	0.09
110	0.08

** Values for unsealed roads RCA (1983).*

For design purposes, it is important to choose values for friction coefficients which will not lead to loss of vehicle control during braking or cornering, and yet will lead to acceptable sight distances and horizontal curvature

C.1.8 Driver Perception/Reaction Time

The time elapsed between the first sighting of a hazard on the road and the time the vehicle begins to slow after application of the brakes is defined as the reaction time.

Values of 2.0 and 2.5 seconds are considered to be appropriate for general use. Driver alertness should increase when driving through tight alignments, and this can provide some justification for lowering the reaction time value below 2.0 seconds. An absolute lower limit of 1.5 seconds for reaction time is suggested (Austroads 2016b).

C.2 Sight Distance

One of the major aims of a road design is to ensure that the driver of a vehicle is able to see an obstruction or hazard on the road and have sufficient time to enable the driver to take evasive action.

Sight distances can be grouped into various categories. In the case of unsealed roads, the main ones to be considered are:

- stopping sight distance
- intermediate sight distance
- overtaking sight distance
- manoeuvre sight distance.

It is important to note that under dust conditions, visibility could be reduced to almost zero, regardless of the geometry of the road.

One measure to reduce this dust problem, suggested by the RTA (1992), is to provide lengths of sealed sections at appropriate intervals to provide safe overtaking opportunities at problem locations or where needed to overcome driver frustration.

Well-vegetated roadsides will help to reduce the spread of dust particles into abutting land but may cause a concentration along the road.

Vegetation is often a major consideration in providing adequate horizontal sight distance around a curve. When selecting vegetation species consideration should be given to the impact of mature fully grown plants on sight distance requirements. Select low height vegetation species in preference to trees and large plants where possible at critical locations particularly near curves and intersections.

It is also important to avoid planting vegetation species that can become a roadside hazard (such as large trees) close to the roadside.

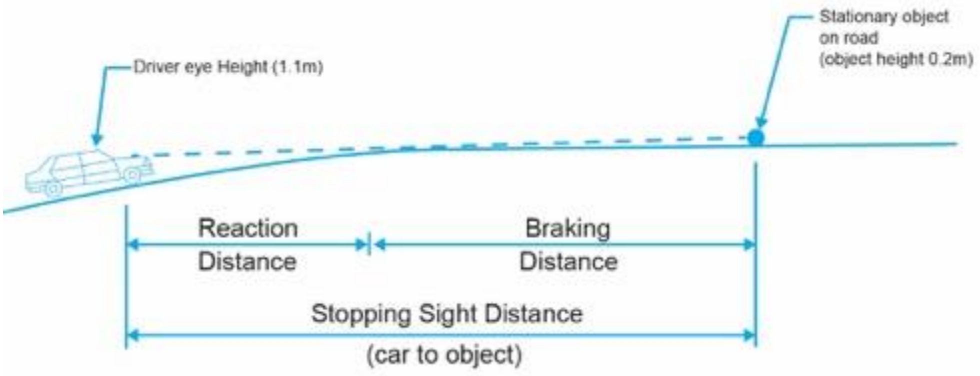
On tight curves, delineation, either with roadside vegetation or markers may be necessary on the outside of a curve to alert drivers to the tightness of a bend to assist them drive to the conditions.

Benches and batters should not be left totally denuded because the problems of weeds, erosion and accelerated regrowth of some species will be the negative results.

C.2.1 Stopping Sight Distance

Stopping sight distance (SSD) provides as a minimum stopping distance for a driver at an eye height of 1.1 m travelling towards a 200 mm hazard on the road (Figure C 3). For a crest or an overhead obstruction in the case of a sag curve the sight distance is as depicted in Figure C 4.

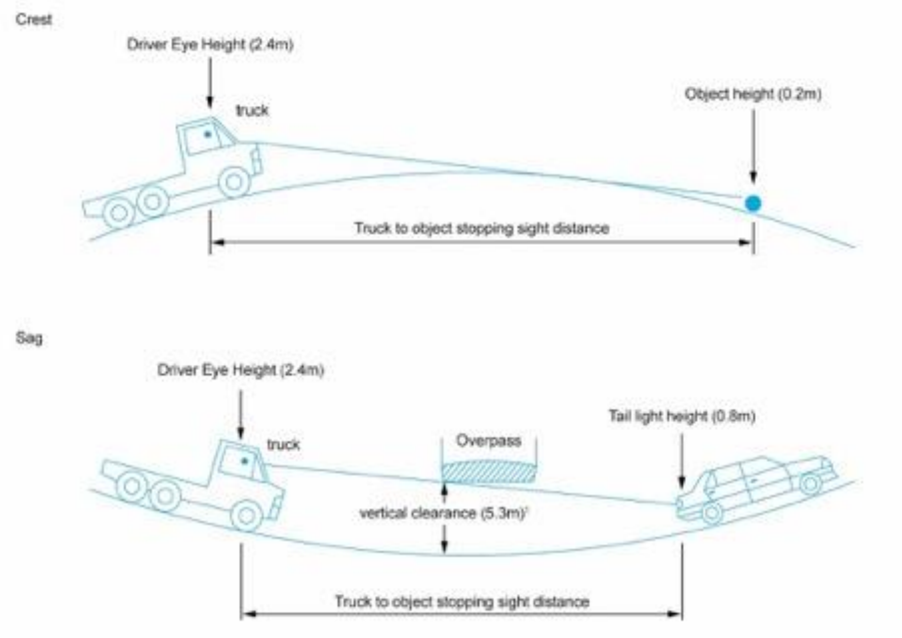
Figure C 3: Stopping sight distance



Source: Austroads (2016b).

In the case of vertical crest curves (Figure C 4) the design car dominates as it has a lower driver eye height compared to a truck and requires the longer stopping sight distance. Truck requirements are critical for horizontal sight distance around a curve (refer to Horizontal Sight Distance in Appendix C.3.5).

Figure C 4: Sight distances on crest and sag curves



1 The vertical clearance requirement of 5.3 m is indicative only. Please refer to relevant road agency for clearance requirements.

Source: Austroads (2016b).

To perceive a surface hazard (say a pothole) a zero object height would be necessary. However, at the required stopping sight distance for high speed values small surface defects (especially at night) would not be seen.

Stopping sight distance calculations comprise two components:

- distance travelled during perception/reaction time
- distance travelled while braking.

Stopping sight distance is represented by Equation A1 (Austroads 2016c):

$$SSD = \frac{R_T * V}{3.6} + \frac{V^2}{254 * (d + 0.01a)} \quad \text{A1}$$

where

SSD	=	stopping sight distance (m)
R_T	=	driver reaction time (s)
V	=	initial vehicle speed (km/h)
d	=	coefficient of longitudinal deceleration
a	=	longitudinal grade % (positive for up-grades and negative for down-grades)

The values for the coefficient of longitudinal deceleration for unsealed roads shown in Table C 2 must be used with caution. An unsealed road surface may have at best a coefficient close to a sealed road and at worst a value approaching zero. As such the resulting sight distance calculation, using the values in Table C 2 will be an underestimation in some cases. Adjustments will therefore be required to compensate for unsealed surfaces that are poorly maintained.

Stopping sight distances for various speeds and reaction times as shown in Table C 5 are again the best case situation and a suitable increase is necessary to compensate for much lower surface coefficient values. A suggested guide is to increase the stopping sight distances by 25% (Cock 1993). This increase is not scientifically based but an arbitrary value, which aims to take into account the many variables which are peculiar to unsealed roads. Studies undertaken specifically to determine safe stopping distances for unsealed roads (Koorey & Cenek 1999) found that allowing for a side friction of 0.12 the longitudinal friction coefficient that should be assumed for calculating stopping sight distances is 0.32. This results in longer stopping distances compared to a sealed road (shown in brackets) and the values for unsealed roads as shown in Table C 5 with no allowance made for grade.

Table C 5: Car stopping sight distance for various operating speeds on unsealed roads (level grades)

<table>
<tr><th rowspan="3">Operating speed (km/h)</th><th colspan="3">Stopping sight distance (m)*</th></tr>
<tr><th colspan="2">Normal design</th><th>Restricted design</th></tr>
<tr><th>RT = 2.5</th><th>RT = 2.0</th><th>RT = 1.5</th></tr>
<tr><td>50</td><td rowspan="3">Reaction time excessive for low speed environment</td><td>65 (50)</td><td>60 (40)</td></tr>
<tr><td>60</td><td>90 (65)</td><td>80 (55)</td></tr>
<tr><td>70</td><td>115 (85)</td><td>105 (75)</td></tr>
<tr><td>80</td><td>160 (115)</td><td>145 (105)</td><td rowspan="3">Reaction time too low for high speed environment</td></tr>
<tr><td>90</td><td>195 (140)</td><td>185 (130)</td></tr>
<tr><td>100</td><td>245 (170)</td><td>–</td></tr>
</table>

** Stopping sight distances in brackets relate to sealed roads.*

Source: Koorey and Cenek (1999) unsealed roads values; sealed roads values adapted from Austroads (2003).

As noted in Appendix C.1 the braking characteristics of heavy vehicles differ substantially from that of smaller vehicles such as cars. Refer to Table C 6 for values for B-doubles, further values for other MCVs can be found in NACoE (2019). Should wet conditions be expected on a consistent basis a wet correction factor (should be applied to the values in Table C 7).

Table C 6: B-double/PBS Level 2 stopping sight distance for unsealed roads (m)

Grade	Operating speed (km/h)						
	40	50	60	70	80	90	100
9%	50	70	90	115	145	175	210
6%	50	70	95	125	155	190	225
3%	55	75	100	130	165	200	240
0%	55	80	110	145	180	220	265

Grade	Operating speed (km/h)						
	40	50	60	70	80	90	100
–3%	60	90	120	155	195	240	290
–6%	65*	100*	135*	175*	220*	275*	330*
–9%	75*	110*	155*	200*	255*	315*	380*

** On extended lengths of this grade, heavy vehicles would need to descend in low gear to prevent overrun. Signage treatments as per AS 1742.2 (2009) should be provided. These should be appropriate for the decent type (i.e. short steep descent, steep descent, long steep descent), which may include detour signage.*

Notes:

- *These SSD values are considered as indicative only for dry roads in good condition. Changes in unsealed road surface conditions (potholes, rutting, delamination, surface gravel) are likely to influence the ability of a vehicle to achieve the rates of deceleration to develop these SSD values, thus longer distances may be required.*
- *Stopping distances on curves with a radius < 400 m should be increased by 10% (Austroads 2016b).*
- *Stopping distances on curves where the approach is 15 km/h greater than the relevant curve operating speed should be calculated with the relevant deceleration rate being reduced by 0.05 g (adapted from Austroads 2016b); these values are provided in NACoE (2019).*
- *The above SSD values have been derived using the formula given in Austroads (2016b) with the following variables (MRWA 2017). A gravel correction factor as in Austroads (2009e) was applied to determine the SSD on an unsealed surface.*

Parameter	B-double/PBS level 2	Type 1 RT/PBS level 3	Type 2 RT/PBS level 4
Reaction time	2.5 s	3.0 s	3.5 s
Deceleration rate (d)	0.24 g	0.22 g	0.20 g

Source: NACoE (2019).

Table C 7: Heavy vehicle wet correction factor for unsealed roads

Operating speeds		
0–60 km/h	60–80 km/h	80–100 km/h
x 1.12	x 1.31	x 1.50

Note: These are multiplication factors applied to values in Table C 6.

C.2.2 Intermediate Sight Distance

Intermediate sight distance (ISD) enables two drivers travelling towards each other at the operating speed to stop before meeting. In circumstances where two vehicles may be travelling the same path (e.g. low volume rural roads with no line marking) it may be appropriate to provide an intermediate sight distance (ISD) equal to twice the stopping distance measured at 1.1 to 1.25 m above the road (Austroads 2016b).

If this sight distance cannot be adequately met at particular locations on a single-lane two-way road, consideration should be given to widening the formation to permit safe passing at these critical locations to provide the motorist with greater manoeuvring space, particularly over a sharp crest. In some cases, to further improve the safety over the sharp crest, the road can be sealed, and a double barrier line placed to ensure drivers do not travel in the middle of the road.

Commonly, short stopping sight distances occur at bends around hillside spurs and at crests and widening the bends and crests to permit safe passing is a preferred treatment than just using appropriate signs to warn motorists.

C.2.3 Overtaking Sight Distance

Overtaking sight distance (OSD) is the distance required for the driver of a vehicle to safely overtake a slower vehicle without interfering with the speed of an oncoming vehicle. On rural roads, providing OSD is unlikely to be warranted as the volumes are so low that the incidences requiring OSD will be rare.

An alternative simple approach is to provide sufficient Intermediate sight distance (ISD), which allows two opposing vehicles on the same path sufficient time to stop before colliding.

Because it may be uneconomical to provide this over the entire length of a road, places where such sight distances cannot be achieved may need to be appropriately signed as 'no passing' areas. This would be difficult to achieve practically and may have to be restricted to those locations where there is an identified safety problem.

Given the low volume of traffic encountered on unsealed roads it is not always necessary to provide this requirement on all road lengths.

C.3 Horizontal Alignment

The standard of horizontal alignment, particularly on curves, should be the highest possible in keeping with the function of the road, operating speed, cost and terrain.

It is best to aim for a lesser standard road pavement on a good alignment than to have a good road pavement on a poor alignment. Road pavements can be improved over time but once the alignment is set it is a more difficult task to correct deficiencies later.

The horizontal alignment is one of the primary determinants of the speed adopted by drivers. In terms of safety, a consistent alignment, which provides no 'surprises' for the driver, is more important than achieving the desired operating speed standard.

The coordination of horizontal and vertical geometry is important to avoid hiding approaching vehicles, giving the wrong impression of the direction of the road ahead, avoiding flat spots on the road surface, as shown in Figure C 5, and improving the appearance of a road. Where possible, the vertical curves should be contained within the horizontal curves.

Figure C 5: Example of poor horizontal and vertical curve coordination

Note: The flat spot at the bottom of the sag coincides with change in superelevation.

Source: ARRB (2009).

Guidelines for the coordination of horizontal and vertical alignment for safety, drainage and aesthetic reasons are provided in Austroads (2016c).

C.3.1 Superelevation

When a vehicle travels around a circular arc, it tends to move towards the outer side of the curve. Superelevation is required to counteract the movement to the outside of the curve.

The radial force required to hold the vehicle to a circular path is a combination of:

- the sideways friction force between tyres and the road
- the gravity force due to the mass of the vehicle and resolved through the superelevation (tilt) of the curve.

This radial force is calculated as the coefficient of side friction and is expressed in Equation A2. The resulting coefficient of friction should not exceed those recommended in Table C 4.

$$f = \frac{V^2}{127R} - n_{2\,rounded} \qquad \text{A2}$$

where

f = coefficient of side friction

V = vehicle speed (km/h)

R = radius of curve (m)

$n_{2\,rounded}$ = rate of superelevation of curve rounded upwards (e.g. 4.0% but 4.1% becomes 4.5%)

For safety reasons superelevation should be used for all roads regardless of traffic volumes.

The only exceptions to this are where speeds are less than 40 km/h or for very large radius curves where a normal two-way crossfall can apply. As a guide, for radius curves > 3000 m for speeds around 100 km/h, or > 600 m for speeds around 60 km/h a two-way crossfall can apply. It is essential prior to adopting adverse crossfall to determine the range of likely operating speeds of the road in order to ensure that the adverse crossfall does not prejudice safe traffic operations.

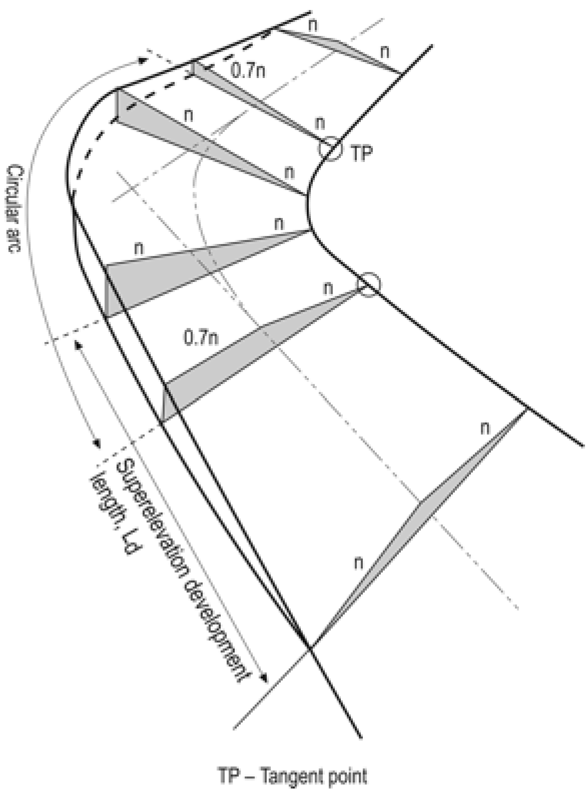
The use of the maximum superelevation (> 6%) generally used on high-volume sealed roads is inappropriate for unsealed roads for two reasons. Firstly, the application of high superelevation could increase the risk of slow-moving heavy vehicles deviating into the inside of the curve. Secondly, if higher superelevation values are used, scouring and erosion of the surface may occur. In order to minimise these effects, the maximum superelevation to be used is one that matches the crossfall of the pavement on straight sections of the road.

A maximum 4–6% superelevation is considered appropriate in most instances.

In cases where an unsealed road is carrying a significant number of heavy vehicles with high loads (such as logging trucks) travelling at a lower speed, a superelevation of 6% can cause instability problems. In these cases, reducing the crossfall will assist heavy vehicle drivers but will, however the reduced crossfall may not be suitable for other vehicles that can operate at higher speeds on the same curve. Ideally in this scenario the curve radius should be increased so that a lower superelevated crossfall can be provided for heavy vehicles without compromising other road users. The minimum should be 4% to ensure adequate surface water run-off.

The change from a normal cross-section on straights to a superelevated section should be made gradually. The rate of pavement rotation should not exceed 3.5% per second for time of travel for speeds < 80 km/h and 2.5% per second for speeds > 80 km/h. The length over which superelevation is developed is known as the superelevation development length. As a guide, two-thirds of the development length is provided prior to the start of the curve. This is illustrated in Figure C 6.

Figure C 6: Superelevation development



Source: ARRB (2009).

Minimum superelevation development lengths can be calculated using Equation A3 and Equation A4 (Austroads 2003).

$$L_d = \frac{(n_1 - n_2)V}{12.6} \; for \; V < 80 \; km/h \qquad \text{A3}$$

$$L_d = \frac{(n_1 - n_2)V}{9} \; for \; V > 80 \; km/h \qquad \text{A4}$$

where

L_d = superelevation development length (m)

n_1 = normal crossfall (%)

n_2 = full superelevation crossfall (%)

V = operating speed (km/h)

Table C 8 shows typical values for superelevation development length for a road crossfall and superelevation of 5% (0.05 m/m). Further details for calculating development lengths for other road crossfalls can be obtained in Austroads (2016c). Between 70% and 80% of the superelevation development distance should be achieved by the tangent point (TP). A value of 70% is commonly used.

Table C 8: Typical values for superelevation development length

Operating speed (km/h)	Development length Ld (m)
50	40
60	50
70	60
80	90
90	100
100	110
110	120

C.3.2 Circular Curves

The use of design maximum superelevation and side friction coefficients leads to limits on the sharpness of curves for various operating speeds. A minimum curve radius is calculated using Equation A5.

$$R_{min} = \frac{V^2}{127(n+f)} \qquad \text{A5}$$

where

R_{min} = minimum radius of circular curve (m)

n = superelevation (m/m)

f = coefficient of side friction

On steep down grades, the minimum curve radius should be increased by 10% for each 1% increase in grade over 3% (Austroads 2016c), see Equation A6.

$$R_{\min\, on\ Grade} = R_{\min\, from\ Equation\ \mathrm{A5}}\left[1 + \frac{G-3}{10}\right] \qquad \text{A6}$$

where

G = grade (%)

R = radius (m)

Table C 9 shows minimum radii calculated for various operating speeds.

Table C 9: Typical values for minimum radius of curves for various operating speeds (on unsealed roads)

Operating speed (km/h)	Minimum radius of curve[1] (m)
50	120
60	180
70	260
80	340
90	460
100	565

1 Assuming coefficient of side friction values shown in Table C 4, and maximum superelevation of n = 0.05 m/m (or 5%).

Vehicles negotiating tight curves will tend to dislodge more aggregate than when travelling on straight sections (Figure C 7). Easing or removing a sharp bend can reduce this gravel loss considerably as well as improving the comfort and safety of drivers around a curve and should be considered (Ferry 1986).

Figure C 7: Curves below the desired radius will require higher maintenance

Source: ARRB (2009).

C.3.3 Transition Curves

It is common practice when designing major sealed roads to use transition curves between straights and circular curves. These are used to increase driver comfort and create a more visually pleasing road. The use of transition curves for unsealed low-volume roads is, however, considered to be unnecessary having regard to the volume of traffic, surface conditions and maintenance requirements (Nyasulu 1989). If the road is later sealed, consideration will need to be given to providing transition curves.

C.3.4 Widening on Curves

Widening of the pavement on tight curves may be required to allow for the larger swept path width of a longer vehicle during cornering (due to the rear wheels tracking inside the front wheels) than on straight sections. Larger vehicles can have considerable difficulties traversing low-radius curves and maintaining in the lane or on the formed section of the road.

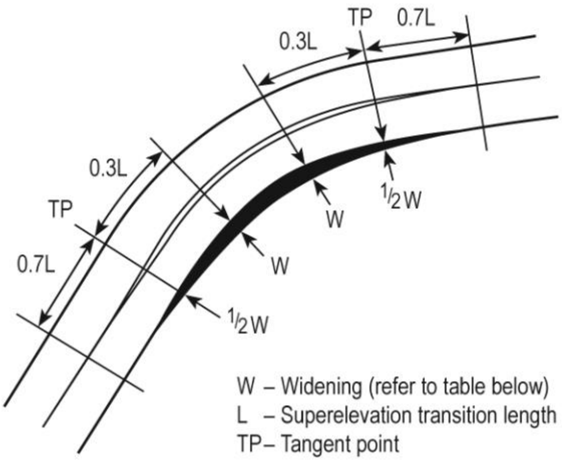
The amount of widening on a curve is dependent on the characteristics of the vehicles using the roads, radius of the curve, speed of long vehicles, width of a lane and the required clearances between lanes.

Approximate values for the amount of widening required by a single unit design truck (semi-trailer) on a pavement on a circular curve are shown in Table C 10, for curve widening requirements for larger vehicles such as B-doubles to Road Trains refer to the NACoE Local Government Heavy Vehicle Route Assessment Guide (NACoE 2019).

Half the widening is applied on each side of the centreline of the curve with transitions. The whole widening may be applied on the inside of the circular curves as would be the case for most unsealed roads (Figure C 8). Note the superelevation run-off length is a part of the total superelevation development length L_d given in Austroads (2016c).

For logging or mine haul routes that carry much larger vehicles (with fewer articulation points) additional widening is required. Details are provided in Appendix C.6.2.

Figure C 8: Lane widening on horizontal curves



Source: ARRB (2009).

Table C 10: Road widening requirements for semi-trailers

Curve radius (m)	Total amount of traffic lane widening (w) where the normal width of two traffic lanes is			
	6.0 m	6.5 m	7.0 m	7.5 m
30–50	2.0	1.5	1.5	1.0
50–100	1.5	1.0	1.0	0.5
100–250	1.0	1.0	0.5	–
250–750	1.0	0.5	–	–

Source: Transit New Zealand (2006).

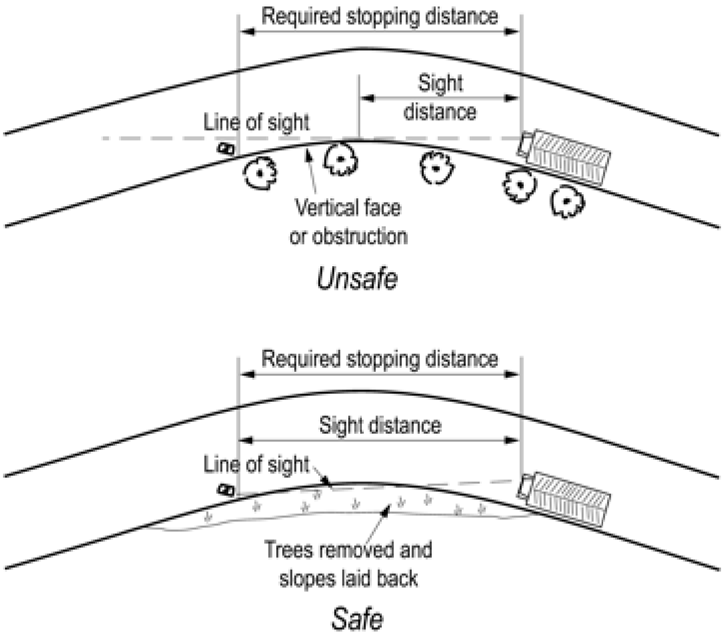
When forming curves, it is prudent to allow the width of the road verge room for vegetation (i.e. on outside curves) to allow for trees or bushes to follow the curve of the road to provide drivers with guidance on the extent of the curve radius. On inside curves cut back benches sufficiently to allow for visibility after plants grow. This will give a saving in maintenance and will also make the road safer and improve appearance.

The role of vegetation along a roadway in the definition of particularly low-radius curves should not be underestimated.

C.3.5 Horizontal Sight Distance

Stopping sight distance is the distance required to enable a normally alert driver, travelling at an operating speed on a wet pavement to perceive, react and brake before reaching a hazard on the road ahead. This distance provides as a minimum stopping distance for a driver travelling towards a hazard (height of 200 mm) on a curve. Figure C 9 shows that the sight distance must be at least that required for a vehicle to stop. For horizontal curves truck requirements are more critical as truck stopping distances are greater than cars.

Figure C 9: Sight distance requirements around a horizontal curve

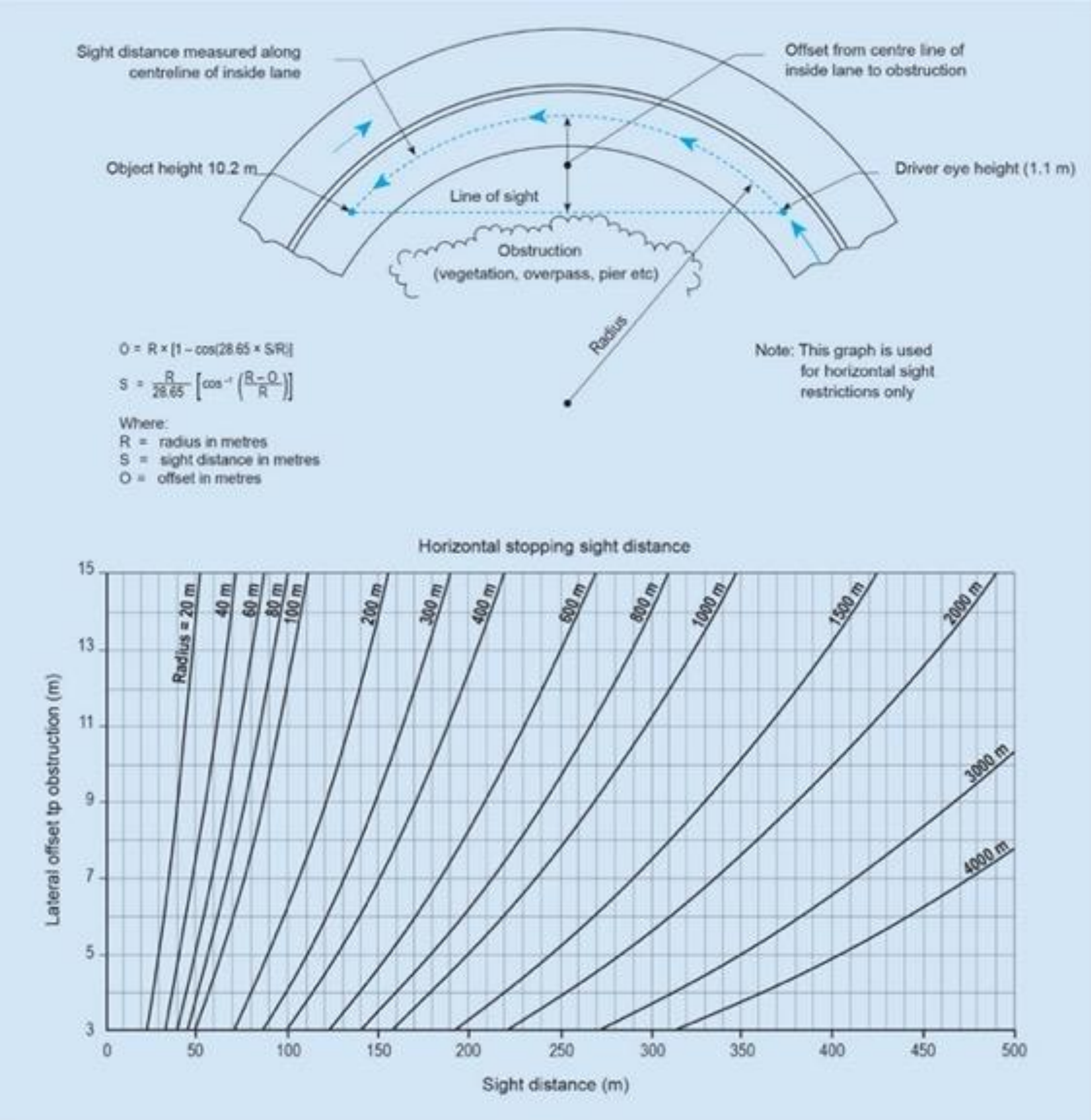


Source: ARRB (2009).

Curves with radii near the minimum for the speed environment may not necessarily meet the horizontal stopping sight distance requirements given in Appendix C.2. Where a lateral obstruction off the pavement, such as a bridge pier, cut slope or natural growth restricts sight distance the minimum desirable radius curve is determined by the stopping sight distance appropriate to the operating speed of the curve. Figure C 10 shows the relationship between horizontal stopping sight distance, curve radius and lateral clearance required.

The values for the coefficient of longitudinal deceleration for unsealed roads can vary significantly based on the condition of the road surface. A conservative longitudinal deceleration value of 0.25 has been adopted to provide a guideline in estimating stopping sight distance. A smaller value will be required for larger vehicles such as B-doubles, refer to Appendix C.2.1 (Stopping Sight Distance).

Figure C 10: Horizontal stopping sight distance



Source: Austroads (2016c).

An example of identifying the required lateral offset to achieve stopping sight distance is as follows:

If the stopping sight distance for a given speed is 120 m and the radius of the existing curve is 300 m then by using the values in Figure C 10 *the lateral offset required to the obstruction is 6 m.*

Table C 11 provides a general guide to horizontal offset based on speed of travel and minimum radius (flat grade assumed).

Table C 11: General guide to horizontal offset distances

Speed (km/h	Stopping distance (m)	Minimum radius (m)	Offset (m)
50	105	140	8
60	135	200	9
70	165	280	12
80	200	360	14

It will be common to find that on many existing tight curves that insufficient lateral sight clearance is being provided. Road agencies should make use of the information provided to readily determine whether existing curves satisfy the minimum stopping sight distance requirements. Figure C 10 provides a sound basis to establish the safety requirements for the extent of vegetation or bank cutback to be cleared.

Where the sight distance is found to be inadequate, measures that can be taken depend on the nature of the obstruction. If it is due to vegetation, it should be cut back and maintained to the required distance. For obstructions due to a cutting, increase the cutting setback or bench cut batters, if practical, or increase the curve radius. Having cut back the vegetation it is essential that ongoing maintenance ensures that the vegetation is slashed on a regular basis to maintain the required sight distance (Figure C 11).

Figure C 11: Adequate offset to allow for horizontal sight distance requirement

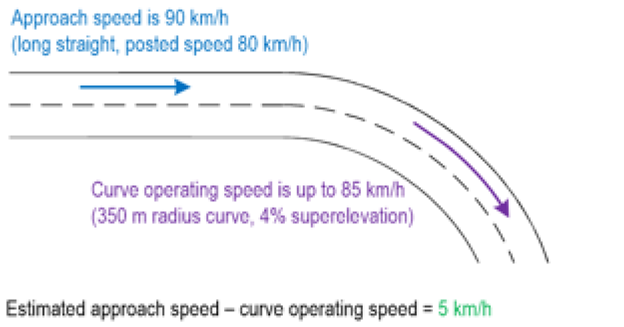
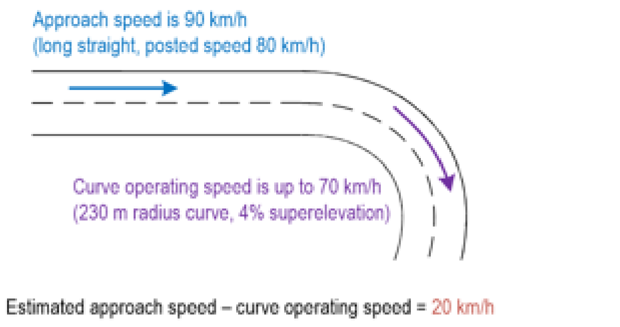
Source: ARRB (2009).

C.3.6 Horizontal Curve Perception Sight Distance and Operating Speed Reductions when Entering Curves

A driver should have enough visibility into a curve from the approach (horizontal curve perception sight distance (Austroads 2016c)) to be able to clearly identify the curve direction and radius so as they can select appropriate curve operating speed (close to the safe curve operating speeds indicated for the minimum cure radii as per Table C 10) and decelerate to that speed in a controlled manner. If drivers are unable to perceive the curvature of the road, they may not slow down to an appropriate speed, which increases the risk of a single vehicle crash. Therefore, curves on these types of alignments should be designed for an operating speed that is no more than 5 km/h less than the operating speed on the approach to the curve (Austroads 2016b). In most instances, visibility into a curve be provided by proper ensuring sight distance is available through a horizontal curve and/or the coordination of horizontal and vertical alignment does not result in a horizontal curve being hidden by a vertical curve.

In addition to horizontal curve perception sight distance, a driver should not be required to reduce their approach speed by more than 10 km/h when slowing to a speed that is safe to traverse the curve (safe curve operating speeds indicated for the minimum cure radii as per Table C 10). An example demonstrating this is provided in Figure C 12. Where curve perception sight distance is available and the reduction in speed is greater than 10 km/h and/or horizontal curve perception sight distance is not provided, the installation of curve warning signage and advisory speeds should be considered.

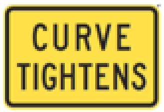
Figure C 12: Reductions in operating speed to curve operating speed

Desirable (speed difference < 10 km/h)	Undesirable (speed difference > 10 km/h)
	

Should a curve or section of curves be identified to present as a risk a formal onsite assessment should be carried out as per Clause 4.4.7.10 in TMR's supplement to AS 1742.2 (TMR 2020) and appropriate signage provided.

Examples of advisory speed signs that could be provided to mitigate risk are provided in **Error! Reference source not found.** and an example of the application of these signs to reduce approach speeds is provided in Figure C 13.

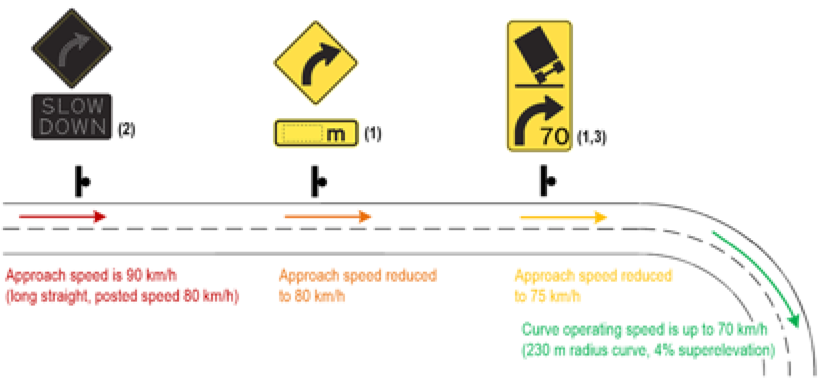
Table C 12: Curve warning signage for curves which are substandard for heavy vehicles

Warning signage on immediate approaches (1,3)				
 Turn warning (W1-1)	 Curve warning (W1-3)	 Hairpin warning (W1-3)	 TC1777 (4)	 W1-8
Special warning signage in advance of the approach (2)				
 TC1790 (vehicle activated LED sign)	 TC1790 (vehicle activated LED sign)	 TC1790 (vehicle activated LED sign)		

1. *Installed as per and AS 1742.2 (2009).*
2 *Installed at a distance that allows the relevant heavy vehicle or passenger vehicle to reduce to appropriate speed before the hazard.*
3 *Advisory speeds should not be provided on unsealed roads as changes in surface condition may reduce the safe curve operating speed to a speed lower than the advisory speed.*
4 *Curve tightens supplementary plate may be used for any curve type where the radius of the curve reduces (compound curve).*

Source: TMR (2016; 2020).

Figure C 13: Reducing approach speed through curve warning signage



Estimated approach speed without signage treatment – curve operating speed = 90 – 70 = 20 km/h
Estimated approach speed with signage treatment – curve operating speed = 75 – 70 = 5 km/h

1 *Recommended if sight line to the curve is restricted. Installed as per AS 1742.2 (2009), maximum distances for Dimension A and B are recommended.*
2 *Recommended if sight line to curve warning sign with distance plate and curve warning (vehicle activated LED) sign is restricted. Installed at a distance that allows the relevant heavy vehicle or passenger vehicle to reduce to appropriate speed before the hazard.*
3 *Advisory speeds should not be provided on unsealed roads as changes in surface condition may reduce the safe curve operating speed to a speed lower than the advisory speed.*

Notes:

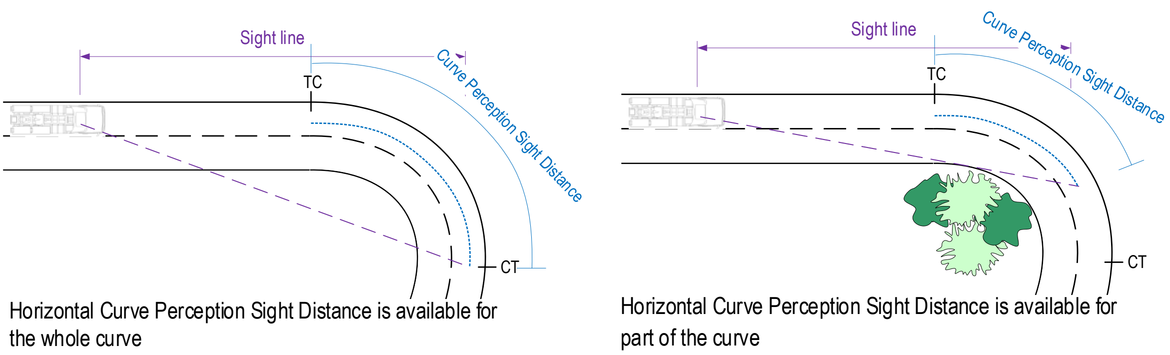
- *Examples use sealed road, desirable minimum curve radius (m) values however the same principles apply to unsealed roads*
- *Examples estimate speed reductions which will depend on signage placement, driver alertness and vehicle braking performance.*

Source: Based on AS 1742.2 (2009) and TMR (2018).

C.3.7 Determination of Horizontal Curve Perception Sight Distance and Approach Speeds

The horizontal curve perception sight distance is the length of the curve that is visible from the approach to the curve, some examples are provided in Figure C 14. To determine if the available horizontal curve perception sight distance is suitable several criteria should be considered, refer to Austroads (2016c) for more detailed information.

Figure C 14: Horizontal curve perception sight distance examples



Source: Austroads (2016c).

C.3.8 Estimating the Radius of an Existing Curve

Engineers and works supervisors will need to know the radius of existing curves to assess the adequacy of the curve for the speeds travelled and sight distance requirements indicated above. A simple and practical way to estimate the radius of a curve is to apply the formula given in Equation A7, as shown in the example (Figure C 15).

The steps to be taken in calculating the radius of an existing curve are:

- On any part of the circular curve, place the end of the measuring tape on the centreline of the road.
- Extend the tape to a given distance (say, 20 m which is the '2X' measurement) and place the tape (reading 20 m) on another part of the circular curve at the centreline.
- At the halfway mark of the tape (in this case 10 m), measure the distance from the tape to the centreline of the road. This is the 'A' distance (say 0.5 m).
- With these two dimensions calculate the radius with Equation A7 as given in this example.

$$R = \frac{X^2 + A^2}{2 * A} \qquad \text{A7}$$

where

R = estimated radius of curve (m)

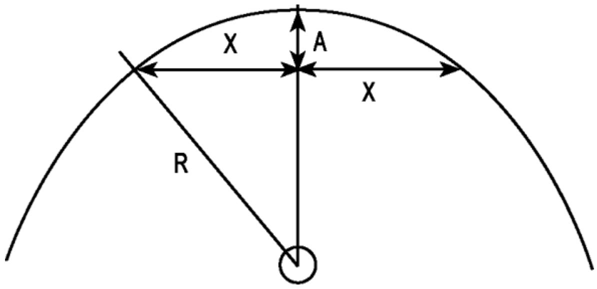
X = half the chord length (m)

A = distance between road centrelines and chord at midpoint (m)

Example:

$$R = \frac{X^2 + A^2}{2 * A} = \frac{10^2 + 0.5^2}{2 * 0.5} = \frac{100 + 0.25}{1.0} = 100\ m$$

Figure C 15: Formula for estimating radius of a curve



Source: ARRB (2009).

To simplify this calculation, if the chord distance is always taken as 20 m in total (i.e. 2X) the radius of the curve is a direct measure of the 'A' distance as given in Table C 13.

Table C 13: Radius of a curve based on chord distance of 20 m

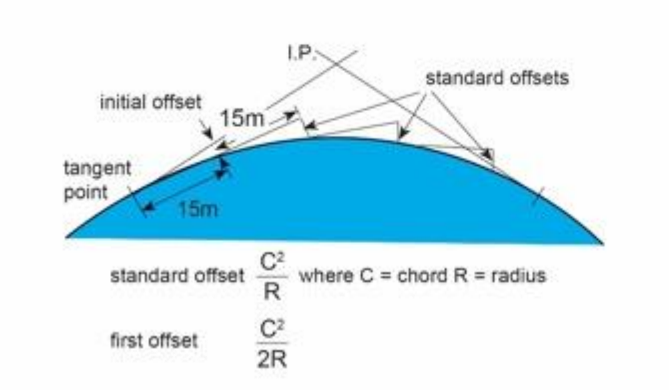
'A' measurement (m)	Radius of the curve (m)[1]
0.15	330
0.25	200
0.50	100
0.75	65
1.00	50
1.25	40
1.50	30

1 Figures rounded down to nearest 5 m.

C.3.9 Laying out a Horizontal Curve

Horizontal curves may be set out using either the deflection or linear method. A practical method of laying out a horizontal curve without instruments is the use of the linear method. It involves the use of a measuring tape and the selection of a standard chord length, usually any multiple of 10 m, an initial offset and a standard offset. Figure C 16 details the application of this method and the calculation of two offsets using a chord of 15 m.

Figure C 16: Setting out a curve using linear measure method



Source: Australian Army (1985).

C.4 Vertical Alignment

The vertical alignment of a road consists of a series of straight grades connected by vertical curves. The curves serve two functions:

- smoothing the transition from one grade to another
- increasing sight distance over crests and sags where opposing grades meet.

The design of the vertical alignment of a road should aim at minimising the earthwork volumes consistent with economics, the importance of the road and sight distance requirements.

In flat terrain, although the alignment will tend to follow the natural surface, adequate provision should be made for drainage and local soil properties.

C.4.1 Vertical Grades

The vertical grade of a road is a measure of its longitudinal rise or fall to the horizontal. It may be expressed as a ratio or percentage. A general maximum grade is determined by the requirement to enable the operating speed to be maintained by most vehicles that will use the road. `Table 3.10 details the general maximum grades to be aimed at for a range of road classes and terrain. In cases where it is impractical to constantly achieve the general maximum grade then it is possible to exceed these values over short lengths. It should be noted that on unsealed roads with grades of greater than 8%, vehicle traction may be difficult to achieve and will cause extra wear and tear of the road surface both for upgrades and downgrades due to braking action. Grades greater than 10% will usually need to be sealed to enable sufficient traction to be achieved as well as for lowering maintenance requirements.

For steep grades > 6% road run-off will generally flow down the road and can cause considerable longitudinal scour if the steep grade is maintained over a long length (Figure C 17). Where this cannot be avoided, special measures could be taken to disperse the water off the road sooner to avoid a high concentration down the road. Techniques to use are 'rolling' the grade, use of water bars or water deflectors. Further details are provided in Appendix D.

Figure C 17: Effects of steep vertical grades causing scour drains along unsealed roads

Source: ARRB (2009).

C.4.2 Vertical Curvature

When selecting vertical curvature, consideration should be given to sight distance requirements along with driver comfort considerations and gradient, both of which are related to vehicle performance and level of service (Bofinger et al. 1990; AASHTO 1984).

In most cases the length of a curve is dictated by three criteria – in increasing order of importance:

- driver comfort
- stopping sight distance
- overtaking sight distance (difficult to achieve).

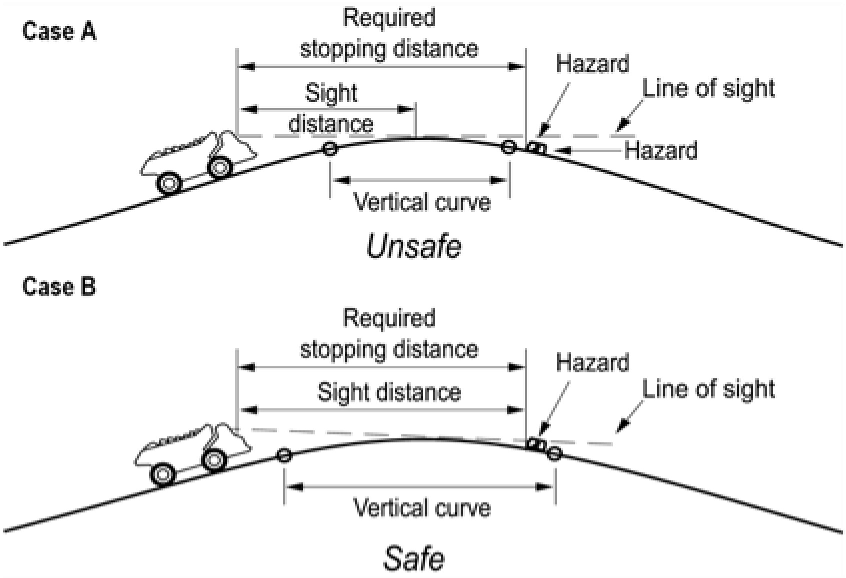
The two types of vertical curves considered in design are crest and sag curves.

Crest curves

On vertical crests it is essential that the sight distance provided to a driver is sufficient to enable a vehicle going at the operating speed to stop before reaching a hazard. The distance measured from the driver's eye to the hazard ahead must always equal or exceed the required stopping sight distance. On vertical crest curves the sight distance may be limited by the road surface.

Case A in Figure C 18 shows an unsafe situation where the sight distance is less than the required stopping distance due to a short vertical curve. Case B shows how this can be avoided by increasing the vertical curve length so that the sight distance is equal to the stopping distance.

Figure C 18: Vertical crest curve sight distance requirements



Source: ARRB (2009).

The length of crest curves should be as long as conditions permit and should not be shorter than established minimum values, usually dictated by stopping sight distance requirements.

It is common practice to design crest curves using stopping sight distance criteria (Bofinger et al. 1990; Nyasulu 1989).

While providing overtaking sight distance would be ideal, consideration is often not given to it on unsealed, low volume rural roads as:

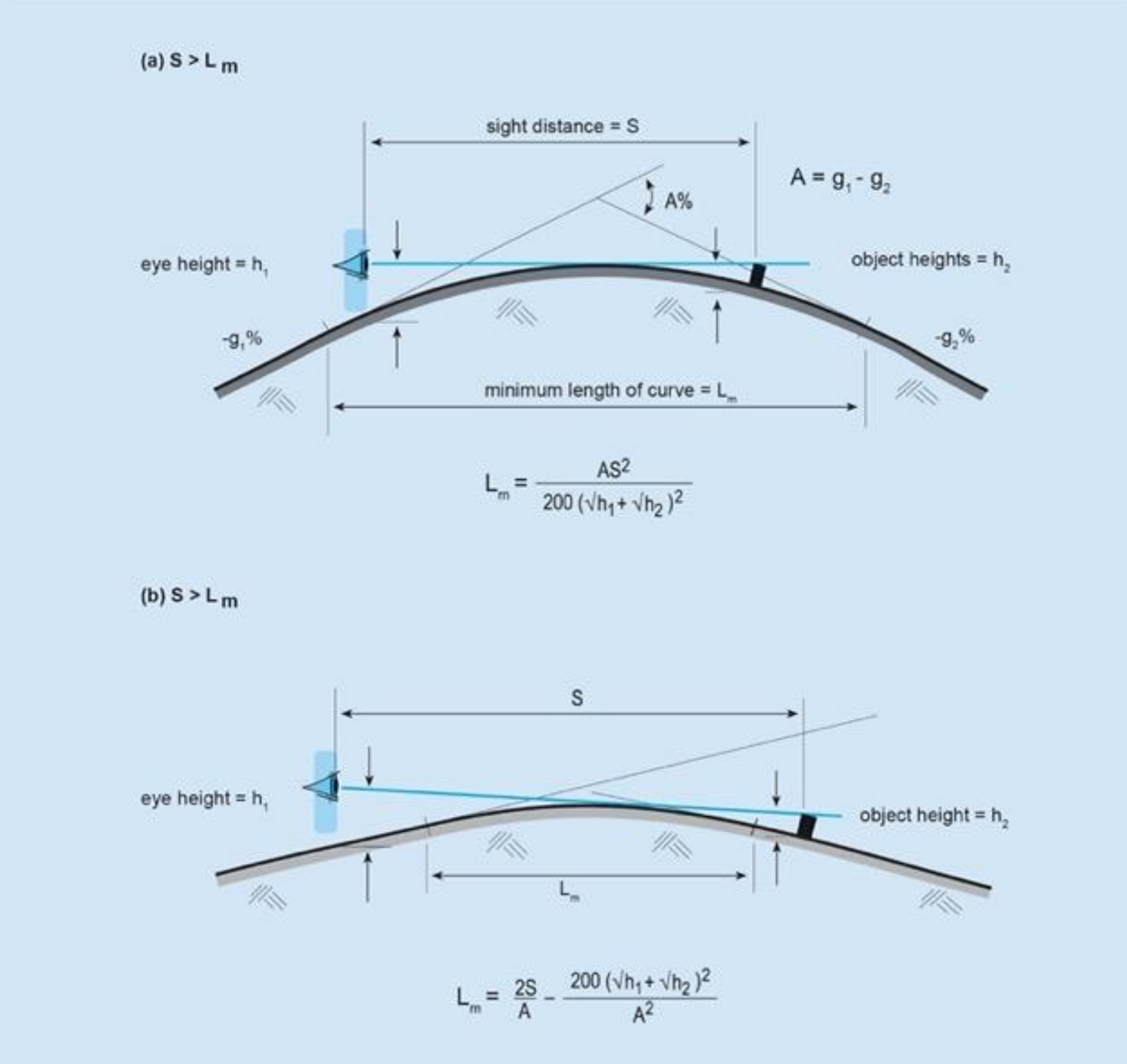
- the equations tend to indicate values implying high cost
- most drivers on an unmarked road will be unaware they have overtaking sight distance provision
- on dusty roads overtaking is often limited by visibility rather than sight distance.

When computing the length of a vertical curve on the basis of minimum sight distance, two conditions exist:

- sight distance is less than vertical curve length
- sight distance is greater than vertical curve length.

The relationships used for these two conditions are shown in Figure C 19.

Figure C 19: Sight distance requirements on vertical crest curves



Source: ARRB (2009).

To calculate the vertical curve length (L_m) for the two cases refer to Equation A8 and Equation A9.

$$L_m = \frac{A * S^2}{200 * \left(\sqrt{h_1} + \sqrt{h_2}\right)^2} \; for\ sight\ distance < vertical\ curve\ length \qquad \text{A8}$$

$$L_m = \frac{(2 * S)}{A} - \frac{200 * \left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A^2} \; for\ sight\ distance > vertical\ curve\ length \qquad \text{A9}$$

where

L_m = minimum length of crest curve (m)

S = required stopping sight distance (m)

A = algebraic difference in gradients (%)

h_1 = driver eye height (m) (1.1 m)

h_2 = object height (m) (0.02 m)

Sight distance less than the vertical curve length is the most common situation encountered in practice (Bofinger et al. 1990). For this case it is convenient to specify the length of curve required for a change in grade of 1% (Austroads 2003). This value will be constant for a parabola and is given by Equation A10.

$$K = \frac{L}{A} \qquad \text{A10}$$

where

K = length required for a 1% change in grade (m)

L = length of vertical curve

A = change of grade (%)

Using this concept, it can be seen that:

$$K = \frac{S^2}{200 * \left(\sqrt{h_1} + \sqrt{h_2}\right)^2} \; for\; S < L$$

Typical K values are given in Table C 14. These values are based on stopping sight distance values shown in Table C 5 and are therefore an underestimate for unsealed conditions because of friction factors.

Table C 14: K values for stopping distance on crest curves

Operating speed (km/h)	Crest curves K values[1]		
	Reaction time 2.5 sec	Reaction time 2 sec	Reaction time 1.5 sec
50	–	10	9
60	–	19	15
70	–	30	20
80	60	50	–
90	85	80	–
100	135	–	–

1 Assuming h1 = 1.1 m, h2 = 0.20 m and S = values in Table C 5 for various reaction times.

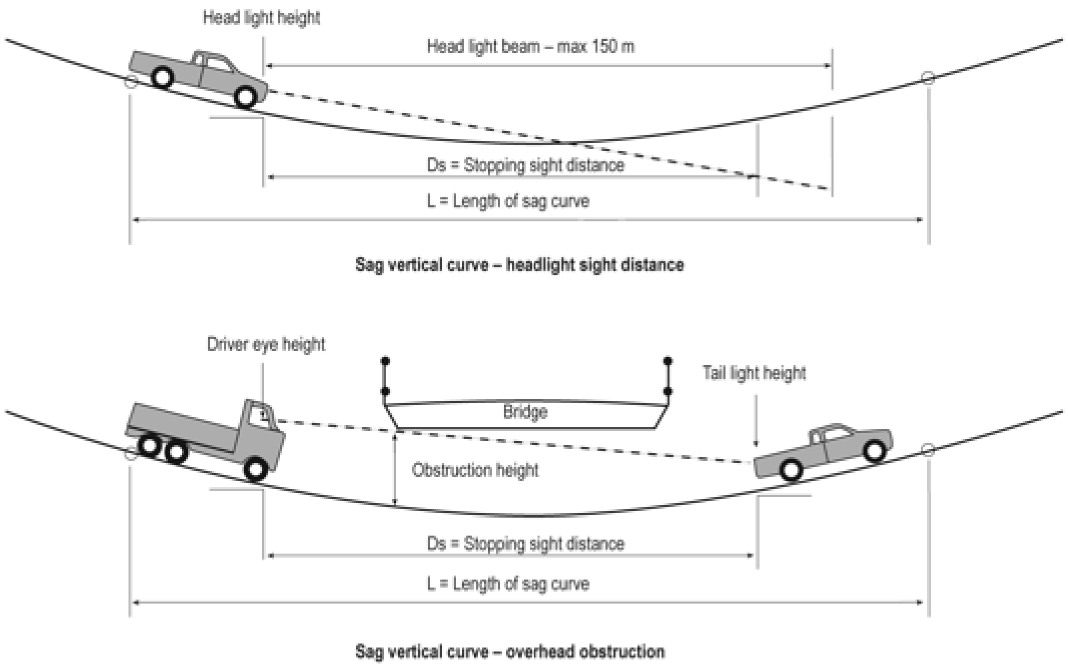
The minimum length of a crest curve is governed by sight distance requirements in this case stopping sight distance. Longer minimum length vertical curves should, however, be provided where possible.

Where adequate vertical sight distance cannot be achieved cost-effectively this may be overcome to an extent by providing greater road width over the vertical curve to enable a driver more manoeuvre space to help avoid an on-coming vehicle. This requirement is important particularly in the case of a one-lane two-way road where vehicles travel along the centre of the road and, without the extra road width, there is little chance that they can manoeuvre in time to avoid a collision.

Sag curves

Sag curves are generally less of a safety concern than crest curves as sight distance is typically not restricted in daylight conditions unless an overhead obstruction exists (Austroads 2016c). The length used for sag curves affects the appearance of the road and in the case of short sag curves it can affect comfort of the ride (Figure C 20).

Figure C 20: Sag vertical curves



Source: Transit New Zealand (2006).

At night vehicle headlight performance limits the effective sight distance to between 120–150 m for an operating speed of around 80 km/h on an unsealed road.

This is of particular importance for low-volume roads on approaches to fords and other similar locations where flowing or standing water may be present on the road surface.

When designing sag curves, the following criteria should be taken into consideration for unsealed roads (Bofinger et al. 1990):

- safety
- driver comfort
- drainage control.

A driver who experiences rapid changes in vertical acceleration will feel uncomfortable. In order to minimise this effect, it is usual to limit the values of vertical acceleration on a vertical curve. Austroads (2016c). suggests that vertical accelerations should be limited to values less than 0.05 g and on low standard roads and intersections to 0.10 g, where g is the acceleration due to gravity (g = 9.8 m/s^2).

Using these criteria, the length of the vertical curve is expressed Equation A11 which is constant for a given operating speed and vertical acceleration.

$$L_m = \frac{V^2 * A}{1296 * a} = KA \qquad \text{A11}$$

where

L_m = minimum length of vertical curve (m)

V = operating speed (km/h)

A = algebraic difference in gradients ($g_1 - g_2$) (%)

a = vertical acceleration (m/s^2)

K = $V^2/1296a$

Table C 15 shows typical K values for headlight and comfort criteria on vertical curves.

Table C 15: Minimal K values for comfort criterion on sag vertical curves for unsealed roads

Operating speed (km/h)	K value vehicle ride comfort control	
	a = 0.05 g	a = 0.10 g
40	3	1.5
50	4	2
60	6	3
70	8	4
80	11	6
90	14	7
100	16	8

Note: g = acceleration due to gravity (9.81 m/s^2)

Source: Adapted from Austroads (2016c).

A check that visibility is not significantly impaired by overhead constructions (such as bridges) should be made. Refer to Austroads (2016c) for further details.

C.5 Intersections

Since the highest number of traffic conflicts occur at intersections, their location and design should attempt to reduce the potential hazards and maintain an acceptable traffic capacity.

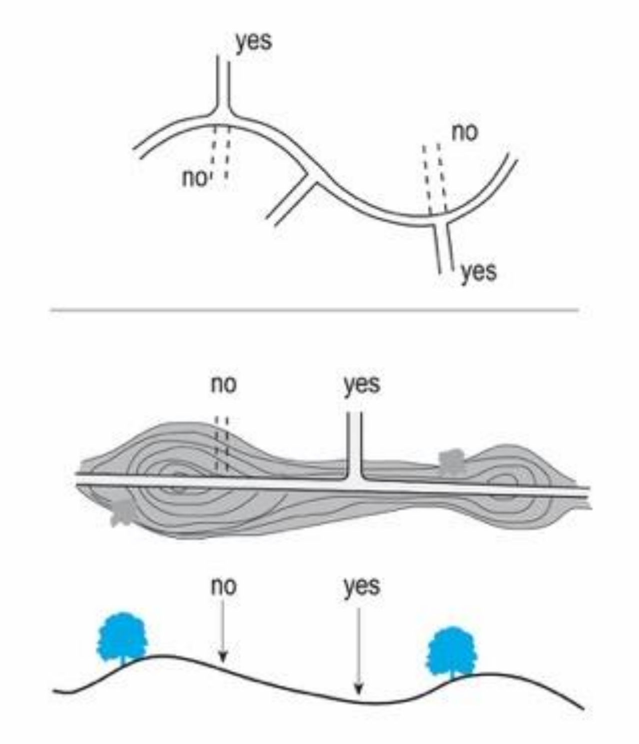
C.5.1 Location of Intersections

In the case of low-volume unsealed roads, the maintenance of road capacity is a lesser concern than safety aspects of the road network. Intersections should be located in a way that does not lead to accident-prone conditions. The predominant accident type at intersections is between two or more vehicles. As one of the major results of an accident between vehicles is one or more vehicles leaving the road, intersections should desirably not be located on high embankments, near bridges, culverts, streams, on small radius curves, on steep grades or superelevated curves (i.e. where possible safe run-off areas and good sight distance on all approaches should be provided).

The best location for an intersection is in a long gentle sag. Figure C 21 shows examples of what is considered good practice for the location of intersections.

Vegetation can significantly affect safety at an intersection. Dense vegetation close to the intersection can reduce visibility; it should be cleared well back and prevented from regrowing. Conversely, vegetation behind a T-intersection can increase the definition of the intersection.

Figure C 21: Location of intersections



Source: ARRB (2009).

C.5.2 Intersection Spacing

Ideally the number of intersections should be kept as low as possible, with the spacing between them as large as can be provided. Adequate separation should be provided for successive intersections, with signposts placed as warnings at critical locations. Access roads to rural properties are usually scattered and intersection spacing, under these circumstances, does not constitute a major problem (Nyasulu 1989).

C.5.3 Intersection Angles

Road centrelines should be designed to intersect as close to 90º as possible so that driver observation angles to potentially conflicting vehicles are satisfactory (Austroads 2017b). An example of a poor intersection alignment is shown at Figure C 22.

Intersection approaches should be straight wherever possible. If curves cannot be avoided, it is desirable that through movements have a constant radius and tangent points are located a suitable distance from the intersection (Austroads 2017b).

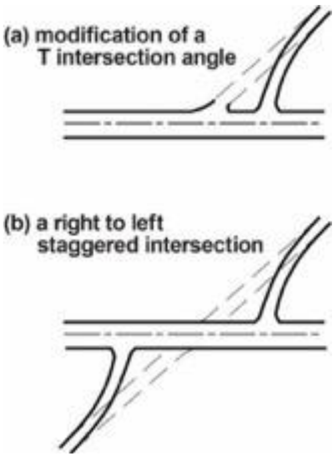
Figure C 22: An existing poor intersection layout with a low intersecting angle

Source: ARRB (2009).

C.5.4 Staggered Intersections

The two most common types of intersections on rural roads are three-legged (T-) intersections and four-legged (crossroad) intersections. The number of conflict points for vehicles is lower for three-legged intersections, and these should be used whenever possible. A staggering to two three-legged intersections is preferred over a four-legged intersection (Nyasulu 1989). Figure C 23 shows a right-to-left staggered intersection, which is preferred to a left-to-right intersection. This is to ensure that a driver crosses the road as soon as possible, reducing the opportunity for rear-end collisions. It is noted that in higher volume road environments a left-right stagger is often preferred as it simplifies gap selection for drivers crossing the main road. Further details are available in NAASRA (1973).

Figure C 23: Intersection angles and staggering technique



Source: NAASRA (1973).

C.5.5 Intersection Sight Distance Requirements

Good intersection design requires the provision of adequate sight distance on both horizontal and vertical planes. The provision of this requirement may influence the location of intersections, design and the physical construction.

There are three sight distance criteria applicable to the various aspects of traffic operations at intersections. They are approach sight distance (ASD), minimum gap sight distance (MGSD) and safe intersection sight distance (SISD). Designers should check the achievement of each criterion using appropriate values of reaction time, approach speed and driver and object height (Austroads 2017).

Details of each are as follows:

- ASD provides a driver with adequate distance to observe and have sufficient time to react and stop if necessary, before entering a conflict area.
- MGSD is the distance required for minor road drivers to enter a major road so that the traffic on the major road is unimpeded.
- SISD provides sufficient distance for a driver on a major road to avoid a collision with a vehicle on a minor road.

SISD is the minimum sight distance to be provided on the major road at any intersection. It provides sufficient distance for a driver of a vehicle on the major road to observe a vehicle on a minor road approach moving into a possible collision situation (e.g. in the worst case, stalling across the traffic lanes), and to decelerate to a stop before reaching the collision point. It is generally sufficient to enable cars to cross a major road safely from a side road.

SISD should be provided at all intersections. It is measured along the carriageway from the approaching vehicle to the conflict point. SISD is viewed between two points 1.1 m above the road surface (Figure C 24). One point is the driver's eye height on the leg with priority and the other represents eye height of a driver in the side street. The driver in the side street is assumed to sit at a distance of 5.0 m (minimum of 3.0 m) from the lip of the kerb or edge line projection of the major road. SISD allows for a 3 second observation time for a driver on the through leg of the intersection to detect the problem ahead, (e.g. car from minor road stalling in through lane) plus the stopping sight distance.

SISD provides sufficient distance for a vehicle to cross the non-terminating movement on two-lane two-way roads including those with operating speeds of 80 km/h or more. SISD also enables approaching drivers to see an articulated vehicle, which has properly commenced a manoeuvre from a leg without priority, however, its length creates an obstruction. ASD and SISD values for cars and B-doubles travelling on unsealed roads at various operating speeds are summarised in Table C 16.

Table C 16: ASD and SISD values for unsealed roads

Operating speed (km/h)	Approach sight distance (ASD)(1)		Safe intersection sight distance (SISD)(1)	
	Car(2)	B-double(3)	Car(2)	B-double(3)
50	65	80	115	115
60	90	11	145	150
70	115	145	185	185

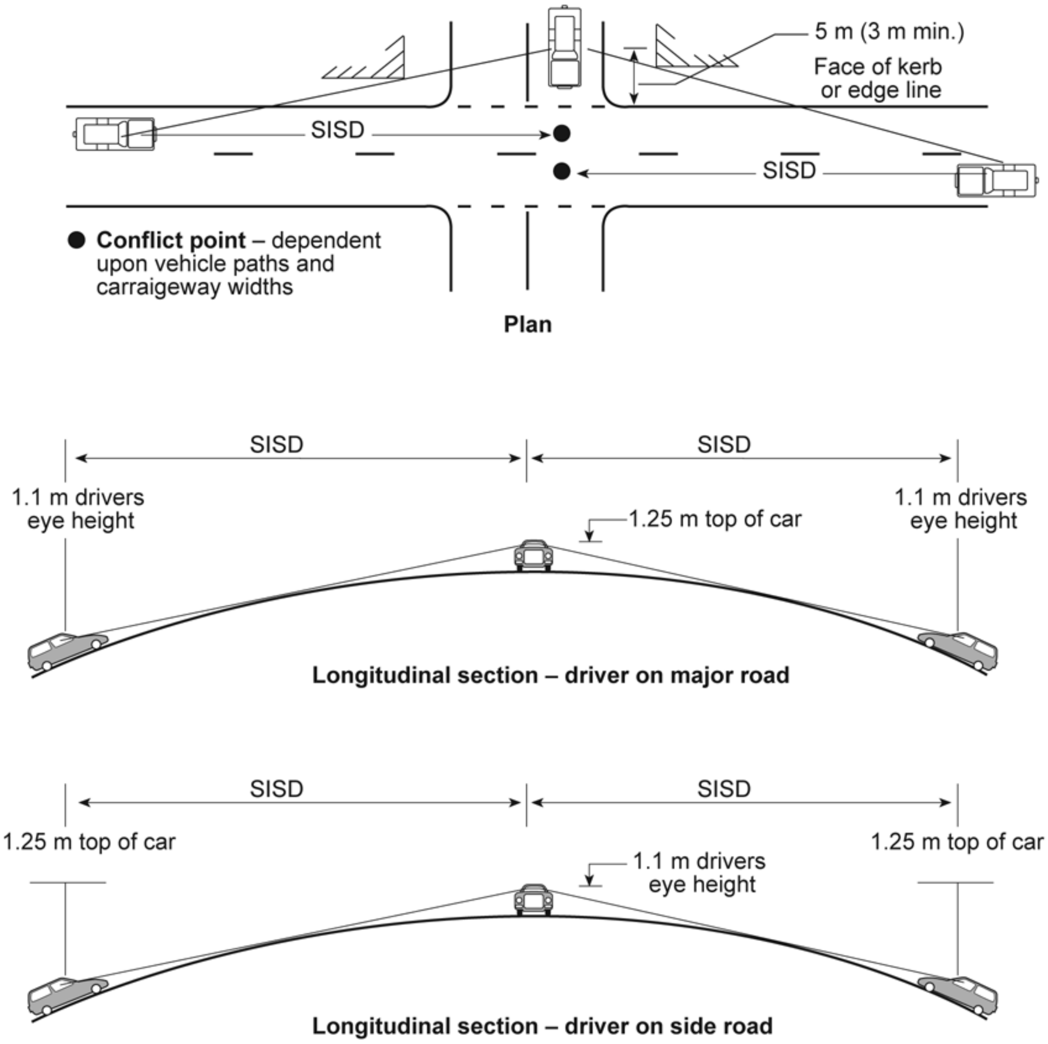
Operating speed (km/h)	Approach sight distance (ASD)(1)		Safe intersection sight distance (SISD)(1)	
	Car(2)	B-double(3)	Car(2)	B-double(3)
80	145	155	225	220
90	185	175*	275	305
100	220	200*	330	365

1 Based on Austroads (2017b), assuming reaction time of 2 seconds.
2 Car coefficients of deceleration based on Table C 2.
3 Truck and B-double coefficient of deceleration based on Table C 3, with gravel correction factor of 1.2 (well compacted surface) applied to sight distance requirements.

Notes:

- *Grade not considered in this table.*
- *NACoE (2019) provides values for other heavy vehicle combinations.*

Figure C 24: Entering sight distance and safe intersection sight distance



Source: Austroads (2017b).

Manual calculation of ASD and SISD may be conducted using Equation A12 and Equation A13, respectively.

$$ASD = \frac{R_T \times V}{3.6} + \frac{V^2}{254 \times (d + 0.01 \times a)} \quad \text{A12}$$

$$SISD = \frac{D_T \times V}{3.6} + \frac{V^2}{254 \times (d + 0.01 \times a)} \quad \text{A13}$$

where

R_T = reaction time

D_T = decision Time = R_T + observation time (3 seconds)

V = operating speed (km/h)

d = coefficient of deceleration

a = longitudinal grade (%)

C.5.6 Maximum Grades at Intersections

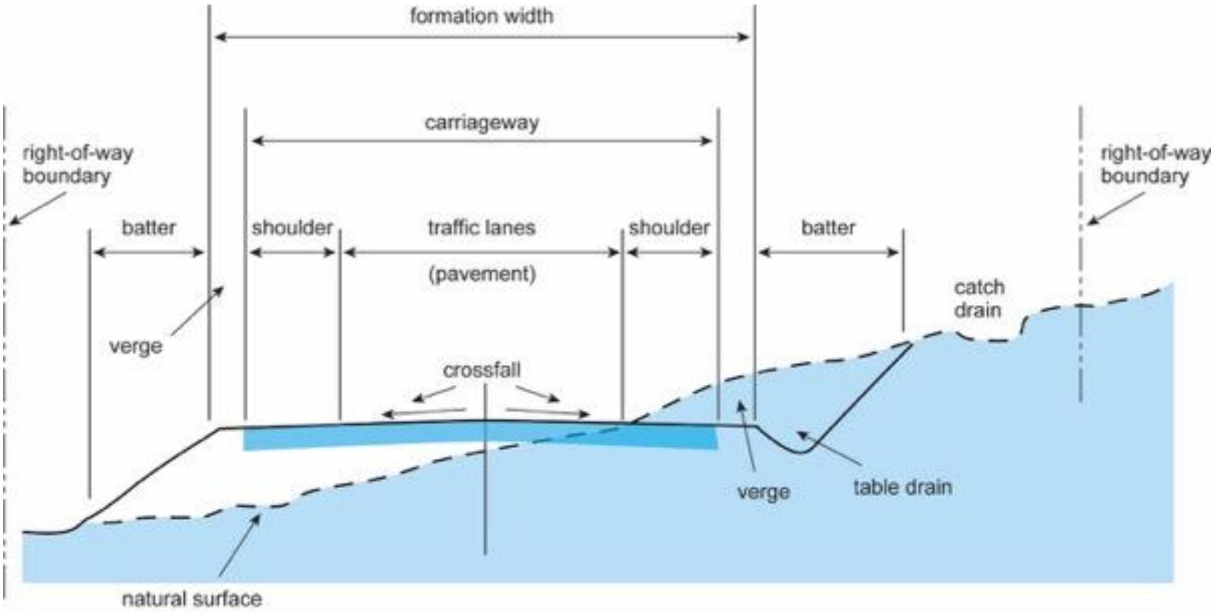
Drivers have difficulty judging extra stopping distance on grades. Nyasulu (1989) recommends that in order for heavy vehicles to operate at reasonable speeds near an intersection, the intersection should not be located on grades steeper than 3%. If it is impossible for all legs to be limited to 3% grade, the major road could have a steeper gradient, as stopping will usually take place on the minor road.

C.6 Road Cross-section

Unsealed roads in the majority of cases are either one-lane two-way roads or two-lane two-way roads. The elements of a road cross-section are shown in Figure C 25. The main deciding factor as to whether a road is one or two lanes depends on the estimated future design traffic volume.

For roads with low traffic volumes < 150 vpd, Austroads (2003) suggests that a single-lane two-way operation is adequate as there is a low probability of vehicles meeting and the few passing manoeuvres can be undertaken at reduced speeds using the shoulders. Providing there is sufficient sight distance these manoeuvres can be performed without hazard and the overall loss in efficiency brought about by reduced speeds when vehicles cross will be small. It is not cost-effective to widen the carriageway in such circumstances and a basic width of 5.5 m will normally suffice. For two large vehicles passing with a legal width of 2.5 m, a 5.5 m carriageway will allow a 0.5 m clearance between vehicles.

Figure C 25: Elements of a road cross-section



Source: Austroads (2016c).

A single-lane two-way road should have a carriageway width of 5.5 m. A two-lane two-way road should have a minimum carriageway width of 7.0 m (Table C 17). Traffic lane width should be either one-lane or alternatively two full lane widths.

Table C 17: Suggested typical minimum unsealed road cross-section widths

Description	Two-lane two-way road (m)	One-lane two-way road (m)
Traffic lane	3.0	3.5
Shoulder	0.5	1.0
Carriageway	7.0	5.5
Table drain	1.0	1.0

For intermediate carriageway widths the crown receives double the wear of the outer wheel paths with the crossfall being reduced due to the extra wear on the crown. Such roads have the distinct 'three wheeled track' signature as shown in Figure C 26. As a result, drainage is impaired, and potholes develop along the centreline. Build-up of material will occur along the outer edges of the traffic lanes and shoulders, further interfering with surface drainage. For single lane widths it may prove practical to adopt a single one-way crossfall to reduce maintenance grading operations as the narrow road does not have to be graded to a crown thereby reducing the number of grading passes. Care needs to be taken on horizontal curves that the crossfall is in keeping with superelevation requirements.

In many cases, two-lane two-way roads are being provided for traffic volumes much less than 150 vpd. While it is desirable to provide more generous road standards, wider roads do cost more to maintain, resheet and can encourage higher speeds.

Figure C 26: Road showing the three wheeled track effect

Source: ARRB (2009).

In some cases road widths can become excessively wide over time as the grader operator chases suitable fines material from the side of the road thereby making the road wider than required (Figure C 27). In these cases, extra maintenance passes are required to grade a wider roadway and excessive loss of gravel occurs due to greater exposure to climatic factors and higher travel speeds. This situation should be avoided. Where wider roads than are needed exist, action should be taken to restore the road to the desirable width. This cannot normally occur straight away as it may cause community concerns that roads are being narrowed but can be achieved with a gradual reduction to the road width over time.

Figure C 27: Avoid making unsealed roads too wide

Source: ARRB (2009).

Practitioners should ensure that existing road widths comply with desired geometric design standards/road class to ensure efficient transport operations, improved safety and reduced maintenance requirements.

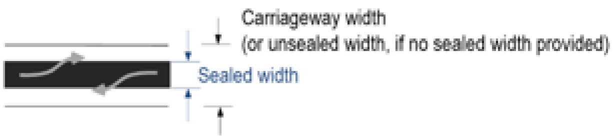
For roads carrying a high percentage of heavy vehicles (> 20%) road widening requirements may be required, particularly around tight curves to match truck configuration. Table C 18 provides a general guide for road widening on horizontal curves for the typical semi-trailer. For logging trucks with longer wheel bases the requirements are given in the following section.

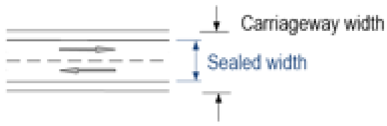
Austroads (2018g) suggests that, for very low-volume roads (i.e. < 150 vpd), a narrow carriageway of between 5.0 m and 6.0 m is adequate. This width will allow vehicles to pass each other by riding half on the traffic lane and half on the shoulders. This will eliminate the need for special sections of road for passing. If this type of road is sealed at a later date, the carriageway will need widening. Austroads (2003) also states that, where traffic volumes are likely to require a carriageway width of 8.0 to 8.5 m, this will allow at least a 3.5 m traffic lane with over 2.0 m shoulders, or two 3.0 m traffic lanes with at least 1.0 m shoulders. This width will also enable easy sealing in the future with little, if any, extra widening required.

Where the road is required to be accessed by larger heavy vehicles, the following widths are recommended in accordance with Table C 18 and Table C 19.

Table C 18: Rural carriageway: single lane and one lane (2 way) road widths for heavy vehicles

	60–70 km/h			80–100 km/h		
	B-double/ PBS level 2	Type 1 RT/ PBS level 3	Type 2 RT/ PBS level 4	B-double/ PBS level 2	Type 1 RT/ PBS level 3	Type 2 RT/ PBS level 4
Undivided carriageway: Single lane (roadside conditions apply [3])						
0–150 AADT or VPD						
Carriageway width (m)[2]	7.6	7.7	8.2	7.9	8.0	8.6
Carriageway width (m)[2]	7.6	7.7	8.2	7.9	8.0	8.6
Undivided carriageway single lane				**One lane (2 way)**		





1 Sealed width should be provided if the AADT is > 150 and annual freight tonnage > 300 000 tonnes per annum. In the absence of AADT and load data, a sealed width should be provided if:
- *uniform annual loaded heavy vehicle traffic volume is more than 10 vehicles per day; or*
- *loaded heavy vehicle traffic volume is more than 60 vehicles per day over a seasonal two-month period.*

2 Carriageway width can be used to assess unsealed roads.

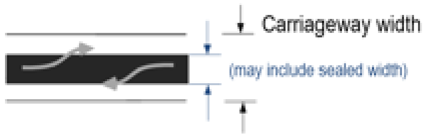
3 If the carriageway width of an undivided carriageway single lane is < 10 m, the embankment or table drain should be 1:6 or flatter, this will allow smaller vehicles to move clear of an oncoming heavy vehicle that stays on the seal:
- *If the sealed width is less than 5.5 m then signage to identify heavy vehicles are operating on the route should be provided.*
- *Some short sections are acceptable where sight distance in both directions (between opposing vehicles) is > 250 m and the sight distance allows the smaller vehicle to stop at a section with adequate width and the embankment or table drains are 1:6 or flatter.*

Source: NACoE (2019).

Table C 19: Rural low-volume (< 75 VPD), low-speed roads: single carriageway 2-way road widths for heavy vehicles

	40 km/h			60 km/h		
	B-double/ PBS level 2	Type 1 RT/PBS level 3	Type 2 RT/PBS level 4	B-double/PBS level 2	Type 1 RT/ PBS level 3	Type 2 RT/ PBS level 4
Local access road 0–75 AADT or VPD(1, 2, 3): 2-way heavy vehicle traffic, roadside conditions apply(6, 7)						
Carriageway width (m) with SSD > 250 m	5.8		5.9	6.1[1]		6.3(1)
Carriageway width (m) with SSD < 250 m	6.1		6.2	6.4(1)		6.6(1)
Formed track 0–75 AADT or VPD(1, 4): 1-way heavy vehicle traffic only restrictions apply(5), roadside conditions apply(6, 7)						
Carriageway width (m) with SSD < 250 m	3.5		3.5			

Low volume single carriageway (2 way)



1. *AADT should consider traffic growth and include consideration of seasonal volumes.*
2. *If a road is at least 1.0 m wider than these widths, an 80 km/h speed restriction should be considered.*
3. *Formed tracks assessed with this width criteria are only suitable for one-way heavy vehicle traffic.*
4. *If the carriageway width of a low-volume single carriageway (2 way) road is < 10 m the embankment and table drains should be 1:6 (or flatter), this will allow smaller vehicles to move clear of an oncoming heavy vehicle that stays on the seal.*
5. *If the carriageway width of a low-volume single carriageway (2 way) road is < 7 m, where heavy vehicles may be required to move off the carriageway when giving way to oncoming heavy vehicles, the embankments and table drains should be 1:10 (or flatter) for at least the first 1.5 m to 2 m.*

Notes:
- *Some short sections are acceptable where sight distance in both directions (between opposing vehicles) is > 250 m and the sight distance allows the smaller vehicle to stop at a section with adequate width and embankment or table drains are 1:6 (or flatter).*
- *Speed refers to the prevailing speed limit for the road. The operating speed could be used (based on operating speed model/simulation or historical speed data).*

Source: NACoE (2019).

C.6.1 Clear Zone

Clear zone is defined in Austroads (2015b) as 'the area adjacent to the traffic lane that should be kept free from features that would be potentially hazardous to errant vehicles' (Figure C 28).

Figure C 28: Clear zone from edge of traffic lane to the major obstacle (i.e. tree)

Source: ARRB (2009).

The clear zone is a compromise between the recovery area for every errant vehicle, the cost of providing that area and the probability of an errant vehicle encountering a hazard. The clear zone should be kept free of non-frangible hazards where economically and environmentally possible. Alternatively, hazards within the clear zone should be treated to make them safe or be shielded by a safety barrier.

The values provided in the Austroads (2018g) guide do not cater adequately for low volume roads as the lowest volume is 750 vpd and in such cases a 5 m clear zone is required if travelling at 85 km/h.

A more appropriate approach is that the designer should provide a clear zone as wide as is practicable within the constraints of cost, terrain, right-of-way or potential social and environmental impacts. Lateral clearances between roadside objects and edge of the shoulder should normally be 1.5 m. Where provision of a clear zone is not practicable none is required (AASHTO 2001), although this is not desirable for roads with a high-speed alignment.

Vertical clearances to bridge structures, tree canopy or any overhead crossing wires should be greater than the legal height limit of vehicles. This is generally 4.5 m unless the road carries abnormal vehicles in which case this may need to be increased to 6 m.

Further information on clear zones can be found in Austroads (2018g). It is noted that this guide is currently being updated.

C.6.2 Haul Routes Requirements

In cases of timber, cartage or mine haulage routes, larger vehicles as shown in Figure C 29 will be involved and special consideration will need to be given to the geometric needs of such vehicles (Giummarra & Blanksby 2006).

Figure C 29: Large haul vehicles

Logging vehicle

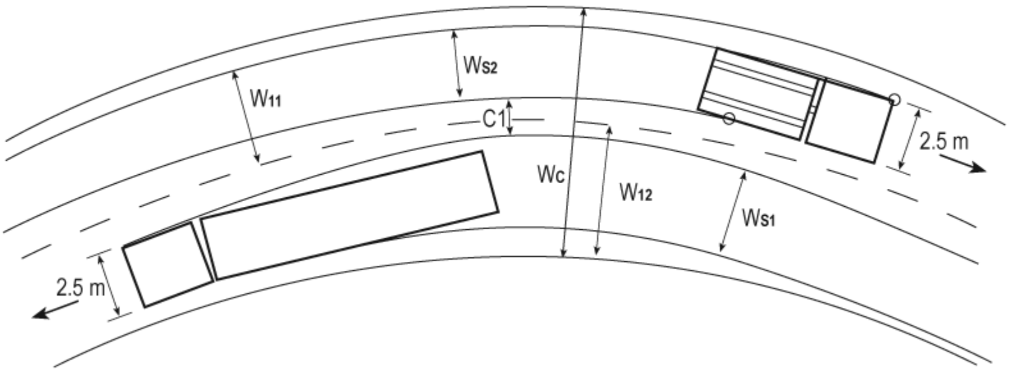
Mine haul vehicle

Swept path requirements

When a long logging vehicle makes a turn at a bend, the rear of the vehicle will follow a path that is inside of the path taken by the front of the vehicle. This is known as off-tracking. A high value of off-tracking is undesirable because the vehicle sweeping a wider path will require more road space for turning than may be available. This may cause the vehicle to encroach into the path of a passing vehicle, or the rear wheels may climb the embankment or fall off the edge of the shoulder. Factors that affect a vehicle's swept path include speed (low speed causes a wider swept path) and vehicle geometry (i.e. wheelbase dimensions).

The swept path width establishes how much lateral space a particular vehicle needs to safely manoeuvre through the curve. Dependent on these values is the carriageway width. When assessing the width of the road at a bend, the worst case scenario is when two vehicles are passing each other and this needs to be considered (Figure C 30).

Figure C 30: Vehicles swepth path passing on a typical curve



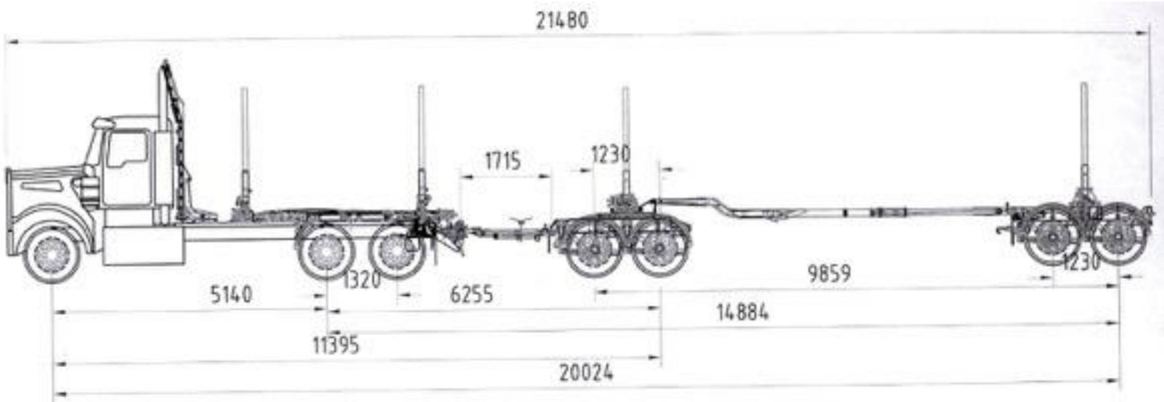
Where:
$C1$ = Lateral clearance between vehicles in adjacent lanes (M)
W_{s1} = Swept path width – laden (m)
W_{s2} = Swept path width – empty (m)
W_{11} = Lane width – unladen direction (m)
W_{12} = Lane width – full direction (m)
W_{c} = Carriageway width (m)

Source: ARRB (2009).

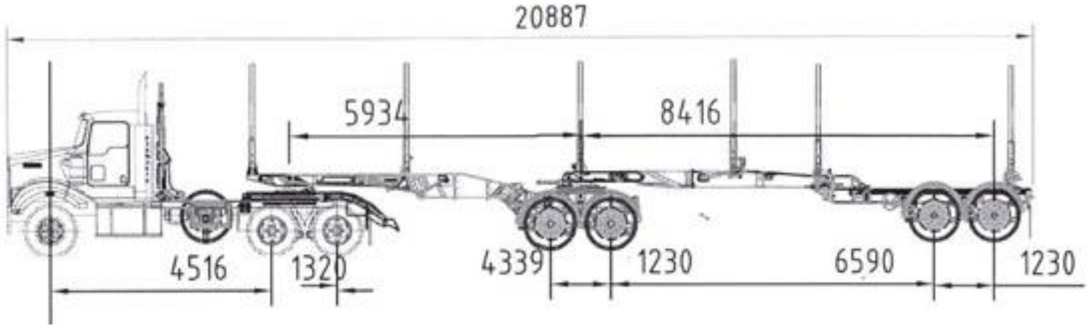
The swept paths of various laden, logging vehicles shown in Figure C 31, are given in Table C 20, through turns with radii ranging from 15 m to 320 m.

Figure C 31: Dimensions of various logging vehicles

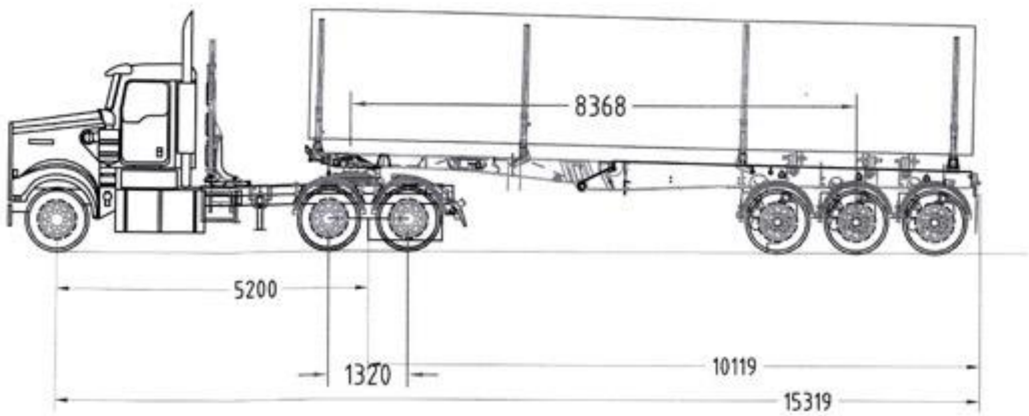
Typical logging truck configurations



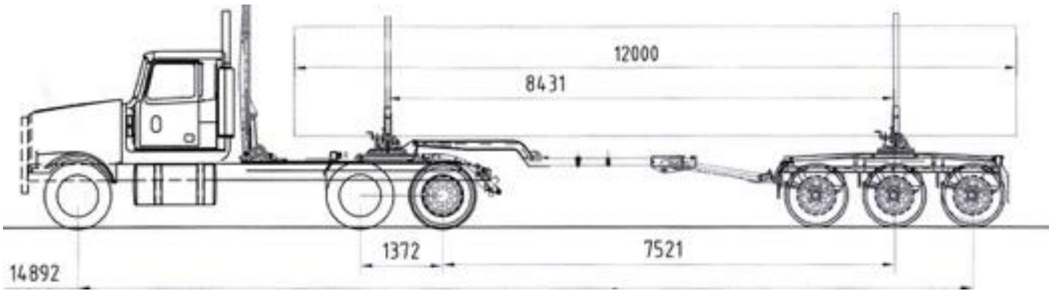
4 Axle pole dog (laden)



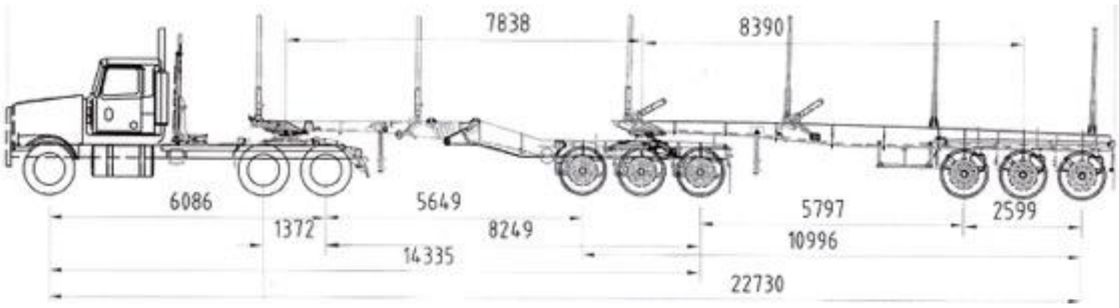
Mini B-double – 3 bay (laden)



Tri-axle folding Skel (laden)



Tri-axle Jinker (laden)



Tri-Tri B-double (laden)

Source: Giummarra (2006).

The swept width is much greater for a laden than an unladen vehicle and as a result it is recommended that the lanes be widened on the side of the road upon which laden vehicles travel (if marked lanes exist). The width of the carriageway should at least be the swept path width of the laden vehicle plus the swept path width of the unladen vehicle plus clearance between vehicles, plus clearance between the passenger side of the vehicle and the verge. This will eliminate the chances of vehicles colliding or falling off the carriageway as they pass each other during the turn.

Using this approach, Table C 20 provides the recommended carriageway widths, for a laden and unladen vehicle to pass one another. In calculating the widths, the clearance between vehicles was set at 1.0 m and the edge clearance was set at 0.5 m.

Table C 20 shows that allowing for the swept widths of both the vehicles, plus necessary clearances, results in significant increases in the required carriageway width for small radius turns, and lesser increases for turns with larger radius. It is important that increases in lane size are applied with respect to the differing requirements of the laden and unladen vehicles. The swept paths of the laden trucks contribute a larger share of the increased road width than the empty trucks, thus this must be considered when widening the roads.

Proprietary computer programs are available to simulate various vehicle types and dimensions to calculate the swept path width of a given vehicle and radius turn.

Table C 20: Carriageway width requirements for unladen and laden vehicles passing

Radius (m)	Carriageway width Wc (m) (includes traffic lanes and shoulders)				
	4-axle pole dog	Mini B-double	Tri-axle folding skel	Tri-axle jinker	Tri-tri B-double
15	12.02	12.12	11.35	11.65	15.21
35	9.38	9.42	9.02	9.16	11.03
45	8.84	8.88	8.57	8.68	10.14
60	8.39	8.41	8.18	8.27	9.35
70	8.19	8.21	8.01	8.08	9.02
100	7.84	7.85	7.72	7.77	8.42
110	7.76	7.78	7.65	7.7	8.29
140	7.61	7.62	7.52	7.56	8.04
160	7.53	7.55	7.47	7.49	7.91
170	7.5	7.52	7.44	7.47	7.86
220	7.41	7.42	7.35	7.37	7.69
250	7.37	7.39	7.33	7.35	7.66
320	7.31	7.35	7.29	7.3	7.59
> 320	Vehicle swept width approaches 2.5 m				

C.6.3 Crossfalls

Unless compaction and surface shape are well controlled during construction, pavements with insufficient crossfall will hold small ponds on the surface, which may cause potholes to develop and hasten surface failure (Figure C 32) (Austroads 2016c). If too great a crossfall is applied, the surface material will be prone to scouring and erosion. Note that where the shoulder has adequate crossfall there is no evidence of potholes.

Figure C 32: Flat roads are most prone to potholes forming

Source: ARRB (2009).

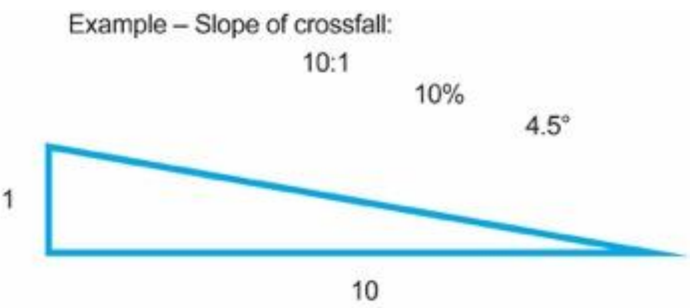
Bofinger et al. (1990) recommend that, for ease of construction and maintenance operations, shoulders should have the same surface crossfall as the traffic lanes for unsealed roads so that they may be constructed and maintained to the same crossfall.

It is common to find that most unsealed roads are not provided or maintained with the desired crossfalls and shaped to a crown. While flat crossfalls may be desirable for the travelling public, it is most undesirable for road maintenance purposes because it will not permit the shedding of surface water off the road, which will lead to rapid development of potholes and deterioration of the pavement.

Crossfall measurements can be expressed in various forms as listed below and is depicted in Figure C 33:

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

Figure C 33: Crossfall measurement expressions



The crossfall measure used in this Guide is based on percentages and batter slopes as a ratio. Table C 21 gives the conversion values between the various measurement types.

Table C 21: Conversion values for various crossfall measurements

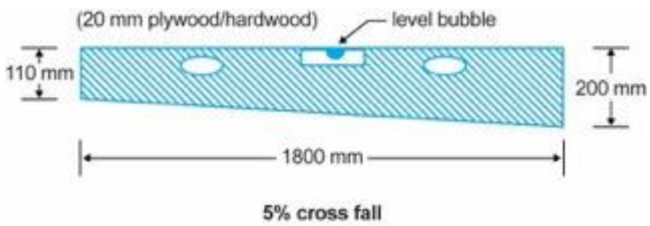
Ratio values m/m (H:V)*	Percentage values	Degrees values
100:3	3%	1.35°
100:4	4%	1.80°
100:5	5%	2.25°
100:6	6%	2.70°
100:7	7%	3.15°
100:8	8%	3.60°
100:9	9%	4.05°
100:10	10%	4.50°

** A way to remember the ratio is that you always have to walk to a tree H before it can be climbed V.*

Crossfalls in the field can be measured in various ways. Some graders have levelling devices that provide the crossfall of the road. Care should be taken that the rear wheels on which the level is based on the actual roadway being measured and the tyres are all correctly inflated. A better method is to use a 'smart level' which provides a digital readout, in either percentage values or degrees, of the actual crossfall of the road being measured. An alternative is to use a camber board which is cut to the required crossfall and has a spirit level on top to show when the desired crossfall is achieved (Figure C 34).

Figure C 34: Devices to measure actual road crossfalls

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



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

The crossfall which should be used depends on the local conditions and material properties. Crossfalls in the range of 4–6% have been used with success. In practice it is recommended that the road crossfall be initially constructed at 6% as it will not be long before it flattens to around 4%. Austroads (2003) cites values for crossfall to be used for various unsealed pavement types, and these are shown in Table C 22. In terms of fall from the crown to the edge of the roadway the values for different crossfalls and road widths are given in Table C 23.

Table C 22: Pavement crossfall on straight road sections

Type of pavement	Crossfall (m/m)	(%)
Earth, loam	0.05	5
Gravel, waterbound	0.04	4–6

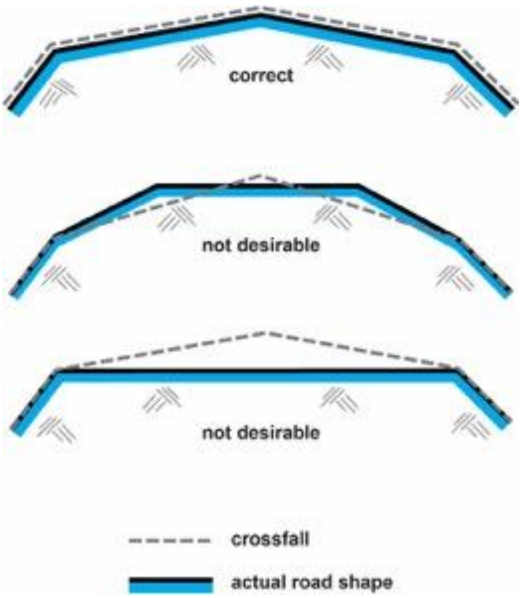
Table C 23: Fall distance from crown to edge of shoulder

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

Lack of adequate crossfall is suggested (Ferry 1986) as the most common defect of New Zealand's unsealed roads as this does not provide adequate drainage of the road surface.

Two-way crossfalls should meet with a crown as shown in Figure C 35. This will help to prevent the development of potholes in the road centre. For single-lane carriageways, it may be best to have a single crossfall for ease of grading during regular maintenance.

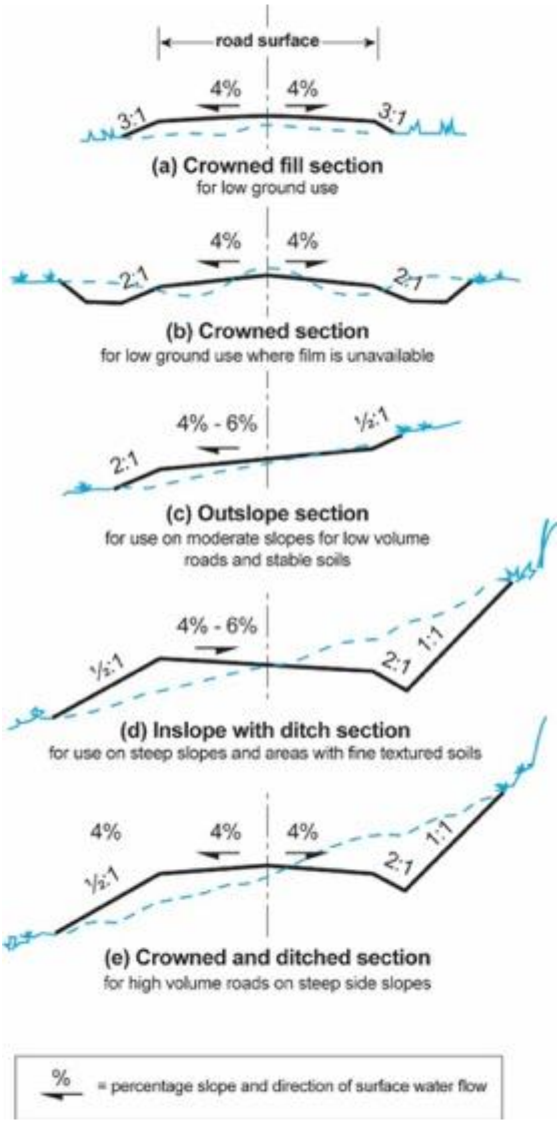
Figure C 35: Correct shape of a two-lane road



Source: ARRB (2009).

Five road cross-sections typically used in road construction are shown in Figure C 36. The choice of which cross-section should be used depends on drainage needed, soil stability, slope and the expected traffic volume on the road.

Figure C 36: Alternative road shapes and crossfalls



Source: ARRB (2009).

A crowned fill section is for use on flat ground where water standing on a road surface may be a problem. An out-slope section is for use on moderate slopes for low volume roads and stable soils. Out-sloping sections are not recommended on roads requiring winter logging. An in-slope section with a table drain is for use on steep terrain, areas with fine-textured soils, winter logging and areas where drainage is necessary. A crowned and ditched section is for high volume roads on steep side hills.

C.6.4 Batter Slopes

Batter slopes to cut faces should be designed to promote stability, safety and the establishment of vegetation. The slope angle should not exceed the stable angle of the particular soil, and high cut faces should be interrupted by benching sloped back into the face to reduce surface erosion and promote revegetation. Erosion of batters causes siltation of table drains and therefore requires more maintenance.

The maximum slope of fill batters is also largely dependent on the stability of the fill material. In order to reduce erosion damage, the slopes on fill batters should be gentle. However, gentle batter slopes will require considerably higher amounts of fill material than steeper slopes.

To aid the revegetation of batters it is desirable that batter slopes be not left smooth but rather rough with horizontal grooves where possible to reduce the velocity of water down the slope and to help plant roots gain a hold into the batter.

If the batter is adjacent to a two-lane one-way road, consideration needs to be given as how two vehicles will pass each other. If the road is less than 10 m wide, then a car may be required to pull off the road to allow an opposing heavy vehicle to pass. In such circumstances, the batter and table drain area should be no steeper than 1:6. Similarly, if it is likely that two heavy vehicles will be required to pass each other, requiring them to overhang the verge, the table drain and batter should be kept to no stepper than 1:10 for the first 1.5–2.0 m (NACOE 2019).

C.7 Drainage

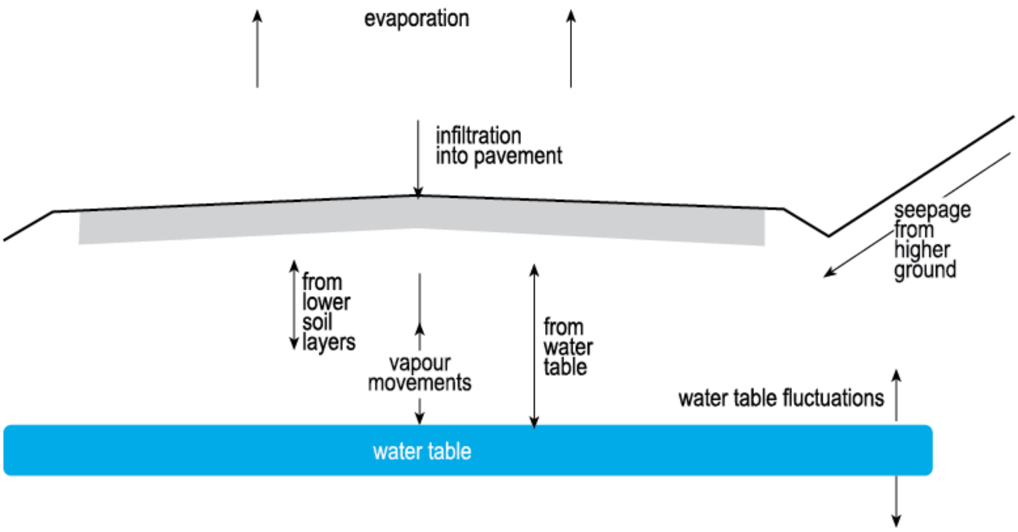
Drainage is one of the most important and critical factors in the ability of an unsealed road to withstand traffic loads.

Drainage provision should always account for three components:

- water falling onto the road surface (provision of crossfalls and side drains)
- water approaching the road on the high side (provision of catch bank drain)
- water from below the road due to high watertable or capillary action (provision of subsoil drains or elevated formation).

These components are illustrated in Figure C 37.

Figure C 37: Key drainage components



Source: ARRB (2009).

The methods employed to account for the three key drainage components are:

- Water that falls onto the road surface must be shed off as quickly as possible by the use of a crowned crossfall of 4–6% on straight sections.

- Water flows approaching a road from the higher adjoining countryside must be intercepted from flowing toward the road by catch drains or banks and diverted into natural watercourses and taken across the road by suitable culverts/floodways.
- Water collected alongside the road must be drained away from the road as soon as possible by the use of deep table drains to intercept water.

Two factors make drainage of higher importance in unsealed roads than in sealed roads. Firstly, the materials used in low-volume unsealed roads tend to be of lower quality than those used in sealed roads and are more likely to be susceptible to water damage. Secondly, due to the lack of a seal, the combination of traffic and water is able to erode the pavement structure much more easily and do more damage than for sealed roads. The importance of drainage should always be kept in mind.

The following sections do not discuss detailed hydrological procedures to calculate flows for culvert sizes, but in Section 3.7.2 a design method for culverts is provided. The drainage methods used for unsealed roads are the same as those used for sealed roads. Designers are referred to texts such as NAASRA (1986) for hydrological calculations.

Drainage for unsealed roads falls into two groups: surface and subsurface. The purpose of surface drainage is to remove water that falls on the road surface and to protect the road from water which falls on the surrounding areas. Subsurface drainage protects the pavement against water that has entered through the road surface, and against subsurface water that enters from surrounding areas or the watertable.

Key Drainage Principles

- *Keep the water off the road by having a crossfall of between 4–6% and the road built to a crown.*
- *Take the water away from the road as quickly as possible by having good table drains, mitre and cross drains.*
- *Keep the water from the road by having catch banks and adequate cross culverts.*

C.7.1 Erosion and Sediment Control

Unsealed roads are a potential source of erosion and sediment production as they interrupt the natural drainage pattern, concentrate flows and are frequently the source of abrasive materials entering the watercourses. This can result in lower water quality in streams and reservoirs for consumption by users and can adversely affect plant and animal life. It is therefore important to the community in general that erosion on and from roads is minimised.

Erosion and siltation caused by run-off from unsealed roads is a problem all over the world. However, these detrimental effects can be greatly reduced by careful planning, construction and maintenance, often at no extra costs. Further information on erosion prevention is provided in Appendix A.3.2.

Vegetation is a major element in protecting soil from the erosion effects of water concentration in drainage channels and the retention of silt.

C.7.2 Surface Drainage

Surface drainage comprises those elements that collect and remove water from the surface of the road. It includes culverts and any other drainage system designed to intercept, collect and dispose of surface water flowing towards and onto the road surface from adjacent areas.

The importance of providing adequate crossfall to allow surface water to run off the pavement is paramount for unsealed roads.

Loder (1970) states that it is '... highly desirable in all relatively flat or very gently undulating country, except perhaps in arid areas, for raised formations to be used'. However, in areas of negligible slope, which are prone to flooding, a raised formation may act as a dam for floodwaters. In such cases the alignment should be chosen to be along the higher elevated sections of the ground surface. If the ground level is such that the road formation will act as a dam, then the road should be designed so that the surface of the road is level with the natural surface level. This implies that the road will not be accessible when wet. The decision of when to re-open the road, after flooding, will depend on the likely initial deformation and other damage caused by traffic on the wet road.

Low formation roads, which closely follow the natural surface level (about 300 mm above), have many benefits and risks. The benefits relate to less earthworks and costs with the risks associated with a higher watertable and increased moisture in the pavement. As a guide, low formation pavements could be constructed in arid to semi-arid regions subject to the influence of the watertable on the pavement. Further details are available in Foley (1997).

Table drains

Table drains, otherwise known as drainage ditches or side drains, run parallel to the road and drain water from the road surface and adjoining slopes. These drains are usually placed in cut sections and at grade sections but can be used along the toe of a fill section if required to collect water to discharge to a suitable location. Table drains can have flat bottoms and may be lined or unlined. For low-volume unsealed roads, most table drains are unlined, unless there is a potential scouring problem.

Table drains on the low side of a road are not recommended as they require resources to build and maintain and have the effect of concentrating water flows. Sheet flows off an embankment should be encouraged. Those on the high side of the road run into cross drains, turn-offs or gullies, which are located at the culvert points. The spacing between gullies and side drain inlets is determined by inspection.

Experience by the Roads and Traffic Authority, NSW (RTA) has found that for unsealed roads in flat terrain, it is best to build up the road formation by winning the material from borrow pits outside the road reservation and deliberately constructing the formation without table drains.

Also, the height of formation in arid areas is partly a function of balancing the need to stop it desiccating in dry spells and saturating in wet spells. Guidance on this practice is given by RTA (1992).

In side cuttings, table drains on one side of a road may be eliminated by either in-sloping or out-sloping the road formation as shown in Figure C 38 and Figure C 39, respectively.

Some of the features of this technique are:

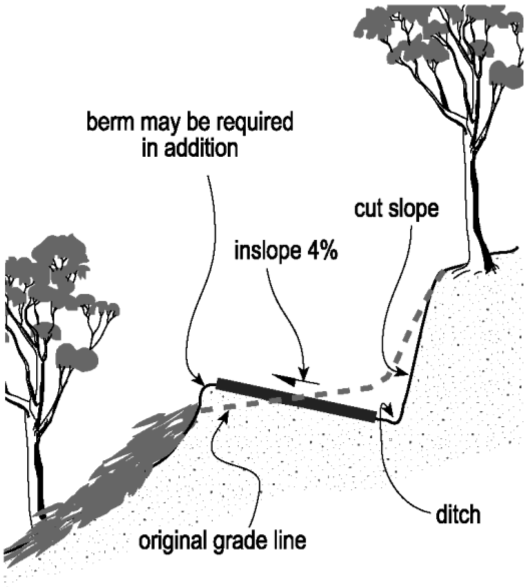
In-sloping

- Used to keep water away from unstable fill slopes.
- Can be used with or without a table drain or ditch (subject to grade).

- Used for short sections of roads.
- Cross drains can be installed as required to avoid build-up of fast running water in table drains.

It is important to ensure at curves that the crossfall conforms to superelevation requirements.

Figure C 38: In-sloping drain



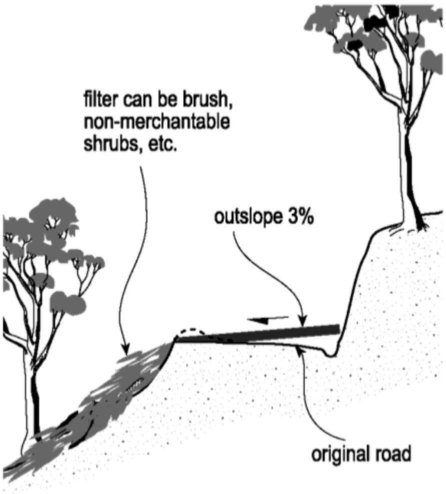
Source: ARRB (2009).

Out-sloping

- Provides a means of dispersing water in a low energy flow from the road surface.
- Appropriate where fill slopes are stable.
- Good for contour roads having gentle gradients.
- Water bars may still be required.
- Not suitable for logging routes in winter.

It is important to ensure at curves that the crossfall conforms to safety requirements.

Figure C 39: Out-sloping drain

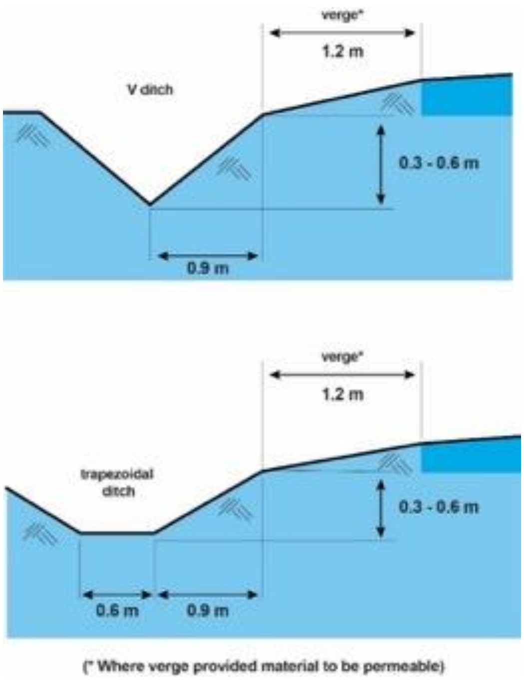


Source: ARRB (2009).

It is preferable to transfer high water flows in the table drain to discharge to the lower side of the road more frequently by the use of cross drains (or culverts) rather than to carry excess water which can cause additional scouring and possible overflow onto the pavement. Lining table drains with beaching or other materials to minimise erosion should be avoided as this is where most of the fines will be deposited and will need to be collected later by the grader for reuse during routine maintenance operations.

In areas not subject to periods of prolonged heavy rainfall, V-shaped drains of the size illustrated in Figure C 40 will be sufficient. Larger volume side drains are usually trapezoidal in shape and have a lower flow velocity.

Figure C 40: Open table drain construction types



Source: ARRB (2009).

Trapezoidal or wide V shaped drains are better as they provide a greater flow capacity, reduce the flow velocity and thereby minimise scour. They should be vegetated with grass where possible and maintained by mowing. Scraping drains only promotes sedimentation. Spraying drains reduces effective plant competition and results in weed invasion.

In flat areas, consideration should be given to the problems of longitudinal flows between widely spaced culverts.

The geometry of the drains should be compatible with the maintenance techniques to be used.

It is important that, at any time, the lowest point in the pavement is well above the free water level in the table drains (aim for a distance of > 0.5 m).

To provide reasonable safety for vehicles which run off the road, the inverts of the ditch should be preferably rounded and Bofinger et al. (1990) recommend that the side slopes should not be steeper than 1:1.5. Use of rotary ditcher equipment, if available, can provide rounded side drains, making it easier to construct and maintain.

Use of swales which have a wide base and gently sloping sides are preferable for safety reasons providing the extra width required does not compromise the environmental value of vegetation that will have to be removed.

The longitudinal slope of the drain should be sufficient to avoid silting, but below the value at which scouring and erosion can occur. Bofinger et al. (1990) recommend a minimum longitudinal slope to avoid silting of 0.5% (1:200) for an unlined ditch, and 0.33% (1:300) for a ditch lined with concrete or asphalt. Also recommended by Bofinger et al. (1990) is a maximum slope of 5% (1:20) for an unlined ditch. Provisions to prevent erosion are recommended for ditches which, due to topography, cannot be restricted to less than 5% longitudinal slope. Check walls and drop walls can be used at intervals on steep slopes, as can stepping the ditches down. However, attention must then be paid to localised erosion damage (e.g. at the steps). Grassing of the drain may also be used to reduce erosion and catch silt. However, during maintenance operations there is a risk that the grass cover may be removed as table drains are cleaned out and re-established.

Cut-off (or mitre) drains, taking water away from the table drains into the surrounding area, should be constructed as often as the terrain will permit water to flow into a natural drainage course (Figure C 41). The principle is to place the cut-off drains at intervals which avoid ponding, adjacent to the road but not too far apart to allow build-up of high concentrations and flow velocities, which lead to scouring.

Figure C 41: Provision of a cut-off drain

Source: ARRB (2009).

Frequent cut-off drains will minimise the amount of water flowing in a table drain, reduce the potential for scouring, erosion and the need for cross drains, and minimise the concentration of water discharge into the surrounding land. Where cut-off drains are constructed it is essential that the water from the drain be dispersed as far as practical to minimise erosion downstream. In some cases, it may be necessary to provide obstructions downstream of the discharge point by the use of a dense cover of filtering ground vegetation. This may consist of windrow trees, logs (100 mm diameter), rocks or brush laid across the slope.

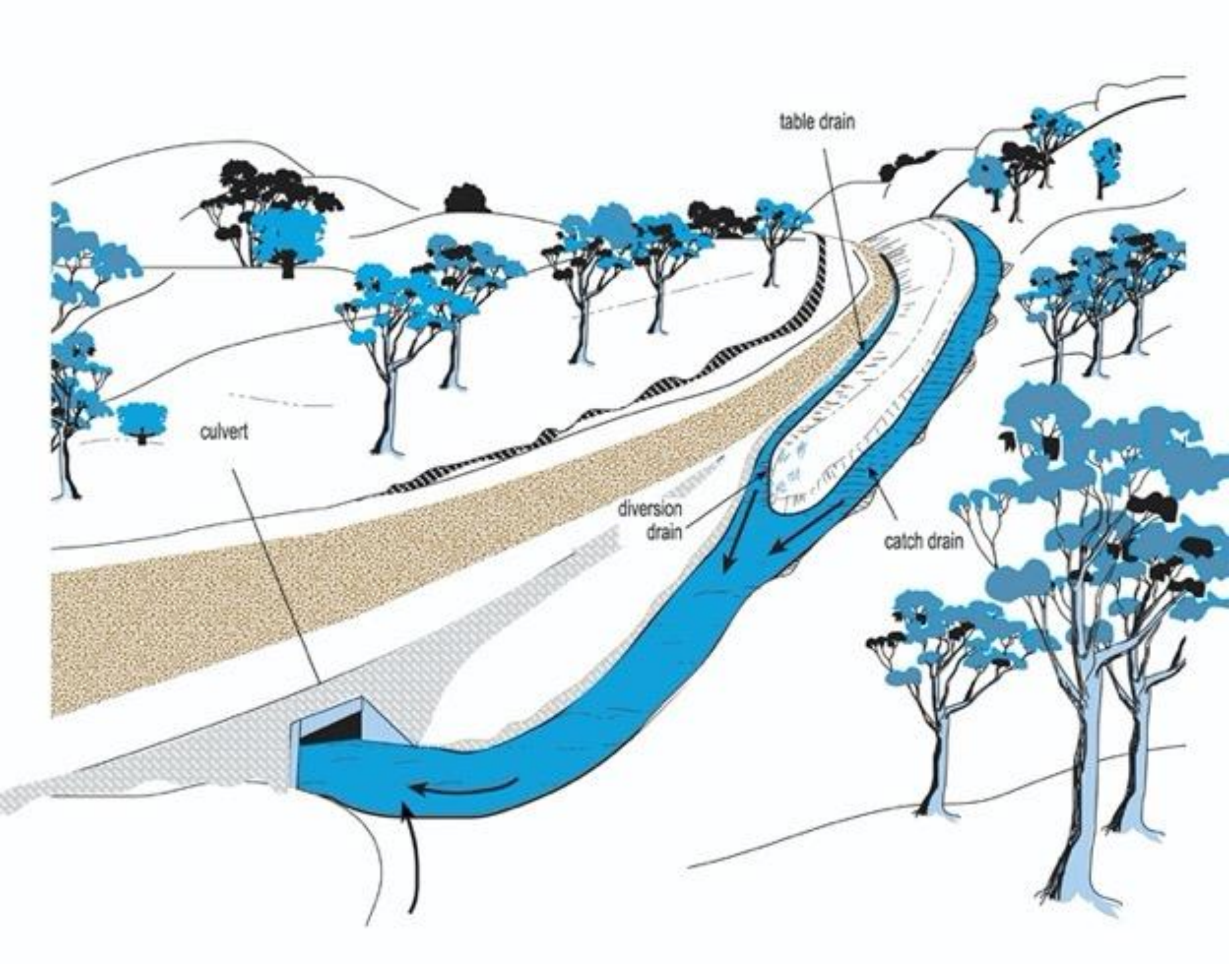
In locations with restricted road reserve widths, it will generally be necessary to negotiate with downstream property owners for access to construct and maintain side drains as well as give consideration to the legal point of discharge.

For unsealed roads it is most desirable to minimise the concentration of water flows as it can lead to high water velocities and consequent drainage scour. Respreading of flows concentrated by road formations and drains as soon as practicable is a good practice to adopt.

Cross drain culverts

The spacing of cross drain culverts to transfer water from the high side of the table drain to the low side is a function of the slope of the table drain, the soil erodibility and quantity of water flow. As a general rule, water should be dispersed from the table drain as frequently as possible either in cut-off drains or across the road. Figure C 42 provides a design layout of a cross drain such as to ensure self-drainage with a slope across the road.

Figure C 42: Cross drain layout



Source: ARRB (2009).

As a rule of thumb, the suggested spacing of cross drains to reduce erosion is presented in Equation A14.

$$spacing(m) = \frac{300}{\%\ grade\ of\ longitudinal\ drain} \quad \text{A14}$$

This must be checked based on local knowledge.

Alternatively, Table C 24 gives various spacing criteria developed for forest roads, which can serve as a guide (Forestry Commission Tasmania 1993).

Table C 24: Maximum spacing between cross drains

Road grade	Soil erodibility class		
	Low to moderate – high (m)	High (m)	Very high (m)
1–5%	150	120	70
6–10%	120	90	40
11–15%	95	70	30
16–20%	50	35	30

Source: Forestry Commission Tasmania (1993).

The minimum diameter of culvert pipes should desirably be 450 mm to minimise frequent blockage. The optimum size will depend on local knowledge of climate and catchment conditions. It is preferable to go for a larger size where possible. Aim to achieve a grade of pipe which will promote scouring velocities to maintain self-cleaning. Provision of a silt trap on the inlet side is desirable to minimise potential silting in a pipe. In some cases, a small diameter pipe may be used (375 mm) due to costs and to provide the required cover over the pipe or outlet depth.

Culvert pipes should be reinforced concrete or alternative materials of sufficient strength with the required soil cover to handle the estimated traffic loads.

Head walls are generally installed to stop piping through the embankment. When a road is overtopped with water, inspection for scour around the head wall will be required. Avoid the use of grater pits and take care in grading a road that culvert ends are not buried and lost.

Catch drains/banks

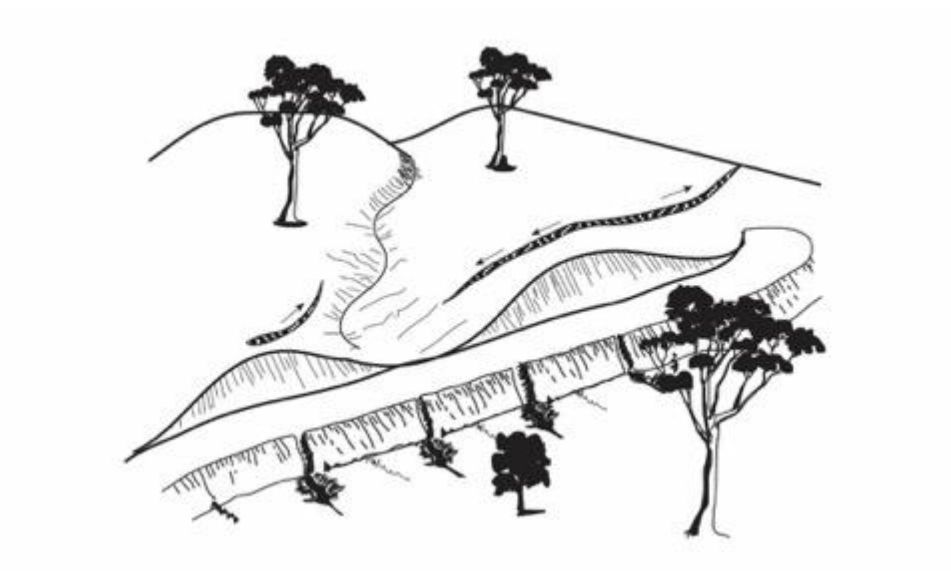
Catch drains/banks are used to drain water flowing towards the road from the higher surrounding area. These drains are often used at the top of deep cuts. If these drains are not used, then severe erosion can occur at cut batters leading to batter instability, higher maintenance cost and table drains becoming blocked (Figure C 43). Where it is not possible to provide a catch drain/bank then special provisions have to made to stabilise the cut batter slope (i.e. use of revetment or retaining walls).

Figure C 43: Example of a badly eroded cut batter without catch drains/banks

Source: ARRB (2009).

The same care should be taken, as for other surface drain types, to prevent erosion and scour. Typical shapes and dimensions of catch drains are similar to those used for table drains. They should be as near as possible to the top of a cutting and channelled into culverts or natural watercourses wherever possible (Figure C 44).

Figure C 44: Provision of catch banks of high side of roadway



Source: ARRB (2009).

If the material surface is prone to scour and it is undesirable to cut the natural surface, catch drains can be formed by creating levees or catch banks. Catch drains at the top of slopes are frequently located beyond the reach of equipment for maintenance, and consideration should be given to gaining access for maintenance purposes in designing a road.

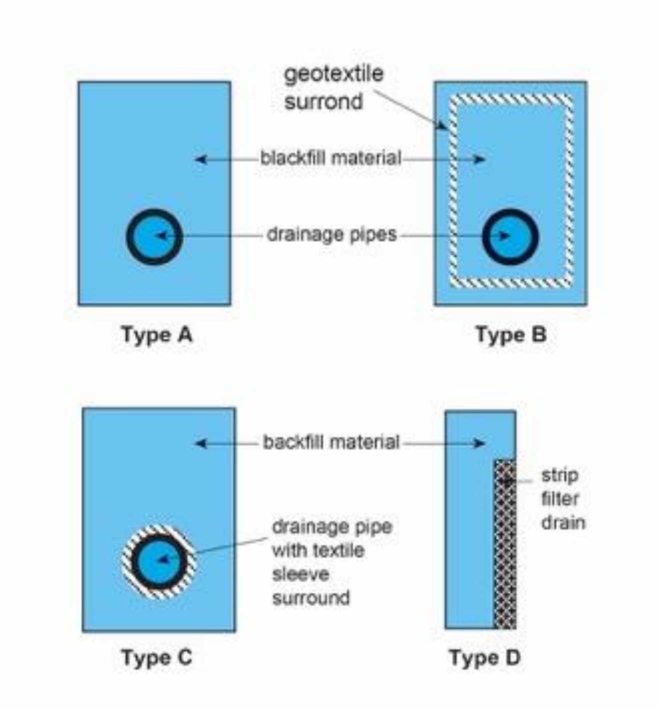
The longitudinal slope of the catch drain should be greater than 1% to prevent pooling of water above catch batters and the potential of creating landslips. To prevent scouring, the slope should be less than 5%, depending on the likelihood of the soil to erode.

Vegetating the drain is an environmentally sound way to minimise erosion, even on difficult soils. This can be carried out by covering the surface of the drain with hessian or plant slashings and applying grass seed.

C.7.3 Subsurface Drainage

The need for subsurface drainage can be reduced by use of adequate surface drainage, which prevents water penetrating into the pavement and subgrade. Typical subsurface drains are shown in Figure C 45. These drains are expensive and may not be justified for low-volume unsealed roads, except for localised areas where no other way of preventing ingress of water into the pavement is possible.

Figure C 45: Typical subsoil drains



Source: ARRB (2009).

Subsurface drainage may be constructed using pipe or rubble drains set into the subgrade or by using a subbase layer of material with free draining properties such as a coarse gravel or sand.

Subsurface drainage may be required:

- when roads traverse marshy or swampy land on which stagnant water collects
- when subgrade soil is poor and seepage from the banks of a cutting is likely to be severe
- when a cutting at the top of a hill cuts into an impervious stratum above which the watertable lies
- as a substitute for table drains on the inside of cuttings when width is severely limited.

The precise layout of a subsoil drain depends on local conditions but should be based on leading the subsoil water away by the shortest route. Typical depth of the subsoil drain from the top of the pipe is 300 mm below subgrade level.

If a geotextile is to be used in the subsurface drainage, some soil types will require tests of the compatibility of the soil and geotextile. These soils include heavy clays, friable mudstone and dispersive soils (Bofinger et al. 1990).

In order to minimise subsurface drainage, elevation of the road on to an embankment should be considered whenever high watertables are encountered. For roads in cuttings, table drains should be constructed to be 600 mm below the wearing surface.

C.7.4 Culverts

Provide an appropriate culvert or water crossing at natural watercourses to take the estimated design flow. A typical example of a culvert is shown in Figure C 46. The rational method for calculating the storm discharge from a road catchment is presented in Section 3.7.2.

The ideal grade line for a culvert is one that produces neither silting nor excessive velocities nor scour. Normally, the grade line of the culvert should coincide with the stream bed; however; in some circumstances it may be desirable to deviate from it to be in the range of 1–3% (Figure C 46).

Examples are:

- Where sediment is expected to occur, the culvert invert may be set several millimetres higher than the stream bed, but at the same slope.
- Where headroom is limited, setting the culvert below the stream bed grade is likely to result in sediment and reduced waterway area. This should be avoided either by using a low, wide culvert such as a box culvert or pipe arch, or by raising the road grade.
- In steeply sloping areas, as on hillsides, it is not always necessary to place the culvert on the same steep grade. The culvert can be put on a ‘critical’ slope and then a spillway provided at the outlet to prevent scouring. This keeps the culvert shorter and under shallower cover.
- At times a shorter length of culvert can be used and/or a better foundation obtained by shifting the culvert to one side of the natural channel. When this is done, care should be taken to construct the inlet and outlet channels to provide for a smooth flow of the water, particularly on the downstream side to minimise or prevent erosion.
- Any new watercourse crossings designated to be of significant environmental value should be designed and maintained to minimise disturbance to the passage of fish and other aquatic fauna.
- Culverts should be provided with minimum cover in accordance with manufacturers guidelines (e.g. 600 mm for reinforced concrete pipe).
- Culvert outlets on watercourses should be protected by energy dissipaters, such as large rocks, to provide sufficient protection against bed scour or erosion.

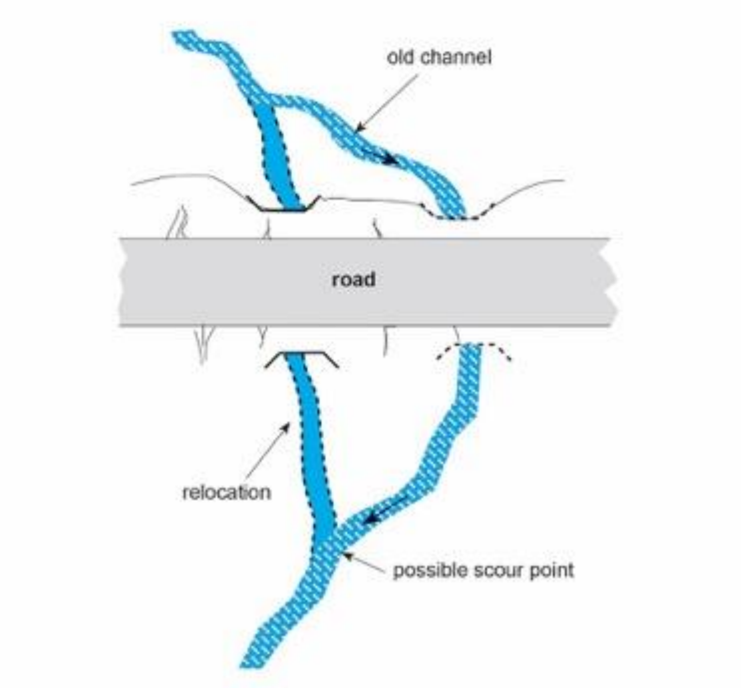
Figure C 46: Typical culvert

Source: ARRB (2009).

Generally, the stream should pass under the road at the first opportunity as shown in Figure C 47. However, this may cause higher water velocity if the water path is reduced in length over the same drop. In such cases consideration will need to be given to additional stream protection to avoid scouring and fish passage requirements, where applicable.

Avoid diverting a watercourse to join another to save on a crossing, as the added water flows could cause erosion problems downstream due to a higher water concentration.

Figure C 47: Relocation of existing stream



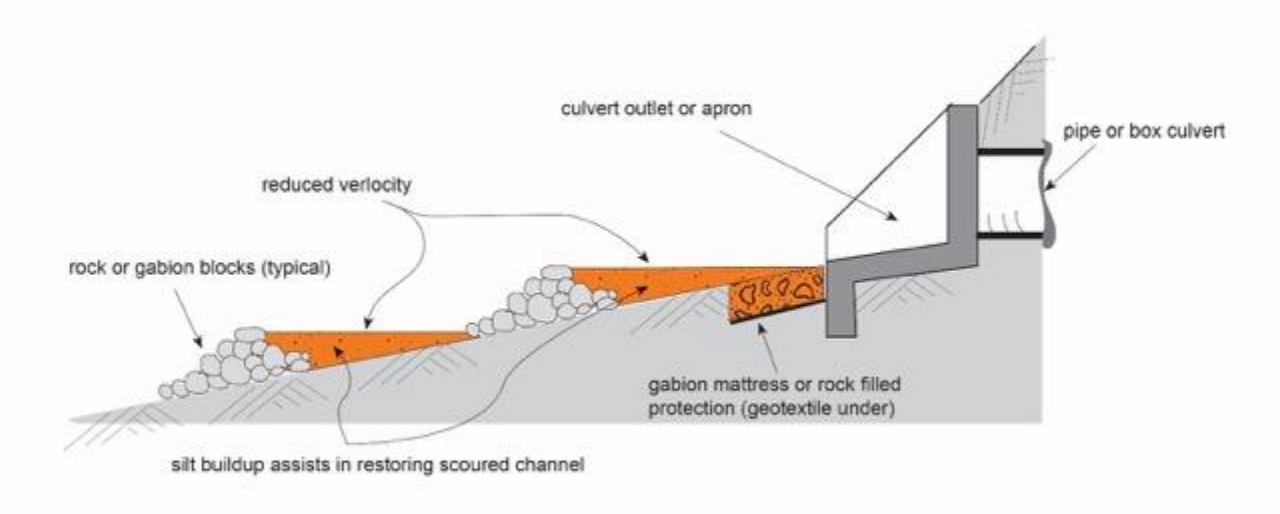
Source: ARRB (2009).

Culvert inlets should be eased to a smooth entry without abrupt changes in direction or drops which can cause turbulence. Where these are unavoidable, they should be adequately protected by concrete, gabion mattresses or riprap. Geotextile material should be placed under gabions or riprap and a cut-off wall to prevent undermining.

For culvert outlets, extension of the protection or energy dissipaters to prevent downstream scour should be considered. An example is the use of a ‘sock’ placed at the outlet of a culvert (Figure A 12).

Rock dissipaters or gabions can be used in channels as shown in Figure C 48. These also assist natural channel restoration by trapping silt and preventing it from reaching downstream waterways. Other forms to help trap sediment can consist of logs, rocks, straw bales etc. These can also be used in places where high flows of water are expected on high erodible soils or other sensitive areas.

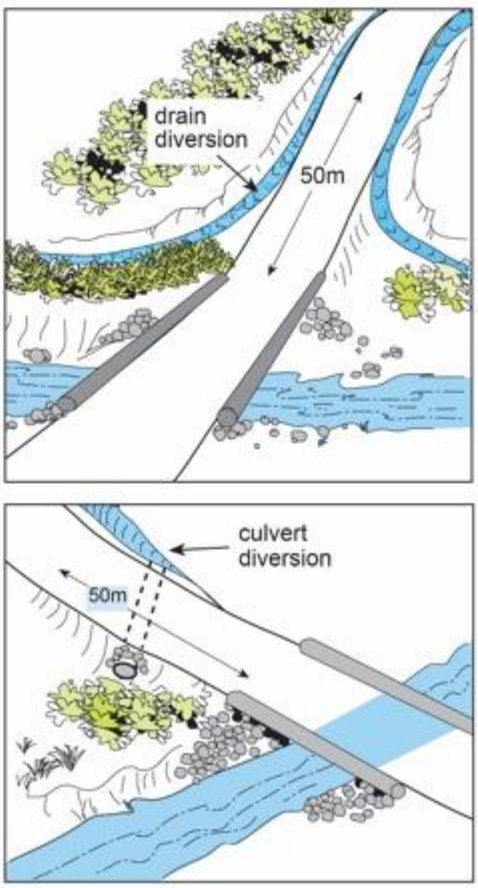
Figure C 48: Culvert outlet treatment



Source: ARRB (2009).

During the last 50 m before a road crosses a significant watercourse the roadside drainage should be diverted into the surrounding vegetation or sediment traps and not allowed to continue to the stream unchecked. Where necessary, a culvert should be installed to pass drainage from the top side of the road to the lower side and then diverted into the surrounding vegetation (Figure C 49). This is to ensure that sediment carried by the water is not discharged directly into a watercourse to the detriment of aquatic life.

Figure C 49: Divert drains before discharging directly into watercourses



Source: ARRB (2009).

The size of a culvert or waterway area to be provided under a road is mainly a function of the catchment size, the rainfall intensity and the nature of the ground cover of the area. The estimation of storm discharge for the detail design of a drainage structure should make use of the Rational Method (Argue 1986). For unsealed roads this method is often not warranted due to higher design costs involved and other less expensive methods being available based on local knowledge or other lower cost design methods.

For unsealed roads because of lower traffic volumes, and where the costs of delays are usually lower than on sealed roads, a lower rainfall intensity is adopted based on lower storm frequencies (e.g. 1, 2 or 5 years). Consequently, in the design of culverts for unsealed roads, it is acceptable that water be allowed from time to time to pass over the road or be temporarily ponded upstream, when the discharge from the catchment is of greater magnitude than the discharge of the culvert. In so doing, care must be exercised to minimise possible damage to the road embankment, and it is strongly recommended that inspections are conducted after such events to assess the extent of damage and works required to restore the road.

As most culverts provided on unsealed roads are not designed to take the higher storm flows, consideration should be given as to the various ways the higher discharge should be accommodated so as to minimise future road repairs and restoration work.

For larger catchments, a floodway with scour protection can be used to supplement a culvert designed to take low flows only. For smaller catchments, a ‘drop-section’ may be used, i.e. a section of the grade line of the road is lowered close to the natural surface to allow part or all of the discharge to pass over the road with the minimum of obstruction and without the need for any substantial scour protection. The maximum depth of water on the road is usually designed not to exceed 150 mm. At greater depths small vehicles can become buoyant and float with the flow.

Where the drop-section takes the whole discharge, an anti-ponding pipe or precast box culvert may be provided through the embankment adjoining the drop-section so as to avoid low flow across the drop-section for substantial periods of time. The invert of the pipe or box culvert is set below the level of the drop-section, but not so low as to cause silting problems.

Where a waterway consists of a low-flow channel and a flood plain, a culvert may be provided in the channel and the grade lowered across the flood plain away from the culvert so that the water passes over the road where the grade is close to the natural surface.

The pavement thickness may be increased at drop-sections to allow for soaked conditions.

Instead of providing a culvert, the discharge from some small catchments may be able to be diverted by a catch drain or catch bank until it can be turned out away from the road.

To minimise silting problems in culverts:

- the level of the invert of a culvert at its outlet should be a minimum of 75 mm below that at the inlet
- pipes of less than 450 mm diameter and box culverts of less than 300 mm high should be avoided
- avoid where possible the use of galvanised steel pipes where water flows have a high acidic value.

Pipe culverts must be designed so as to accommodate traffic loads and the depth of superimposed fill. There are also minimum cover requirements for pipes and box culverts. For detail of strength classes, design requirements and installation practices, refer to the relevant Australian Standards.

C.7.5 Stream Crossings

Bridges and other forms of stream crossings are key elements in any road network and represent a major investment of community resources. It is therefore necessary to manage bridge assets to ensure that all bridges are maintained in a safe condition with the most cost-efficient use of resources. This subject is covered in more detail in Giummarra (2000). This section deals with key elements on site and structure type selection.

Because of the cost and degree of importance of road structures, main water crossings warrant careful selection of site, structure type and design.

Site selection

Careful site selection provides the greatest potential for cost savings. Poor site selection can result in longer, wider or higher structures than are really needed or may result in a costly curved bridge, or complex, costly foundations. Poor site location can cause operational difficulties, unsafe alignments and shorten structural life.

Determining the optimum stream crossing site requires balancing many variables, involving road design, structure type and bridge design.

An ideal stream crossing from the perspective of a bridge designer is as follows:

- A road would cross the stream in an area with well-defined banks. The stream is generally narrower at these locations and the stable banks indicate a stable stream flow.
- The road would cross the stream away from curves in the stream. These areas are often unstable because the stream tends to move to the outside of a curve. Additionally, a stream usually is wider in a curve than at a tangent. A curve may require channel straightening if a pipe type structure is installed or cause roadway fill retention problems if a bridge is installed.
- A road would cross the stream in an area with uniform stream gradient. An increasing gradient increases erosion and scour potential. A decreasing gradient can cause stream bed loading and debris deposition.
- It would cross the stream at a location where the channel has relatively non-erodible stream bed materials. Non-erodible stream bed materials reduce scour potential and thereby allow some deviation from the above listed constraints.
- The road should cross at right angles to the stream to reduce the span length of the bridge, pipe or other structure used.
- The road crossing point, considering both horizontal and vertical alignment, should be at the tangent point. Crossing on a horizontal curve means widening and curving the structure, which are both very costly. Crossing on a vertical curve (at a sag point) would be no problem for a pipe structure but can significantly increase the bridge costs if the bridge deck has to conform to the curve.
- The road should cross the stream at the minimum elevation necessary to pass the design flood flow. Raising the elevation of the bridge increases the abutment costs and, in some cases, lengthens the bridge or pipe, if used.

Obviously ideal crossing locations are seldom found and balancing all of the above variables is a complex process. Solving the problem in the most cost-effective way requires training of personnel who make the selection and working closely with road and bridge design engineers.

Selection of structure type

After site selection the next greatest cost savings potential occurs in structure type selection. There are several possible structures for different stream sizes. It is taken that fish passage is required at nominated stream crossings.

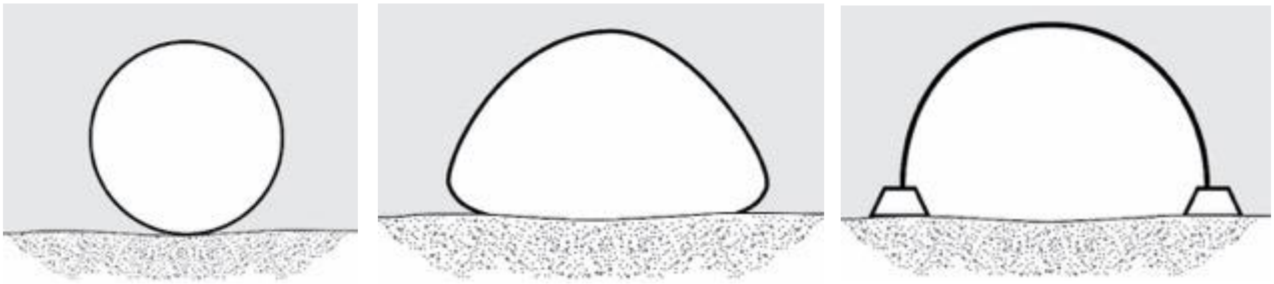
Final structure selection would be based on sound engineering judgement of environmental considerations, structural design, hydrology, hydraulics, foundation conditions and costs.

Small stream crossings (< 6 m)

For small stream crossings, culverts, bottomless pipe arches or buried pipe arches with about 0.5–1 m of native steam bed material over the invert are possible alternatives to bridges (Figure C 50).

If concrete is available and the construction area is limited, the bottomless arch is probably the more cost-effective. Where the stream can be easily diverted during construction the pipe arch type would probably be more cost-effective. These structures provide a natural stream bed for fish passage and are usually less costly to construct and maintain than a similar span bridge.

Figure C 50: Three common types of metal culverts classified by shape



Source: ARRB (2009).

Medium stream crossings (6–15 m)

Where culverts are available and can handle the run-off required and overflow is not a serious problem, they can be cost-effective and require minimum maintenance. Other advantages of culverts compared to a bridge structure include no bridge rails for drivers to run into, no bridge icing and no deck deterioration. Also, the culvert can carry heavier loads and the continuity of the riding surface over a culvert eliminates the bump that is often found at bridge ends. For larger sizes, with spans up to 15 m, the culvert requires special site considerations including adequate depth of embankment to allow space for the structure plus 1.5 m of fill over the pipe.

Culverts can be constructed faster than most bridges and often at substantially less cost. When site conditions are right for large culverts a careful study should be made to determine the relative merits of a culvert or bridge. Structure choice at these locations should be based on comparative cost of construction and maintenance, life span of crossing type, risk of failure and damage to property, traffic safety, fish passage requirements, environmental and aesthetic considerations.

At some sites the culvert seems to be an ideal structure from an environmental point of view. In other locations, especially in the urban areas, the openness of a bridge, possible passage for pedestrians underneath and the smaller right-of-way required, make it more desirable.

For bridges across medium stream crossings, concrete precast, prestressed multi-beam sections can provide an economical alternative to conventional treated timber or cast in-place concrete superstructures.

Most bridges on low volume roads are of simple configuration, based on standard drawings, which are made to order for precast work. The precast bridge can be constructed much faster than the cast in-place type and erection can proceed during cold weather.

Large stream crossings (> 15 m)

For large stream crossings, it is generally cost-effective to design a spill-through type bridge. This type of bridge differs from the retaining wall in that the abutment fills are laid back from the edge of the stream channel on a slope no steeper than 1.5 horizontal to 1 vertical. Laying back the abutment fills lengthens the bridge but substantially reduces the abutment costs.

For bridge lengths of 25 m or under, consider using single spans. They present the minimum obstruction to the waterway and may also be the most economical. For longer structures over flood plains, consider using span lengths of 15–30 m as they often will be more economical than shorter spans depending on bridge height and type of intermediate piers.

The relationships between the type of material, the span length of the superstructure and the cost have been analysed (Berger et al. 1987). The results showed that simple timber bridges made with stringers and laminated decks are the most economical for spans up to 10 m for heavy vehicles. Simple span, split-deck reinforced-concrete superstructures are feasible for spans up to 30 m. Spans can be as long as 45 m if prestressed girders are used. Typical bridge types are shown in Figure C 51.

Figure C 51: Typical bridge types and spans

Single span timber bridge

Concrete deck/steel beams

Prestressed concrete girders

Low-water crossings

Where funds are limited to build a structure to carry the anticipated flood flows, there are other possibilities available relating to low-water crossings. There are many variables involved in deciding what the best form of water crossing is and the notes below provide some general guidance.

A low-water crossing is an option that should be considered under specialised conditions and can substantially reduce costs. Typical design standards that can be adopted for low-cost crossings are as low as a one in two-year flood (Otte & Pienaar 1995) with greater floods overtopping a low bridge structure.

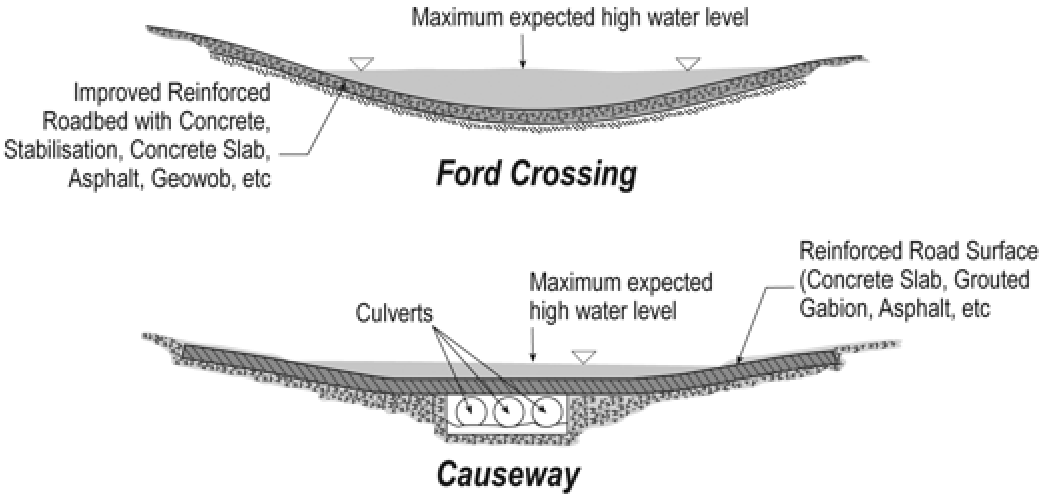
Low-water crossings involve compromises and trade-offs between providing access and often conflicting objectives to:

- provide for traffic safety
- permit water, sediment and debris passage on flooded plains
- limit construction and maintenance costs.

Designing a crossing aims to optimise these objectives. Road access needs and water crossing characteristics largely control whether a structure, if designed for overtopping, will be appropriate. Detail design considerations for low-water crossings can be found in US Department of Agriculture (USDA) Forest Service (2006).

A low-water crossing is a possible alternative for any size of stream. Low-water crossings come in two basic forms, as illustrated in Figure C 52.

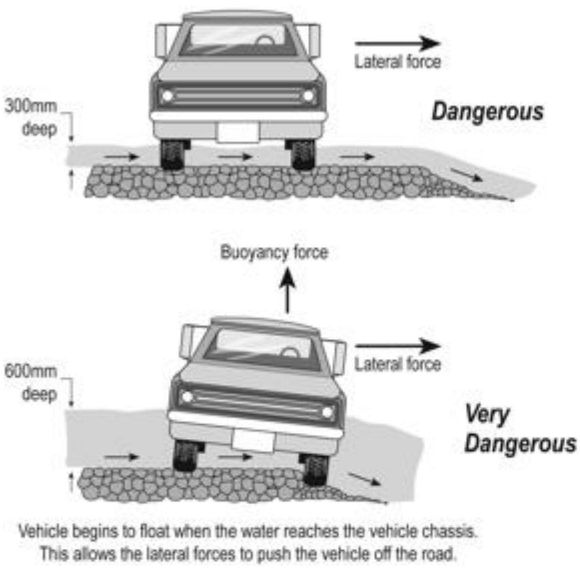
Figure C 52: Low-water crossing types



Source: ARRB (2009).

Low-water crossings can have substantial limitations and are most suited for roads with low traffic volumes and tracks. Safety is of primary concern and a number of deaths have occurred when people drive into flooded crossings. Drivers may underestimate how fast small streams can rise in some parts of the country during a flood. Even 600 mm of water can float a car or truck causing it to lose control and overtopping (Figure C 53).

Figure C 53: Effect of water flows on crossing vehicles



Source: ARRB (2009).

Selecting the best structure for a low-water crossing depends on several factors. Listed in Table C 25 are general selection factors for low volume crossings.

Table C 25: General selection factors for low volume crossings

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

Floodway (ford) – The road crosses the stream at the location where the stream banks are low, and the road grade follows the cross-section of the stream. It is often used when the stream flows infrequently and traffic disruption is minimal during the year.

In order to minimise bank erosion, floodways should be designed to cause minimal interference to the natural stream flow. This is best achieved by siting them at right angles to the direction of water flow and level to the existing stream bottom for buried floodways. This is the case for wide riverbeds or creeks, which are normally dry, but at times carry considerable volumes of water. If they are elevated, floodways will create a weir effect and the downstream velocity of flow may increase to a level which will cause erosion of the stream bottom. Construction of a causeway at grade generally consists of excavating any soft material until firm material is reached and replacing the excavated material with sound granular material to provide a sound trafficable surface.

Gabions can be used to provide a strong road base across a stream bed. It is desirable to strengthen the road surface against scour using either a sealed surface or concrete base or providing a cement stabilised pavement.

Typical floodways are shown in Figure C 54.

Figure C 54: Typical floodways

Sealed road to protect pavement surface

Use of rock gabions to strengthen road crossing

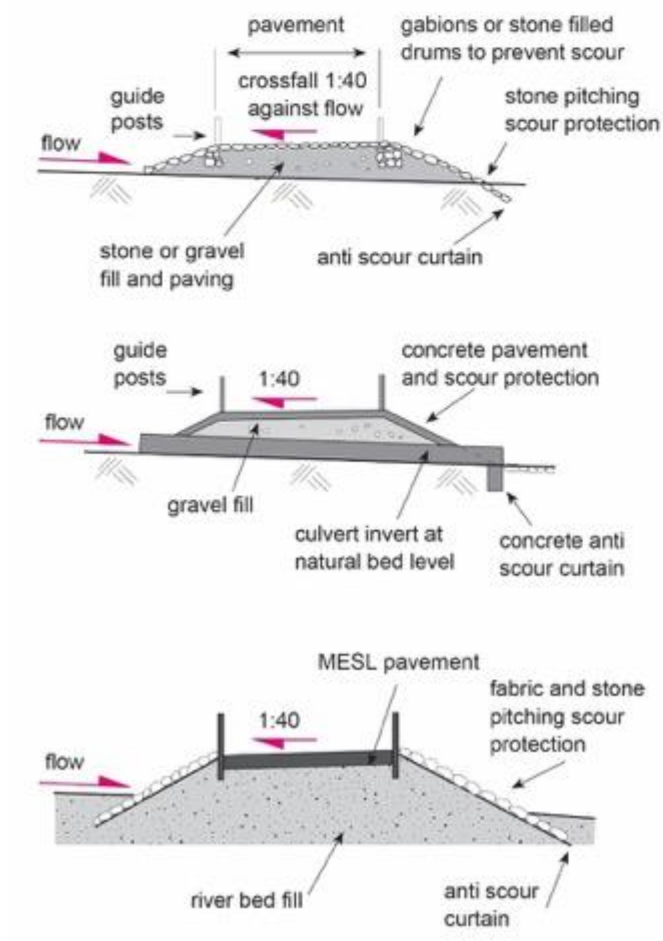
Causeways – These are a form of floodway except that the roadway is elevated above the stream bed. They have a more substantial roadbed constructed and a number of culverts provided for the passage of low water flows. The frequency of flooding and disruption to traffic is less than a floodway.

Causeways are sections of roadway designed to be temporarily overtopped by water flow. They are used when it is more economical and practical to ford an intermittent flowing creek or river than to use major culverts or bridging, and when interruptions to traffic for short periods are not of great importance. Various types are illustrated in Figure C 55.

When it is necessary to elevate a causeway in order to minimise the time it will be covered by water during flooding, it must be designed as a series of culverts using hydrological design procedures to calculate flows and culvert sizes. The ends of the structure must be well anchored into the banks and obstruction to flow should be kept to a minimum by using gentle batter slopes on the up and downstream faces. It is essential to erect guide posts and flood gauges so that the edges of the causeway are defined, and water depth can be determined.

The best material for elevated floodway constructions is concrete. However, when this is not economical, any type of construction that will resist the effects of water and provide a suitable wearing surface for as long as required may be used. One method which is simple, economical to use and particularly relevant when suitable materials are not available is to construct a membrane encapsulated soil layer (MESL) (Australian Army 1985). This is achieved by encapsulating the material to form the pavement in a waterproof membrane as illustrated in Figure C 55.

Figure C 55: Typical forms of floodways/causeway constructon



Source: Australian Army (1985).

Experience has shown that well-graded riprap, dumped on the roadsides of a causeway, is superior to a mass of uniformly large stone, since the latter has large voids through which the filter material can be drawn by the action of water.

Low-water bridge – This form of bridge passes low flows and allows high flows to pass over the bridge structure (Figure C 56). Sometimes an overflow channel is provided possibly with a dip in the approaching road alignment so as to cause the high flow to pass around the bridge or to a portion of the embankment fill built with a sand core that will wash out when flooding becomes critical. This is to save the bridge at the expense of the roadway which can be more readily replaced.

Figure C 56: Low-water bridge under heavy flows

Source: ARRB (2009).

When designing this type of structure, special attention should be given to the elevation of the structure, streamlining of the section and type of anchorages. Since water drift is supposed to pass over the top of low-level bridges it is advisable to omit the railing.

Low water crossing structures are generally designed to allow flooding during periods of high annual run-off. However, the design flow is something that should be evaluated in the design process.

The standard of the road, its importance and use, the magnitude of the stream flow and its variability, the topographical characteristics of the crossing site are all factors that should be considered in determining the design flow of the low-water crossing structure.

There are various publications that can assist an engineer design a low-water stream crossing. For example, one such design manual (Rossmillar 1984) provides the various steps in the design of a stream crossing, considering the hydrology of the area, hydraulics, road geometry and material selection.

C.8 Floodways

Floodway design is based on the objective of providing a path for floodwater across a road under controlled conditions. The design should be such that this can be achieved safely and with minimal damage to the road asset. Examples of floodway design are shown in Figure C 52.

Floodways can be utilised where (Austroads 2015b):

- traffic volumes are low
- some interruption to access is acceptable
- flooding is infrequent
- constructing a bridge or (larger) culvert would be impractical or not economically viable.

It is important to consider the various aspects of floodway design. This should include ensuring that sufficient discharge capacity is provided to safely convey the design floodwater flow, both in terms of depth and flow velocity. It should not be so deep as to present a risk of road users being washed away, or such that it would cause significant damage to road asset.

Adequate sight distance should be provided to the floodway to allow vehicles significant time for vehicles to stop prior to entering flooded sections of road.

Some the current signage standard for water crossings are shown in Figure C 57. These are often accompanied by ‘Next x km’ or ‘x m’ signage to indicate the length of road subject to flooding or to provide prior warning. The ‘Ford’ sign should be accompanied by depth indicators.

Figure C 57: Water crossing signage

W5-6 **W5-7-1** **W5-7-2**

Source: AS 1742.2 (2009) as cited in Austroads (2015).

The above information provides some basic design considerations with regards to the safe design of floodways. Further information can be found in Austroads (2015).

C.9 Roadside Vegetation

The importance of roadside vegetation should not be overlooked, as it aids in many different aspects of the road. Additionally, designers should be aware of the importance of vegetation to the local ecosystem. In many cases the road reserves provide the only remnant of the native vegetation of rural Australia.

Some of the contributions made by roadside vegetation to the road system and the environment are described in this section. Roadside safety is also a consideration in determining the extent of clearing required or the setback necessary for any significant tree plantations. The most effective vegetation to replant along roadsides is local indigenous plants. Barwick (1992) provides the following reasons:

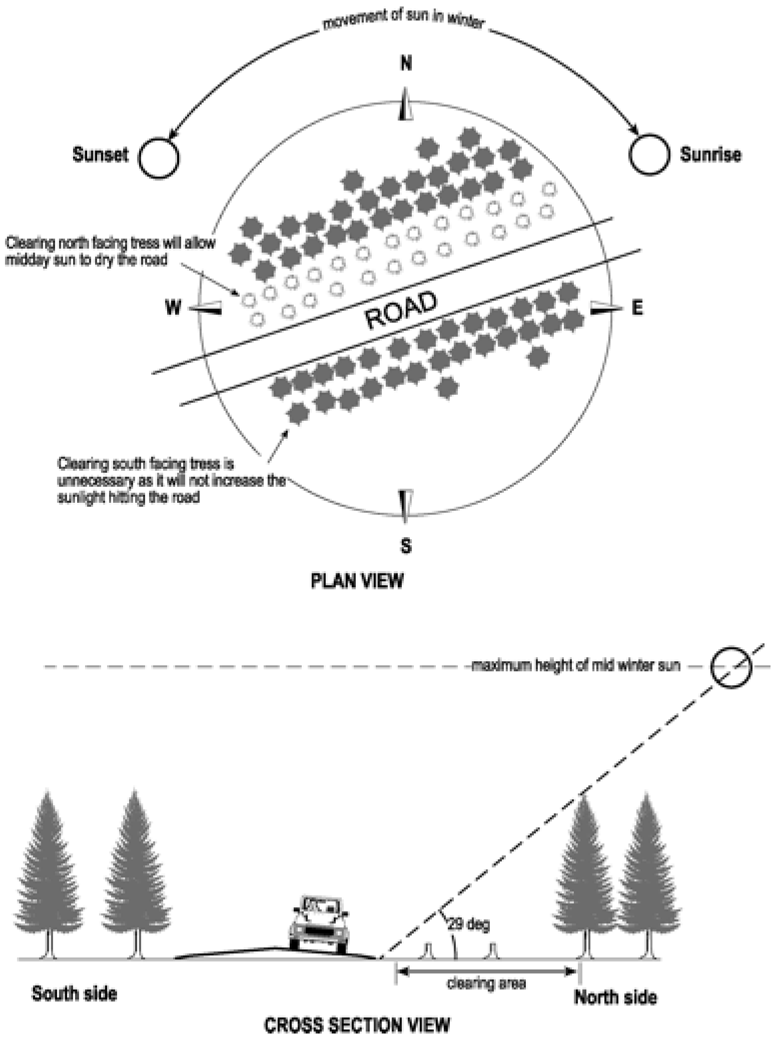
- it is suited to the soil and climate of the area
- it is a complete ecosystem of species the land will support.

Roadside vegetation and trees that are closer to the road (< 5 m) can at times be a hazard to vehicles which accidentally run off the road. Vegetation may restrict sight distance, overhanging limbs present a danger to high vehicles, and may cause the blocking of table drains. Care should be taken in any new tree plantation to avoid this occurring. Also, certain vegetation can affect road surfaces when tree debris falls onto the road or root growth damages the pavement.

In the design of roadways and maintenance activities, it is often necessary to undertake some tree clearing to accommodate a new road or to allow sunlight in to dry the road. 'Daylighting' is the process of removing trees on either side of the road to allow sunlight onto the road and assist with drying, which in turn will result in a firmer road and reduce rutting. The clearing width is very dependent on the position or aspect of the road. There is little point in clearing a 5 m width of trees on either side of the road if the sunlight will not reach the road in the middle of winter. It may be more beneficial to remove more of the north-facing trees and leave the south-facing trees standing (Figure C 58).

The daylighting width should be kept as small as possible to ensure that the maximum amount of natural vegetation in the road reserve is allowed to remain.

Figure C 58: Posiition of mid-winter sun and effect of cutting north-facing trees for daylighting



Source: Larcombe (1999).

Appendix D Typical Road Defects and Maintenance Treatments

Unsealed roads can be prone to rapid deterioration due to the exposed nature of the unsealed wearing course and often use of lower quality materials. The typical defects and possible maintenance treatments are summarised in 5.1.3 of this Guide. This Appendix however provide further details on the defects most common in Australia.

D.1 Loose Material

The generation of loose gravel under traffic, termed ravelling, is a significant safety and economic problem. Loose gravel may be distributed over the full width of the road but is commonly concentrated in windrows between wheel tracks. The problems caused relate to safety hazards, damage to vehicles and windscreens, increased fuel consumption and lack of adequate lateral drainage.

Loose material is a significant problem on unsealed roads. Many single vehicle accidents are caused by windrows of loose materials on the road. These windrows interfere with the directional stability of vehicles which may cause them to eventually overturn: the higher the vehicle speed the greater the interference. It is important that these windrows are not permitted to become higher than 75 mm (Committee of State Road Authorities (CSRA) 1990).

A well-designed wearing course should not readily produce loose material. Loose material on the surface is caused through the lack or loss of binder to hold the surface aggregate in place. Surfaces with loose material can have a major effect on vehicle operating costs and safety.

During wet periods, water-bound pavements hold together. However, when allowed to dry out, the pavements may start to break up with dust emissions and ravelling of the surface material leading to excessive quantities of loose aggregate. The surface can be restored by replenishing with a well-graded material and binder mixed with the existing surface material. The new surface needs to be watered and compacted to form a crust after blending of the new and existing materials.

Loose material on the road can be a safety hazard as the unbound stones can act as marbles on the road surface and reduce skid resistance, or for roads in the drier parts with a running surface of silt or dry clay, loose material can form into 'bull dust' (Figure D 1).

Figure D 1: Loose surface materials

Source: ARRB (2020).

Routine smoothing operations, while respreading the stones across the road to give the appearance of a well-maintained road, may produce little benefit for the effort. Without the replacement of the fines lost (i.e. the binder), rolled and compacted to the optimum moisture content the surface will ravel very quickly back to the state before the smoothing operation. An alternative is to bring in new material with more fines with the road shaped and compacted at the appropriate moisture content. Should this not prove practical then one option, in areas that have dry periods, is to grade the loose aggregate to the side(s) of the road (Figure D 2).

Figure D 2: Use of side windrow to store loose materials

Source: ARRB (2009).

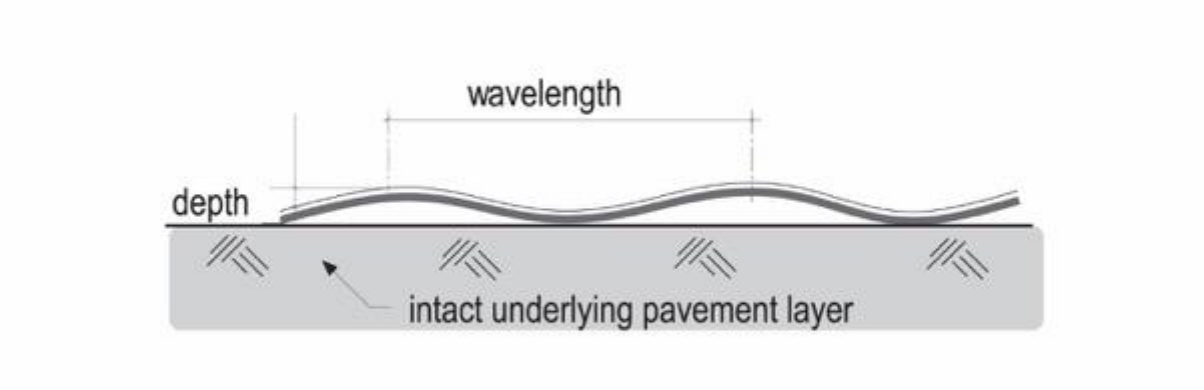
This operation can be repeated several times in the dry period, and when there is adequate moisture on the road and sufficient pavement material in the windrow, it can be respread across the road and compacted. Note that in order to achieve effective compaction the minimum depth of loose gravel needed is two and a half times the nominal stone size. For this operation to be effective there should be sufficient road width to accommodate the windrow(s) without impeding traffic and blocking the table drains. Regular openings should be left in the windrows for surface water from the roadway to discharge into the table drains.

Stoniness is the relative percentage of material in the road which is larger than the recommended maximum size (usually 20–25 mm for a wearing course or 37.5 mm for a basecourse). Excessively stony roads result in problems associated with high road roughness, poor compaction, difficulties with grader maintenance and the need for more loose material to be brought in to cover the stones.

D.2 Corrugations

Corrugations are formed through material displacement as a result of tyre action coupled with the mass and speed of the vehicle. The surface material arranges itself into parallel ridges which lie at right angles to the direction of traffic. Spacing (wavelength) can vary from 500 mm to 1 m and depths can range up to 150 mm. Figure D 3 illustrates wavelength and depth of corrugations. Any irregularity in the surface can start the process which then develops at a rate dependent upon the traffic, acceleration and deceleration areas, suspension systems and tyre pressure.

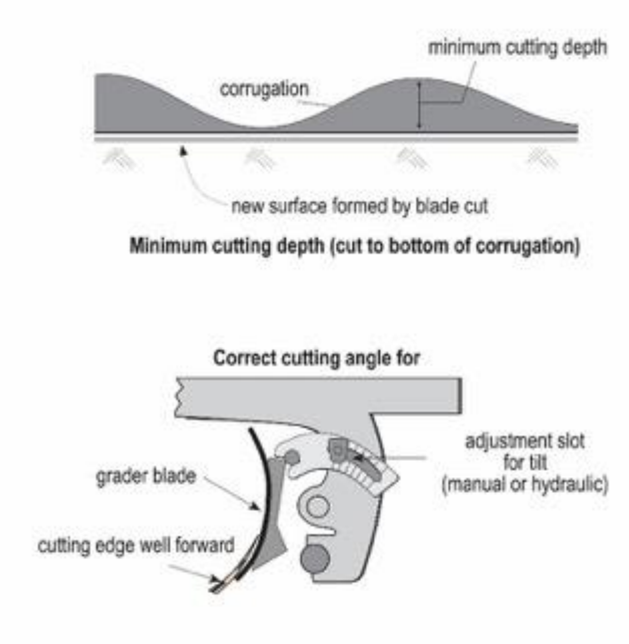
Figure D 3: Corrugation formation in dry climates



Source: OECD (1987).

Granular materials with particle sizes greater than 5 mm, low plasticity and limited fines, or which have lost fines due to traffic action, are susceptible to corrugations. In dry climates only the material that forms the ridges is affected with the underlying material remaining in place. Maintenance or corrective action consists of cutting to the depth of the corrugation and respreading the materials. Figure D 4 indicates the corrective action necessary to remove the defect.

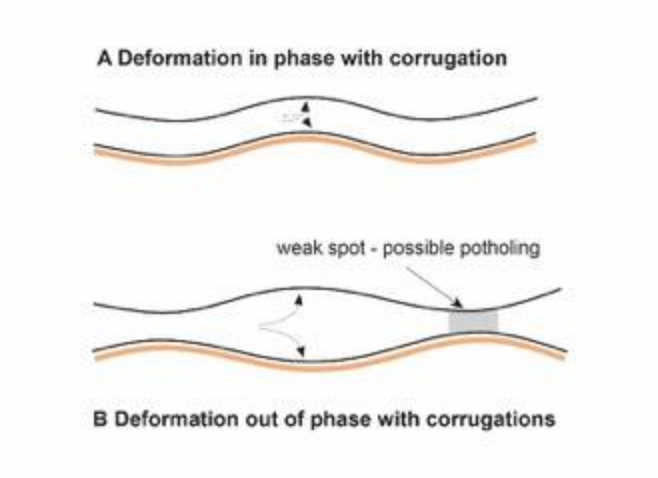
Figure D 4: Cutting corrugations



Source: Ferry (1986).

In wet climates the development of corrugations and remedial action depend on the season. In the dry season corrugations develop similarly to that in dry climates with the same remedial action necessary to correct the defect. However, in the wet season surface deformations may be transmitted into subgrades and lower pavement layers by water penetrating the surface, causing structural defects. Deformations in subgrades and lower pavement layers may, as a result, be in or out of phase with the corrugation. Where the deformation and corrugation are out of phase, weak spots may appear as potholes at the trough of the corrugation. Figure D 5 illustrates deformations which are in and out of phase with the corrugations.

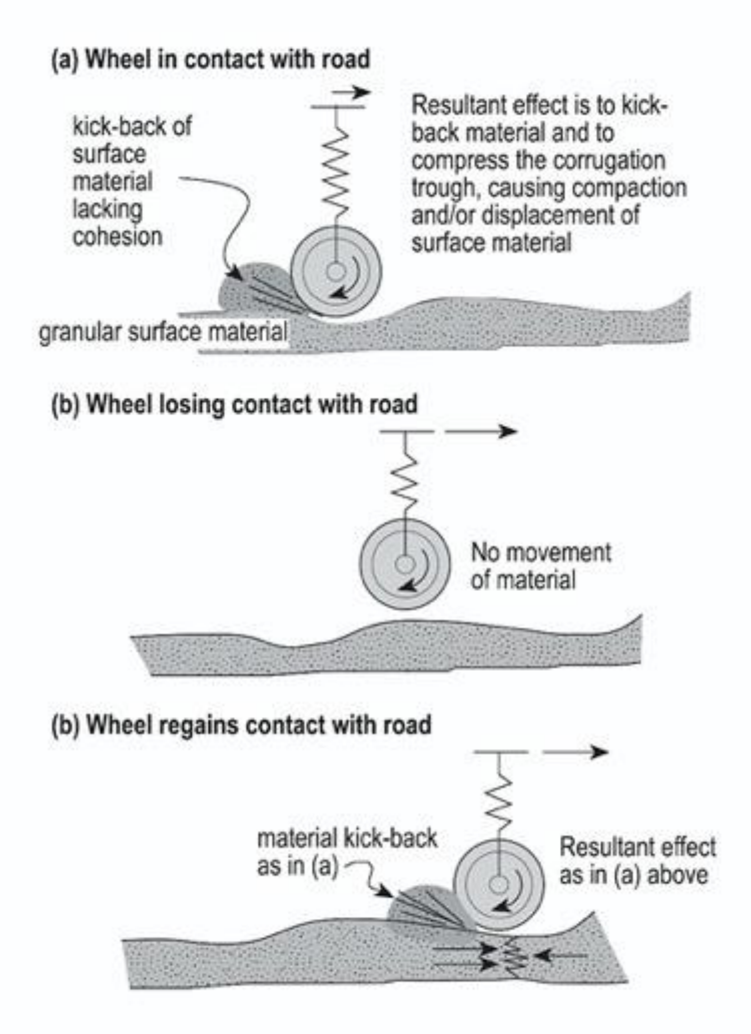
Figure D 5: Corrugation formations in wet climates



Source: OECD (1987).

The process of how corrugations form can be explained by the illustrations shown in Figure D 6. The explanation is based on initiation of wheel bounce by some irregularity in the road or possibly even worn suspension components. The process results in kick-back of non-cohesive material, followed by compression and redistribution of the wearing course as the wheel regains contact with the road. Normally corrugations can form where loose surface material is found at natural points of gear change, braking or acceleration (Figure D 7).

Figure D 6: The formation of corrugations



Source: Heath and Robinson (1980).

Figure D 7: Corrugations in gravel surface

Source: ARRB (2020).

Corrugations can be either loose or fixed. Loose corrugations consist of parallel crests of loose, fine-sandy material at right angles to the direction of travel. Fixed corrugations on the other hand consist of compacted, parallel crests of hard fine-sandy material. The troughs are compacted by the force of the wheel regaining contact with the ground. Loose corrugations are easily removed by blading, whereas fixed corrugations need cutting or even tyning with the grader before the material is respread. The wavelength of the corrugations has been found (CSRA 1990) to be dependent on the modal speed (i.e. most frequent occurring speed) of the vehicles using the road, with longer wavelengths formed by faster traffic. Numerous observations in South Africa indicate that the wavelength of corrugations in centimetres is approximately equal to the average speed of the vehicles in km/h (i.e. 70 km/h speed will generate a 70 cm corrugation wavelength).

The absence of a tight surface, combined with coarse sandy material, if present in high proportions, can lead to the rapid formation of corrugations.

High speed grader operations can be another source of corrugations developing. The combined horizontal speed and vertical movement of the blade can initiate wave formations in the surface. These can develop into corrugations as vehicle wheels transverse the road surface.

Short-term amelioration of corrugations centres on cutting just below the trough of the corrugation. The use of lightweight ‘drags’ towed behind a vehicle can be an effective low-cost treatment for corrugations formed in sandy material and in their initial stages of development (Figure D 8).

Figure D 8: Low-cost drags

Source: ARRB (2009).

Towing speeds of up to 15 km/h can be achieved while still eliminating the corrugations. At these speeds, considerable lengths of unsealed roads can be treated in their initial stages of corrugation formation, effectively reducing the cost of maintenance operations. However, like grading and cutting corrugations below the trough, the use of drags is a short-term solution only.

Longer-term solutions may be found by the careful addition and blending of selected clay binder, particularly where dry weather corrugations appear. When available the importation of higher quality crushed aggregate for isolated trouble spots may be necessary. Short sections of seal may also provide the solution in critical locations, particularly on bridge approaches, at cattle grids or steep grades and low-radius horizontal curves.

If corrugations are a problem, check for:

- particle size distribution and cohesive properties (refer to the ARRB *Road Materials Best Practice Guide* (ARRB 2020b))
- compaction of material at optimum moisture content
- worn wear plates in blade
- grader operating speeds
- correct depth of cut to remove corrugations with grader blade.

If, after checking the above and taking appropriate corrective action, the corrugations still persist, sealing may be the last resort.

D.3 Potholes

Potholes play a significant role in the development of ride quality or roughness of unsealed roads and can cause substantial damage to vehicles if allowed to develop and increase in size.

The effect of potholes on vehicles depends on both the depth and diameter of the pothole. Potholes which affect vehicles most are those between 250–1500 mm in diameter with a depth of more than 50–75 mm (Figure D 9).

Figure D 9: Typical road where crossfall is too low (< 3% crossfall)

Source: ARRB (2009).

Roads particularly susceptible to potholing are those with flatter grades and crossfalls – particularly at bridge approaches, alignment changes from ‘left to right’, superelevation at S bends, and intersections where water can lie on the surface, particularly in wheel paths. On gravel roads with correct crossfall and superelevation pothole occurrence is rare. The development of potholes is triggered by stripping of the surface material and the infiltration of water. Solids in suspension are carried away by wheel action on the surface and, as water penetrates the pavement further, the action continues, forming a hole in the pavement.

The remedy is to restore the surface shape and crossfall to prevent water retention in flat spots. It may be difficult in places to achieve the required crossfall if the road section is controlled by longitudinal drainage such as in low lying areas or in curve transitions points.

Patching alone will not solve the problem if the road lacks adequate crossfall. In some cases, minor potholes may be corrected with the use of a grader fixed with tipped blades. Where potholing is severe, the surface will require scarifying, remixing and reshaping. New material will need to be added and mixed with the existing material to replace material displaced by traffic, erosion or blown away. Potholes are difficult to repair, very few being successfully repaired by routine grader maintenance or by manual filling behind the grader. The only successful way to repair them is by enlarging the hole, overfilling it with moist gravel, similar to the existing pavement material, and compacting it in layers, if necessary. Although success has been reported by some road authorities in using stabilised material to fill potholes, it is recommended that material with the same properties as the pavement is used to ensure even wear of the road surface and reduce contamination of the pavement materials.

At bridge approaches or locations where crossfalls are reduced below that required for shedding of water, consideration should be given to either stabilising the pavement or providing short lengths of seal over the affected areas. In cases where a sealed section is provided it is essential that the crossfall of the sealed road at the junction with the unsealed road is 4–6%. This is to ensure that the potholes are not transferred to the edge of the sealed section (Figure D 10).

Figure D 10: Sealing approaches to bridges to minimise potholes, typical bridge approach with potholes due to flat crossfall on bridge (left), sealed bridge approach treatment to eliminate potholes – cross fall on seal/unsealed interface should be 4–6% (right)

Source: ARRB (2009).

Isolated potholes can, however, be repaired manually. All contaminated material should be removed and new, sound material compacted at optimum moisture content used to fill in the hole.

If potholes occur, check for:

- correct crossfall on pavement
- superelevation transition points close to where a straight joins a curve
- compaction of pavement material
- shading on pavement preventing drying of the pavement material.

Where shade retains moisture in the pavement, the use of a moisture-resistant paving material or alternatively stabilising of the pavement may be desirable.

For an unsealed road with a running surface of silt or dry clay, potholes may form with varying sizes and depths, which fill with fine dust. These potholes are commonly referred to as ‘bull dust’ holes. Drivers often have difficulty in seeing the dust filled holes and vehicles may be severely damaged if they enter them at high speed. As time passes small potholes can increase in size and depth unless remedial action is taken to rectify some of the underlying causes.

Where manual patching of isolated potholes or groups of potholes is carried out, the procedures listed below should be considered. This is rarely done because other works are also necessary which will require a grader and other equipment being provided. The procedures are nevertheless listed for cases where there are isolated sections requiring manual labour.

- Remove loose material or standing water from the area to be patched.
- Large or deep potholes should have their sides cut back to be vertical with square corners and to reach sound material.
- If the material is dry, the area to be patched should be moistened and moisture added to the patching material.
- The moisture content of the material to be used to backfill the hole can be checked by squeezing in the hand. If the material is at the correct moisture content, it will stick together. If moisture runs out of the material, it is too wet.
- Fill the hole in multiples of 100 mm thickness and compact with a roller or vibrating plate. Rolling with truck wheels is inadequate and will not provide correct compaction.
- The hole is filled and compacted to give a finished surface which is marginally above the surrounding pavement surface.

D.4 Rutting

Ruts are longitudinal deformations in wheel paths, caused by the passage of vehicles (Figure D 11). Ruts pose potential problems as they tend to retain rainwater which softens the wearing course and allows deformation under traffic. Ruts can also cause a safety hazard due to the accumulation of loose material between ruts. Routine blading of unsealed roads replaces gravel in ruts and compensates for any subgrade deformations which may have occurred.

Dry season rutting is found in non-cohesive materials such as sands or gravels which have low fines content and where loose material is displaced sideways and traffic utilises the same wheel paths.

Figure D 11: Rutting in road surface

Source: ARRB (2009).

In contrast, wet season rutting is found in materials sensitive to water. Water enters the pavement either from the surface or through capillary action from the subgrade and as a result deformations are formed.

Rutting can be caused through failure of the subgrade, basecourse or surface material as a result of excessive quantities of water entering the pavement and/or subgrade or insufficient pavement depth.

Surface ruts can form for several reasons:

- poor grading of material
- poor compaction
- inadequate pavement depth
- poor surface drainage
- excessive fines in pavement materials
- infrequent maintenance
- possible overloaded vehicles
- vehicle tracking.

Surface rutting may be reduced by providing correct crossfall. Stabilisation may also help solve this problem. Refer to the ARRB *Road Materials Best Practice Guide* (ARRB 2020b) for guidance on stabilisation. As with corrugations and potholes, ruts can be removed by cutting to the bottom of the rut, blending material and compacting at the optimum moisture content.

If the material contains too many fines, then it will be necessary to improve the grading of the material and drainage. On the other hand, the addition of fines may be necessary if loose aggregate exists on the surface. In both cases visual inspection followed by sieve analysis will be necessary to determine the amount of material to be added to correct the grading deficiency. Refer to the ARRB *Road Materials Best Practice Guide* (ARRB 2020b) for guidelines on the correct grading of material.

If rutting occurs, it is advisable to check:

- particle size distribution
- crossfall on pavement
- drainage
- pavement depth
- compaction
- aggregate breakdown
- pavement width (three-wheel effect).

D.5 Slippery Surface

Slipperiness of the surface of an unpaved road is a significant safety problem. In wet weather, slipperiness is caused by excessive fines or plastic material in the wearing surface and lack of adequate crossfall to shed water off the pavement (Figure D 12). Clayey materials, clay/gravel mixes, or even clay deficient materials fouled by mud or other foreign material, can exhibit slippery properties. In dry weather small size stones on a tight surface can act like ball bearings and care should be taken by grader operators not to leave the surface covered with loose stones. Also, loose materials accumulated on the outside of a curve are a safety concern (Figure D 13).

Figure D 12: Slippery surface

Source: ARRB (2009).

Figure D 13: Loose stones on outside of curve

Source: ARRB (2009).

Slippery surfaces can be dangerous irrespective of the cause and require consideration on how to correct the problem once the matter has been brought to the attention of the road agency. The extent to which remedial action can be taken will depend on the agency's available resources.

Once a surface becomes slippery, the surface will require restoration, subject to the available resources. This can range from the use of clean gravel or crushed aggregate placed over the surface, providing adequate crossfall to remove excessive water, grading and reshaping of the surface, to the removal and replacement of affected areas with clean well-graded material.

D.6 Surface Scour

Scour is the loss of surface material caused by the flow of water along and/or over the road. Scouring is caused through poor drainage allowing concentration of running water on the pavement, lack of compaction of road surface, excessive crossfalls, and longitudinal grades and the build-up of debris on shoulders preventing surface water from flowing off the pavement.

Figure D 14 shows examples of transverse scour where the road crossfall exceeds the ability of the wearing course to prevent scouring. Crossfalls > 6% can lead to transverse scours. The ability of the surface material to resist erosion depends on the shear strength under which the water flow occurs, the rate of water flow and wet strength of the pavement.

Figure D 14: Transverse scour example

Source: ARRB (2009).

Erosion can be prevented by:

- increasing the shear strength of the wearing course material by providing a well-graded, cohesive mix, using angular crushed stone and good compaction
- retarding the rate of water flow
- lowering the crossfall to < 6%.

Pavements with high fines content and small aggregate are more inclined to scour compared to those with a well-graded mixture containing crushed stone of 19 mm or larger size. Up to 40 mm stone size can be appropriate in high rainfall environments.

Scouring includes both along and across the pavement. Transverse scour may commence at the edge of the shoulder or on less compacted areas and work towards the road centreline. Alternatively, lack of slope on the shoulders may lead to water standing on the road and eventually finding an escape route. Plant growth on shoulders and the consequent entrapment of debris and earth, prevent water draining from the pavement, particularly in areas where longitudinal grades encourage water to flow along the pavement in preference to the direction of the crossfall, and give rise to longitudinal scours. Scouring of the surface not only creates adverse driving conditions but it also leads to further deterioration of the pavement through exposure to the environment.

Scouring can be pronounced when combined with material susceptible to rutting.

When scouring is a problem, the use of high-quality aggregate that relies on mechanical interlock is most suitable to minimise the problem. Stabilisation can also assist; particularly where longitudinal scouring occurs. Attention to drainage of the pavement, and grading of materials all help in reducing the incidence of scouring. On longitudinal grades of 4% and above, crossfall may have to be increased to 5 or 6% depending on alignment and other factors to ensure that the water finds the shortest possible route off the pavement. The most cost-effective precaution against scouring is to pay attention to drainage, material grading and shape.

Longitudinal scouring is most likely to occur for steep vertical grades as the water path will be generally down the road (Figure D 15). Scouring is best avoided by decreasing the grade to that of no more than the crossfall (maximum 6%) to ensure that the water flows across the road rather than down the road.

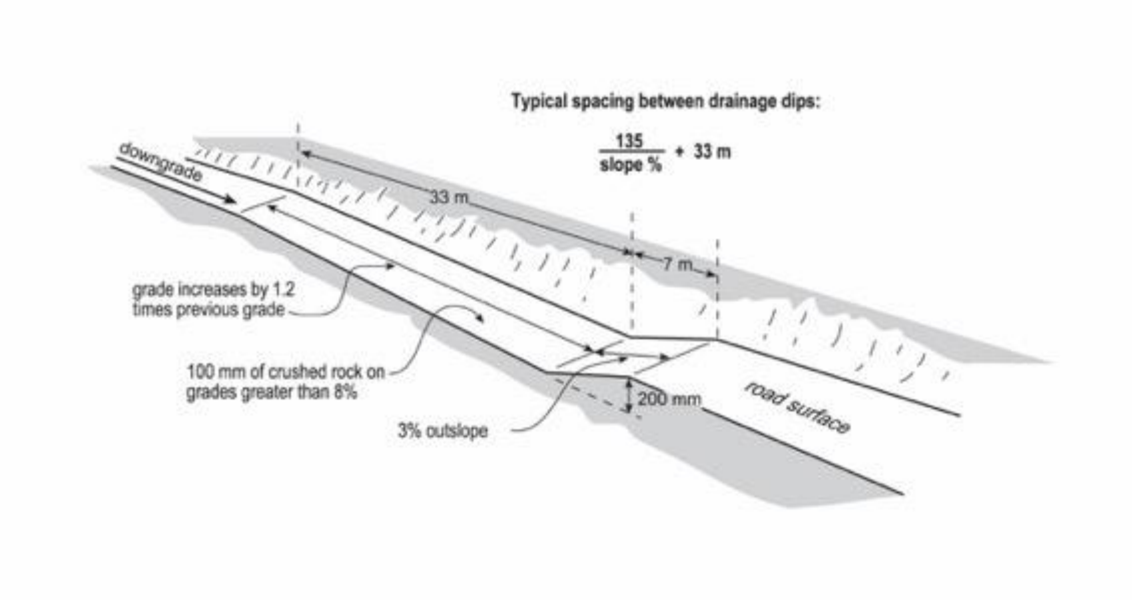
Figure D 15: Longitudinal scour

Source: ARRB (2009).

If a steep grade cannot be removed, a few options are available that may help reduce longitudinal scour. These include:

- Sealing the surface over the critical length, especially for high volume roads.
- Introducing 'open' type cross drains (form of a cattle grid) to capture the water flowing down the slope, at regular intervals.
- Use of rollover drains or 'whoa boy', for low volume roads, which involves rolling the vertical grade to allow water to discharge at regular intervals to the side drains. These can also be referred to as water bars or rollover drains. Details are shown in Figure D 16 and Figure D 17. While steeper out-slopes in Figure D 16 of up to 6% can be used to prevent the gully silting up too soon, the uphill grade over the rollover can be excessive. If used too frequently the ride will no longer be acceptable and alternative methods have to be used.
- Use of vertical rubber deflectors which are imbedded into the road surface to divert water to the side (Figure D 18).

Figure D 16: Drainage dip or rollover (whoa boys) used on road with steep grades > 6%



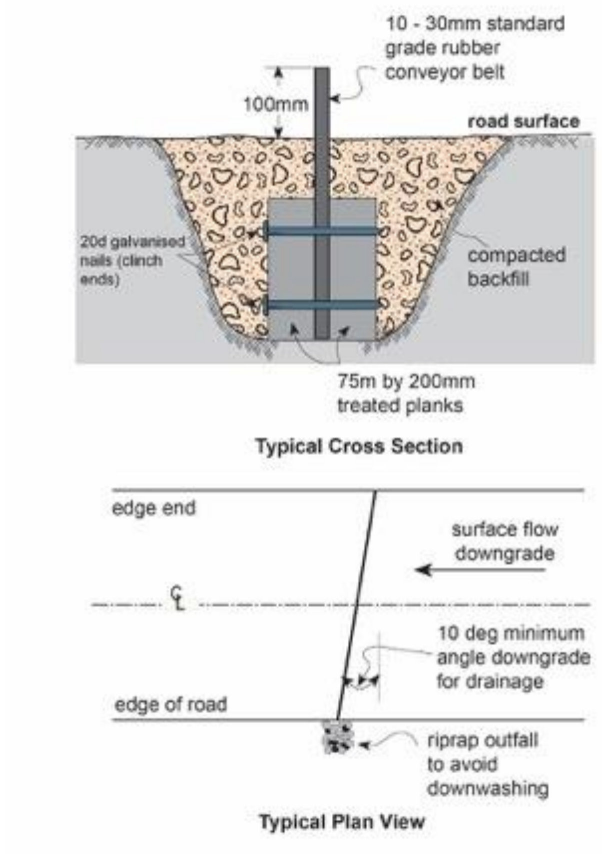
Source: ARRB (2009).

Figure D 17: Example of a rollover drain

Source: ARRB (2009).

The water deflector is a low-cost, low maintenance method to deflect surface water from a steep roadway which works as well as an open top culvert. The deflector is simply a piece of rubber belting fastened between treated timbers, as shown in Figure D 18. The cost to install a deflector is equivalent to an open top culvert. Deflectors have the advantage that there are no abrupt changes of grade, as for 'whoa boys' and can be used on grades greater than 10%. Care is needed by the grader operator when using these deflectors, as the rubber can be easily sheared off and some manual work may be necessary in maintenance operations.

Figure D 18: Water deflectors



Source: USDA Forest Service (2006).

D.7 Foundation Defects

The recognition and identification of pavement foundation defects is a pre-requisite to economic solutions to road defects. Foundation defects, in contrast to surface defects, are generally characterised by large area settlements and heaving. Understanding the material and drainage characteristics making up the foundation is important in resolving the problem.

Heaving of the pavement is caused through movement of material under load and results from a weak spot further softened by water and/or low-quality material. To resolve the problem, removal of existing material to a depth of sound, relatively firm material is required, along with subsurface drains (if necessary) and replacement with suitably compacted material.

At times a ‘wet spot’ may be created due to a possible natural spring coming up the road pavement (Figure D 19). In these cases, the use of subsoil drains is often the most cost-effective way to minimise the ongoing maintenance problems.

Figure D 19: Wet spot that needs subsoil drain

Source: ARRB (2009).

Settlement in road embankments is a slow process and may require attention over a number of years. Consolidation is the cause of settlement and is the result of moisture being forced out of underlying material in embankments and bridge approaches (Figure D 20).

Figure D 20: Settlement of fill embankment

Source: ARRB (2009).

The only solution is to periodically build up the surface to match the design profile and longitudinal grade. Care should be exercised in not allowing the deformation to reach excessive levels before remedial action is taken. Differential settlement can result in poor safety and pavements holding water and contributing to further surface defects.

Intrusion of subgrades into the pavement is another foundation defect aggravated by lack of drainage. Overloading of the subgrade is a cause of subgrade and pavement materials mixing. In some circumstances the use of geotextiles between the subgrade and basecourse is an appropriate solution to segregate layers of material. Placing additional pavement material over just the subgrade will only serve as a short-term solution without appropriate measures to separate the basecourse and improve drainage. Use of large coarse stones can also be applied to get the road foundation to a suitable standard quickly.

Defects in the drainage system should be corrected before, or in conjunction with, correction of pavement and foundation defects. The filling of drains or subsoil drains by siltation over time can be attributed to insufficient gradients, poor filter design or lack of routine maintenance. Where subsoil drains are used the outlets should be clearly marked by a stake or similar device to enable maintenance crews to readily locate the drains for cleaning operations (Figure D 21). Where it is not possible to increase gradients, then additional turnouts may help to reduce siltation.

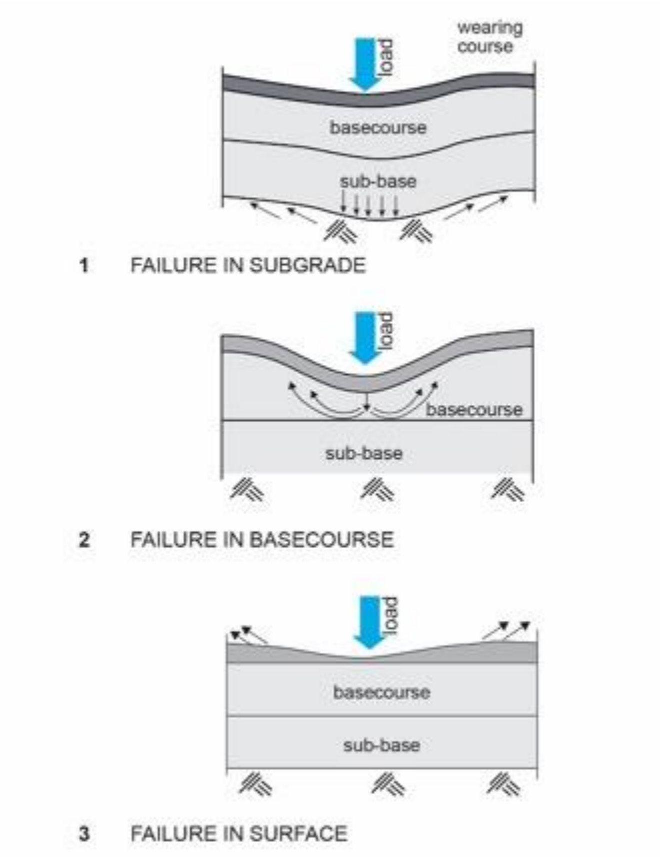
Figure D 21: Use of markers to identify location of subsoil outlet

Source: ARRB (2009).

Structural defects are generally characterised by large area settlements, heaving or rutting and require investigation into the causes. Causes can be a lack of drainage, poor compaction and the use of inappropriate or insufficient material to carry the axle loads.

Figure D 22 depicts some common surface and structural defects as a way of understanding the underlying causes of a failure.

Figure D 22: Development of pavement deformation



Source: Ferry (1986).

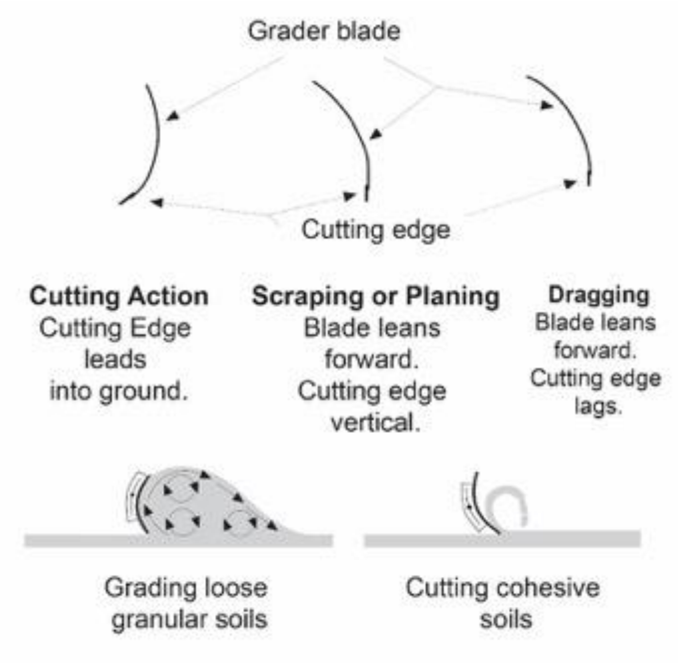
Appendix E Best Practice Grading Operations

Graders are designed primarily for the work of trimming, mixing, shaping and finishing in road construction. They are not designed for heavy excavating, but a good operator can take a fairly heavy cut, casting the spoil to one side. In paving work, they are used for blending materials, including incorporation of water.

Graders vary in size and configuration (e.g. four-wheel drive, six-wheel drive, rigid frame, articulated frame, etc.). Usually, a heavier machine is required for construction.

The main implement of the grader is the blade. This consists of a curved metal plate, ranging in length from 3 m to 5 m. The use of the grader blade is shown in Figure E 1. Its action depends on the pitch angle of the blade. The correct pitch will depend on the type and hardness of material being worked. For example, for grading loose granular soils, the blade is set with the blade vertical or with the top slightly forward. To slice off a layer of cohesive soil (e.g. in trimming a subgrade), the blade is set with the top tilted backwards. When trimming a compacted granular material (e.g. a paving gravel), the top of the grader blade is tilted forward. The horizontal blade angle is about 30–45°.

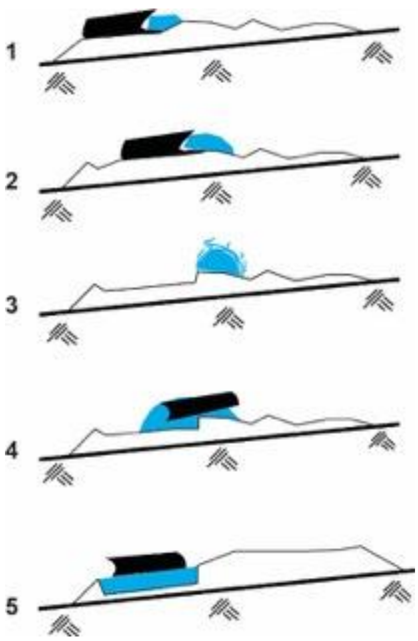
Figure E 1: Grader blade positions including mouldboard



Source: OECD (1987).

Grading should commence from the edge of the road and work towards the centre, making sure to maintain the correct crossfall with each successive pass and to remove all surface defects. The number of passes will be governed by the depth of irregularities and width of formation. The windrowed material is deposited beyond the centreline and spread back across the surface, depositing the material on the cut surface to give correct crossfall. Heavy grading should normally be done in moist conditions or in conjunction with a water truck and roller. Figure E 2 illustrates the grading sequence for maintaining a smooth surface with correct crossfall. The material is then compacted, and the procedure repeated for the opposite side of the formation.

Figure E 2: Heavy grading sequences for removing defects



Source: OECD (1987).

In these operations the grader blade should not pass the centreline and checks should be made, using either a camber board at 100 m intervals, or a grader slope indicator installed in the grader (for higher production) to ensure the desired crossfall is being achieved, particularly when reshaping and resurfacing an unsealed road.

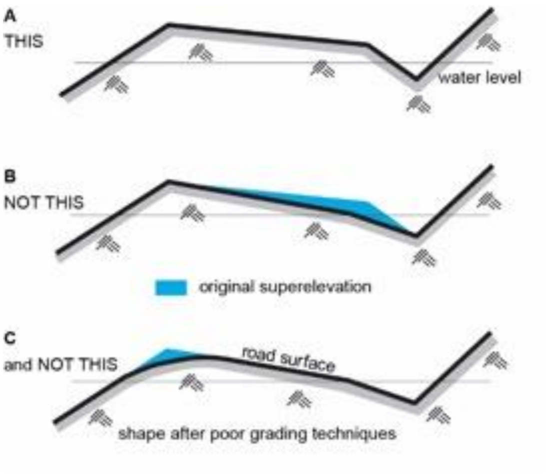
It is important that the grader does not make a final pass down the centre of the road with the blade horizontal as this will remove the crown and accelerate deterioration.

Particular care is required in shaping and maintaining the transition in cross-slopes between tangents and curves. Nevertheless, superelevation should be developed as quickly as possible, commensurate with design speed and ride quality requirements, to limit the length of pavement with less than desirable minimum crossfall for drainage purposes. Appendix C.3.1 covers the development of superelevation through a curve.

It is common to find at most curves, where superelevation should be provided, that maintenance activities are not in keeping with good practice. In many cases the superelevation is not maintained from edge of shoulder to edge of shoulder leaving a flat spot on the higher side which accumulates a lot of loose gravel. This situation compounds the safety hazard on the outside of the curve.

Poor grader operation sometimes leads to undue cutting down of the freeboard on the inside of the curves. Check to see that as shown in Figure E 3, A does not deteriorate into B. Undue cutting down on the outside of a curve can lead to a potentially dangerous condition, as shown in diagram C.

Figure E 3: Maintenance of correct superelevation



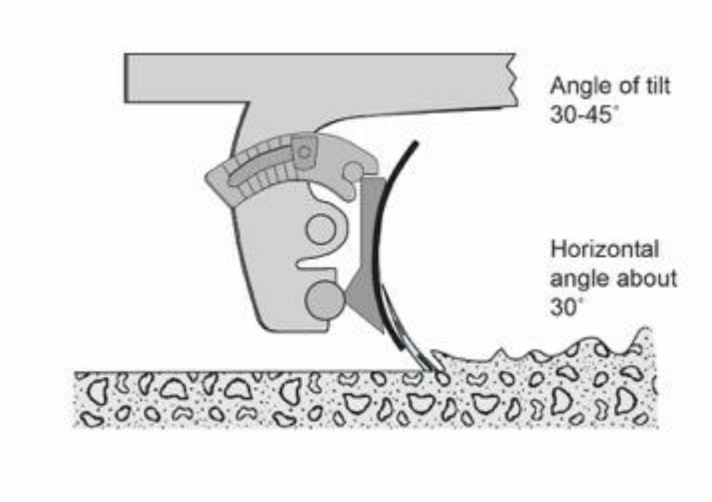
Source: Ferry (1986).

E.1 Light Grading

The blading operations normally would start with a pass in the table drain to clear the drain to ensure water flow and to extract many of the road fines that have been deposited there. This material is then mixed with the loose aggregate spread across the road. In some cases, grader operators in their desire to find sufficient fines to add to the loose aggregate often go beyond the road formation, gaining soil from batters. Use of this practice over a prolonged period has the adverse effect of widening the road well beyond that required. This leads to higher maintenance costs in the future due to greater road width to grade and re-gravel.

A dragging, rolling action, created by the curve of the grader's mouldboard helps compact the road surface as it is bladed. Blading speed will depend on the grader, tyre pressure and condition of the road surface. Going too fast will cause the grader to bounce, making a good job impossible. The mouldboard should be tilted forward to get a dragging rather than a cutting action as shown in Figure E 4. Angle the mouldboard at about 30 to 45° to spread loose material to the centre of the road. Lean or slightly tilt the front wheels about 10 to 15° from the vertical in the direction the aggregate rolls across the blade, as shown in Figure E 5. Remember to repair minor bad spots, such as holes, rutted areas, poor surface drainage areas and clean out blocked mitre drains or turn outs. Always have a shovel available.

Figure E 4: Tilt mouldboard forward to get a dragging action



Source: ARRB (2009).

Figure E 5: Example of dragging action

Source: ARRB (2009).

The smoothing operations should on completion ensure that the road surface is shaped to a crown with crossfalls of 4–6% on straight sections and a uniform crossfall across the total formation (i.e. from shoulder edge to shoulder edge) on superelevated curves. Where this is not possible then medium to heavy grading may be necessary to restore the road to a proper shape.

For medium grading the use of grader bits connected to the cutting edge of the blade (Figure E 6) has been found to be beneficial on many gravel roads. They have the ability to lightly scarify the surface (to about 50 mm depth) to correct minor deformations and to bring out the fines which helps develop a better blend with the loose aggregate than just using the grader blade. With the use of a free roller attached to the grader and the right moisture conditions one operator can achieve a reasonable standard road finish.

Figure E 6: Blade with grader bits

Source: ARRB (2009).

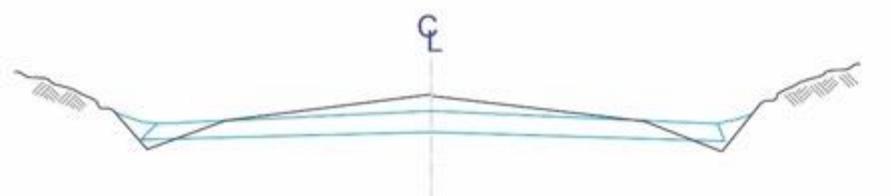
It should be noted that where the aggregate size is greater than the spacing between the grader bits large stones will be dragged along by the blade and not provide the blending required. The free rollers while providing a level of compaction will not achieve the higher compaction provided by a separate roller. On the other hand, some compaction is obtained and can save on the use of an additional operator.

E.2 Medium Grading

Table E 1 shows a grading sequence to restore the shape of the road from a flat surface to the desired crossfall with a six-grader pass. This is achieved by using the existing gravel materials mainly in the table drains to restore the shape of the road to a crown. For narrower roads (< 5 m) this may only require four grader passes (Smart & Giummarra 2005).

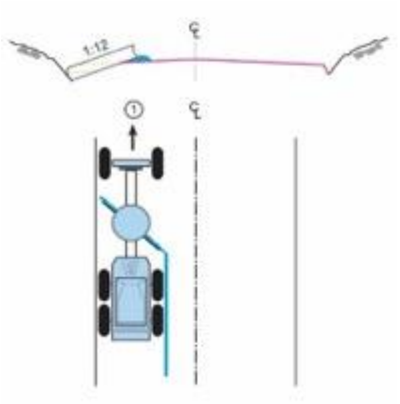
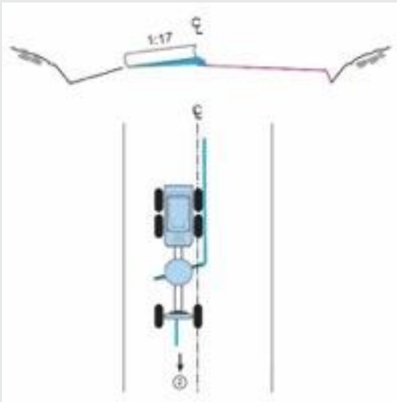
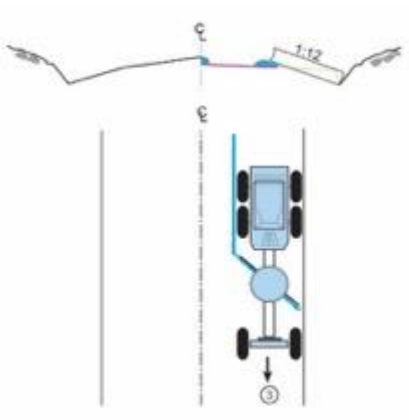
Figure E 7 shows the existing surface level (red) and the desired profile (black) and the various grader positions to restore shape and profile. Table E 1 shows the sequence to achieve the desired shape in six grader passes.

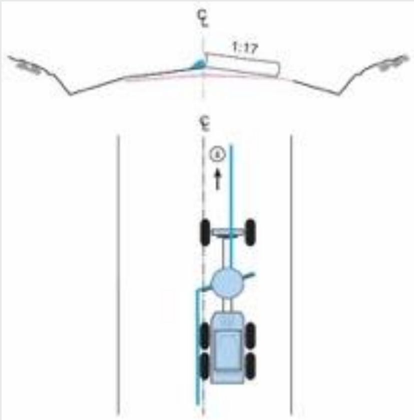
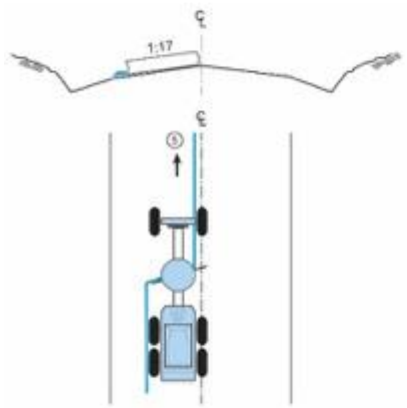
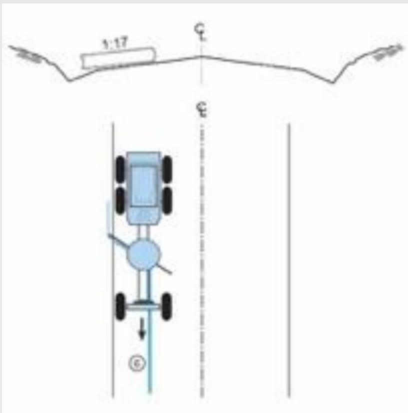
Figure E 7: Existing shape (red line) to the desired shape (black line)



Source: ARRB (2009).

Table E 1: Grading sequence for medium grading operations

Pass no.	Road shape	Illustration
1		
2		
3		

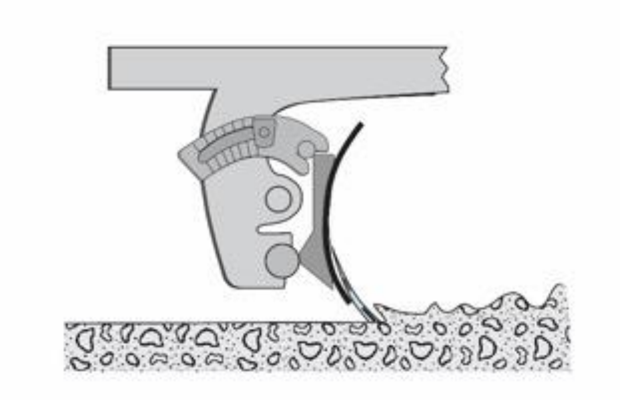
Pass no.	Road shape	Illustration
4		
5		
6		

E.3 Heavy Grading

For heavy grading, scarifying when necessary should go as deep as the average pothole, usually 100 mm, providing the pavement depth is > 150 mm. This is providing that the gravel depths are available otherwise contamination of the subgrade material with basecourse will occur.

Angle the mouldboard at about 30–45 degrees to the horizontal to provide for moving and rolling aggregate in a mixing action towards the road with the mouldboard tilted slightly backwards to give a cutting action as shown in Figure E 8. Put enough pressure on the blade to cut shoulders and ridges. Spread half the aggregate back over each side of the road and shoulders, grading the material into a proper crown.

Figure E 8: Mouldboard slightly back for pavement reshaping



Source: ARRB (2009).

Special attention is needed when grading an unsealed road to join a sealed road, a bridge, an intersection or on approaching a railway crossing because of different crossfalls. In these cases, begin at a point about 20 to 30 m before the intersection so that the crown crossfall can be gradually changed to match the crossfall of the intersecting feature. It is, however, far more practical to have where possible the sealed road match the crossfall of the unsealed road to avoid potholes forming on flatter grades on unsealed roads. Where this is not practical then adding sealed approaches in the case of a bridge, or intersection with a crossfall that matches the unsealed road, will avoid potholes forming at the junction. Care should always be taken not to have aggregate bladed onto a sealed pavement or rail crossing.

For heavy grading operations (Figure E 9) where the pavement material has been lost and new pavement material is to be added it is important that before the resheeting operations begin that the road is shaped to the desired cross-section, lightly scarified, to aid bonding of pavement layers, and the aggregate is added and compacted. This enables a uniform and consistent depth of aggregate to be laid and compacted.

Figure E 9: Heavy grading

Source: ARRB (2020).

Appendix F Generic Maintenance Specifications

F.1 Prescriptive Specification

F.1.1 Preamble

The extent of the road system to be maintained is shown in Table F 1. Details of the road locations, road category and road names are given in Appendix 1 of the contract specification.

This is a specification of works for:

- Routine Maintenance:
  - Patrol maintenance.
  - Light formation grading.
- Periodic Maintenance:
  - Medium formation grading.
  - Heavy formation grading.
  - Resheeting.

All works are to be carried out under a schedule of rates for a period of 3 years with the option of extension for a further period of 2 years. Administrative clauses, annexure, insurances etc. are contained elsewhere in the General Conditions of the contract and not in these specifications.

Historic data or conditions and previous periodic works for the network will be made available to tenderers (Appendix 2 of the contract specification).

The Contractor will as soon as practical gain knowledge of the road network, and this knowledge shall be made use of at regular fortnightly meetings. As indicated in

Table F 2, the Contractor shall identify works to be added to programs for patrol maintenance and light formation grading (which may increase Contractor returns).

This specification can refer to this Manual on matters of current works practice.

F.1.2 Nature and Scope of Work

The scope of the work is:

- Routine maintenance:
  - Patrol maintenance – minor repairs to pavements, shoulders, drains, culverts and road furniture plus off-road maintenance undertaken on a day-to-day basis.
  - Light formation grading of pavements and shoulders as directed and usually undertaken at least annually.
- Periodic maintenance:
  - Medium formation grading including watering plus compaction.

- Heavy formation grading, as for medium but including ripping and may include additional material in parts.
- Resheeting which includes preparation of road subgrade, placing of imported material, and two months defect liability period.

F.1.3 Schedule of Works for Routine Maintenance

Patrol maintenance – refer to Table F 2.

Light formation grading – refer to Table F 3.

Table F 1: Extent of the road network (example)

Item	Road category	AADT	Local factor	Length (km)	Normal operating speed (km/h)	Frequency of service
1	Main gravel	> 150		40	90	As directed in Table F 2 to Table F 5
2	Secondary gravel	> 50	May be < 50 vpd if of special economic, social or recreational importance	200	80	As directed See note to Table F 4
3	Minor gravel	< 50	No special importance	600	70	As directed

Notes:

- *The location, category, and name of each road is shown on the locality plan at Appendix 1. (Appropriate plan to be attached. Schedules which follow have been derived from the above table to illustrate the process).*
- *The work standard and the work activities as described in Appendix F.1.7 and Appendix F.1.8 are the same for all categories of road, but the intervention level is different for minor roads. The level of acceptable roughness prior to intervention is higher for minor roads, so that busier roads have a better ride quality.*
- *Earth formation roads and tracks are not included in this contract.*

Table F 2: Schedule of patrol maintenance

Item	Activity description	Frequency of service	Unit	Estimated quantity for tendering	Tendered amount ($)
1	Inspection of gravel roads, and surface drains	Quarterly	km	4	
2	Inspection of bridges, culverts and road furniture	Annually	No.	1	
3	Open drain clearing, water ponding and reforming (long lengths to be done with light or medium formation grading)	Blockage of 50% drain cross-section, on carriageway	m	500	
4	Culvert cleaning depth at entrance	Silted to 1/3 culvert	m	300	
5	Removal of isolated hazards at day work rates (Appendix F.1.7) and signing of isolated hazards	Any	Provisional Sum	–	
6	Complaints to be investigated and reported	Any	No.	50	
7	Emergency call-out, as directed, and response time 1 hour (Appendix F.1.7)	Hour	No.	100	

Item	Activity description	Frequency of service	Unit	Estimated quantity for tendering	Tendered amount ($)
8	Remove obstacles or fallen limbs from formation within 24 hours	Any	Hour	100	
9	Clean up fallen timber, prunings and unwanted seedlings from road reserve	As directed	Hour	100	
10	‘Digouts’ and pothole patching prior to light formation grading where depth of defect > 150 mm (excluding material supply)	As directed	m^2	500	
11	Replace or install signs, signposts and guide posts	As directed	No.	150	
12	Repair or replace guardrail	As directed	m	75	
13	Collect litter from wayside stops	Monthly	No.	12	
14	Spray kerbside and remove noxious weeds	Annually	ha	2	
15	Apply dust suppressants as directed	Annually	ha	1.5	
16	Mowing and slashing as directed	Annually	ha	5	

Note: The Contractor during day-to-day operations shall identify activities and faults which can be carried out by patrol maintenance or by light formation grading in addition to the quarterly inspections specified.

Table F 3: Schedule of light formation grading

Item	Activity description	Frequency of service	Unit	Estimated quantity for tendering	Tendered amount
1	Light formation work on pavement and shoulders – no added water	Annually	km	800	
2	Light formation grading – with added water on pavement and shoulders of unsealed road	1/8 of all roads	km	100	
3	Light formation work on pavement and shoulders – no added water – plus clean and restore table drains and cut-off drains	1/8 of all roads	km	100	

Note: The frequency shown is for estimating and is based on past experience but cannot be guaranteed. For reporting purposes, the combined surface defects used to identify candidates for light grading shall be at the warning threshold (refer to Section 2.5 of the ARRB Unsealed Roads Best Practice Guide (2020c)) where surface defects reduce safe travel speed by 15% (refer to Appendix F.1.16).

F.1.4 Schedule of Works for Periodic Maintenance

The schedule includes medium and heavy grading and periodic resheeting on unsealed roads.

These works will be as directed by the Engineer and the quantities shown are based on past experience and are commensurate with available funds. The order of works will be discussed at fortnightly meetings and then decided by the Engineer (Appendix F.1.16).

The schedule of works is shown in Table F 4.

Table F 4: Schedule of periodic grading and resheeting (medium and heavy formation)

Item	Activity description	Frequency of Service	Unit	Estimated quantity for tendering	Tendered amount
1	Medium formation grading	1/8 of all roads	km	100	
2	Medium formation grading plus cleaning table and cut-off drains	1/10 of all roads	km	70	
3	Heavy formation grading	1/10 of all roads	km	80	
4	Heavy formation grading with additional material of 100 mm thickness	1/12 of all roads	km	63	
5	Resheeting of pavement and shoulders including preparation of bed and 2 months defect liability period, 8 m width	1/30 of all roads	km	27	
6	Supply of material for periodic resheeting and to Item 10 of patrol maintenance schedule (Table F 2)	As required	m^3 (loose)	32 500	Determined by price in Appendix F.1.14.
7	Load and transport material	As required	m^3 (loose)	32 500	Determined by lead distance and rates in Table F 7.

Note: For the information of tenderers, the above estimated quantities are based on frequencies of work shown in Table F 5. Columns 2 and 3 of Table F 5 may be exceeded or not attained in any one year.

F.1.5 Rates for Day Work

Tenderers are to indicate rates required for day work outside of the schedule of works items in Table F 2.

A suggested frequency of service for varying road categories is provided in Table F 5.

Table F 5: Frequency of service

Road category	Frequency/year		Condition at intervention	
	Surface grading (number)	Resheet (fraction road length)	Approx. roughness (NRM/IRI)	Approx. loss in operating speed (%)
Main	4	1/20	180/7	20
Secondary	2	1/20	180/7	20
Minor	1⅓	1/40	220/9	30

Note: Condition at intervention is indicative only of Council's objective when shown in the form described in Section 5.1.4 of the ARRB Unsealed Roads Best Practice Guide (2020c). It is expected that intervention will be judged from % loss in operating speed and not from the physical measurement of roughness. Method of obtaining loss in operating speed due to surface defects is described in Appendix F.1.16.

Day work is not expected to exceed the lump sum figure shown in Table F 2, Item 5, and must have prior approval of the Engineer before commencing. Day work rates shall cover all overhead administrative costs, down time, all operator costs and allowances, fuel, servicing and profits.

The schedule for tendering day work rates is Table F 6. The Contractor shall have access to Items 1 and 3 at all times.

Table F 6: Day work rates

Item	Description	Hourly rate ($)	Standby rate ($)
1	Front-end loader – 1.7 m^3 bucket		
2	Backhoe/loader 45 kW		
3	Grader 100 kW and free roller		
4	Grader 100 kW		
5	Water tanker – 5000 l or larger		
6	10 tonne multi-wheel roller		
7	10 tonne smooth drum roller		
8	Combination roller		
9	Site supervisor		
10	Traffic controller		
11	Day truck 5 tonne		

F.1.6 Cartage Rates

Cartage rates shall include the cost of loading and cover all overhead administrative costs, operator costs and allowances, fuel, servicing and profits. Written approval of the Engineer shall be obtained for the travel route and lead distance before carting commences. Trucks must adhere to the approved route. The schedule for tendering cartage rates is shown in Table F 7.

Table F 7: Cartage rates schedule

Lead distance (km)	Price/m^3
0–2	
2–4	
4–6	
6–10	
10–15	
15–20	
over 20 rate/km for lead distances	

F.1.7 Description of Work

Routine maintenance

Patrol maintenance

Patrol maintenance covers the day-to-day activities required for the upkeep and preservation maintenance on unsealed road carriageways and road reserves.

The work is carried out with the use of a light truck and equipment such as chainsaw, pump, posthole borer, weed sprayer, to be supplied by the Contractor.

Emergency callouts to an accident or natural disaster require mobilisation within 1 hour of notification by a Police Superintendent or the Engineer. Payment shall be for a minimum of 3 hours at day rates. Subsequent work at the site shall be at the appropriate schedule rate, or at day rates if no schedule rate is appropriate.

Isolated hazards (Item 5, Table F 2), consist of depressions, large potholes, bulldust holes, washouts, protruding rocks, fallen trees across road, and any occurrence which is to be attended to at short notice, and cannot be deferred in the interests of safety until resources are on-site for programmed work in light formation grading or in periodic maintenance. Warning signs are to be erected upon the situation being brought to notice or on report from the travelling public.

Where treatment of a hazard consists of excavation, replacement with fresh gravel and compaction, it will be paid for at the schedule rate for ‘digouts’ and pothole patching (Item 10, Table F 2), and otherwise at day rates. ‘Digouts’ are areas of less than 50 m^2 which have failed and may be excavated by front-end loader or backhoe, backfilled and compacted by wheel rolling with the day truck.

Off-road maintenance is described in Appendix F.1.15.

Light formation grading

Light formation grading consists of an initial cut with the grader blade of 25 mm to windrow material for possible later back-spreading of the material as described in Periodic maintenance medium formation grading and heavy formation grading. Light grading is best carried out when conditions are suitable, such as shortly after rain when gravel is moist. Surface defects should not yet be as severe as tolerability level and will, therefore, be improved by being filled with windrowed material. Any loose or shoved gravel shall be spread in the process. Care shall be taken to retain the existing road shape and existing thickness of wearing course gravel. Light grading is essentially a smoothing activity to restore ride quality, but if not done at a suitable time, the treatment may be short-lived.

Periodic maintenance

Medium formation grading

Medium formation grading is carried out where surface defects are close to the tolerability level (and more severe than when light grading is carried out), but defects are not so deep as to warrant deep scarifying (ripping) of the pavement and shoulders. The other prerequisites are that formation shape should be generally satisfactory, and existing gravel thickness is 50 mm or more, with no bare patches of road subgrade.

Medium grading consists of an initial cut of 50 mm to windrow sufficient gravel to enable a back-spread layer of at least 50 mm (or two and a half times the nominal size of wearing course gravel, whichever is the greater) to be watered and compacted. Water sprayers and both steel drum and multi-tyred rollers are to be used.

Heavy formation grading

Heavy maintenance grading is carried out if one or more of the following conditions exist:

- the nature and depth of surface defects are severe and exceed tolerability levels, i.e. IRI greater than 7 or loss in operating speed of > 30% for minor roads, and > 20% for other roads (Table F 5)
- the road shape is poor, does not conform to the specified crossfalls required for drainage, and has ponded water on the insides of curves

- gravel depth is variable and while an overall resheet is not required, there are places where additional wearing course material is required.

Heavy grading consists of ripping and restoring the formation to correct profile with the addition of pavement material to a minimum depth of 100 mm of wearing course gravel as directed. As an alternative if the pavement has adequate strength a wearing course may be only 50 mm thick on top of a structural basecourse.

As with medium formation grading, water sprayers, a steel drum roller and multi-tyred roller are to be used. During reforming care has to be taken to avoid any mixing of subgrade with gravel that may lead to an inferior surface.

For all grading activities (light, medium and heavy), grading shall be carried out working from outside edges towards the crown as described in the ARRB *Unsealed Roads Best Practice Guide* (ARRB 2020c) with a crossfall of 4–6%, retaining a crown on straight sections, and retaining design superelevation on curves. On the inside of curves, it is important to keep the shoulder level up and avoid water ponding on the inside edge of the shoulder. On the outside of curves, superelevation must continue to the edge of the formation and not be rolled over with loss of material and reduced safety.

On no account is there to be a final pass down the centre of the road with a horizontal blade to remove the crown.

Where drainage is specified to be attended to in the schedule of works in conjunction with grading (Table F 2, Item 4; Table F 4, Item 2), table drains shall be cleaned where accessible by the grader to allow for the free flow of water to culverts and other outlets. The base of table drains is to be 0.5–1.0 m below shoulder level. Other outlets and cut-off drains shall also be cleaned to carry water away from the road as described in the ARRB *Unsealed Roads Best Practice Guide* (ARRB 2020c).

Compaction of pavement material required for medium and heavy formation grading is described in more detail in Periodic Resheeting and in the ARRB *Unsealed Roads Best Practice Guide* (ARRB 2020c). In medium and heavy formation grading, the minimum thickness of the compacted layer is to be at least 50 mm (or two and a half times the nominal gravel size, whichever is greater).

On completion of formation grading, the work site shall be left in a neat and tidy condition, tussocks and root balls shall be removed, any loose gravel on verges will have been salvaged by working into the pavement, the shoulders are to be left free from sticks and rubbish is to be cleaned from drains. Roadside furniture, which has been removed or damaged during the work, is to be replaced in prior positions.

Periodic resheeting

Resheeting becomes necessary when there is insufficient gravel to protect the subgrade, or insufficient wearing course gravel to cover stony or bare areas by formation grading. Resheet thickness in this contract is to be 100 mm compacted thickness, to be placed in a single layer.

The initial work is to prepare the road subgrade by shaping from edge of shoulder to edge of shoulder to form a surface parallel to the finished level. Crossfall of the subgrade shall be 4–6% on straight sections and correctly shaped on curves with the required superelevation. Before placing imported gravel, the shaped subgrade shall be rolled to the correct crossfall with the steel drum roller, adding water as necessary, until there is no visible deflection under the roller.

Gravel will be supplied to the Contractor at the nearest Council-operated pit at a price of \$x/m^3 loose and the Contractor is required to load and transport material to the job site (see Appendix F.1.14).

Gravel shall be carefully tipped at the rate of 8.5 m^3 per 10 lin. m and a tally docket made out after tipping. Gravel may be run out of moving trucks in the middle of the road when it is safe to do so (Appendix F.1.11).

Gravel is to be spread, shaped promptly to retain moisture and additional water is to be added to the loose surface to enable gravel to be worked at optimum moisture content. Care is to be taken to ensure that gravel is not spread over-width but nevertheless will be 100 mm at the shoulder edge after compaction. Mixing of gravel with verge material is to be avoided. After spreading, compaction shall begin with a steel drum roller starting at the outer edge (lower edge if superelevated). The overlap for successive passes of the steel roller shall be 500 mm or 30% of the roller width, whichever is the greater. Sharp turns and sudden changes of direction by the roller shall be avoided. After the initial compaction of at least 3 coverages with this roller, the surface shall be trimmed, watered and rolled with at least 2 coverages with a multi-tyred roller.

It is expected that the above rolling pattern will be sufficient provided that the moisture content during rolling is at or slightly above optimum. However, a satisfactory rolling process should be established quickly, and the process maintained for the balance of the work.

On completion, the surface shall be sound and tight and show no visible deflection under construction equipment. For the next 2 months, the Contractor shall maintain the surface by watering, trimming and rubber-tyred rolling as necessary. At commencement of the defects liability period, the completed pavement is to be 'dipped' at the centreline and edge of pavement at 200 m intervals to verify that a uniform thickness has been achieved, and the depths certified.

F.1.8 Standard of Work

The standard of work is to be the same for all categories of roads. For all formation grading and resheeting, the finished surface shall:

- be true to shape being 4–6% on straight sections and either maintain existing superelevation on curves or change the superelevation as directed
- for medium and heavy grading, and resheeting, shall be given at least 3 passes with the steel roller after shaping, and 2 passes with the multi-tyred roller after trimming, or more if required, until a sound tight surface is obtained. It shall show no visible movement under compaction equipment
- be free from surface defects and enable a comfortable ride in a sedan car driven at normal operating speed for the road as shown in Table F 1.

F.1.9 Hours of Work

Work shall be performed between 6.00 a.m. or sunrise, whichever is the later, and 8.00 p.m. or sunset, whichever is the earlier, on Mondays to Fridays, excluding Public Holidays.

Emergency works and weekend work for a particular job may be carried out only if the prior approval of the Engineer has been given. In arid zones permission may be given for watering at night.

F.1.10 Limitations on Work

Routine maintenance:

- Patrol maintenance – no limitation.
- Light formation grading – work may be suspended as for Periodic maintenance.

Periodic maintenance

- Medium and heavy formation grading.

During adverse weather conditions, e.g. floods or extremely dry conditions, Council reserves the right to suspend maintenance grading for an indefinite period. One week's notice shall be given in these circumstances and the Contractor shall resume regrading after one week's notice to do so.

On a short-term basis, as directed, work shall cease when windy conditions prevail so that dust is not a nuisance or hazardous.

No work shall be carried out during or immediately after heavy rain while there is free water on the surface.

No resheeting shall continue during heavy rain or when surface water is visible.

Extensive heavy cartage during wet periods will result in damage to adjoining gravel roads. Therefore, resheeting works in the vicinity of all Council pits may not be undertaken within the months of June to October, inclusive, without written approval of the Engineer.

F.1.11 Provision for Traffic

The Contractor shall take over the site and assume all responsibility for the safety of traffic on the work in progress, and for completed work during the maintenance period until such work is accepted by the Engineer. In some situations, a traffic management plan for the works proposed is to be prepared. Road signs, traffic cones, and flashing lights will be loaned to the Contractor from the Council Depot.

In particular, the Contractor shall:

1. Erect and remove warning signs as appropriate and in accordance with AS 1742.3.
2. Restrict the length of work in progress to enable completion by the stipulated finish time of day so that windrows are not left overnight. The maximum length of work in progress shall be:
   - maintenance grading – 5.0 km
   - resheeting – 0.5 km
   - rip, reform and reshape – 0.5 km
3. Employ traffic controllers during resheeting works while gravel trucks are tipping, and the cost included in the tendered price for resheeting works.
4. Obtain (at Contractor expense) and erect replacement signs for any lost or damaged as a result of the Contractor's work.

F.1.12 Plant Specification

In addition to the tendered rate for plant hire required in Appendix F.1.6, the Contractor is to supply details of the make, model and age of plant proposed to be used for the contract. The Contractor is reminded that graders are key items and must have engine power of not less than 100 kW for reforming and resheeting works. Cutting blades are to be in good order and replaced appropriately. Plant maintenance, adjustments, repairs, etc. shall be carried out on wet days or outside normal working hours. Maintenance graders working alone are to be fitted with 2-way radio. In respect of plant items which are motor vehicles, the Contractor must produce certificates and licences to the Engineer, as required, to confirm that legal responsibilities are complied with.

F.1.13 Plant Operation

Operators shall be suitably experienced and shall hold appropriate licences. Because of the importance of grader operation to the success of the contract, the experience and skill of proposed operators may be taken into account during the consideration of tenders. The Contractor shall supply the name, age, experience and training of current grader operators.

F.1.14 Materials and Cartage

The location of quarries and gravel pits presently used by Council for resheeting works is shown on the map in Appendix 3 (of the contract specification). It is intended that material be obtained from the source closest to the resheeting site. Material from all Council pits will be charged to the Contractor at a price of $x/m^3 loose, with the Contractor being responsible for loading and transporting gravel to the job site at the rates tendered in Appendix F.1.6. Material for patrol maintenance, Table F 2, Item 10, shall be provided on the same basis.

In general, material quality at all pits falls into the ranges required in the ARRB *Roads Materials Best Practice Guide* (ARRB 2020a), namely:

- 100% passing 26.5 mm sieve
- fines to sand ratio of between 0.25 and 0.45
- PI in range 4–15 (or LS in range 2–8).

Gravel selected for resheeting must be free from clay balls, oversize rocks, vegetative matter, and otherwise consist of sound, clean material, free from mica and sufficiently mixed in winning and loading to ensure a uniform product.

Typical samples of satisfactory material from each source are contained in glass containers held at the Council office and available for inspection. During the loading operation into trucks, any noticeable departure in appearance by way of colour, texture or particle shape should be brought to the Engineer's attention.

F.1.15 Roadside Environment and Native Vegetation

On-road and off-road activities to be performed under this contract shall assist rather than harm the roadside environment. In particular, the activities shall not disturb stable land and shall not damage areas of indigenous vegetation. Further details on which to base specifications are available in the ARRB *Road Materials Best Practice Guide* (ARRB 2020b).

A permit from the Council will be required prior to the removal, destruction or lopping of any native vegetation on a roadside unless:

- the vegetation is dead
- the vegetation is bracken fern
- the vegetation is weeds
- it is necessary for fuel reduction and fire breaks
- it is necessary for clearance to powerlines
- it is cleared by hand tools to establish survey sight lines
- it is a roadside safety hazard
- it is required where seedlings are less than 10 years old and occurs within the road formation.

Any removals under the above exemptions must be reported with details of date, site and nature of work at the next fortnightly site meeting following the removal.

Maintenance activities shall be carried out in such a way that:

- road plant remains within the formation and does not park, traverse or turn around on areas of native ground cover
- gravel, screenings, and materials are not stacked under the drip line of trees or vehicles parked there
- cut-off drains, or preferably banks do not cause erosion
- used engine oil and contaminants are not left on the road reserve and are disposed of according to government regulations
- Council permits are obtained before trees are trimmed for clearance or sight distance. Trees are then pruned correctly at branch collars as directed
- no material infected with fungal disease or weeds is introduced to the road network
- Aboriginal and historic heritage sites are protected
- threatened flora and fauna are protected
- declared plants and noxious weeds are prevented from spreading.

F.1.16 Inspections, Programming and Reporting

Routine maintenance

Patrol maintenance

Only approved works are to be undertaken. During programmed inspections and in the course of day-to-day work, the Contractor shall identify faults and defects which are at the intervention levels shown in Table F 2 and Table F 3, which can be rectified by patrol work or light formation grading. A check should be made as to the road signs required during inspections. The program of routine patrol maintenance is to be prepared within 14 days and approved by the Engineer. Some proposed patrol works may be deferred if programmed periodic maintenance is imminent and patrol items can conveniently be done then.

Light formation grading

For reporting purposes and to assist in deciding the order of works, the combined surface defects are to be at the warning threshold; i.e. when a medium sedan car driven in a safe manner, and so as to not damage the car, has its operating speed due to surface defects reduced to 85% of normal operating speed immediately after formation grading or resheeting. Alternatively, exceed IRI roughness intervention values.

Periodic maintenance

The order of works detailed in Table F 2 and Table F 3 will be as directed by the Engineer following the initial meeting with the Contractor, and as directed at subsequent fortnightly contract meetings. The Contractor shall assist in identifying and proposing some capital works where present maintenance is excessively frequent or costly – even though this could reduce profits on the contract if the proposed capital works are able to be funded and carried out during the contract term.

In general, grading works will proceed on a road face, proceeding from one road to the next, in order to minimise transportation of road plant, with most major roads being graded as the face proceeds, but some minor gravel roads with few surface defects will not be graded until the next time around.

From time to time a major road at a more distant location may require urgent attention, in which case the Contractor may elect to transport equipment from the present work site or elect to employ temporary additional resources on the contract.

As indicated in Appendix F.1.10, grading and resheeting works may have to be curtailed altogether in certain adverse conditions.

F.1.17 Complaints

The Contractor's representative shall make it clear that it is operating on behalf of the Council and is to take courteous note of complaints and suggestions made by the travelling public or affected landowners and ratepayers.

The Contractor shall report all such discussions to the Engineer at the next fortnightly contract meeting, or sooner, if the matter is urgent. In cases where there is a free phone help desk provided for complaints these are to be dispatched to the appropriate Contactor.

F.1.18 Compliance with Regulations and Relevant Acts

The works shall be conducted at all times in a workmanlike manner in accordance with any relevant federal and state Acts or Regulations, Council Local Laws, and Australian Standards.

The specification should also make reference to the Unsealed Roads Manual on matters of current works practice.

In addition, and in particular, the Contractor shall comply with:

1. Occupational Health and Safety Acts, as relevant to the state/territory.
2. Australian Standard AS 1742.3 – Manual of Uniform Traffic Control Devices.
3. Relevant state/territory Worksite Traffic Management (Roadworks Signing) Code of Practice (or similar publication).
4. Relevant state/territory *Environmental Guidelines for Road Construction and Maintenance Workers* (Western Australian Roadside Conservation Committee 1998) (or similar publication).

F.1.19 List of Appendices (supplied by Council)

1. Map – location, category and road name (to be provided).
2. Historical data on road condition and previous period works (not provided for prescriptive specification).
3. Map – location of quarries and pits.
4. Any cultural and heritage site maps.

F.2 Performance Specification

F.2.1 Preamble

This is a specification for works on unsealed gravel roads within the municipality comprising the location, category, and name of each road as shown on the locality plan at Appendix 1 (of the contract specification).

- Routine maintenance:
  - Patrol maintenance.

  - Light formation grading.
- Periodic maintenance:
  - Medium formation grading.
  - Heavy formation grading.
  - Resheeting.

For the contract duration, the works shall be undertaken to fulfil the Council's objectives, namely:

- to provide a level of service as specified in maintaining the riding surfaces of gravel roads to allow a degree of safe, convenient travel commensurate with the volume and type of traffic
- to preserve the pavements by careful use of often marginal local gravels so that the asset value at contract completion date, as measured by total thickness of gravel in place, is not less than at commencement
- to enhance the roadside environment.

Historical data on conditions and previous periodic works for the network will be made available to tenderers (Appendix 2 of the contract specification). Works are to be carried out under a lump sum contract, subject to rise and fall and to quality assurance for a period of 5 years. Administrative clauses, annexure, insurances etc. are contained elsewhere in the General Conditions.

The Contractor has to provide all plant, fuel, equipment, labour, roadmaking materials, works signs, and road furniture necessary for the task.

Council presently may have a maintenance management system (MMS) which records, collates and analyses condition data regarding the unsealed road network. The maintenance management system is a tool to assist the Contractor to perform the contract according to Council's objectives stated above. Data collection is a necessary part of the management of unsealed roads, not only for this contract but also for long-term planning and asset management. Software and data will be made available to the Contractor, who shall update the condition database following inspections and record the details of works carried out to maintain the required level of service on the network. At the conclusion of the contract all software and records are to remain the property of Council.

This specification refers to the ARRB *Unsealed Roads Best Practice Guide* (2020c) on matters of current works practice.

F.2.2 Nature and Scope of Work

The scope of the work is:

- Routine maintenance
  - Patrol maintenance – minor repairs to pavements, shoulders, drains, culverts, and road furniture plus off-road maintenance undertaken on a day-to-day basis.
  - Light formation grading of pavements and shoulders undertaken at least annually.
- Periodic maintenance:
  - Medium formation grading including watering plus compaction.
  - Heavy formation grading, as for (a) but including ripping and may include additional material.
  - Resheeting, which includes preparation of the roadbed and placing and compaction of imported material.
- Maintenance management:

- Maintaining Council's existing system of recording condition data on the surface integrity of pavements, and the roadside environment.
- Maintaining quality assurance documents to ensure that works are done according to best practice.
- Investigating and taking action on complaints and emergency callouts.
- Preparing economic analyses where capital improvements may result in overall economy through reduced routine maintenance (and in some instances through improved travel time and safety).

The extent of the road network to be maintained is shown in Table F 8.

F.2.3 Intervention Levels for Routine Maintenance

Intervention levels of tolerable severity and extent for patrol maintenance are shown in Table F 9.

Intervention levels of tolerable severity and extent for light formation grading are shown in Table F 10.

The intervention levels for routine light grading are shown in Table F 10. The degree of acceptable roughness prior to intervention is higher for minor roads so that greater maintenance effort can be given to the major roads and busy roads to provide a better ride quality.

Table F 8: Extent of the road network (example)

Item	Road category	AADT and local factors	Length (km)	Normal operating speed (km/h)
1.	Main gravel road	> 150	40	90
2.	Secondary gravel road	> 50, or < 50 if of special significance	200	80
3.	Minor gravel road	< 50 and no special significance	600	70

Table F 9: Intervention levels for patrol maintenance

Item	Activity description	Severity intervention level	Extent intervention level
1.	Removal of isolated hazards and erection of warning signs. Attend to within 24 hours.	Likely damage to vehicles or injury to occupants.	Any
2.	'Digouts' and patching.	Failed areas.	> 50 m^2
3.	Culvert cleaning and clearing of table drains.	Waterway blockage ***> 50%***, ponding ***< 450 mm*** below shoulder point.	Any
4.	Emergency callout. Mobilise within 15 minutes.	Accident, natural disaster.	Any
5.	Remove obstacles, fallen limbs, etc., from road formation.	Clear trees within ***3 m*** of edge of pavement. Trim if sight distance obscured or vehicle clearance impeded.	Any
6.	Replace, install or clean signs.	Reflectivity ***< 50%*** on signposts and guide posts. Not legible at ***150 m*** on low beam. Missing guideposts.	Any
7.	Clean up fallen timber, prunings and unwanted seedlings from road reserve.	Fire hazard or unsightly.	Any
8.	Repair guardrail.	Damaged by vehicle.	Any

9.	Collect litter from wayside stops and areas of grass prior to mowing.	Quarterly and when bins overflow.	Any
10.	Remove weeds from road reserve or spray herbicide.	Noxious, declared plants.	Any
11.	Mowing and slashing.	Fire hazard or sight distance obscured.	Any
12.	Investigate complaints and report. Take justifiable action where required.	Other than frivolous.	Any

Table F 10: Intervention levels for light formation grading

Item	Activity description	Severity intervention level	Extent intervention level
1.	Light formation grading on pavement and shoulders with or without water and may include restoring table drains and cut-off drains. General defects to be restored include windrows, scours, channels, corrugations, soft or slippery areas, coarse surface texture, loose material, roughness.	Scours, soft or slippery areas, loose material. IRI < 9 or safe travel speed < 70% (minor roads) and IRI < 7 or safe travel speed < 80% (other roads) and ruts, corrugations, potholes < 50 mm.	5% of sub-length of 1 km 20% of sub-length

Note: The warning threshold for reporting of surface condition is when IRI values are higher than Table F 10 or speed of safe travel is reduced to 85% of normal operating speed by the combined effect of surface defects.

Table F 11: Intervention levels for periodic medium and heavy formation grading and periodic resheeting

Item	Activity description	Severity intervention level	Extent intervention level
1.	Medium formation grading of pavement and shoulders including watering and compaction and may include restoring table drains and cut-off drains.	Crossfall < 3% or > 7% and/or ruts, potholes and corrugations ***> 50 mm*** deep.	***20%*** of sub-length of 1 km
2.	Heavy formation grading including watering and compaction. This may include supply and placing of imported material.	Defect depth ***> 150 mm*** or water ponds and cannot be drained longitudinally, or crossfall < 3% or > 7%.	Any. ***20%*** of sub-length
3.	Resheeting of pavement and shoulders including supply and placing of imported gravel.	Depth of wearing course gravel ***0 mm*** (bare subgrade surface).	***20%*** of sub-length

F.2.4 Intervention Levels for Periodic Maintenance

The intervention levels for periodic medium and heavy formation grading and for periodic resheeting are shown in Table F 11.

F.2.5 Schedule of Works

The tendered amounts in Table F 12 are to cover the full annual cost of maintaining the road network to present standards of ride quality and gravel thickness, and to improve shape quality as described in Table F 11 and in Appendix F.2.7. While fair wear and tear, including emergency callouts to accidents, is to be the Contractor's responsibility, the costs of abnormal events (e.g. bushfires, floods) shall be borne by the Council.

Table F 12: Schedule of works

Item	Schedule item	Tendered amount ($)
1.	Establish communication and reporting	
2.	Routine maintenance – patrol maintenance	
3.	Routine maintenance – light formation grading	
4.	Periodic maintenance – medium and heavy grading	
5.	Periodic resheeting of roads and shoulders	
6.	Total bulk sum	

F.2.6 Description of Work

The descriptions that follow are a guide to good practice and are not intended to be directions to the Contractor. The contract directs the Contractor to achieve a particular level of service and to act within specified response times. The Contractor's performance is judged on these criteria and not on the methods used to achieve the end results. Response times given are in Appendix F.2.7, Table F 13.

Routine maintenance

Patrol maintenance

Patrol maintenance covers the day-to-day activities required for the upkeep and preservation of unsealed road carriageways and road reserves. The work is carried out with the use of a light truck and all necessary equipment such as chainsaw, pump, weed sprayer, and posthole borer, is to be supplied by the Contractor.

Isolated hazards (Item 5, Table F 9) consist of depressions, large potholes, bulldust holes, washouts, protruding rocks, fallen trees across road, and any occurrence which is to be attended to at short notice, and cannot be deferred in the interests of safety until resources are on-site for programmed work in (b) below or in Periodic maintenance (a), (b), or (c). Warning signs are to be erected upon the situation being brought to notice or on report from the travelling public.

'Digouts' are areas of less than 50 m^2 which have failed and may be excavated with front-end loader or backhoe, backfilled and compacted by wheel rolling with the day truck.

Off-road maintenance is described in Appendix F.2.10.

Light formation grading

Light formation grading is essentially a smoothing process to restore ride quality and if not done at a suitable time, the treatment may be short lived. It consists of an initial cut with the grader blade of 25 mm to windrow material for later back-spreading of material as described in Periodic maintenance below. Light grading is best carried out when climatic conditions are suitable such as shortly after rain when gravel is moist. Watering may be necessary in dry weather to reduce dust.

Surface defects should not yet be as severe as the tolerability level (severity intervention level) and defects will therefore be improved by being filled with moist windrowed material. Any loose or shoved gravel shall be spread in the process. Care shall be taken to retain a surface parallel to the designed road shape (crossfalls between 4–6%) and to maintain a uniform thickness of wearing course gravel. The thickness will reduce over time owing to wear, but gravel is to be preserved as far as possible.

Periodic maintenance

Medium formation grading

Medium formation grading (possibly with the use of blade tip attachments) is carried out when surface defects are close to the tolerability level (and more severe than when light grading is carried out) but defects are not so deep as to warrant deep ripping (scarifying) of the pavement and shoulders. The other prerequisites are that formation shape should be generally satisfactory and existing gravel thickness is 50 mm or more with no bare patches of subgrade.

Medium formation grading consists of an initial cut of 50 mm to windrow sufficient gravel to enable a back-spread layer of at least 50 mm (or two and half times the nominal size of the course gravel, whichever is the greater) to be watered and compacted. Water sprayers and both steel drum and multi-tyred rollers are to be used.

Heavy formation grading

Heavy maintenance grading is carried out if one or more of the following conditions exist:

- The nature and depth of surface defects are severe and exceed tolerability levels.
- The road shape is poor, does not conform to the specified crossfalls required for drainage, and/or has ponded water on the insides of curves.
- Gravel depth is variable and although a resheet is not required, there are places where additional wearing course material is required.

Heavy grading consists of ripping and restoring the formation to correct profile with the addition of up to 100 mm thickness of basecourse gravel to which may be added a wearing course. As with medium formation grading, water sprayer, steel drum and multi-tyred rollers are to be used. During reforming care has to be taken to avoid any mixing of subgrade with gravel that may lead to an inferior pavement.

For all grading activities (light, medium, and heavy) grading shall be carried out working from outside edges towards the crown with a crossfall of 4–6%, retaining a crown on straight sections, and maintaining superelevation from shoulder edge to shoulder edge on curves. On the inside of curves, it is important to keep the shoulder level up and avoid water ponding on the edge of the shoulder. On the outside of curves, superelevation must continue to the edge of the carriageway and not be rolled over with loss of material and reduced safety. On no account is there to be a final pass down the centre of the road with a horizontal blade to remove the crown.

Where drainage is required to be attended to, in conjunction with grading (Table F 10, Item 1), table drains shall be cleaned where accessible to the grader, to allow for the free flow to culverts and other outlets. Table drains are to be 0.5–1.0 m below shoulder level. Other outlets and cut-off drains shall also be cleaned, to carry water away from the road as described in the ARRB *Unsealed Roads Best Practice Guide* (2020c).

Compaction of pavement material required for medium and heavy formation grading is described in more detail in Periodic resheeting (below) and in the ARRB *Unsealed Roads Best Practice Guide* (2020c). In medium formation grading, the minimum thickness of the compacted layer is to be 50 mm (or twice the nominal size of the gravel, whichever is greater).

On completion of formation grading, the work site shall be left in a neat and tidy condition, tussocks and root balls shall be removed, any loose gravel on verges will have been salvaged by working into the pavement, the shoulders shall be left free from sticks and rubbish cleaned from drains. Roadside furniture which has been removed or damaged during the work is to be replaced in prior positions.

Table F 13: Response times

Item	Activity description	Response time
1.	Emergency callout to accident or disaster (flood, fire) or another event.	Mobilise resources within *15 minutes* of notification by Police Superintendent or the Engineer.
2.	Isolated hazard – bulldust hole, tree across road, washout, etc.	Attend within *24 hours* of notification by Police, travelling public or the Engineer and make safe or erect warning signs and lights until the hazard is removed.
3.	'Digouts' and failed areas of defect depth *> 200 mm*.	Erect signs and restore road condition within *one week* of detection.
4.	Ride quality affected by surface defects so that loss in operating speed, or extent of defects, is outside specified intervention levels.	Commence appropriate formation grading within *2 weeks* and complete grading within *3 weeks* of intervention levels being exceeded.

Periodic resheeting

Resheeting becomes necessary when there is insufficient basecourse gravel to protect the subgrade, or insufficient wearing course gravel to cover stony or bare areas of the basecourse by formation grading. Resheet thickness in this contract is to be 100 mm compacted thickness, to be placed in a single layer.

The initial work is to prepare the subgrade by shaping from edge of shoulder to edge of shoulder to form a surface parallel to the finished level. Crossfall of the subgrade shall be 4–6% on straight sections and correctly shaped on curves. Before placing imported gravel, the shaped subgrade shall be rolled with the steel drum roller, adding water as necessary, until there is no visible deflection under the roller.

Gravel will be supplied to the Contractor from the nearest Council-operated pit at a price of $x/m^3 loose. The Contractor is required to load and transport material to the job site. Gravel shall be carefully tipped at the rate of 8.5 m^3 per 10 lineal metres and a tally docket made out after tipping. Gravel may be run out of moving trucks in the middle of the road when it is safe to do so (Appendix F.2.8). Gravel is to be spread and shaped promptly to retain moisture and additional water is to be added to the loose surface to enable gravel to be worked at optimum moisture content. Care is to be taken to ensure that gravel is not spread past the road width but nevertheless will be 100 mm thick at the shoulder edge after compaction. Mixing of gravel with verge material is to be avoided.

After spreading, compaction shall begin with a steel drum roller starting at the outer edge (lower edge if superelevated). The overlap for successive passes of the steel roller shall be 500 mm or 30% of the roller width, whichever is the greater. Sharp turns and sudden changes of direction by the roller shall be avoided. After the initial compaction of at least three coverages with this roller, the surface shall be trimmed, watered and rolled with at least two coverages of a multi-tyred roller. It is expected that the above rolling pattern will be sufficient provided that the moisture content during rolling is at or slightly above optimum. However, a satisfactory rolling pattern should be established quickly, and the process maintained for the remainder of the work.

On completion, the surface shall be sound and tight, and show no visible deflection under compaction equipment. The completed pavement is to be ‘dipped’ at the centreline and edge of pavement at 200 m intervals to verify that a uniform thickness has been achieved, in the presence of the Engineer, and the results are to be entered into the maintenance management system.

F.2.7 Standard of Work – Service Levels and Response Times

The Contractor has to maintain the network in a condition that is at least equal to the ‘as found’ condition, except for shape deficiencies, which are to be improved as indicated in gravel thickness and road shape below. It is necessary for the Contractor to make interventions which are both timely and successful.

Ride quality

Normal operating speed for road categories is shown in Table F 8 and intervention levels for surface defects are shown in Table F 9 and Table F 10. When taken in combination, safe travel speed reduction due to surface defects must not be more than 20% (30% for minor roads) on any particular road during the course of the contract. At the as found condition, the extent and severity of ride quality measured by IRI or in loss of speed on the entire network will be recorded. On completion of the contract, the surface condition of the network shall be at least equal to the as found condition in respect of defects and travel speed. If any capital works have been carried out during the contract term which affect travel speed, these shall be taken into account in the final assessment.

Gravel thickness and road shape

The as found condition for pavement composition is to be taken from the maintenance management system records and the initial dipping of suspect roads by the Contractor. During the contract period, all roads with bare surface at intervention level in Table F 11 shall be resheeted and the thickness of gravel placed shall be recorded after dipping as described in Appendix F.2.6. At contract completion, the total computed depth of pavement in place shall be at least equal to the ‘as found’ condition.

Shape deficiency of individual roads has to be treated if outside the limits shown in Table F 11. At the as found condition, the extent and severity of poor crossfall and low formation shall be recorded. On contract completion, the total length of out-of-shape portions of road shall be at least 10% lower than the as found length. It is known that many roads are out-of-shape and approaching the intervention levels in Table F 11.

Roadside environment

The standard of all off-pavement works shall comply with the Council’s Roadside Management Plan.

Response times

The Contractor shall commence to restore the level of service to tolerable levels according to the response times in Table F 13.

F.2.8 Provision for Traffic

The Contractor shall assume responsibility for the safety of all traffic on the network.

For works in progress, the Contractor shall:

- supply, erect and remove standard warning signs as appropriate, and in accordance with the state/territory Worksite Traffic Management (Roadworks Signing) Code of Practice applicable to the Council
- restrict the length of work in progress to enable completion by nightfall so that windrows are not left overnight. A build-up of loose gravel on the edge of shoulder in the dry seasons may be permitted, provided that carriageway width is not reduced
- employ flagmen during resheeting works whilst trucks are tipping.

For the road network, the Contractor shall:

- supply, erect and remove standard warning signs in accordance with AS 1742.3 when treating hazards
- carry out a safety audit as set out in Chapter 11 of the Unsealed Roads Manual. If capital expenditure is needed to improve geometry or road widths at isolated locations, these should be assessed by economic evaluations (Appendix F.2.11).

A useful guide regarding choice and placement of the correct signs is given in the appropriate Australian Standards *Manual of Uniform Traffic Control Devices for Works on Roads* (AS 1742.1-2014, AS 1742.2-2009, AS 1742.3-2009).

F.2.9 Materials and Cartage

The location of quarries and gravel pits presently used by Council for resheeting works on unsealed roads is shown on the map at Appendix 3 (of the contract specification). Material from all pits will be charged to the Contractor at a price of $x/m^3 loose measurement, with the Contractor being responsible for loading and transporting gravel to the job site.

In general, material quality at all Council pits falls into the ranges required in the ARRB *Road Materials Best Practice Guide* (ARRB 2020b).

- 100% passing 26.5 mm sieve
- fines to sand ratio of between 0.25 and 0.45
- PI in the range 4–15 (or LS in the range 2–8).

Gravel selected for resheeting must be free from clay balls, oversize rocks, vegetative matter, and must otherwise consist of sound, clean material free from mica and sufficiently mixed in winning and loading to ensure a uniform product. A typical sample of satisfactory material from each source is contained in glass containers held at the Council Office and available for inspection. During the loading operation into trucks, any noticeable departure in appearance by way of colour, texture or particle shape, segregation and loss of material shall be brought to the Engineer’s attention.

The Contractor may elect to supply material from an independent source if that product is cheaper and/or superior to the Council source in ease of handling, resistance to wear, and in producing less dust. Before the use of untested and untried material, the Contractor will be required to give test results of maximum size, fines to sand ratio and LS, and in addition place a test section of 100 m length in order to evaluate the physical properties of handling, resistance to wear, and dust production. Any alternative proposals for mixing or armour coating local materials would be tested and trialled in the same manner. The period of the trial should desirably be over 12 months to enable assessment over the various seasons.

F.2.10 Roadside Environment and Native Vegetation

The objective of a Roadside Management Plan is to perform road activities in such a way as to:

- assist rather than harm the roadside environment
- not disturb stable land
- not damage areas of indigenous vegetation
- remedy soil erosion.

(Further details on environmental considerations are provided in the ARRB *Unsealed Roads Best Practice Guide* (2020c).

Maintenance activities shall be carried out in such a way that:

- road plant remains within the formation and does not park, traverse or turn around on areas of native ground cover
- gravel screenings and materials are not stacked under the drip line of mature trees
- cut-off drains do not cause erosion
- used engine oil and contaminants are not left on the road reserve and are disposed of according to government regulations
- Council permits are obtained before trees are trimmed for vehicle clearance or for sight distance
- no material infected with fungal disease is introduced to the road network
- Aboriginal and historic heritage sites are protected
- threatened flora and fauna are protected
- sacred sites, rare plants and listed trees are not disturbed
- grading of batters and drains is minimised
- declared plants and noxious weeds are prevented from spreading.

Any clearing, trimming or lopping is to be carried out skilfully by trained personnel, and the expert advice of a tree surgeon sought when necessary.

In particular, a permit from the Council will be required prior to the removal, destruction or lopping of any native vegetation on a roadside unless:

- the vegetation is dead
- the vegetation is bracken fern
- clearing is necessary for fuel reduction and firebreaks
- clearing is necessary for overhead powerlines
- it is cleared by hand tools to establish survey sight lines
- the vegetation is a roadside safety hazard
- it is required where seedlings are less than 10 years old and occurs within the road formation on shoulders and batters.

Any removals under the above exemptions must be reported with supporting details of date, site, and nature of work at the next fortnightly contract meeting following the removal.

F.2.11 Economic Evaluation of Alternative Proposals

The Contractor has an interest in carrying out timely and successful interventions by doing the right job at the right time by the best method – and thereby reducing overall maintenance costs. However, there will be some locations where maintenance is either unusually frequent or excessively costly and a capital improvement may be more appropriate than ‘sending good money after bad’.

The Contractor may prepare an economic analysis where capital improvements may result in overall economy through reduced routine maintenance (and often improved travel time and safety). These shall be presented as described in the ARRB Unsealed Roads Best Practice Guide (2020c) and should consider likely savings in travel time, accident costs, vehicle operating costs, and future maintenance arising from an upgrading or improvement of the road. An economic analysis may also arise from the Contractor’s safety audit (refer to Appendix F.2.8).

If Council decides to go ahead with a capital improvement, then the cost of any analysis and the cost of the works is to be borne by the Council. Depending on the nature and timing of the improvement, the Council may make a deduction on the contract as an offset for maintenance works deleted from the contract on account of the capital work.

F.2.12 Inspections, Programming and Reporting

Inspections

The Contractor is to make two inspections of the entire length of major and minor gravel roads in each calendar year and shall:

- record condition data of each link or sub-length in maintenance management system format
- take ‘dippings’ at centreline and pavement edge (not shoulder edge) on 50 km of road, initially on links suspected of nearing the intervention level for resheeting, and thereafter on links where no recent dippings or resheet history is available.

The first of these inspections shall be completed during the first month of the contract and will become the basis of the ‘as found’ condition. The second inspection shall be at six months and inspections thereafter shall be at six-monthly intervals or as directed.

Programming

As soon as practicable after the first inspection, the Contractor shall draw up a proposed program of works nominating candidate roads where observed defects are at or approaching the intervention levels pertaining to each candidate. The warning threshold of ride quality in term of IRI or speed reduction of 15% due to combined surface defects is an appropriate level for nominating candidates for formation grading.

In drawing up the program, the Contractor must keep in mind the Council’s objectives set out in Appendix F.2.1 and any restrictions imposed by seasonal or adverse weather, and the length restriction in Appendix F.2.8 for the safety and convenience of traffic. The Contractor must exercise judgement in programming maintenance grading where the bulk of grading should be carried out in damp conditions to minimise the cost of adding water and losing pavement material to dust. Thus, prior to the dry season, it may be better to grade a road which has not quite reached the intervention level in order that it may last through the dry months, rather than deferring the grading and being later forced to make a more costly and possibly unproductive intervention. It is well to carry out drainage maintenance just prior to the wet season.

For the Council's part, the Engineer should not unnecessarily cause the Contractor to move resources long distances for few jobs when some other grouping of work could produce a similar effect in achieving the service level of the road network. It is, therefore, expected that the program will be revised from time to time at regular meetings.

Meetings and reports

The Council and Contractor representatives will meet regularly twice each month to discuss progress and the short-term program. At the regular meetings, the Contractor will report on job progress, details of finished work for job records (including dippings on finished resheets), complaints and comments from travellers and ratepayers, the roadside environment, and contract variations arising from abnormal events.

On a monthly basis, minutes will be taken, the Contractor's claim for progress payment will be submitted and the quality assurance system reviewed. Payment shall be one-twelfth of the annual lump sum, subject to the specified level of service being achieved.

Quality assurance

The Contractor shall prepare and maintain a documented system in accordance with Australian Standards to cover all works under the contract. Tenderers shall submit a description of their system with the tender. The successful tenderer shall, within one month of acceptance, submit a copy of the contract quality plan to the Engineer. The plan shall clearly identify hold points by the letters HP in the left margin and by bold print in the document. The plan shall include a component for occupational health and safety.

Occupational health and safety

The Contractor is responsible for the safety of all personnel on work sites and for ensuring that all work is carried out in a safe manner and complies with regulations. Personnel must wear high-visibility clothing and protective clothing as required. The Engineer is to be informed promptly of any injury or accident on the job.

F.2.13 Complaints

Contractor representatives shall make it clear that they are operating on behalf of the Council and are to take courteous note of complaints made by the travelling public or affected ratepayers. If, after investigation, the complaint is found to be outside of tolerance levels set, the Contractor shall take action to remedy the situation. The Contractor shall report all such investigations and actions to the Engineer at the next regular fortnightly meeting, or sooner if the matter is urgent.

F.2.14 Compliance with Regulations and Relevant Acts

The works shall be conducted at all times by current best practice and in accordance with any relevant federal and state Acts or Regulations, Council Local Laws, and Australian Standards. This specification makes reference to the Unsealed Roads Manual on matters of current works practice.

In addition, and in particular, the Contractor shall comply with:

1. Occupational Health and Safety Acts, as relevant to the state/territory.
2. Australian Standard AS 1742.3 – Manual of Uniform Traffic Control Devices.
3. Relevant state/territory Worksite Traffic Management (Roadworks Signing) Code of Practice (or similar publication).
4. Relevant state/territory *Environmental Guidelines for Road Construction and Maintenance Workers* (Western Australian Roadside Conservation Committee 1998) (or similar publication).

F.2.15 List of Appendices

1. Map – location, category and road name (to be provided).
2. Historical data on road condition and previous periodic works (to be provided for performance specification).
3. Map – location of quarries and pits.