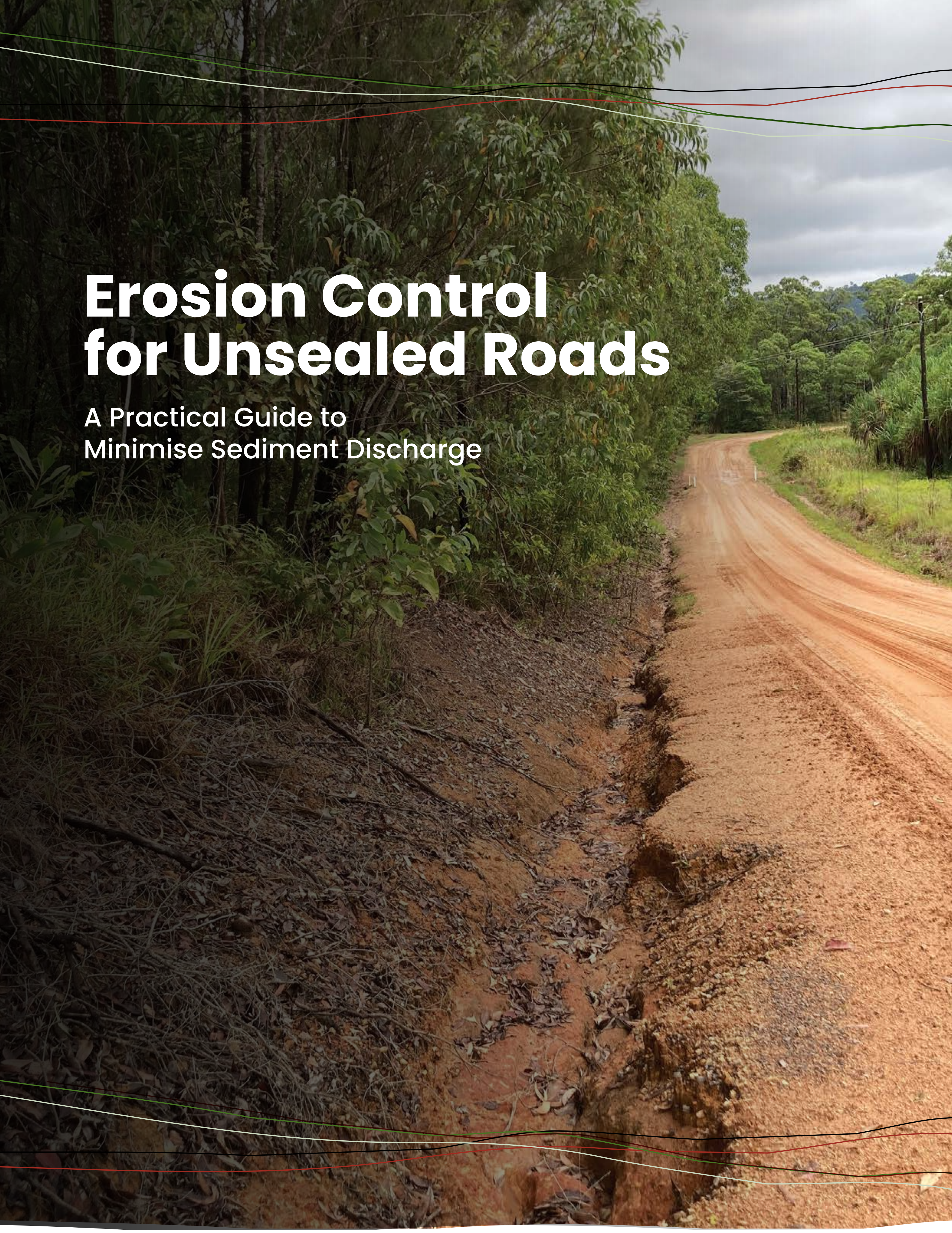

Erosion Control for Unsealed Roads

A Practical Guide to Minimise Sediment Discharge

Australian Government | Reef Trust

Great Barrier Reef Foundation

South Cape York Catchments

SEEC

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LGAQ Every Queensland community deserves to be a liveable one

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Authorship

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Disclaimer

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Document Overview

Unsealed roads are a common feature in many rural and regional areas of Queensland. They can be a significant source of fine sediment entering nearby waterways, especially during rainfall events. Excessive sedimentation can locally degrade water quality, impact aquatic habitats and increase maintenance costs for infrastructure. Furthermore, fine sediment can be transported long distances and impact sensitive receiving environments such as the Great Barrier Reef. This guide has been developed to assist road managers plan and educate crews in understanding the sources of sediment from unsealed roads and to outline practical, effective measures to minimise sediment run-off.

The guide is presented in two parts:

PART 1

Overview of Sediment Discharge from the Unsealed Road Network within Great Barrier Reef Catchments: provides background information on the environmental impacts of sediment pollution from unsealed roads and why sediment control is necessary.

PART 2

Erosion Control for Unsealed Roads—A Practical Guide to Minimise Sediment Discharge: outlines the principles of effective erosion and sediment management and a range of treatment measures that can be implemented to reduce sediment loss. These include planning considerations, maintenance practices, surface and drainage treatments and capital works.

This guide is intended to support—not replace—existing engineering guidelines, standards and legislation. The intended function or level of service (LoS) provided by the unsealed road network is not expected to be impacted by the proposed treatment measures.

The information presented in this guide is intended to inform all stages of unsealed road management—including planning, design, operation and maintenance—with the goal of supporting best management practices (BMPs) for practice erosion and sediment control. By incorporating these considerations early in the process, rather than as reactive measures, potential issues can be addressed proactively and more effectively.

Importantly, the guide encourages practitioners to look beyond standard "business as usual" road surface maintenance. Drains and batters should be assessed and maintained based on their individual condition and functional requirements, rather than being automatically linked to the maintenance cycle of the unsealed pavement. This approach enables more targeted and efficient maintenance interventions across the road corridor.

The *Professional Engineers Act 2002*, Section 115 requires that engineering work in Queensland is to be undertaken by a Registered Professional Engineer of Queensland (RPEQ). The Act stipulates that it is an offence for an individual to carry out professional engineering services unless they are registered as an RPEQ or are working under the direct supervision of an RPEQ. The Act defines a "professional engineering service" as one that requires, or is based on, the application of engineering principles and data to a design, or to a construction, production, operation, or maintenance activity relating to engineering. Services that are provided only in accordance with a prescriptive standard are excluded from this definition, such as routine or regular maintenance activities. Therefore, some activities recommended by this guide may require input and assessment by an RPEQ.

Safety is the highest priority throughout planning, design, implementation and maintenance of any road works. The adoption of any treatment or maintenance activity provided in this guide must not create a safety hazard or impact the safety of road users and the public. However, this does not excuse the road manager from their legal obligation to incorporate appropriate erosion controls and environmental protection *(Environmental Protection Act 1994 [EP Act]; Biosecurity Act 2014)*. All legislative Acts must be followed in combination.

Changes to maintenance practices may prompt questions or concerns from the community, particularly where current approaches have focused on re-grading batters and drains and widespread removal of all roadside vegetation. To support the successful implementation of revised maintenance regimes, additional communication and engagement may be necessary. Clear messaging should explain the rationale and benefits of the updated practices, including improved environmental outcomes, more efficient use of resources and the continued functionality and safety of the road corridor. Reassurance and education will play a key role in aligning public expectations with best practice approaches.

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PART ONE

Overview of Sediment Discharge from the Unsealed Road Network within Great Barrier Reef Catchments

Part 1 Contents

1. Introduction

1.1 Scope and Purpose of this Guide

The purpose of this document is to provide roads asset managers, engineers, managers and supervisors with a practical guide to better understand best management practices (BMPs) for of unsealed roads to minimise the generation and discharge of fine sediment. Minimising the erosion of road pavements and associated drains and batters will reduce maintenance time and costs, in addition to reducing fine sediment discharged to local waterways and ultimately the Great Barrier Reef (GBR).

Queensland has approximately 39,000 kilometres of unsealed formed roads that Local Government directly manages, with an additional 600 kilometres managed by the State Government (LGAQ data). These roads serve as cost-effective transport routes in areas where sealed roads are not financially viable due to there being fewer road users. However, unsealed roads are a significant source of sediment to freshwater streams and marine ecosystems, including the GBR for fine sediment particles smaller than 20 microns (Figure 1). The GBR 2022 Scientific Consensus Statement identified fine sediments as one of the three greatest water quality risks to the Reef, as they reduce the availability of light to seagrass beds and inshore coral reefs[73].

In addition, coarser silt and sand sediment eroded from unsealed road corridors impacts freshwater ecosystems through increased turbidity and sedimentation of water holes and stream beds, altering local habitat.

Erosion from unsealed roads, drains and their embankments not only results in environmental degradation but also incurs substantial financial and social costs. There is a need to improve current practices to make these roads more resilient and reduce sediment generation.

This Guide draws on erosion control trials and insights gained from collaboration with seven Queensland Reef Councils from 2021-2024 [60, 25, 69]. Detailed methodologies and study results are reviewed in Section 2.5. Additional studies and guidelines have been used as listed in the references. A separate “Unsealed Road Erosion Control Best Management Practices: Operators Manual” is also available, offering a more concise version of the guidelines for easier use by field staff and equipment operators[25]. A two-page summary on Maintenance Crew Operator Unsealed Roads BMPs for Erosion Control is included in Appendix A.

Figure 1:
Unsealed road in July 2021 (top), Nov 2021 after grading works (middle), and Dec 2021 (bottom).

1.2 Limitations of this Guide

The Guide presents best practice maintenance and improvement to minimise erosion along unsealed roads. It is important to acknowledge that rainfall patterns and soil conditions vary significantly across Queensland, making local environmental conditions and knowledge essential when it comes to understanding sediment generation and required road design, construction, maintenance and performance specifications.

Therefore, proven local practices should be maintained where demonstrated to control erosion and reduce sediment export.

This publication is intended to supplement existing design and maintenance guidance. It provides additional information regarding the sediment generation potential of unsealed roads and methods to limit fine sediment washing into local waterways, wetlands and marine waters including the GBR.

Unsealed roads and their associated drainage systems are exposed to rainfall events capable of causing erosion or scour, necessitating repair and maintenance. Improvements outlined in this document may require time to take effect and may remain vulnerable to erosion until fully established.

In Queensland, the *Professional Engineers Act 2002* requires that engineering advice and design can only be provided by a Registered Professional Engineer of Queensland (RPEQ). RPEQ sign-off is required where significant changes are proposed to the road or drainage infrastructure. This does not include work that is in accordance with a prescriptive standard or routine maintenance.

2. Background

2.1 Unsealed Formed Roads in Queensland

Unsealed formed roads are typically shaped from local materials within the road reserve, and many are capped with gravel road base from local quarries and borrow pits[2]. Locations can be remote, and suitable materials can be scarce. Standards for design, construction and maintenance vary across the state. Unsealed roads are built to meet a specific LoS, based on traffic loads and available annual or periodic maintenance funds.

Road authorities face challenges due to insufficient resources to construct and maintain roads to acceptable standards. Consideration of run-off water quality and downstream impacts are often secondary to the consideration of LoS.

Unformed roads and tracks are not the focus of this Guide. They are common across Queensland and used for a variety of access purposes. Guide for erosion control on unformed roads and tracks can be found elsewhere[22,28,29,30,41].

Figure 2:
Photos of unsealed roads in Queensland (Cassowary and Mareeba Shires).

2.2 Legal Responsibilities

Everyone in Queensland has a General Environmental Duty (Section 319 *EP Act 1994*) to not cause environmental harm, which includes sediment pollution run-off from the design, construction and maintenance of unsealed roads. While the focus below is on the relevant environmental legislation, there are additional duties of care under the *Civil Liability Act* and the *Professional Engineers Act*.

There are wide variations in the application and enforcement of the Queensland Acts and Policies by local governments[16].

The Queensland Government has commissioned Erosion and Sediment Control Decision Support Tools for Local Government to help with application and enforcement of policies and acts[17].

Key environmental legislation includes:

The Queensland Environmental Protection Act (1994):
A person must not deposit a water contaminant [including sediment] (i) in waters or (ii) in a roadside gutter or stormwater drainage, or (iii) at another place, and in a way, so that the contaminant could reasonably be expected to wash, blow, fall or otherwise move into waters, a roadside or stormwater drainage (Section 440ZG). Measures must be taken to rehabilitate the environment to its previous condition, if any harm occurs (Section 319C).

Planning Act (2016) and State Planning Policy (2017):
State Policy focus on erosion and sediment control seeks to ensure disturbed surfaces are effectively stabilised to prevent sheet, rill or gully erosion, and water contamination.

The Queensland Environmental Protection Policy (Water and Wetland Biodiversity) 2019:
Water Quality Objectives include thresholds for turbidity and suspended sediment for freshwater and coastal areas of High Ecological Value.

Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Act 2019:
Policy intent of "no net decline in water quality" from new and expanded development within GBR catchments to avoid a residual impact from the presence of fine sediment or inorganic nitrogen that is likely to remain in the water despite mitigation measures.

Fisheries Act (1994):
Waterway barrier works permits for assessable development, or conditions for accepted development requirements (ADR), must be adhered to for any dam, weir, culvert, crossing, fill or other complete or partial barrier within a waterway (Queensland Government 2018). The ADR also states that "impacts on water quality are to be minimised by [following] Best Practice Erosion and Sediment Control (IECA)".

The Aboriginal Cultural Heritage Act (Qld 2003):
Establishes a duty of care for activities that may harm cultural heritage, including road management activities such as tree clearing, ground disturbance, quarrying. The Act is tenure blind and is not related to Native Title.

Biosecurity Act (Qld 2014):
Obligation to manage biosecurity and invasive weeds under your control (such as, prevent spreading weeds through annual grading, vehicle wash downs, herbicide spraying weed expansion from disturbance activities).

The Civil Liability Act (Qld 2003):
Reformed the law of civil liability for negligent acts, including provisions for damages for personal injury, and applies to any civil claim for damages for harm, including property damage, economic loss and personal injury. The Act addresses negligence and liability for harm caused by defects in public infrastructure, including roads and footpaths, and by outlining standards of care for professionals such as engineers.

The Professional Engineers Act (Qld 2002):
The Act's primary goal is to safeguard the public by ensuring that only qualified and competent engineers, registered as Registered Professional Engineer of Queensland (RPEQ), are permitted to carry out professional engineering services in Queensland or for Queensland-based projects.

2.3 The True Cost of Erosion Along Roads and Economic Considerations

Erosion of roads, drains, batters and stream crossings has real economic, environmental and social costs. All these factors need to be considered when making decisions about unsealed road maintenance and investment.

Minimising the financial cost of road maintenance is well understood and is typically factored into road design and maintenance. This Guide aims to reduce the environmental and social costs associated with unsealed roads and unsealed road maintenance. In the past, these costs have been externalised as they do not impact the performance of the road. However, an inclusive cost-benefit analysis (CBA) of unsealed road maintenance has quantified that when the real costs of environmental impacts are considered, the alternative maintenance practices or improvements are more cost-effective in the long-term for the taxpayer, community and ecosystems[55].

Financial Cost:

- The capital cost for construction and subsequent improvements to unsealed roads.
- The annual maintenance costs for the roads, drains and batters summed over the road's lifetime.
- The annual maintenance costs of any infrastructure installed to protect road assets (e.g., road running surface, drains and rock at stream crossings).
- Depreciation is a major non-cash expense that reflects the yearly use of road assets.

Social Costs:

- Ride quality along the road.
- Vehicle damage.
- Air quality - health impacts (e.g. asthma, silicosis and respiratory carcinoma).
- Economic productivity influenced by the road (people's time, seasonal access).
- Safety and liability issues.
- Challenges in emergencies such as wildfire.

Environmental Costs:

- Sediment pollution to local creeks, wetlands and marine ecosystems.
- Air quality.
- Damage to aquatic life.
- Impacts to the GBR coral and seagrass ecosystems.
- Weed spread and biodiversity loss from annual grading.
- Rock quarrying and associated environmental impacts.
- Climate change impacts due to machine emissions for maintenance and supply of materials over the road's lifetime.

2.4 Sediment Impacts to Downstream Ecosystems

Unsealed roads are a significant generator of both coarse and fine sediment delivered to roadside drains and local waterways. This is particularly the case for fine sediment (less than 20 microns) that is readily flushed far downstream during rainfall events. However, coarse sediment (silt, sand and fine gravel) is also transported from roads to local creeks and rivers where it deposits and causes sedimentation of freshwater and estuarine habitat.

Fine sediment is one of the three greatest water quality risks to the GBR lagoon[73]. The Reef 2050 Water Quality Improvement Plan includes water quality targets of a 10% to 25% reduction (catchment dependent) in anthropogenic fine sediment loads (<20 µm) by 2030[64]. Unsealed roads are an increasingly appreciated, but poorly measured or modelled, source of anthropogenic fine sediment in GBR catchments[50].

Key impacts of fine sediment on downstream ecosystems include:

1. reduced water quality and increased turbidity,
2. sedimentation of the beds of rivers, lakes, and coastal areas, smothering and changing habitat,
3. fish and other aquatic animal impacts such as gill irritation, oxygen availability, and feeding ability,
4. increased pollutants such as heavy metals associated with fine sediment,
5. nutrients associated with fine sediment leading to excessive algal growth and lower oxygen levels,
6. coral reef and seagrass impacts due to blocking sunlight, suffocation due to sedimentation, stress and disease,
7. degraded water quality and habitats that affect industries that rely on healthy ecosystems, such as fisheries and tourism along the GBR [52, 58, 49, 74, 65, 66, 72, 73, 59].

Figure 3:
Sediment laden run-off from a road into a creek (top) and a typical river sediment plume in the GBR lagoon (bottom).

2.5 Erosion Rates Along Unsealed Roads

2.5.1 Unsealed Road Erosion Rate Literature

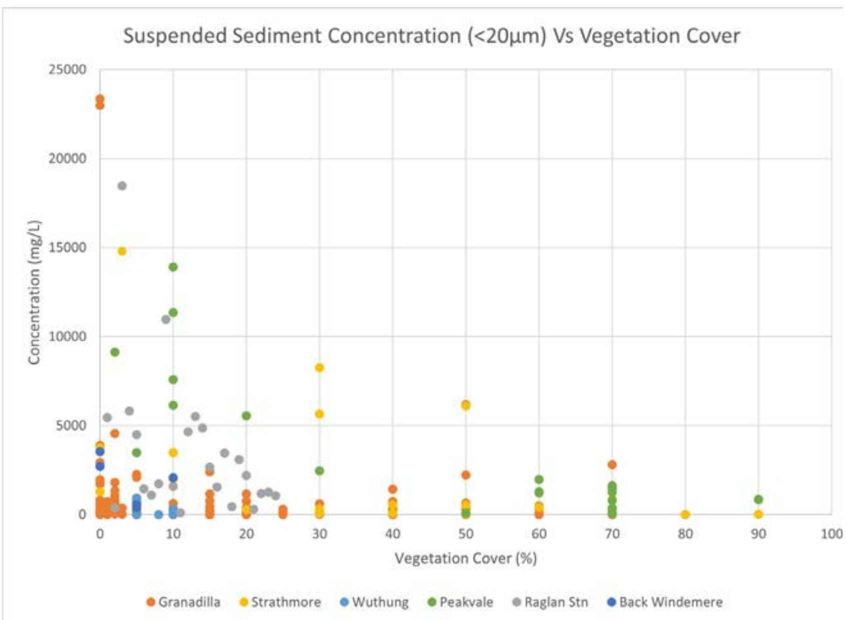
Unsealed roads and their construction and maintenance are a purely anthropogenic source of sediment in catchments. They create persistent bare ground exposed to rainfall and run-off, alter water run-off processes, increase gully frequency and increase coarse and fine sediment supply to the stream network[68, 62, 75, 53, 61]. Unsealed road erosion rates around the globe range from 273t/ha/yr with a median of 22 t/ha/yr or use brackets (median 22 t/ha/yr)[56]. Variability depends on rainfall, slope, parent soils, road surface material, drainage design, management regime, time since construction or grading, vegetation cover, and traffic[56,48]. Unsealed road erosion is usually an order of magnitude (10x) higher than background rates in surrounding less disturbed catchments[65,66]. Stream suspended sediment concentrations in Queensland are > 10x higher downstream of unsealed roads compared to upstream[58,57,51]. Application of effective erosion control best management practices (BMPs) can significantly reduce unsealed road erosion[71,69].

2.5.2 Cleaner Road Run-off Project – LGAQ Case Study

The LGAQ, in partnership with the Great Barrier Reef Foundation, launched the Cleaner Road Run-off Project in 2022 with the Cassowary Coast, Whitsunday, Isaac, Gladstone and Bundaberg Regional Councils. The research project collected over 250 water quality samples from roadside drains between March 2022 and April 2024 to gain an understanding of the fine sediment loads and the characteristics that drive erosion of unsealed roads[60]. The samples were collected by dedicated council staff and analysed at Griffith University to determine event mean suspended sediment concentrations (SSC) and particle size distribution, including the fraction < 20 µm (Figure 4).

The study found that unsealed roads generate a wide range of fine sediment concentrations between 113 mg/L and 1,966 mg/L (< 20 µm). An inverse relationship was found between SSC and vegetation cover in drains, highlighting the impact of repeated grading to bare earth (Figure 4). Flumes installed in the catchments allowed estimates of annual run-off to be undertaken and highlighted that unsealed roads can generate a significant volume of sediment during run-off events, between 1.8 t/ha/yr and 11.5 t/ha/year. Reducing the fine sediment load from unsealed roads will improve the health of local waterways and the GBR. This guidance document is based in part on the testing and knowledge gained from working collaboratively with the five Reef Councils[60].

Figure 4:
LGAQ sediment sampler (left) and inverse relationship between sediment concentration and vegetation cover (right).



2.5.3 Erosion Rates, Best Management Practices and Cost-Benefits: South Cape York Peninsula

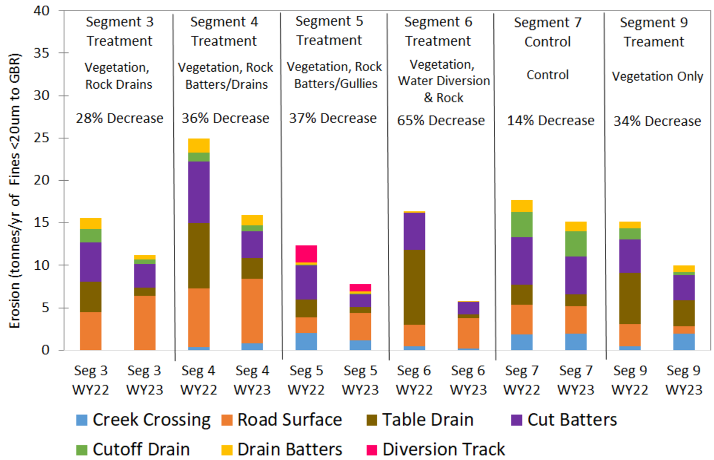
South Cape York Catchments partnered with Cook Shire Council between 2021 and 2025 to conduct a trial erosion control project at eight approaches to stream crossings (± 300 m) of unsealed roads. Repeat high-resolution terrestrial laser scanning (TLS) was used to quantify unsealed road erosion rates across 3.7 ha over two years each with average rainfall (1486-1562 mm)[69]. The goals were to assess:

1. baseline erosion from status quo maintenance, and
2. reductions in erosion from applying BMPs to reduce fine sediment loads delivered to the GBR.

Baseline erosion rates were 142 t/ha/yr locally of all size classes and 42 t/ha/yr < 20 µm to GBR. Suspended sediment concentrations (SSC < 63 µm) were 14 times higher downstream of the road crossings compared to upstream.

Erosion control BMPs implemented in the second year included no grading disturbance of drains and batters to allow for grass recovery, woody vegetation control with herbicide, drain grade control structures, rock mulching steep batters, rock chutes at gully heads and selective drain maintenance. Normalised by a control segment compared to treatment segments with BMPs, vegetation recovery on batters and drains had the lowest (but cheapest) erosion reduction (22%), compared to the addition of rock mulch and check dams (38 to 42%) and more frequent water diversion (66%) (Figure 5). SSC values downstream of the roads were 65% lower during the second year at treatment sites compared to no change at the control site. An "Unsealed Road Erosion Control Best Management Practices: Operators Manual" was produced from the trial outcomes[25] and this guidance document is based in part on that work.

Figure 5:
Erosion rates by road element over two years at treatment and control sites.



A Cost-Benefit-Analysis (CBA) of alternative management practices was conducted[55]. Four different scenarios of road maintenance and betterment were analysed, inclusive of sediment abatement costs externalised to the environment (Figure 6). These included:

1. Business-As-Usual (BAU),
2. Vegetation Management,
3. Major Erosion Control, and
4. Full Betterment.

The present value of total societal costs (30-year appraisal period) was least for full betterment and most for the BAU. The net present value (NPV, benefits minus costs) was positive for all the alternative management scenarios (2 to 4), which all provided better economic outcomes and society benefits than the current BAU.

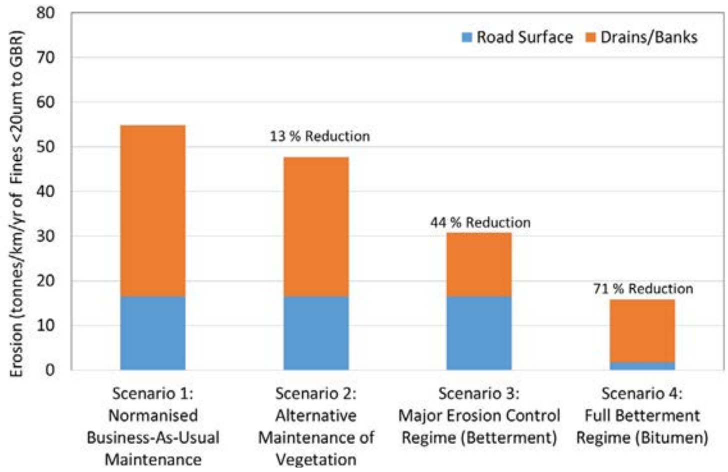


Figure 6:
Scenarios of erosion used for the CBA.[55]

3. Unsealed Road Design and Maintenance Guidelines

3.1 Existing Unsealed Road Design Guidelines

Current unsealed road design guidelines are reviewed below and should be adopted where applicable. However, most of these guidelines do not address in detail the erosion and sediment control issues in the drainage systems of unsealed roads. Therefore, the erosion control BMPs detailed in this document should be implemented in addition to these guidelines.

3.1.1 Austroads

The Austroads Guide to Road Design Part 5: Drainage – General and Hydrology Considerations and Part 5B: Drainage – Open Channels, Culverts and Floodways provides road designers and other practitioners with guidance on the design of drainage systems including the hydrology, safety and environmental aspects and the maintenance and operations of these systems[6,7]. The Guide includes design processes and formulae necessary to design effective drainage systems and infrastructure, as well as considerations for water quality and the roadside environment[5].

3.1.2 ARRB Unsealed Roads Best Practice Manual

The Australian Road Research Board (ARRB) Best Practice Guide for Unsealed Roads has been developed for local government with the aim of expanding the understanding and capacity to manage road infrastructure[2]. The Guide reflects current global best practice and information to effectively manage unsealed roads[2] and road materials[3] across Australia to improve mobility and safety. The manual does include an environmental considerations section with important erosion control guidance. ARRB (now National Transport Research Organisation) also provides training on unsealed road management.

3.1.3 IPWEAQ Lower Order Road Design Guideline

The Institute of Public Works Engineering Australasia Queensland (IPWEAQ) Lower Order Road Design Guideline (LORDG) specifies minimum standards for the design and construction of lower order road assets and provides practitioners with a risk-based approach to capital improvements[20].

3.1.4 QTMR Road Drainage Manual

The Queensland Department of Transport and Main Roads (QTMR) Road Drainage Manual (RDM) sets out a multi-disciplinary approach to the provision of drainage infrastructure for State-controlled main roads[34]. It is a guide to those involved in the planning, design, operation and maintenance of road drainage infrastructure for small, simple rural and urban catchments. The sizing and location of drainage structures are addressed by taking into account relevant hydraulic, environmental, safety and maintenance requirements. The RDM incorporates and cross-references Australian Rainfall and Run-off (ARR) 2019, the Queensland Urban Drainage Manual (QUDM) and Austroads Guide to Road Design.

3.1.5 Local Guidelines

Each council has design guidelines they reference for new engineering works. They typically include key references for recognised national and state guidelines such as Austroads or IPWEAQ guidelines but can include local development manuals and design guidelines. Local manuals define procedures involved in operational works that will ultimately be in the ownership and maintenance responsibility of council or other service authorities, or works which are subject to approval by council.

3.2 QRA Treatment Guidelines for Reconstruction

The Queensland Reconstruction Authority (QRA) Treatment Guide[38] provides a common set of treatments for unsealed road reconstruction works (and maintenance by default) following damage by natural disasters. It represents commonly used treatments across the state to enable consistency of language and a common understanding of treatment inclusions/exclusions and the benchmarking local rates.

Most often 'medium formation grading' (USP_MFG) on unsealed gazetted roads is a standard practice. Where significant gravel displacement occurs during the previous disaster, a 'heavy formation grading' (USP_HFG) and 'gravel/material supply' (USP_GMS) or 're-sheeting' (USP_GR) are nominated for grant funding. Re-grading of table drains occurs to recover some displaced material, or major reshaping of the table drains (USP_RSTD)[38].

By default practice, table and diversion drains are cleaned of sediment and vegetation, and road batters and verges are regularly graded to remove grass and trees (Figure 1; Figure 7; Figure 14).

Figure 7:
Gravel resheeting works and heavy formation grading on an unsealed road.

3.3 Current Council Maintenance Regimes

Councils rarely construct new unsealed roads. On the occasions that new unsealed roads are constructed, it is expected that industry standard drainage design and construction practices are employed. The vast majority of work focuses upon maintaining and improving the existing unsealed road network.

Road safety and pavement protection are the highest priorities in maintenance decision making and practices. The approach to drainage focuses on protecting the road pavement. This is achieved by best utilising council's limited resources to move the stormwater away from the road as efficiently and as quickly as possible.

Current maintenance drainage practice can be summarised as follows:

- All road surface and drainage maintenance is completed using a grader.
- Grader operators work with the existing profile and drainage. They generally 'eye in' levels, falls and depths.
- The pavement, shoulders, table drains and batters are routinely graded for maintenance during heavy formation grading. In some instances, drain and batter reshaping may also be associated with medium formation grading[38].
- Diversion drains (turn-out or cut-off drains) are extensively used at regular intervals to divert water out of table drains and move the stormwater away from the road pavement regardless of the outfall or the receiving environment.
    - Unsuitable material and vegetation are usually pushed off to the side of the road and drainage corridor. Over time, this practice forms a vegetated bund running parallel to the road, with drains and batters cleared of vegetation regularly.
    - Vegetation on road batters is managed by removal with a grader, as it is assumed to be the easiest way to manage vegetation since a grader is already on-site. Most often, the result is a bare earth formation 12-18 m across the road width and associated verges, batters and drains following road maintenance, and in some cases at the start of each wet season.
    - Drain depth and shape varies based on the topography. Cross-sectional shape can vary from a V-drain to a dish-shaped spoon-drain. In flat country, dish-shaped spoon-drains < 150 mm depth can be common. Drains less than 300 mm deep generally result in poor pavement drainage outcomes.

Noted below are some erosion control practices that council road maintenance teams **do not** normally implement:

- Flat bottom drains – these can be difficult for grader operators to cut and shape.
- Soil binding polymers or hydromulch.
- Check dams and rock chutes in steeper drains.
- Rock protection in eroding drains.
- Maintain vegetation linings in drains and on batters.
- Erosion protection at stream crossings.
- Gully erosion control at the outfall of diversion drains.
- Rock mulch to batters.

3.4 Existing Erosion Control Guidelines and Gaps in Existing Guidelines

Best practice for road construction and management are often different and not always inclusive of erosion control BMPs for preventing erosion or reducing non-point source pollution along roads[42,20,38,2]. For example, Queensland's Lower Order Road Design Guidelines[20] mentions erosion just once. While the Unsealed Roads Best Practice Guide[2] has a useful appendix that covers sediment and erosion risk.

For Queensland's unsealed roads, the key erosion control BMP references familiar to road engineers and practitioners include:

- Australian Road Research Board (ARRB) Unsealed Roads Best Practice Guide[2] and Road Materials Best Practice Guide[3].
- International Erosion Control Association (IECA) Best Practice Erosion and Sediment Control[45,46].
- NSW OEH Erosion and Sediment Control on Unsealed Roads[27].
- NSW RMS Guideline for Batter Surface Stabilisation Using Vegetation[26].
- Austroads Guide to Road Design Part 5 Drainage and 6B Environment[6,5].
- TMR Road Drainage Manual[34].
- TMR Erosion and Sediment Control Technical Specification MRTS52[33].
- TMR Managing Slaking and Dispersive Soil Risks in Transport Infrastructure Projects: Technical Note[31].
- Wet Tropics Road Best Practice Guidelines[15,43].

Additional international guidance is available for erosion control BMPs along unsealed roads[21,13,39,8,9,18,42,14], some of which have been validated with rigorous monitoring of erosion rates over time (e.g., Turton et al. 2009)[71].

Many gaps exist in these current guidelines in terms of practical and effective erosion control along unsealed roads in Queensland's challenging soil and climatic environments. For example, most of these BMPs do not adequately address the erosion issues associated with highly dispersive and erodible soils or regolith, which are commonly found near stream crossings or on weathered alluvium/colluvium in Queensland and in GBR catchments. Other erosion control BMPs need to be drawn upon to address these gaps[40,44] as well as innovative treatments recently demonstrated in the field[60,69,25].

This detailed guide (PART 2; Section 4) for *"Erosion Control for Unsealed Roads: A Practical Guide to Minimise Sediment Discharge"* aims to provide fundamental strategies for effective erosion control on unsealed roads in Queensland, synthesise knowledge and practice from the literature and field experience, fill gaps in the guidance reviewed above, and ensure environmental integrity and sustainable road maintenance.

PART TWO

Erosion Control for Unsealed Roads: A Practical Guideline to Minimise Sediment Discharge

Part 2 Contents

4. Erosion Control for Unsealed Roads: A Practical Guide to Minimise Sediment Discharge

4.1 Scope

This section of the Guide is intended to be a stand-alone document for minimising erosion along unsealed roads using Best Management Practices (BMPs) for maintenance and infrastructure improvement (betterment). It has been developed as a guide for road managers, road crews and operators. A summary for this section is included in Appendix A titled Maintenance Crew Operator Unsealed Roads BMPs for Erosion Control, along with a site inspection checklist.

The goal is to minimise annual and long-term erosion of the road infrastructure, the surrounding drainage environment and downstream watercourses, ultimately leading to a reduction in fine sediment loads reaching waterways, wetlands and the Reef.

The treatment measures outlined in this guide are intended to complement and support the intended function and LoS of the unsealed road network—not to diminish or compromise it. To ensure successful implementation, it is essential that road managers engage in early and proactive discussions with maintenance crews. These conversations should take place well in advance of any on-site work to allow the selected measures to be appropriately integrated into existing maintenance schedules, workflows and operational practices.

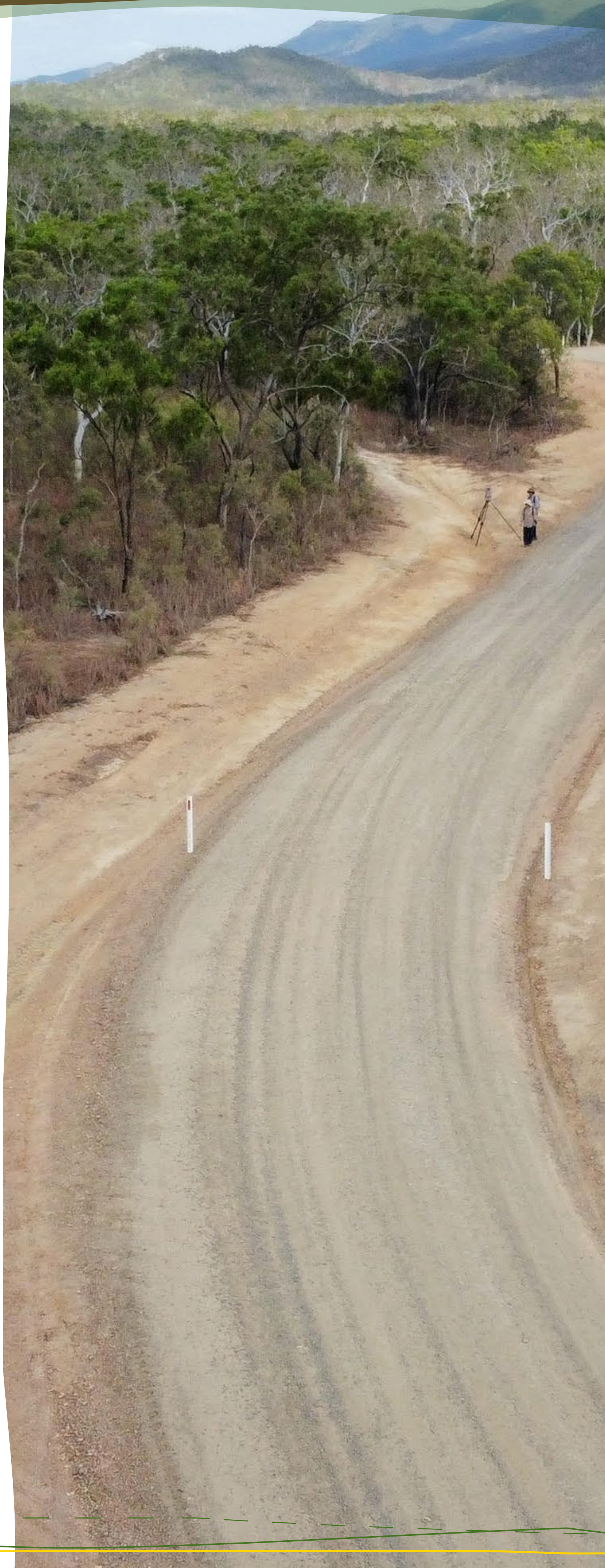
Unsealed road maintenance typically prioritises the road surface condition, road safety, ride comfort and minimising damage in wet weather. However, this focus can potentially result in inefficiencies. For example, when a road pavement reaches a condition threshold that triggers a heavy maintenance grade, associated works may also be undertaken on adjacent drains and batters, even when those components are still performing as desired. Conversely, batters or drain that require attention may be overlooked if the road pavement has not yet reached its maintenance trigger, leading to deterioration, increased fine sediment generation and increased long-term maintenance needs.

These BMPs are intended for application in the improvement of unsealed roads where there is an opportunity to change and improve maintenance or construction practices to minimise soil disturbance and control erosion along the road drainage system. Implementing these BMPs will contribute to social and environmental benefits and, importantly, maintenance cost savings where applied[55].

The Guide contains a section on risk factors contributing to increased sediment generation in addition to a set of key principles to minimise sediment mobilisation. These elements are essential for assessing site specific conditions and should be used to inform the selection of appropriate treatment measures outlined in Sections 4.4–4.10.

It is important to understand that not all sediment control measures listed in these sections will be required for every site. The selection and application of controls should be risk-based and tailored to the specific characteristics of the site, including factors such as soil type, slope, rainfall intensity, vegetation cover and proximity to sensitive receiving environments. While some measures may independently provide a reduction in sediment mobilisation, in general, the implementation of multiple complementary treatments is expected to significantly reduce sediment discharge. Therefore, a multi-tiered approach—combining structural and non-structural controls—is strongly encouraged, especially on high-risk or environmentally sensitive sites.

The use of natural materials is preferred over synthetic materials (i.e. plastics and polymers), except where they are readily biodegradable and will not cause environmental problems.



4.2 Erosion Risk

4.2.1 Key Risk Factors

Soil erosion, sediment run-off, water quality and potential impacts to local waterways and marine ecosystems from unsealed roads is influenced
by a wide range of factors. Key factors to be considered when managing unsealed roads:

- Proximity to a waterway (connectivity to any stream channel), wetlands, coastal marine waters and the GBR.
- Parent soil material, dispersibility and erodibility (including the average suspended sediment particle size).
- Area of disturbance (bare ground without vegetation cover, poor vegetative cover).
- Magnitude, intensity and duration and frequency of rainfall events.
- Land slope and drain slope.
- Existing drain state including drain shape and lining.
- Gully erosion susceptibility and proximity.
- Maintenance frequency of unsealed road.
- Vehicle type and frequency.
- Interaction with livestock (cattle).

4.2.2 Erosion Risk Scores

A risk score has been developed to categorise unsealed road segments (e.g., 1 to 10 km segments). This will allow road managers to prioritise areas most at risk and ensure limited funding is directed to the most appropriate locations for maximum erosion control outcomes (Table 1). This assessment only focuses on erosion risk factors, and there are other factors on how to categorise roads for maintenance.

Table 1
Sediment Generation and Impact Score for Road Segments.

Item	Description	Selection	Score	Adopted
1	Area of Bare Ground without Vegetation Cover at Start of Wet Season (batters, verges, drains, turn-around areas, excluding gravel running surface)	Small < 25% Bare	1	
		Medium 25 to 75% Bare	3	
		Large >75% Bare	5	
2	Soil Type	Low Erodibility (Stable)	1	
		Moderate Erodibility (Non-dispersive)	5	
		Highly Erodibility (Sodic/Dispersive)	10	
3	Presence of Gully Erosion Near the Road	No	0	
		Yes	5	
4	Existing drain state – eroded or depositional (% damaged or eroded)	0-33%	1	
		33-67%	5	
		67-100%	10	
5	Distance to stream crossing or waterway (any active channel)	> 500 m	1	
		100 to 500 m	3	
		< 100 m	5	
6	Road Gradient	Flat (< 1%)	1	
		Moderate (1 to 3%)	3	
		Steep (> 3%)	5	
7	Stream Crossing Stability	Engineered Floodway or Culvert	1	
		Infrequent maintenance	3	
		Frequent maintenance	5	
8	Distance to the Coast (Estuary or GBR)	> 100 km	1	
		10 too 100 km	3	
		< 10 km	5	
9	Annual Rainfall (mm/year)	< 600 mm	1	
		600 to 1200 mm	5	
		> 1200 mm	3	
10	Roughness of Road (Score or Number of Complaints)	Low	1	
		Medium	3	
		High	5	
11	Pavement Erodibility and Binder % Fines < 20 μm (Section 4.9)	Low	1	
		Medium	3	
		High	5	
Total Hazard Score				

Score less than 25 (Low Risk/Priority); 26 to 45 (Medium Risk/Priority); greater than 45 (High Risk/Priority).

Road segments with the highest risk and priority should be targeted first for erosion and sediment control (Scores more than 45 in Table 1). In practice, most often these will be locations near unstable stream crossings with bare ground along approaches, steeper local slopes, dispersive soils, eroding drains, downstream gully erosion and repetitive maintenance issues. Photo examples are provided below for high, medium and low risk situations (Table 2).

Table 2
Photo examples of high (top), medium (middle) and low (bottom) risk situations for sediment generation just before the wet season at stream crossings.

High Risk		No floodway, dispersive soils, steep batter slopes, gully proximity and connectivity, no vegetation cover.
Medium Risk		New concrete floodway, dispersive soils, moderate batter slopes, gully proximity, vegetation retained by not grading.
Low Risk		Non-dispersive soils, shallow slopes, no gullying in drains, shallow wide drains, perennial grass vegetation retained by slashing.

4.2.3 Soil types and Erosion Risks

Soil types play a critical role in determining both erosion rates and the effectiveness of control measures. Understanding the specific characteristics of different soil types is essential for implementing the most effective erosion management strategies.

Coarse texture soils, such as sandy or gravelly materials, tend to have less cohesion and can be easily mobilised. However, their coarser particle sizes drop out of suspension relatively quickly once mobilised. Coarse particles are less likely to be transported over long distances by water flow, which makes them easier to manage. The strategies for controlling erosion in coarse soils typically focus on preventing disturbance to reduce mobilisation during run-off events and containing mobilised sediment by applying localised barriers.

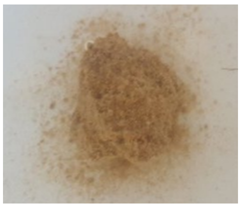
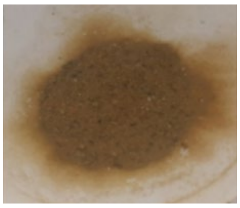
Fine texture soils, such as silty or clay soils, tend to have greater cohesion, except for chemically dispersive soils (see below). However, once mobilised, fine soil particles do not settle easily, can be carried significant distances from the original source and cause widespread sedimentation issues. Traditional sediment control methods, such as rock check dams and vegetative filters, are often ineffective for trapping these fine particles. Alternative solutions, such as the use of geotextile fabrics, sediment ponds and chemical flocculation treatments may be necessary to prevent long-distance sediment transport. These controls are extremely difficult to adopt in a road corridor, highlighting the need to prevent erosion at the source with good ground cover rather than attempting to capture and retain fine sediment after it has been mobilised.

4.2.3.1 Identification of Dispersive Soils

Dispersive soils lose their binding ability when in contact with water, as the clay particles within the soil separate (disperse) once wet. Dispersive soils are difficult to manage, as they are highly prone to erosion, resulting in high fine sediment concentrations delivered to local waterways. They require specific management controls to reduce fine sediment generation and need to be identified prior to adopting any controls.

Dispersive soils often have high levels of exchangeable sodium or magnesium (e.g., sodic or magnesic soils). They can be diagnosed by undertaking a simple field test (Emerson Aggregate Test). Place small pieces of DRY soil (about 5 mm across)[54] into distilled water and wait up to 24 hours to see if the soil disperses and the water become cloudy or milky (Figure 8). Highly dispersive soils may react within minutes. Alternative soil tests will be needed for some soil types (e.g., saline or acid sulfate) and more detailed soil tests will be needed if chemical amelioration measures are warranted or planned[67].

Figure 8:
Dispersion Index class upon wetting of dry soil aggregates.

0	1	2	3	4
				
No milky halo	Slight Milkiness	Obvious milkiness, less than 50% of the aggregate affected	Obvious milkiness, greater than 50% of the aggregate affected	Total dispersion leaving only sand grains
			Dispersive soils	

An example of a roadside batter with dispersive soils is shown in Figure 9 before and after rainfall. Multiple rills or small channels are evident where the dispersive soil has scoured. Treatment and management options for dispersive soils include:

- Chemical treatment to improve clay particle binding (e.g., gypsum or calcium sulphate),
- For class 3 and 4 soils, apply 1 to 3 tonnes gypsum per 1000 m^2 mixed 200 mm deep (10 to 30 t/ha, depending on exchangeable sodium percentage, ESP).
- Cover dispersive sub-soils with a stable layer of organic rich topsoil and revegetate with suitable grass species (native preferred). OR
- Cover dispersive sub-soils with unscreened well-graded rock mulch armour (low permeability rock).

Figure 9:
Dispersive sub-soils (score 3) at a road cutting with rill erosion one wet season after grading, with no vegetation growth or colonisation due to the harsh soil environment and erosion.

4.3 Principles of Soil Erosion and Sediment Control Along Unsealed Roads

Depending on the location, the following principles should be adopted in the management of verges and drains of unsealed roads. The following sections of the guide provide further explanation and examples of how these principles can be achieved.

It should be noted that preventing erosion through increased groundcover is the preferred management control to limit sediment generation.

Minimise Vegetation and Soil Disturbance

Avoiding all unnecessary soil and vegetation disturbance within the road corridor (not the unsealed road pavement) is the most important factor for erosion control along unsealed roads. Soil surfaces that are disturbed or bare will erode many times faster than if the soil and any vegetation are left undisturbed. Minimising the footprint of road corridor disturbance and maximising vegetation cover (particularly grass) along road verges and drains will reduce erosion.

Adopt alternative maintenance schedules to minimise removal of vegetation.

Avoid using a grader to manage vegetation.

Protect Exposed Surfaces (Batters and Drains)

Batter and drain surfaces that are vegetated, stabilised with rock mulch or sealed with bitumen will erode less. Bare batters should be stabilised as soon as practical and not disturbed repeatedly. Do not assume that bare batters will revegetate naturally. This is particularly the case for steep batter slopes and cut banks as well as dispersive soils. Apply surface treatments such as re-vegetation, mulching (including gravels), binders or hydromulch to reduce exposure to rainfall and run-off erosion.

Treat and/or Cover Dispersive Sub-soils

Dispersive sub-soils are prone to rapid erosion and should be identified, ameliorated and covered under stable soil. Exposed dispersive sub-soils within batters and drains should be covered with non-dispersive topsoil or rock mulch and revegetated. Organic or rock mulch will aid revegetation. In more severe cases, exposed dispersive sub-soils should be treated chemically (e.g. gypsum) before capping and revegetating.

Reduce Water Flow or Discharge

Reducing flow volume within drains minimises the erosive power of run-off. This can be achieved by turning water away from table drains into diversion drains more frequently. Diversion drains should discharge into safe disposal areas to prevent erosion. Cross-drain relief culverts are important to reduce flow from in-slope road drains. Ensure that these structures are appropriately spaced and maintained to handle expected flow rates and velocities. Catch-drains can be located above batter slopes to capture run-off from adjacent land to prevent batter erosion and overloading table drains with additional stormwater flow.

Reduce Sediment Discharge

Sediment-laden water should be treated prior to discharge from the road network to limit sediment moving into local waterways. The best form of treatment is to retain sediment at the source or close to the road by directing diversion drains to flatter well-vegetated areas where possible to allow the sediment to drop out. Run-off from diversion drains can also be routed through stilling basins (traps) to capture sediment, particularly sand and coarse silt. Routine, regular maintenance of these is required. Stilling basins are less effective for fine silt and clay.

Slow the Flow by Lowering Slope, Increasing Width and Roughness

Slower flow velocities on flatter slopes with more roughness (vegetation or rock lining) are less able to erode and carry sediment. Encourage vegetation growth which provides better erosion protection than bare earth. Drains with a higher roughness may need to be constructed deeper or wider to contain the slower moving flow and preserve the required hydraulic capacity. Lowering channel slopes can effectively be achieved by using check dams as steps in the flow path. Steep channels may require drop structures or rock lining. Wide flat-bottom drains spread the flow and have less erosive power than narrow V-drains that concentrate flow in the middle of the channel. Triangular V-drains should not be cut into dispersive soils.

Reduce Direct Connectivity to Streams Crossings and Gullies

Most sediment delivery to streams occurs where table drains and diversion drains are connected directly to streams near road crossings. Reduce the length and catchment area of table and diversion drains that discharge directly into streams, even if it is difficult to do so. More frequent diversion drains should be used closer to stream crossings to turn water out of table drains onto stable vegetated areas where sediment can settle out. Where connectivity is high and space is limited, other erosion control measures, such as rock lining, are warranted.

Control Gullies

Gully erosion can be triggered where road drainage is diverted as a concentrated flow to natural drainage lines, slopes, streams and creek banks. The formation of gullies is very common at road creek crossings with dispersive soils. Where water cannot be safely diverted away from potential or existing gullies, the gullies and drains should be stabilised with engineered rock chutes or grade control structures and revegetated.

Bed Level Stream Crossings

Roadbed level stream crossings can be protected from scouring by constructing rock or concrete floodways at the natural streambed level to prevent undercutting and bank erosion, also allowing fish passage. For rock floodways, coarse angular rock is used to ensure stability. Smaller rock and medium gravel fill the pore spaces of the larger rock to improve rock stability and driveability. Avoid using material with a fine sediment binder, as found in road base, as the fine material will wash into the water column as a pollutant. Consider pouring concrete floodways in two halves (two lanes) and alternating traffic to single driving lanes during construction to prevent the need for construction and rehabilitation of diversion tracks causing more erosion disturbance.

Culvert Crossings

Cross-drain culverts are required to prevent the build-up of water flows in in-slope table drains. The spacing of the culverts is a function of the catchment area, the slope and depth of the drain, the erodibility of the drain and the quantity of flow. Culverts at stream crossings need careful engineering design, may need to allow for fish passage and must include erosion control such as rock protection at inlets and outlets, particularly where the channel bed and banks downstream may experience concentrated flow and scour.

Maintain Road Shape

Table drains are required to efficiently collect run-off from unsealed pavements to improve safety and prevent scour and damage. Maintain road crossfall of between 4%-6% to direct run-off into table drains to minimise longitudinal flow down the road. Remove any windrows left after regrading to allow water to freely enter drains. Repair rills/scouring of the road surface to limit further damage to the road pavement.

Pavement Integrity

Constructing a running surface with a well-compacted and bound gravel wearing course will provide a better road for users and will contribute less sediment to the drainage system. Particular attention should paid to: 1) providing stable non-dispersive fine sediment binder in road base from quarries, 2) optimising the shrinkage product, plastic index, grading coefficient and California Bearing Ratio to improve binder stability in different climates, 3) on-site mixing of road base to avoid segregation, 4) compacting at optimal moisture content (OMC), 5) ensuring complete compaction with a minimum number of passes, particularly along shoulders, and 6) avoid losing road base into table drains as waste.

Gravel Pit Rehabilitation

Rehabilitate gravel pits progressively each year that they are utilised. Create sediment traps. Control outflow erosion and gullying with rock lining. Batter walls to a stable angle and install contour banks and batter chutes. Rehabilitate with stockpiled topsoil, additional organic material and seeding with native grasses, trees and shrubs. Control the invasion of weed plant species with follow-up treatment over time.

4.4 Minimise Vegetation and Soil Disturbance

4.4.1 Minimise Worksite Footprint

To effectively reduce erosion, it is essential to minimise the overall worksite footprint and to minimise the size of the disturbed area along unsealed roads (Figure 7; Figure 10; Figure 11). All non-essential machine disturbance should be avoided. This is particularly the case where vegetation is removed from native soils which are then graded on batters and in drains, as well as side tracks and turn-around areas disturbed by trucks, and quarry borrow pits. Retention of vegetation on batters and in drains results in a significant reduction in soil erosion (Figure 11). Where areas are disturbed, all practical measures should be taken to stabilise and cover those surfaces promptly, while also avoiding repeat disturbance. Do not assume that bare batters will revegetate naturally, particularly in dispersive soils. Major earthworks that expose large areas of soil should be scheduled outside the wet season, with erosion control and rehabilitation measures put in place before rain.

4.4.2 Protect All Exposed Surfaces

The retention and re-establishment of groundcover are the most effective forms of erosion control. Any exposed surface needs to be protected as soon as possible to limit erosion and sediment run-off. Treatments can include organic mulching, rock mulching, gravel cover, revegetation, soil binders and others.

Imported road-base (gravel and binder), well-compacted at optimum moisture content (OMC) generally resists erosion to a greater degree but still produces much fine sediment run-off < 20 µm (see Section 4.9).

Vegetation is preferred outside the road pavement area, except perhaps for steep slopes or areas that cannot be easily accessed for maintenance, when rock or gravel mulching may be better suited along with vegetation re-colonisation.

Ground cover selection considerations include whether vegetation can establish and stay healthy (rainfall, topsoil, shade, etc.) and the availability of gravel/rock mulches (suitability, size, distance to be delivered to site).

Where vegetation is to be disturbed, planning should be undertaken on how best to undertake rehabilitation as soon as practicable. Rehabilitation should consider reuse of stockpiled topsoil, incorporation of sufficient organic material to sustain vegetation growth, and local plant species, especially native grasses. Newly rehabilitated areas require monitoring to review successful establishment and any ongoing maintenance activities.

Figure 10:
Unsealed road disturbance area shown in Air Photo (top) and LiDAR hillshade (bottom).

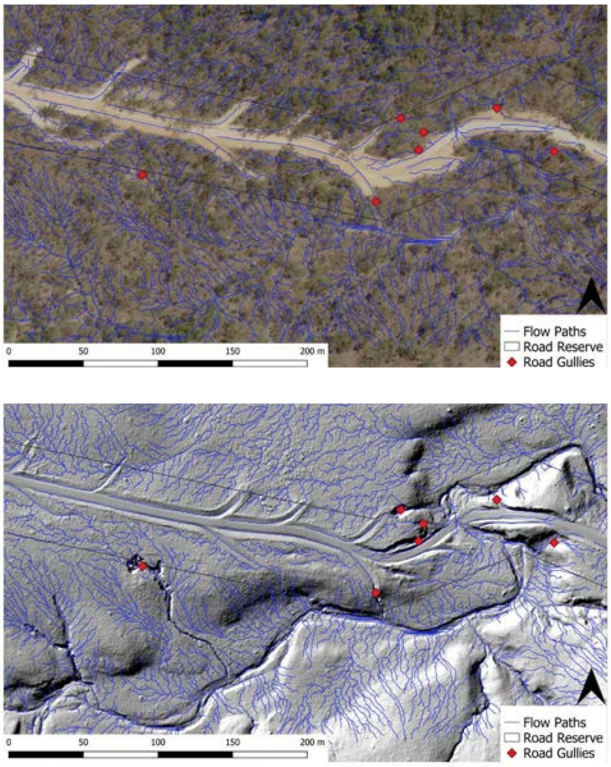


Figure 11:
Unsealed road just after full maintenance including batter disturbance (top) and the same section a year later just after maintenance with no grading disturbance on the batters and drains (bottom).

4.4.3 Vegetation Management

Roadside vegetation management by grading (and removal) before the wet season will result in large areas of exposed soil. This causes significant soil disturbance, erosion of batters, drains, and associated gullies, weed spread and ditch sedimentation. Grading leaves road batters and drains in a 'high erosion risk' and 'weed invasion risk' category before each wet season.

Better management of vegetation entails not disturbing the soil, and managing vegetation with either herbicide or slashing leaving plant roots, organic mulch cover and gravel lag (Figure 12; Figure 13).

Maintaining vegetation along batters and drains is very important for long-term drain stability and road safety. Alternative options to grading include:

Maximise vegetation cover (particularly grass) along road verges.

- Leave vegetation in place where stable and not a visual hazard to drivers.
- Slashing or herbicide spray vegetation to leave organic mulch cover.

Slashing vegetation can be used to minimise soil disturbance and maintain vegetation root cohesion.

- Slashing should occur before weed seeds set to avoid weed spread.
- Tractor or boom slashers can be used depending on slope and soil wetness.

Herbicide can be used for road corridor vegetation management.

- Grazon or similar to manage broadleaf weeds and tree sapling regrowth.
- Roundup (glyphosate) to manage invasive grasses (e.g., grader grass) before seed set. Avoid spraying near water.
- Avoid mixing herbicides for blanket kills of all vegetation (broadleaf and grasses).
- Follow best practice to target species based on management need and conservation of desired species (native grasses).
  - First Pass: target spray herbaceous/woody weeds with Grazon.
  - Second Pass: target spray invasive grasses with glyphosate.

Manage vegetation variability across different road sections and local conditions. Consider:

- Maintaining driver sight lines through corners.
- Wildlife using vegetation as cover near the road edge.

Figure 12:
A stable roadside batter with tree sucker regrowth and good grass cover (top) that needed either slashing with a tractor (middle) or broadleaf herbicide application to avoid soil disturbance from grading (bottom).

Figure 13:
Grader grass (Themeda quadrivalvis) invasion of an annually disturbed road corridor (top) and after management with two rounds of slashing during the early dry season (bottom).

Different vegetation management regimes along roadside batters and drains can strongly influence cycles of erosion or stabilisation, weed spread and repeated funding investment each year, especially full grading of the road, batters, and drains to bare earth (Figure 14).

The preferred vegetation management regime shown in Figure 15 includes no machine or soil disturbance of batters and drains, management of vegetation with slashing or selective herbicide spraying, retention of mulch and gravel lags on batters, reduced weed spread, increased perennial vegetation, less erosion on vegetated batters, less drain sedimentation due to less upslope erosion, and rock capping of steep slopes or eroding drain hotspots where needed. The net result is a management regime focused on the road running surface, vegetation management and localised erosion hotspots.

If you are addressing the cause/source of upstream erosion, you will not need to remove deposited material out of the drains.

Full Re-Grade of Running Surface, Batters and Drains

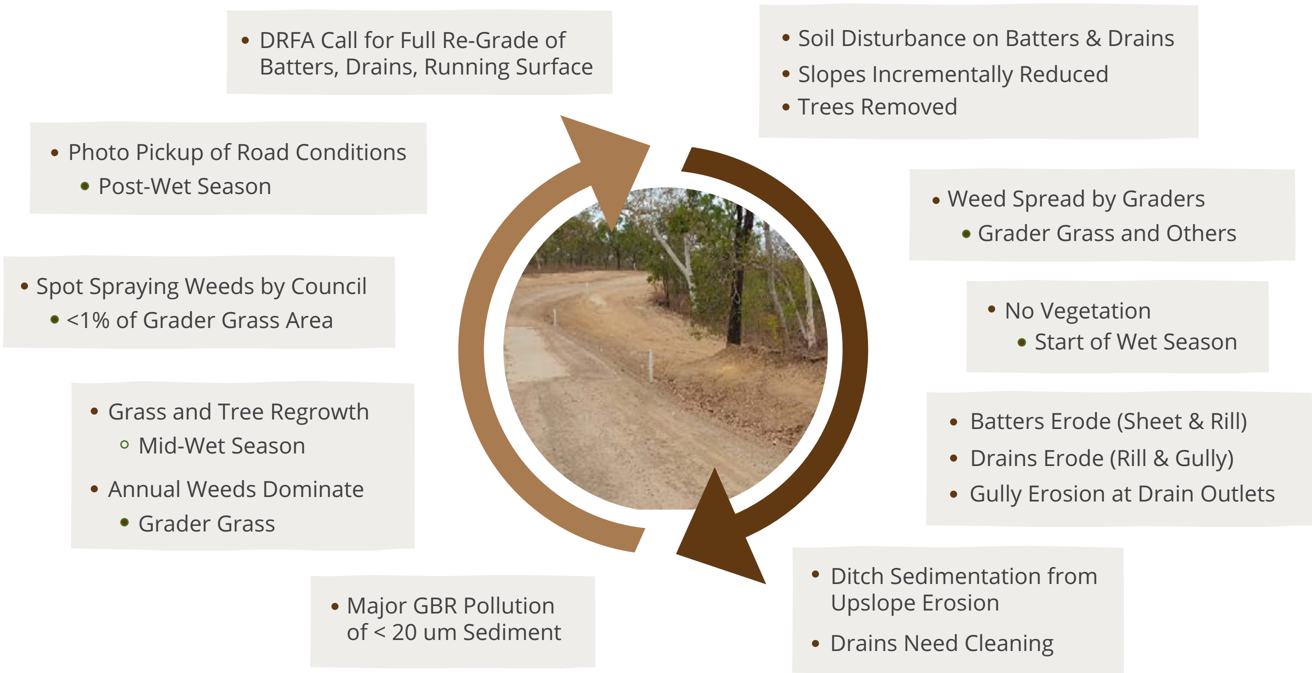


Figure 14:
Status quo current management of roadsides with full grading.

Full Re-Grade of Running Surface Only | Hot Spot Drain Cleaning + Erosion Control Works

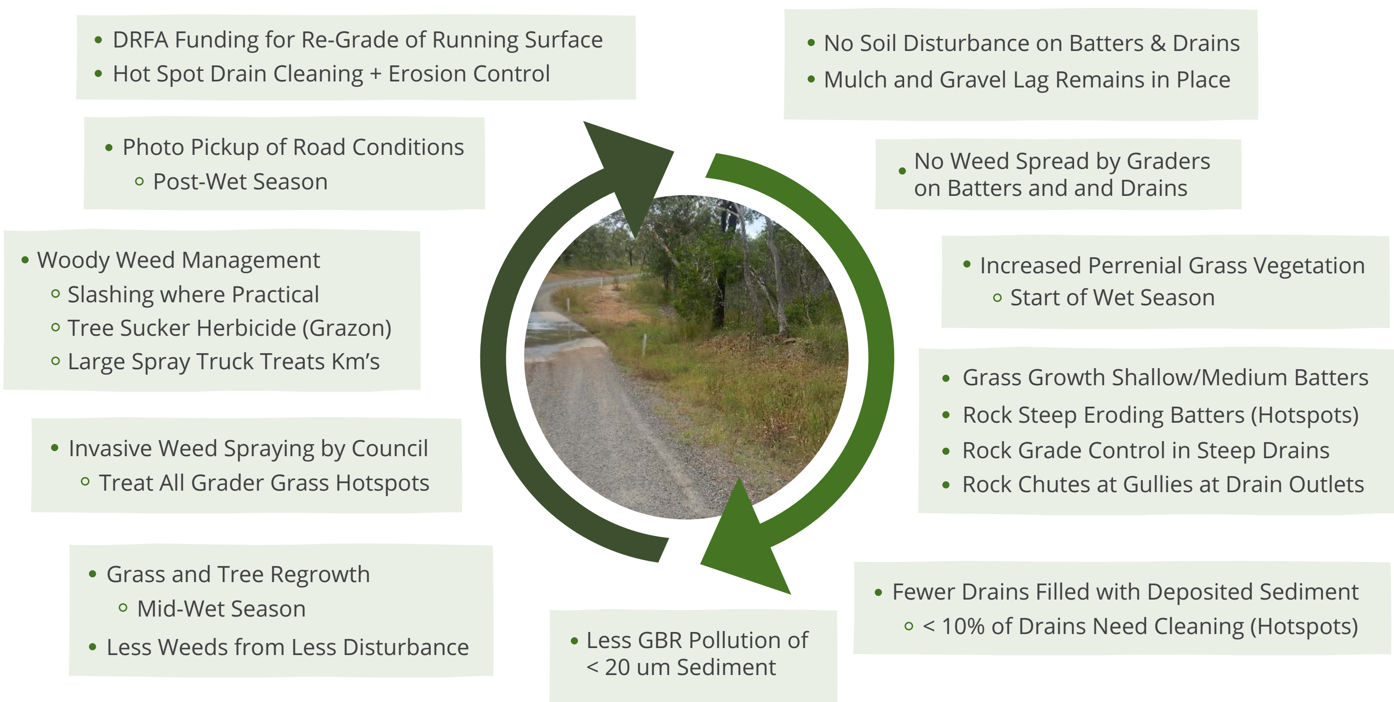


Figure 15:
Alternative management of roadsides with vegetation retention and slashing or herbicide.

4.5 Batter Erosion Control

4.5.1 Batter Maintenance

Disturbance or grading of existing stable batters should be avoided whenever possible (Figure 16). This will maximise perennial grass vegetation cover, improve soil health, organic cover and long-term slope stability. It will also protect coarse gravel lags on the surface. Options for batter maintenance include:

- Vegetation slashing or selective herbicide can maintain native grass vegetation and organic cover over the soil of batters. This is particularly important on dispersive soils.
- Exotic annual grasses (e.g. grader grass) should be slashed or treated with herbicide before seed set, while leaving native grasses to expand.
- Disturbing the surface of sloped batters should only be done selectively on a site-by-site basis, where the need to fix an erosion or bank stability issue exists.
- Where disturbed, steeper sloped surfaces should be treated with topsoil and revegetated or capped with rock mulch (see surface treatments below).

Figure 16:
Batters with native grass cover retained for erosion control over multiple years (top) will be more stable than if annually graded (bottom).

4.5.2 Batter Improvements

The following improvement actions can be adopted to minimise erosion of roadside batters.

4.5.2.1 Slope

A shallower, shorter batter slope will encourage long-term stability and vegetation growth. Batter erosion is a function of batter slope and length (i.e. longer and steeper slopes will erode more than shorter and flatter batter slopes). A shallower slope will generally promote long-term stability and the establishment of vegetation. Key actions:

- Earthworks for batter slope reduction should be completed in one operation and then proactively stabilised with vegetation or rock mulch immediately.
- Where possible, a maximum slope of 1:4 should be used for banks and batters to minimise erosion, maximise vegetation growth and allow maintenance machinery to access the batter where needed (e.g., slashing).
- Always seek expert geotechnical RPEQ and soil science advice for steep or high batters that pose environmental or safety risks to maintenance crews (Figure 17).

Figure 17:
Some steep slopes are difficult to lay back without major earthworks and need to be stabilised in place with native vegetation, rock mulch and/or chemical treatments.

4.5.2.2 Surface Stabilisation

Exposed batters should be stabilised as soon as possible following works (Figure 18). Bare and newly graded/constructed batters should be stabilised by covering with topsoil or organic mulch, binders and revegetated, or covered with rock mulch. Do not assume that bare batters will revegetate naturally, particularly in dispersive soils.

Factors to consider before adopting any embankment protection include:

- Slope and slope length (erosion risk, stability, vegetation establishment, maintenance)
- Level of erosion protection needed (soil type, slope, run-off, distance to stream)
- Growing media (establishment of vegetation)
- Time to establish vegetation and provide effective erosion control
- Upstream catchment/drainage requirements (cut-off drain, batter chutes)
- Access (maintenance)
- Visual amenity and ecology
- Cost of establishment and maintenance.

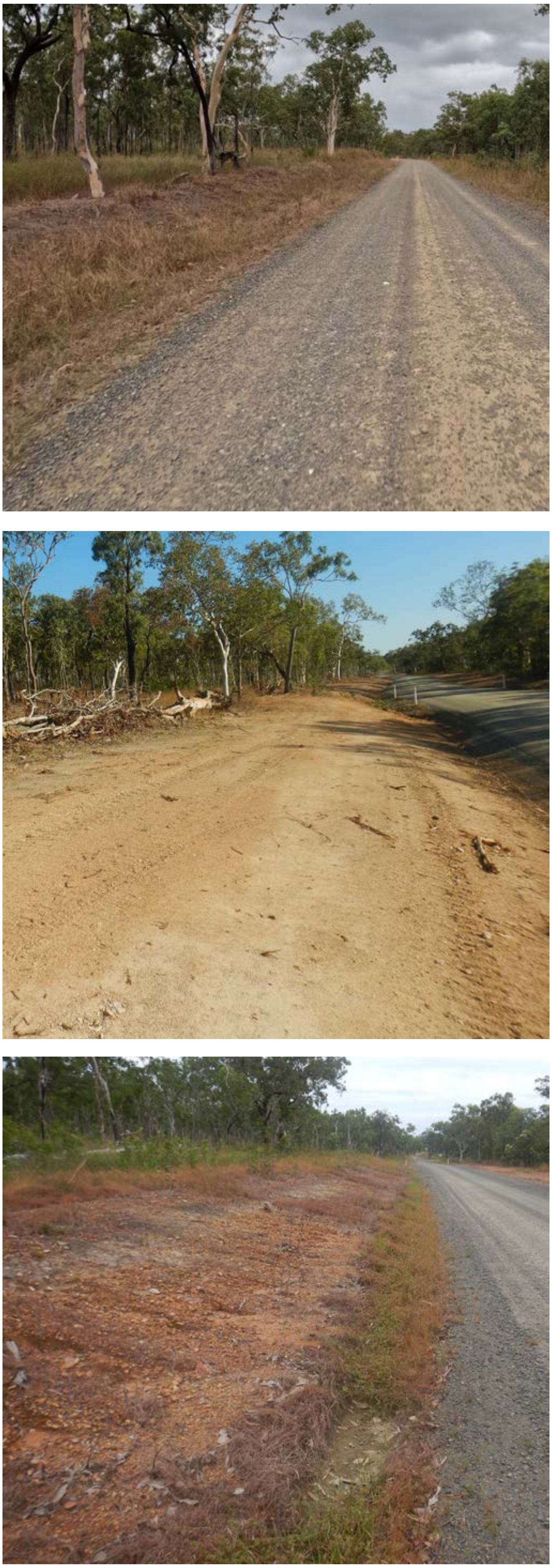


Figure 18:
A stable grassed batter with native grass (top), that was re-sloped and graded with trees and grass removed down to sub-soil (middle), with subsequent rilling and sheet erosion from a longer slope length after one wet season and patchy grass colonisation (bottom).

The slope, slope length and soil type are often the most important factors in the type and level of batter intervention[26].

Intervention levels or trigger factors will depend on the risks to infrastructure, maintenance regimes and water quality impacts (Figure 19). Batters with long-term stability problems and annual maintenance needs will trigger engineering solutions, as will highly erosive batters in dispersive soils well-connected to stream crossings. Potential solutions include capping with well-graded rock mulch, revegetation with hydromulch or treating dispersive subsoils with gypsum and capping with organic topsoil before revegetation. Passive intervention on lower slope batters in more stable soils may include only the cessation of annual grading to promote vegetation recovery and alternative management such as slashing.

Figure 19 provides examples of intervention levels treatment for different batter conditions near stream crossing with:

- A (top) needing passive vegetation recovery and cessation of annual grading
- B (second from top) needing hydromulch application to assist patchy vegetation recovery and gravel lags in sodic soils
- C (second from bottom) needing native grass seeding or hydromulch on re-profiled batter, and
- D (bottom) needing reshaping, compaction, capping with well-graded rock mulch to limit water ingress, and larger rock overlay in the drain to prevent deep incision into sodic soils.

Figure 19:
Intervention levels treatment for different batter conditions near stream crossings

4.5.2.2.1 Vegetation on Batters

Proactive revegetation will be needed in many situations using vegetative covers that include direct seeding onto topsoil capping, hydromulch spray application, erosion control and compost blankets, or cellular confinement systems. Key aspects include:

- Native perennial grasses are preferred for slope stabilisation in remote areas.
- Low-rise grasses are preferred near road bends.
- Exotic perennial grass should not be used for revegetation unless these species have already naturalised in the surrounding private properties.
- Rake to mix grass seed into a topsoil seed bed, and track roll on contour. Do not sow grass seed on the surface of compacted bare ground.
- Soil binders (polymers, lignin etc.) can be sprayed over seeded surfaces to prevent erosion during first rainstorms before vegetation establishment. The addition of gypsum aids revegetation in sodic soils.
- Hydromulch solutions can be applied by contractors in difficult revegetation areas.

Detailed guidelines for batter surface stabilisation using vegetation are available[26].

4.5.2.2.2 Rock on Steeper Slopes

Rock mulch capping can be applied to steeper batters and batter toes in dispersive soils to improve stability (Figure 19). Rock mulch is defined as a well-graded mix of unscreened crushed rock containing a reasonable proportion of fines (D10) to fill the pore spaces between larger rocks (D90) to create a dense protective layer to the batter.

- The finer rock fills the gaps in the coarser rock and reduces but does not eliminate rainfall infiltration into the dispersive subsoils.
- The finer rock and associated dirt promote water retention and natural vegetation colonisation compared to a screened, coarse, porous rock layer alone (Figure 20).
- In highly dispersive and sodic soils, it may be necessary to add soil ameliorants (e.g., gypsum) to the underlying soils, and/or place the rock mulch over a layer of geofabric.
- Topsoil could also be added on top of the rock mulch and seeded with native grass (low-rise type) to accelerate vegetation recovery.
- The size of the rock mulch (D90 diameter) depends on the slope, slope length, and catchment area, but commonly varies from 125 to 200 mm. Refer to engineering guidance on the required rock size.
- Rock mulch durability only needs to be suitable for mulching and not trafficable purposes.

Figure 20:
A batter with deep rilling in dispersive sodic soils (left) compared to the same slope with rock mulch (125 mm well-graded) applied (right).

Figure 21:
Rock mulch over sodic dispersive soils after 10 year of vegetation colonisation (left), and the same untreated soils (right).

4.5.2.3 Clean Water Diversion

Limiting off-site hillslope run-off from entering batters and table drains will reduce on-site erosion. Diversion drains can be put in place to re-route and divert hillslope run-off water to safe and stable disposal areas. Care should be taken to not initiate gully erosion within drains or at diversion drain outlets, especially at steeper slopes or creek banks (see Section 4.7 on Gully Erosion).

- For table drains, excess hillslope run-off can cause drains to be overtopped from higher flows. Where the use of diversion drains is not possible, ensure that road table drains have been sized to cater for the entire catchment draining to them.
- For batters, diversion drains may be required where catchment areas are large or the batter has long slope lengths. Rock chutes down the face of batters can be constructed where diversion drains are not feasible and the batter is prone to erosion from concentrated flow (Figure 22).

Refer to Austroad[6,7] for details on diversion drain design.

Figure 22:
A clean water diversion drain re-entering the road batter and table drain causing gully erosion (top), and a small batter chute to control scour where clean water diversion re-enters the road system (bottom).

4.6 Drainage Erosion Control

4.6.1 Drain Maintenance (Existing Drains)

4.6.1.1 Intervention Levels for Drain Maintenance

Traditionally, long sections of drains have been repeatedly "cleaned out" using graders. This is particularly the case where sediment accumulates in diversion drains due to erosion of batters or table drains from upslope disturbance (Figure 14; Figure 15). In most cases only a small percentage of drains and only short sections of individual drains require either cleaning of silt or stabilising against erosion in any given year. Attending only to the hot spots that require attention in many areas can reduce the cost of drain maintenance significantly. Some erosion or sedimentation in drains is acceptable. If the drain is functional, don't disturb it, leave it and reassess next year (Figure 22 top). If the drain is unstable, then apply appropriate erosion control measures rather than just re-grading it (Figure 22 bottom).

How often drains are cleaned out or reshaped greatly affects erosion rates and drain stability. Sediment may be present in a drain if upslope areas are too steep, have poor vegetation cover, are frequently disturbed, or have large catchment areas (Figure 14; Figure 15). It is better to address the erosion at the source (i.e. the upstream location) rather than continuing to regrade or clean out the drains.

Key maintenance actions include:

- Assess the stability of the drain. Is it eroding or accumulating sediment?
- Look for and repair the source cause of the sedimentation in the catchment above the drain (erosion/slumps/scour upstream) rather than just assuming the drain is the issue and continually regrading it.
- If the drain depth is at least 300 mm (150 mm below sub grade) and reasonably stable, there is no need to regrade the drain. Observe changes to the drain shape over time as it may be close to stabilising. Allow a year or two to see if the erosion stabilises.
- If the drain does not have a depth of 300 mm, remove the build-up of sediment only in these areas using a backhoe with a 4-in-1 bucket, or excavator. There is rarely a need to clean or grade the whole drain (Figure 23).
- If erosion continues, assess how the drain can be stabilised, i.e. change the drain shape (flat bottom or parabolic shape), vegetative linings or rock check dams may be a viable solution.
- Slash or spray herbicide to manage vegetation in stable drains as required.

Figure 23:
A functional semi-stable drain that does not need grading maintenance (top) compared to an unstable drain needed erosion control (rock) maintenance rather than just re-grading (bottom).

Figure 24:
Hotspot of drain sedimentation (gravel, sand, and coarse silt > 20 μm) before (top) and after (middle) the wet season, with subsequent silt removal with a backhoe along a 10 m drain length (bottom).

4.6.2 Drain Design and Improvements

The shape, size, slope, frequency, location and outlet stream connectivity of table and diversion drains are important for both road stability, maintenance costs and erosion reduction.

To reduce erosion and maintenance costs, the following can be used as a guide:

- Shape: Wide flat-bottom drains are better than V-drains which should be avoided. Drains should have side slopes no steeper than 1 in 3 if possible.
- Size: Larger drains better accommodate flow volume and allow some sedimentation or vegetation growth and require less maintenance.
- Lining: Adopt an appropriate drain lining that can cater for the expected flow rate and velocity (i.e. larger catchment areas draining to steeper table drains will experience higher velocities).
- Slope: Lower the slope of drains. Add check dams if needed.
- Frequency: Increase the frequency (number) of diversion drains to reduce flow volume. Where necessary install culverts or cross drainage structures.
- Drain Connectivity: Discharge diversion drains to flatter well-vegetated areas, not to gullies or water courses where possible. Where possible on the downslope side of the road prism, allow water to sheet flow off the road and disperse into vegetation on the road verge.

Construction with an excavator or backhoe 4-in-1 front bucket is better suited to achieving a trapezoid shape. The shape and slope of table and diversion drains affects water flow depth and erosive power (Figure 24).

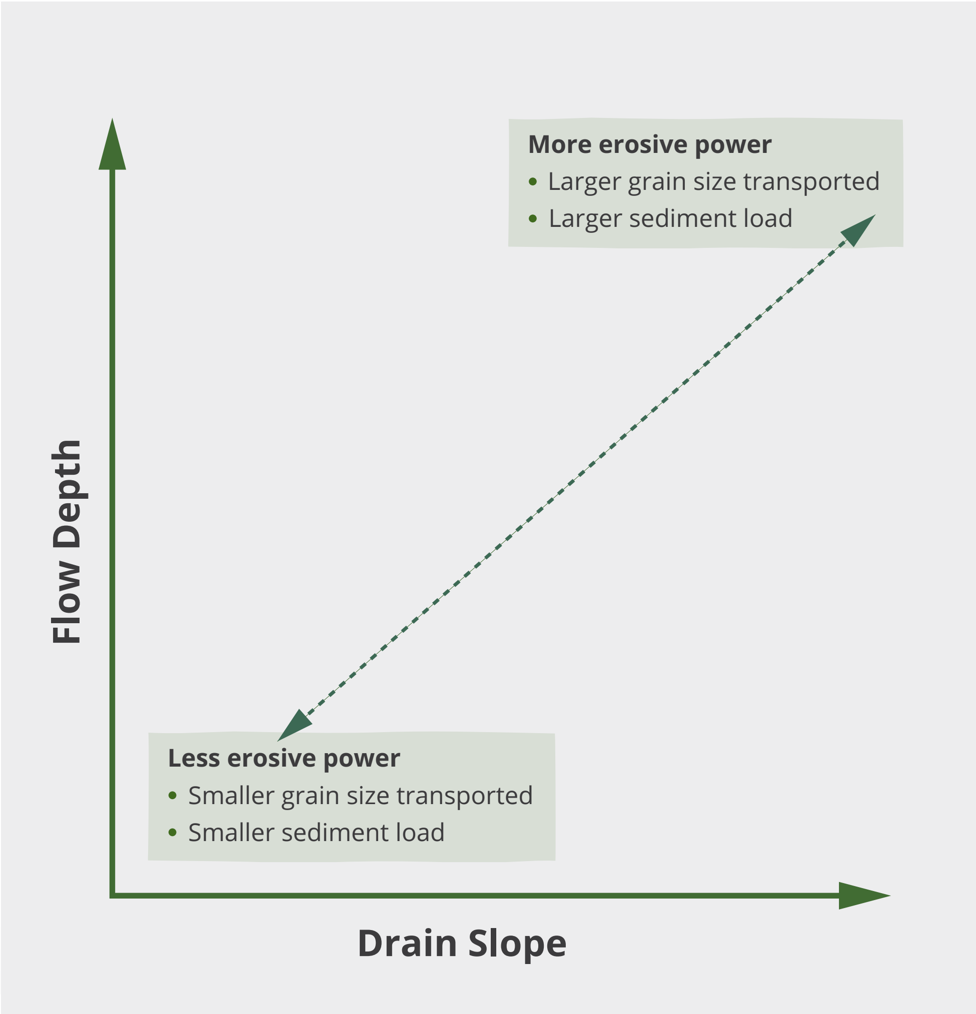


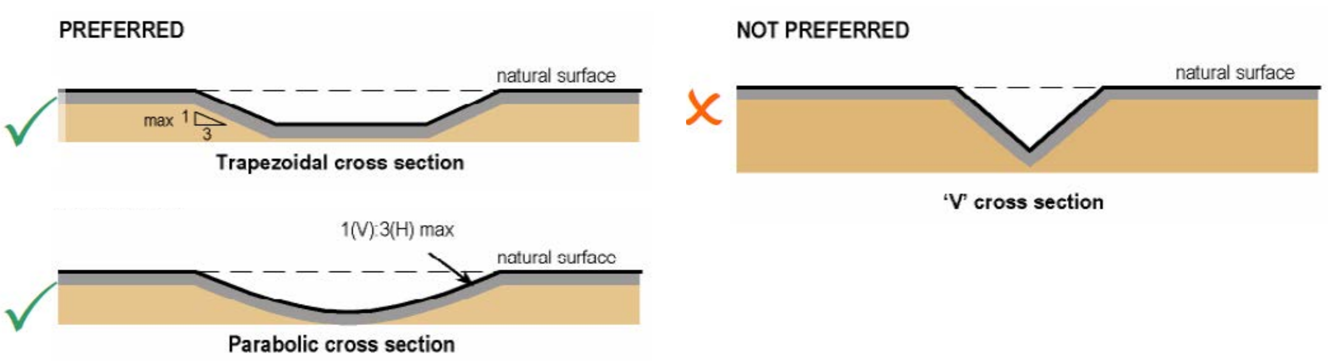
Figure 25: *The relationship between flow depth, drain slope and erosion.*

4.6.2.1 Drain Shape

The shape of a drain has a significant effect on the erosion potential. An example of how V drains can scour compared to flat-bottomed (trapezoidal) or parabolic shaped drains is provided in Figure 25. Preferred drain shapes are shown in Figure 26.

Figure 26:
A V-Shaped Table Drain with erosion (left) versus a Flat-Bottom Table Drain (Trapezoid-Shaped) (right).

Figure 27:
Preferred drain shapes [27].



4.6.2.2 Drain Size (Depth, Area)

The cross-sectional area and depth (shape) of a drain impacts flow depth, velocity and the potential for scour and erosion. Key aspects of drain design include the following.

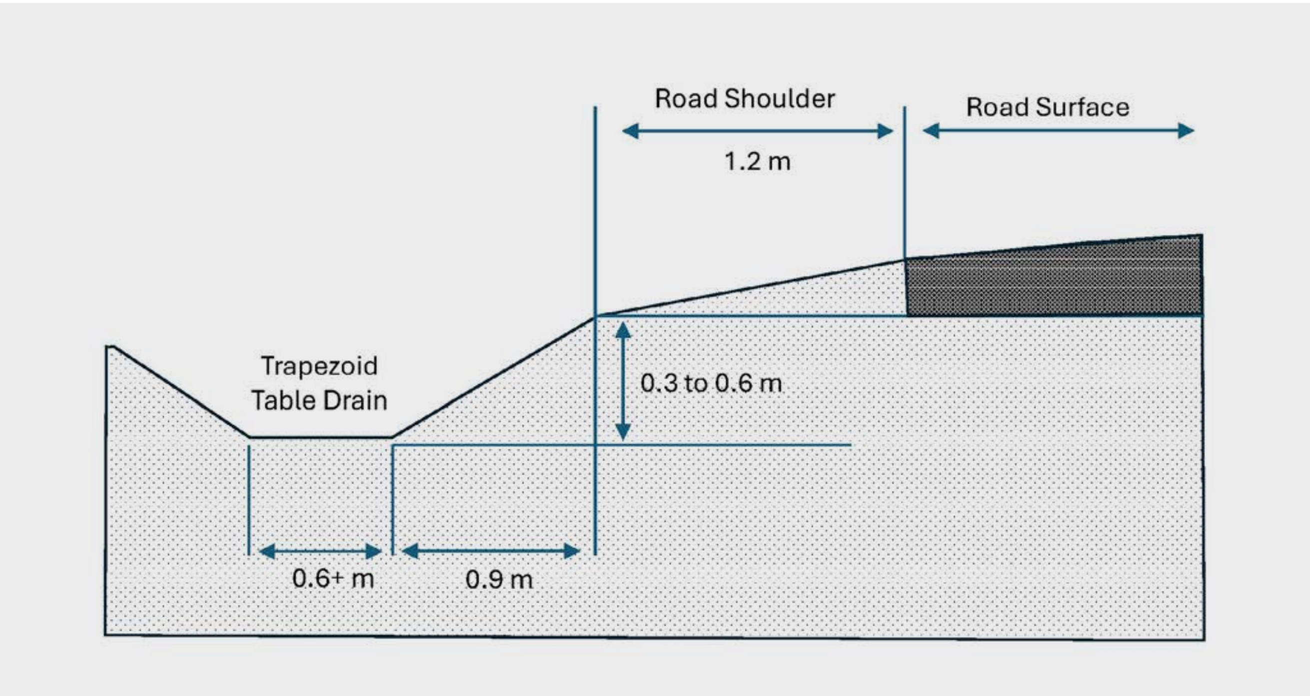
- Drain depth and cross-sectional area (width x depth) should have sufficient capacity to accommodate expected peak flows rates (water discharge) from the drain catchment area.
- Drain area should be large enough to accommodate some silt deposition as well as vegetation growth over a longer period of time.
- Table drains should where possible be a minimum 300 mm deep (below road shoulder level and at least 150 mm below subgrade level) (Figure 27).
- Cutting deep drains in dispersive soils will be problematic unless additional erosion control measures are put in place (i.e. gypsum, rock, or cover with stable soil).
- Add road base to raise the elevation of the road prism relative to drain depth in dispersive soils, as an alternative to cutting deeper drains into fragile soils.

4.6.2.3 Drain Longitudinal Slope

Drain slope affects flow velocity and the erosive power of the flow (Figure 24). This is commonly seen in steeper drain sections where incision or scour of the drain occurs.

- Flatter drains are typically more stable however they must be deeper to cater for slower flowing run-off. Stable slopes will vary depending on the soil type, vegetation cover and flow. However drains between 0.5% (1 in 200) and 3% (1 in 33) are typically stable.
- Unlined drains (i.e. no vegetation) can only cater for flow rates with low velocities (small catchment areas, wide flat bottom drains and flat longitudinal slopes) in erosion resistant soils (Table 3).
- Drain slopes > 3% can result in scour and erosion, particularly in dispersive soils.
- Steep drains may need to be treated with rock lining or rock grade control structures (check dams) if they are unstable and begin to erode.
- Diversion drain outlets at steeper creek banks > 5% often result in scour and gully formation, which needs to be avoided or treated (Section 4.7).

Figure 28:
Minimum drain depth and width[2].



4.6.2.4 Drain Lining

Table drain construction typically consists of a grader/excavator cutting the drain into in-situ native soils leaving bare and exposed bed and banks. Unlined earth drains are expected to scour if flow velocities exceed about 0.3-0.7 m/s, which is regularly exceeded in drains with a moderate slope.

A number of drain linings can be used which will reduce the risk of erosion in the drain. An assessment of expected flow velocity is required to allow the selection of an appropriate drain lining (Table 3).

Table 3

Appropriate drain linings[19].

Type	Description	Expected Flow Velocity	Approximate Max Channel Longtitudinal Grade (%)	Comments
Open Earth (unlined)	Extremely erodible soils	Very Low (0.3 m/s)	N/A	• Dispersive clays are highly erodible even at low velocities. • Highly erodible soils may include: Rudosols, Tenosols, Hydrosols, Kurosols, Sodosols, Podzolic, Siliceous sands, Soloths, Solodized solonetz, Grey podzilics, some Black earth, fine texture-contrast soils and Soil Groups ML and CL. • Erosion resistant soils may include: Dermosols , Ferrosols, some Red earth soils and Soil Groups GW, GP, GM. GC, MH and CH.
	Moderately erodible soils	Very Low (0.6 m/s)	0.5	
	Stiff clay very colloidal soils	Low (1.1 m/s)	1.0	
Established Grass	Easily erodible soils	Low-Medium (1.0-1.5 m/s)	3	• Easily eroded soils include: black earths and fine surface texture-contrast soils (dispersive). • Long establishment time when seeded.
	Erosion resistant soils	Medium (1.5 - 2.0 m/s)	5-6	• Erosion resistant soils include: Ferrosols and red earth soils. • Long establishment time when seeded.
Turf	Turf slabs laid perpendicular to the flow direction	Medium (1.5 - 2.0 m/s)	6	• Binds dust and soil particles to limit erosion. • Typically applied to unsealed roads and haul roads and embankments but can assist to stabilise drains, particularly during vegetation establishment). • Needs to be reapplied after several months as required.
Loose Rock	Angular weathered rock	Medium-High (2.0-3.5 m/s) Allowable velocity varies with rock size and channel shape	10-15	• Used mainly as a liner for chutes and steep drains. • Rock must be recessed below the surrounding ground to allow flow to freely enter the drain. • Requires an underlying filter cloth. • Larger sized rock is required for higher velocities. • Requires detailed design from a RPEQ.
Concrete	Concrete floodways or drains	Very High (7.0 m/s)	>50	• Used to provide a stable major water crossing. • Needs upstream and downstream protection (cutoff walls, rock armouring etc). • Requires detailed design from a RPEQ.

*Note that individual calculations should be undertaken for each drain. This is provided as a general guide only.

4.6.2.4.1 Vegetation in Drains

Vegetation retention, specifically grass cover, is key to drain stability and is very cost effective. Avoiding frequent drain disturbance by machinery will promote the natural recruitment of grass in drains. In poorer soils with more extensive erosion, proactive revegetation may be needed. This includes direct seeding of grass species, hydromulch spray application when appropriate, erosion control and compost blankets, or other methods. Where vegetation needs to be managed in drains, slashing or herbicide management is preferred to grading.

4.6.2.4.2 Rock Lining Drains

For short steep sections of drain, it may be necessary to rock line the drain to minimise the risk of scour (Figure 28). Use well-graded generally angular, durable rock that is resistant to weathering. However, in many rural areas, less durable local rock is suitable for erosion control in drains. The size of the rock required will vary based on the peak flow rate and drain shape and size. Acceptable rock sizing for various drain shapes are provided below. The largest rock sizes (D_{90}) should not exceed twice (2x) the nominal (D_{50}) rock size. The rock layer depth should be between 1.5-2.0 times the D_{50} rock size. The well-graded rock should contain abundant finer gravel tailing towards a D_{10} of 5% of the D_{50} size.

Figure 29:
Rock-lined table drains on unsealed roads.

Table 4
Rock sizing selection table, D_{50} (mm), based on drain slope and flow depth. Use well-graded rock with the D_{90} < 2x the D_{50} and D_{10} of 5% of D_{50}

Adapted from[11].

Drain Slope %	Maximum Flow Depth (or Channel Depth)							
	0.1 m	0.2 m	0.3 m	0.4 m	0.5 m	0.6 m	0.8 m	1.0 m
0.5	50	75	100	100	100	100	200	200
1	50	75	100	100	150	200	200	200
2	50	75	100	200	200	200	300	300
3	50	100	150	200	250	300	400	400
4	75	100	150	200	250	300	400	500
5	100	200	250	300	350	400	500	600
6	100	200	250	300	350	400	600	700
7	100	200	250	300	350	400	500	700
8	100	200	250	300	350	400	600	700
9	100	200	300	300	400	500	600	700
10	100	200	300	300	400	500	600	800

4.6.2.4.3 Check Dams in Drains

Sequential check dams can assist to stabilise eroding drains by slowing water velocity by effectively lowering the local bed slope. The lower velocities encourage coarse sediment to settle within the drain and promote revegetation. Some sediment may be trapped within the dam itself, however, they are not a fine sediment collection measure. The main purpose of check dams is to control the grade (slope) of the drain and prevent future channel incision (cutting) and associate downstream pollution.

Rock check dams are preferred as semi-permanent solutions, in contrast to temporary check dams (sand bags, coir, brush, hay). Two different types of rock check dams are recommended (Type 1 and 2) and their use strongly depends on the soil and terrain environment outlined below. Improper construction or use in incorrect situations can often lead to failure.

4.6.2.5 Type 1 Rock Check Dams: Low-height, well-graded gravel and cobble

In low to moderate gradient drains along unsealed roads, Type 1 rock check dams are appropriate with their low-height, well-graded gravel and cobble rock, and long scour protection (Figure 29; Figure 30; Figure 31). Their mattress sized length along the drain channel and banks, and well-graded, unscreened crushed rock provides a resilient solution to scour protection. Rock size and hence check dam height can be varied according to flow depth and slope (reference rock size table above).

Using low-profile versions prevents flow backwater up drains that could impact road prisms. They also could be driven over if needed during dry conditions (i.e., slashing vegetation) with less potential to compromise the structures.

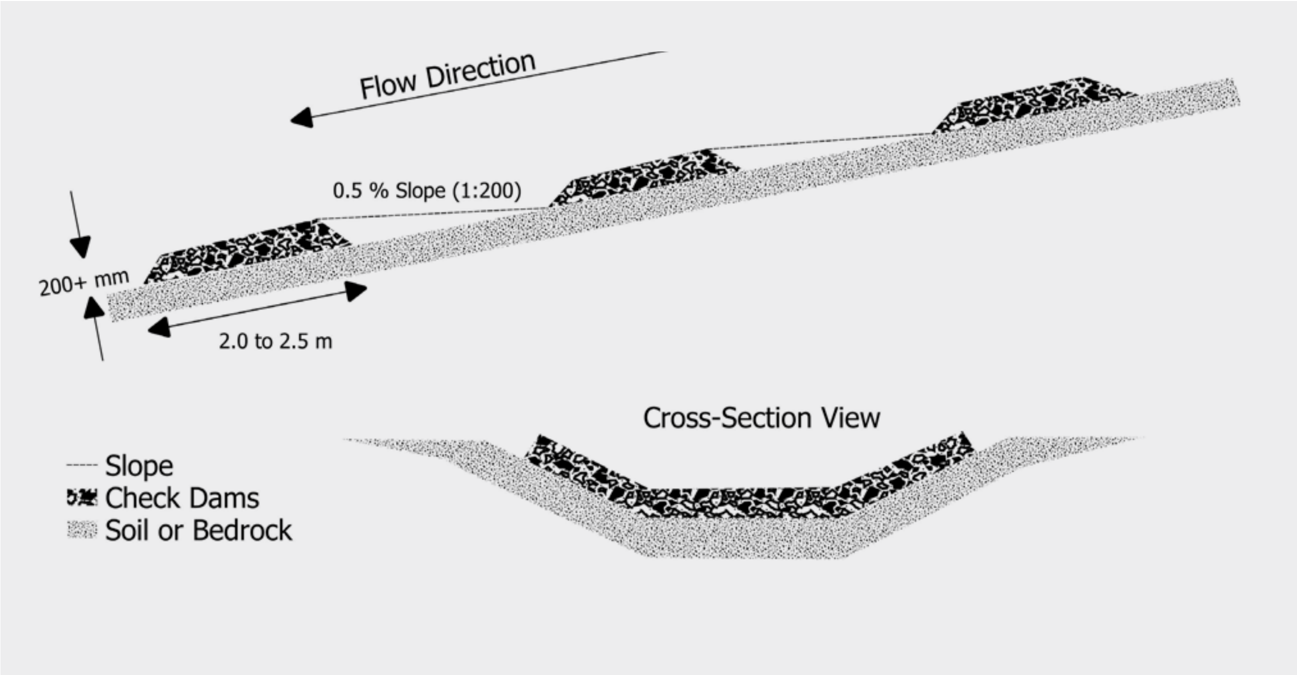


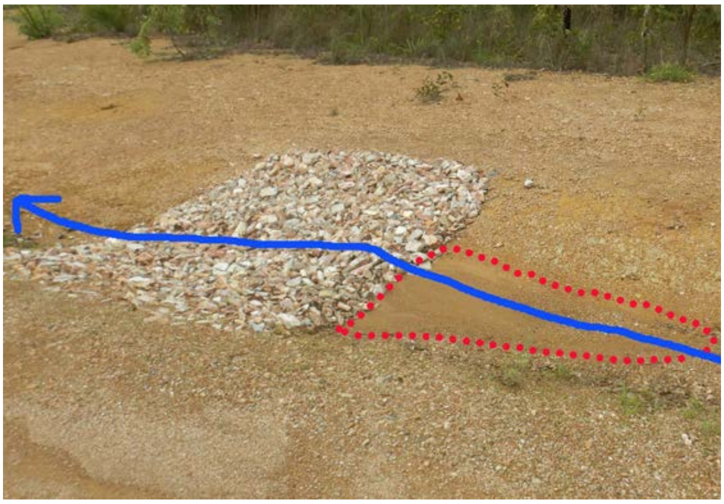
Figure 30:
Type 1 rock check dam longitudinal profile and cross-section in a road table drain.

Figure 31:
Type 1 rock check dams at the correct frequency and 0.5 % grade line between the crest of the downstream check dam and toe of the upstream check dam. Before (top) and after (bttom) a major cyclone. Note dumpy level on left used in construction.

As a general guide, Type 1 rock check dams in drains should include:

- Well-graded unscreened rock with a reasonable proportion of fine gravel (D_{10}) to fill the pore spaces of larger rock (D_{90}) to reduce the porosity of the check dam.
- Rock size (D_{50}) will depend on the drain catchment area, slope, and drain width.
- Construct the check dam onto the surface of the drain bed and banks, and follow the shape of the drain with rock up the full width of the drain in a curved shape.
- Ensure that the check dam does not compromise drain capacity by reducing the cross section of the drain significantly.
- Ensure that flow spills over the centre of the structure, and that this weir is as wide as possible.
- Type 1 rock check dams should be about 2.0 – 2.5 m long (along the drain), so that sufficient rock is available on the downstream end to resist and adjust to scour.
- Some of the rock at the downstream end of the check dam will move downstream and fall into a small scour hole that is expected to develop at this location. This is not a cause for concern due to the extra length of the rock along the drain.
- The frequency of check dams should be constructed so that the crest of the downstream check dam is on about a 0.5 % grade line below the toe of the upstream check dam (Figure 29; Figure 30). The backwater pool behind the check dam should extend toward the toe of the next upstream check dam.
- Type 1 rock check dams are appropriate to prevent incision in V-drains with limited water flow capacity due to depth or width, to ensure that water is not backed up onto the road running surface.
- The shape and size of the check dam has been chosen to make construction easy (using a 4-in-1 bucket) while maintaining its function and effectiveness.
- Use geofabric under check dams in dispersive soils, and key into bed and banks where necessary for extra stability.

Figure 32:
Type 1 rock check dams in V-drains can control the slope and channel erosion without blocking drains or backwatering the road.



4.6.2.6 Type 2 Rock Check Dams: Medium-height, poorly-graded cobble and boulder

In moderate gradient drains (<10%) along unsealed roads, Type 2 rock check dams are appropriate in drains that have a depth of at least 500 mm and sufficient width to maintain flow capacity. The dams are designed to temporarily slow and detain water before eventually draining through the porous rock (poorly-graded cobble and boulder).

As a general guide, Type 2 rock check dams in drains from unsealed roads should include:

- Poorly-graded screened rock size (D_{50}) should be 150-300 mm.
- Have a maximum crest height of around 500 mm.
- Have a flat crest width of at least 1.5 m.
- Construct the check dam onto the surface of the drain bed and banks with the crest of the dam in a curved shape with the middle portion of the dam being at least 150 mm lower than the bank elevation at the outer ends of the structure to concentrate flows in the centre of the drain.
- Ensure that the check dam does not compromise drain capacity by allowing a sufficient weir depth over the crest. The drain may need to be deeper and wider than usual to provide adequate cross-sectional area within the protected spillway.
- The maximum slope of the downstream face of the check dam is 2:1 (H:V) however flatter slopes are preferred to prevent scour.
- Additional rock should be placed at the downstream toe of the check dam to act as a splash pad and prevent scour failure.
- The frequency of check dams should be constructed so that the crest of the downstream check dam is level with the toe of the upstream check dam. The backwater pool behind the check dam should extend to the toe of the next upstream check dam.

Figure 33:
Type 2 rock check dams with correctly graded rock and overflow weir shape of at least 150 mm within the centre of the drain. Check dam on left includes collected sediment.

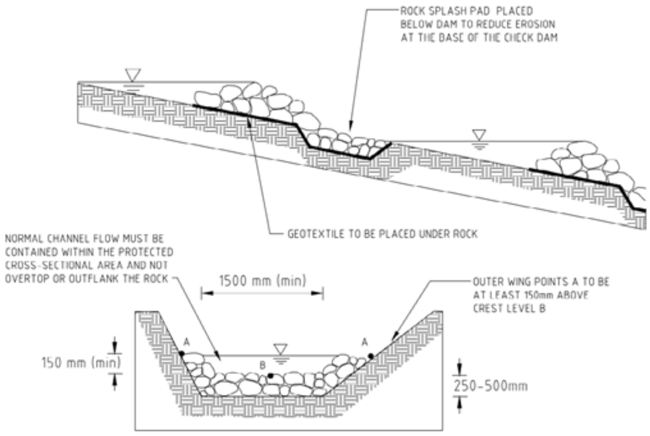
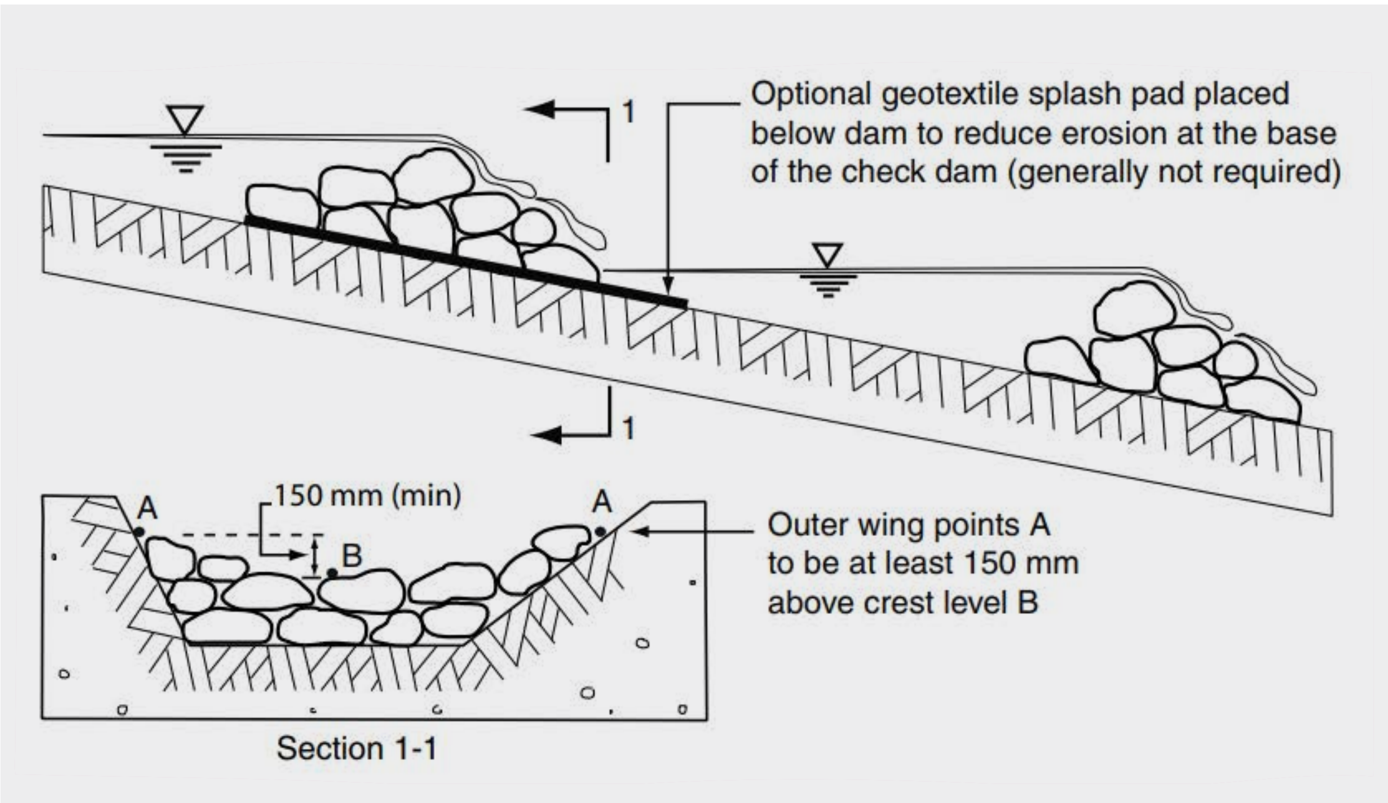


Figure 34:
Type 2 rock check dams longitudinal section highlighting the required spacing and the cross section with a weir with sufficient width and depth.



4.6.2.7 Limitations and Failure of Type 2 Rock Check Dams

Type 2 rock check dams typically fail by outflanking or undermining because they are either installed in the wrong location, not frequently enough, or do not have sufficient capacity or scour protection to cater for the drain flows.

Type 2 rock check dams should not be used in the following instances:

- Drains with dispersive soils without amelioration or sufficient capping to limit contact of the dispersive soil with water.
- Shallow drains without the capacity to allow the expected drain flow over the rock crest/weir.
- Rocks that are placed flat across the drain providing no flow path which forces water to spill out of the drain and scour the adjacent soil.
- Drains steeper than 10% that require drain spacings that are impractically close (rock lining preferred in these situations).
- Spacing dams excessively far apart and not resulting in ponded pools extending between individual dams.

4.6.2.7.1 Grade Control Structures for Major Erosion in Drains

Major erosion in drains can include gully incision, headcuts, and widening into road prisms, batters or stream banks. Grade control structures may be required for larger drains or steeper slopes for stability. Gully erosion should be treated with site specific designed rock chutes, particularly where drains flow over creek banks (see Section 4.7). Grade control structures need to be constructed to a site-specific design undertaken by a RPEQ (Figure 45).

Figure 35:
Failed Type 2 check dams in non-dispersive soils due to outflanking (top) or excessive plunge pool scour (bottom) due to insufficient width up the drain batter (top) or insufficient frequency of check dams (bottom), note absence of check dams in the upstream direction.

4.6.3 Reduce Connectivity to Gullies and Stream Crossings

4.6.3.1 Diversion Drain Frequency (Cutoff or Turnout)

Roadside table drains collect and convey stormwater before discharging run-off as concentrated flow. Current practices use diversion drains (turnouts) to remove stormwater from table drains, which limits flow depth in the table drains and prevents erosion and inundation of the road pavement. This also limits erosion within the table drain. Diversion drains should turn away from the road and direct run-off into adjacent land as sheet flow by widening and flatting out the longitudinal gradient of the diversion drain and allowing water to disperse over a wider area.

Diversion drains need to be spaced specifically for the road environment (i.e. soil type, erodibility, slope, upstream catchment area and drain dimensions/capacity). As a general rule for low gradient roads on stable soils, turnouts should be placed around 75-100 m apart.

For non-dispersive soils the ARRB[1] equation can be a useful guide:

Spacing (m) = 300 / (% Slope of Drain)

In high soil erodibility situations such as with dispersive soils or steeper slopes, drain spacing must decrease significantly to reduce the stream power on fragile soils. In practice, drains should be located as frequently as possible to safely divert water. Spacing guidance is proved in Table 5.

Key aspects of effective diversion drains include the following:

- Drains should be installed as frequently as reasonably possible to safely disperse water into flatter more vegetated areas. Do not connect the outlets to local creeks or gully prone areas.
- Triangular V-drains should not be cut into dispersive soils[33,35]. Type B catch drains as shown in IECA Standard Drawing CD-01[19]: Catch Drains, should not be used in dispersive soils.
- Drain spacing must be decreased with increased drain slopes.
- In high rainfall intensity areas, dispersive soils or steeper terrain, diversion drains should be < 40 m apart and catchment areas should be less than 0.2 ha (50m x 40m) due to high run-off rates and erosion potential[25,69].
- The transition point from a table drain to diversion drain should be built up with an earth bund or armoured with rock so that diversion drain entrances do not break or over-top and flow into the next downhill section of table drain (see Figure 34).
- Drain transition points are often hot spot points for sediment deposition and require monitoring and management.
- Relief culverts or cross-drains are needed to remove water from upslope roadsides with long table drain lengths (see Section 4.6.3.2). Where possible, culvert frequency should be similar to diversion drain spacing.

Table 5
Diversion drain frequency in relation to slope and soil erodibility.

Table Drain Slope %	High Soil Erodibility* Drain Spacing (m)	Moderate Soil Erodibility# Drain Spacing (m)
1%	75m	120m
2–3%	50m	90m
4–6%	40m	65m
7–10%	30m	45m
11–15%	20m	35m
>15%	15m	25m

Adapted from sources: [22,21,13,25,69]
Adapted from source: [1]

Figure 36:
Diversion drain with an earth bund to turn run-off away from the road (top) and a breached earth bund due to drain sedimentation from a large drain catchment and inadequate drain slope and flow capacity (bottom).

4.6.3.2 Cross-Drains and Relief Culverts

Diversion or turnout drains cannot be installed on the up-hill side of the road. Relief culverts or cross drains are needed across roads to reduce the volume of stormwater in table drains where there are long-sections of drain on the up-hill (in-slope) side of the road. This will minimise table drain erosion and sediment connectivity to streams (Figure 35). Floodways installed as trafficable dips can also be used to relieve flow in long-sections of table drains.

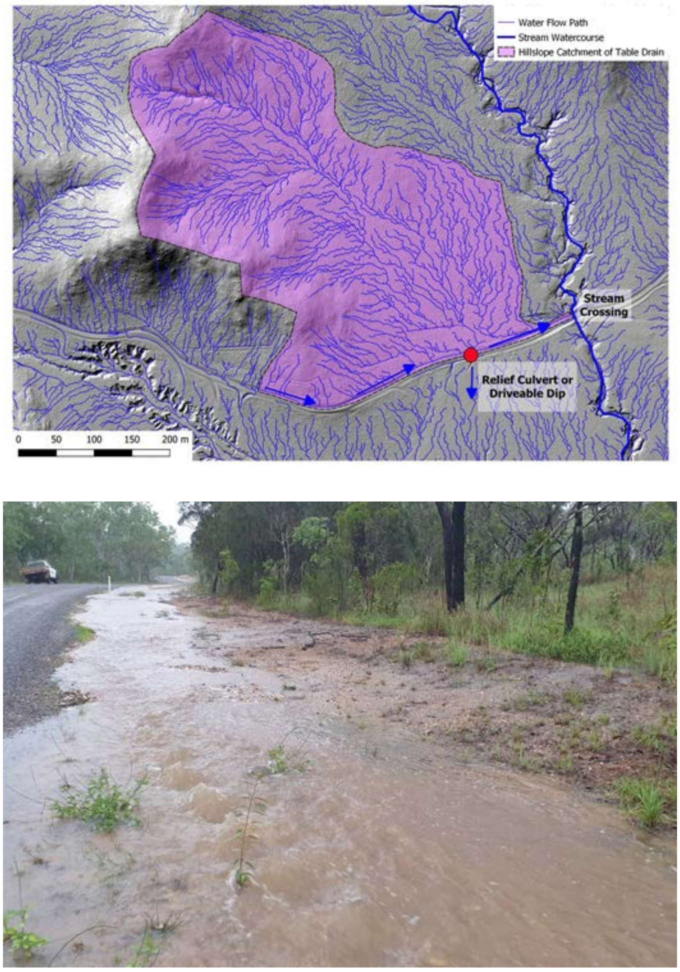


Figure 37:
A hillslope catchment (16 ha) captured by a road table drain (> 500m) and discharged to a stream, with the location of a constructed rock floodway (driveable dip) (Figure 50) to relieve water along a stable flow path. Alternatively, a large relief culvert could have been used.

It is important to match the location, size, and frequency of cross-drains and relief culverts to the local topography.

- Location: at natural flow paths or gentle slopes not close to streams, where water can be dispersed and sediment deposited before reaching watercourses. Often these locations are scarred where water spills out of table drains and over the road prism during intense rainfall.
- Size or Diameter: is a function of catchment area, design rainfall intensity, table drain slope and frequency of other cross-drains and relief culverts. Note that culverts must be sized based on the upstream catchment area, available headwater height (distance from the pipe invert to the road/shoulder level), and expected outlet velocity. Always seek assistance from a Registered Professional Engineer of Queensland.
- Frequency: will be based on natural topography but should be generally similar to turn-out drain spacing (Table 5) of around 100 m depending on funding, slope, soil erodibility and drain catchment area. Larger spacings can be accommodated if the table drain and disposal areas are stable and the culvert size increased.
- Type (culvert or floodway cross-drain): concrete pipe culverts ranging from 450 to 900 mm diameter are typically adopted for most cross-drain culverts that do not have large upstream catchments. Box culverts may be needed for larger catchment areas. Floodways (trafficable dips) armoured with sub-surface rock can also be used for low traffic volume roads and larger catchment areas.

More detail on culvert installation and erosion control can be found in Section 4.8.2.

4.6.3.3 Drain Connectivity to Streams and Gullies

Diversion drains and table drains that are a short distance from local creeks and gullies are a major source of sediment delivery from unsealed roads. Diversion drains are often poorly constructed and either increase erosion downstream by discharging concentrated flows onto steep slopes, or pond water leading to flooding the upstream road pavement. Depending on the receiving environment, the outlet of diversion drains needs to be constructed and stabilised to:

- Proactively spread flow with level spreaders where enough space is available and risks due to soil disturbance are minimal (Figure 38), or
- Stabilise steeper slopes with rock chutes or grade control structures to prevent gully erosion (Figure 45).

Key aspects to consider include:

- Avoid directing table drains and diversion drains to discharge directly into waterways or gullies. This requires a visual assessment to determine whether a potential flow path might drain water to a vulnerable gully location, such as a steep creek bank (Figure 39) (i.e. walk the flow path from the diversion drain).
- Divert sediment before it reaches the stream using diversion drains and natural vegetation that can filter and trap sediment.
- Where possible, place diversion drains on gentle vegetated slopes that will not cause erosion at the outlet.
- Install level spreaders where enough space is available and risks to soil disturbance are minimal (Figure 38).
- If drain connectivity cannot be reduced, consider other erosion control measures such as rock armour or rock chutes to minimize erosion (Figure 37; Figure 44; Figure 45; see Gully Section 4.7).

Figure 38:
Table drains well connected to streams with few places to divert sediment laden water from bare batters.

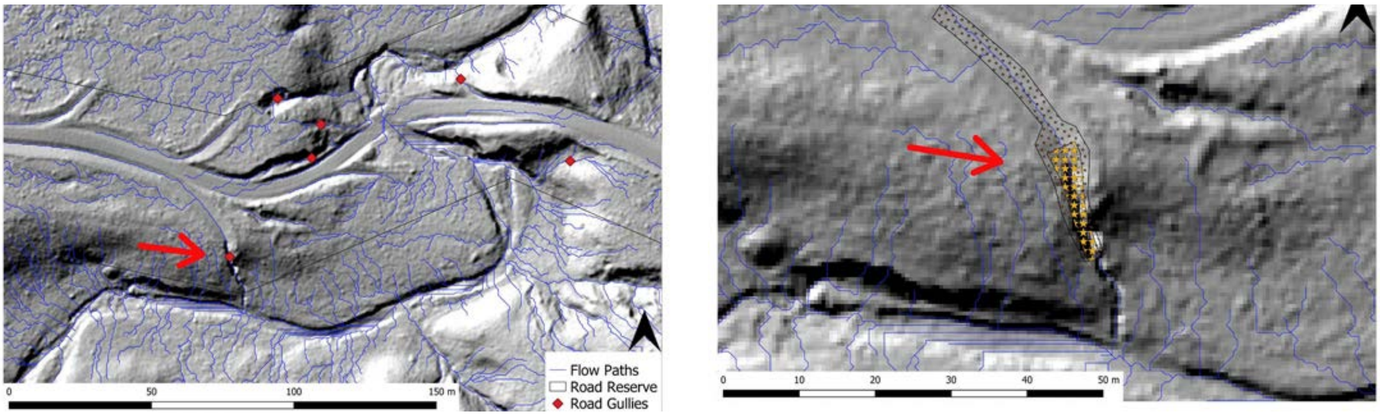


Figure 39:
Poor drain placement (left). Drain placement is important to avoid discharging onto gully prone areas near creek crossings. If no drain placements alternatives exist, then rock chutes may be needed in gully prone areas (right).

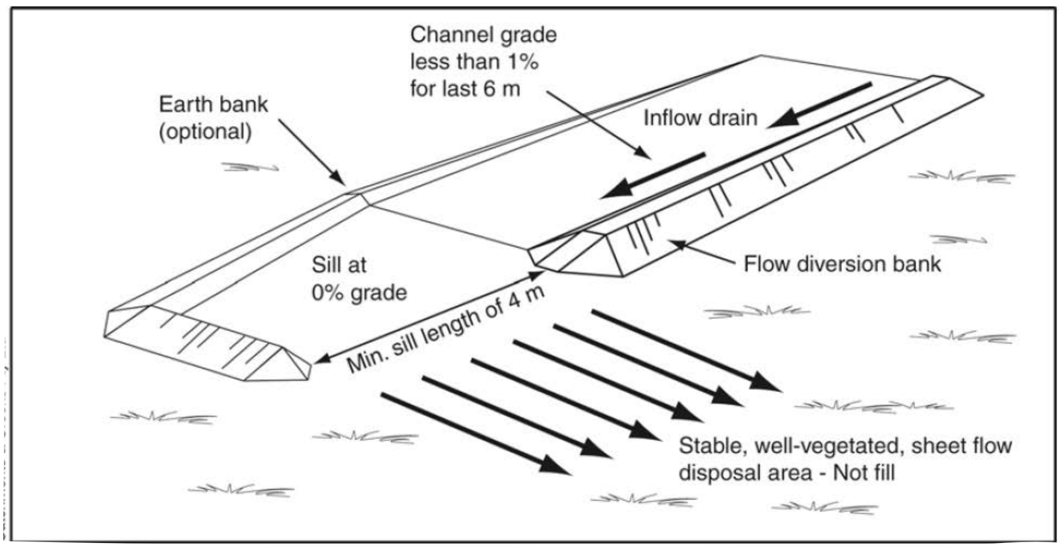


Figure 40:
Level Spreader (Source: Catchments and Creeks Pty Ltd)[10,11,12].

4.7 Gully Erosion Control (Road Drains, Batters, and Creek Crossings)

4.7.1 Gully Erosion

A gully is a channel that has been eroded into the soil by running water, typically with a head cut (a drop in the channel bed) greater than 0.3 m deep that continues to grow and move upstream until an equilibrium slope is reached (Figure 39). Gullies are common in dispersive soils at the outlets of diversion drains, along old road alignments, and near creek crossings. Roadside gullies are caused by past and current road maintenance activities (Figure 40).

Figure 41:
A gully at the bottom of road diversion drain looking upstream (left) and downstream (right).

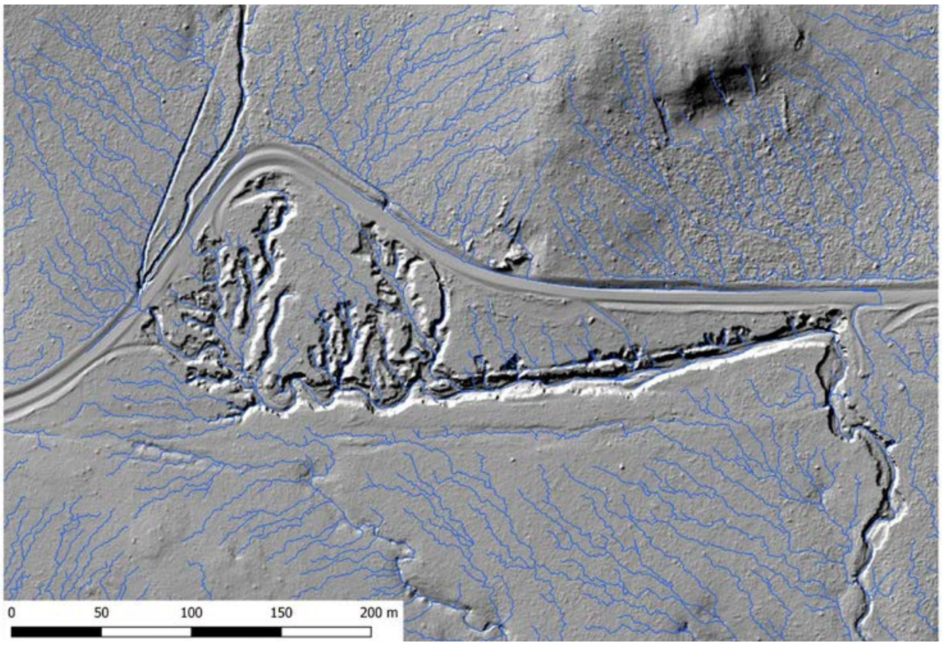


Figure 42:
Legacy roadside gully erosion (LiDAR hillshade) created along an old, straight road alignment and affecting current drainage and road configuration.

4.7.2 Preventing Gully Erosion

Prevention of gullies caused by road drainage run-off can be achieved by properly locating diversion drain outlets along the road and assessing the stability of each location.

- Prevention is almost always better than coming back to site to make repairs.
- Inspecting the discharge area will help to understand whether a potential flow path might drain water to a vulnerable gully location, such as a steep slope or a creek bank.
- Measuring gradients with a dumpy level will help identify diversion drain sections that are too steep (more than 1:33 or 3%) and thus prone to gully erosion.

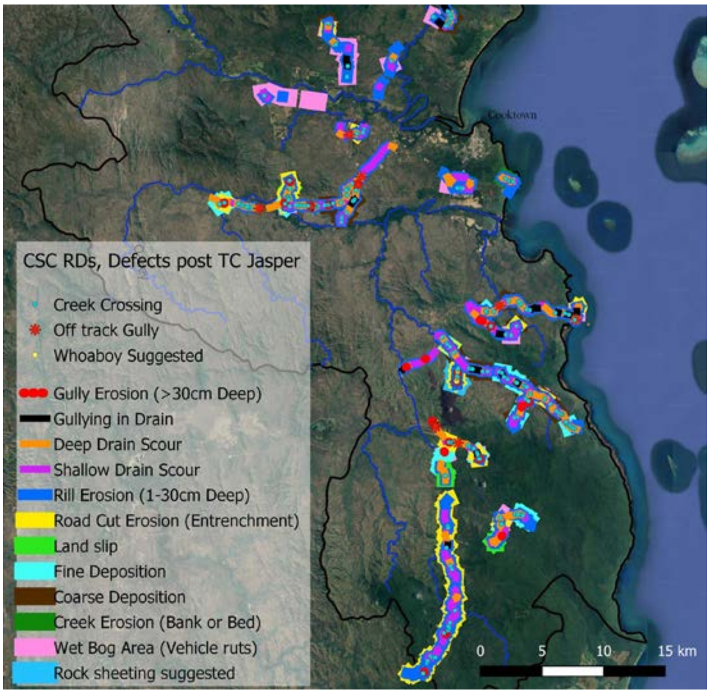


Figure 43:
Example mapping of hot spot erosion areas.

4.7.3 Identifying and Inspecting Gully Erosion Hotspots

Knowledge of the spatial distribution and erosion condition of drain and gully erosion hotspots along road networks are essential for their management (current and legacy gullies).

Gully identification and drain assessment surveys could occur annually or periodically in association with road condition surveys. However, the inspector would be required to walk a select number of suspicious drains that could lead to drain instability or gully problem areas caused by road run-off and drainage. High resolution air photos and LiDAR data (https://elevation.fsdf.org.au/) can also be used to identify gully problem areas along the regional road network.

GPS photo inventories of gully location, cause, size and rates of erosion can be used to prioritise hotspots for erosion control intervention and modification of road drain management. Key metrics for drain and gully assessment include:

- Drain functionality (capacity, incision, deposition, vegetation cover)
- Frequency of drain disturbance by machinery.
- Degree of drain incision (leading to rilling and gullying)
- Presence of gullying at drain outlets near stream channels
- Gully volume (depth, width, length)
- Headcut retreat rates and annual growth upslope.
- Threat of erosion to the road, drainage system or environment (water quality).
- Availability of local or quarry rock resources for control (drain lining or rock chutes).
- Design of protection measures.

4.7.4 Controlling Gully Erosion

Controlling gully erosion in drains is essential where water cannot be diverted away from potential or existing gully heads:

- Drains prone to gully erosion should be rock-lined or have grade control structures (or check dams) installed to prevent further scour and channelling.
- Rock chutes should be used to stabilise gully heads or gully prone locations, such as creek banks at drain outlets in dispersive soils.

4.7.5 Small Gully Control

Small rock lined chutes must be constructed so that flow entry is unrestricted and the chute has sufficient depth and width to contain the flow. Some rock movement may occur, and chutes will need to be inspected periodically and prior to expected heavy rainfall. Vegetation can be encouraged within the chute; however the vegetation cannot block or reduce the hydraulic capacity of the chute.

An example is provided below of a small rock chute construction for a typical diversion drain outlet in steep terrain.

- Chute base width no greater than 1.0 m.
- Chute depth no greater than 0.5 m.
- Flow depth no greater to 0.3 m.
- Chute slope to suit location.
- Chute with 1:3 side slopes.
- Well-graded rock size with D50 250 mm diameter with underlying geofabric.
- Rock lining thickness 400–500 mm preferred.
- Flat apron 3.0–6.0 m long at chute outlet for scour protection (Figure 47).

Figure 44:
An incising V-drain outlet (top) and rock chute (bottom) at the same location to control erosion incision.

Figure 45:
Small rock chutes at diversion drain outlets can prevent gully head-cutting upstream into drains.

Figure 46:
Failed rock stabilisation due to use of porous coarse rock (poorly-graded screened rock) in gully heads in dispersive soils. The gully head will seep and migrate around the rock unless a proper rock chute is shaped, layered and constructed (Figure 45).

4.7.6 Large Gully Control

Larger gullies along unsealed road reserves and adjacent property require major reshaping and rock chutes to manage rainfall impact and the flow of water, otherwise gullies will redevelop and continue to grow. Large gully control could trigger capital works and will require RPEQ advice. The preferred treatments for larger gullies are:

- Batter all the steep gully walls and profile to a stable slope and compact.
- Install a flat-bottom rock chute from top to bottom of the flow path using large size rock with underlying filter rock over geofabric (Figure 47).
- Adjust rock size to the catchment area, peak water discharge, and chute slope following standard hydraulic calculations[10,23].
- Cover the side walls of the rest of the gully with rock mulch and leave to revegetate (Figure 46, Figure 48).
- Water diversion banks may be needed for larger catchment areas to direct water into the chute and prevent water flowing over the sides of the gully.
- Specialist engineering (RPEQ) and geomorphology design advice must be sought for large rock chute design and control of larger gullies (Figure 48).

Figure 47:
Rock chutes constructed at the outlets of road diversion drains to control gully erosion.

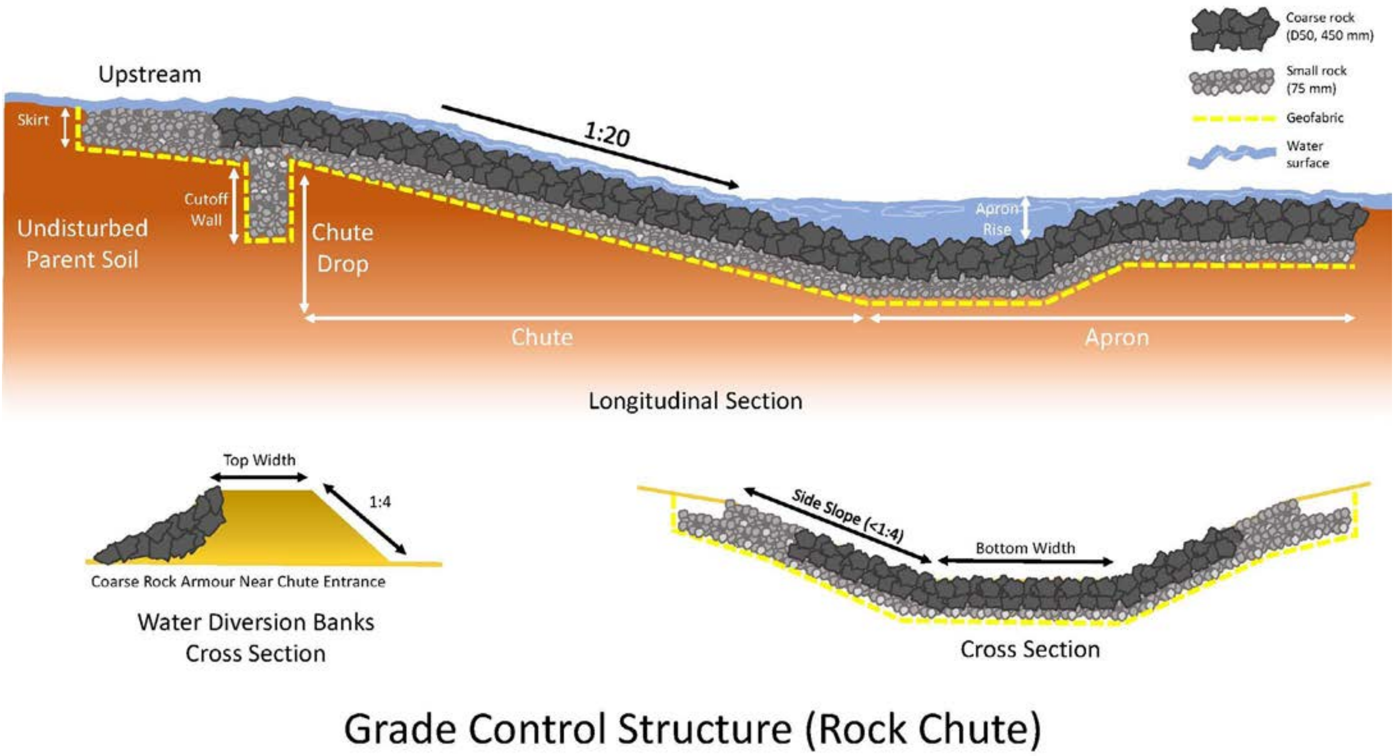


Figure 48:
Design of a rock chute (grade control structure) for gully control.

Figure 49:
Gully bank collapse downstream of a concrete culvert and concrete chute due to a lack of rock scour protection in the receiving environment beyond the immediate structure (left), and after gully control and rock chute installation (right).

4.8 Floodway and Culvert Improvements

For most local governments the activities described in earlier sections of this document are typically categorised as 'operational works' or 'maintenance'. The following sections describe works that are typically categorised as 'capital works'.

Capital works activities require additional planning work to determine the validity of the business case.

Once confirmed as a project further engineering design and approval processes are undertaken before construction can begin. The intent of the following sections is not to provide detail description of this planning process, rather to highlight key opportunities for sediment reduction via capital works.

Figure 50:
A concrete floodway installed at a creek crossing to reduce bed scour, but with associated erosion at the diversion track (Figure 53). Note downstream scour below concrete due to lack of rock protection; and rill erosion on batters

4.8.1 Floodways and Bed Level Creek Crossings

4.8.1.1 Concrete Floodways

Unsealed floodways and bed level creek crossings are very high maintenance areas and can pose a significant safety hazard for traffic. The construction of a concrete floodway is economical when compared with the annual maintenance cost of an unsealed floodway over a ten-year period. Constructing concrete or rock floodways at bed level creek crossings protects both the stream and road surface against scouring, improves drivability, and reduces downstream pollution.

Concrete floodways are the better long-term solution to ensure integrity of the crossing and provide excellent scour protection (Figure 49).

- A rock apron should be installed downstream of floodways to transition flow from the concrete back to the waterway and prevent scour. The length and rock size of the apron will vary and advice from a RPEQ should be sought. An apron length of about 6 m and a well-graded rock up to about 350 mm is usually adequate for a flow depth no greater than 1.2m and a velocity less than 3 m/s.

- Consider providing a bitumen seal to the steeper sections of the approaches to a concrete floodway. Sealing the steeper section of approaches to floodways:
  - Improves safety by improving road grip where traffic is often breaking hard.
  - Reduces the maintenance required to the road surface from breaking traffic.
  - Reduces fine sediment run-off from the steeper sections of the road prism.
- Concrete floodways can be constructed in two (2) sections side by side, the 1st half of the floodway width is constructed, and then driven on while the 2nd lane is constructed (Figure 50).
  - This avoids the need for a diversion track and associated erosion and the added costs of rehabilitation.
  - The curing time will increase due to consecutive concrete pours.
  - Any increased construction costs (e.g., additional traffic control) are offset by reduced costs associated with not constructing and then rehabilitating a diversion track, in addtion to reduced pollution costs.

Figure 51:
A concrete floodway poured in two (2) sections side by side to avoid the need for a temporary diversion track and associated erosion disturbance.

4.8.1.2 Rock Floodways

Rock floodways are a cost-effective alternative to concrete floodways for low traffic roads in rural or remote areas.

- For low traffic, low speed roads, rock floodway pavements can be constructed using clean well-graded unscreened rock with a D50 of 150 mm diameter and smaller interlocking rock for small streams. Larger unscreened rock up to 300 mm could be needed for larger stream crossings, but also with voids filled with smaller rock. This rock is suitable for flows up to about 2.5 – 3.0 m/s (Figure 51).
- The location of the rock floodway needs to be boxed-out so the rock is inset into the creek bed and extends along the road approaches either side of the stream crossing (Figure 51; Figure 52).
- Use of fine road base over rock floodways and creek crossings should be avoided, as the associated fine sediment binder in the road base will be washed downstream during floods causing pollution (Figure 52). Depositing fine sediment into a streambed knowing that it will be washed further downstream is illegal (EPA 1994; 440ZG).
- Gravel road base without fine sediment binder less than 1 mm could be used instead as a finer material on top of a coarser rock floodway (Figure 52). This gravel material is less likely to be transported into local waterways when associated with a downstream rock kerb, and will not pollute the stream with fine sediment or deliver fine sediment to the Great Barrier Reef.
- A downstream road edge (or weir or kerb) made from larger rock and a scour apron should be installed to retain the rock mattress in the floodway and prevent scour. Well-graded rock up to about 350 mm is usually adequate for this apron (Figure 51).

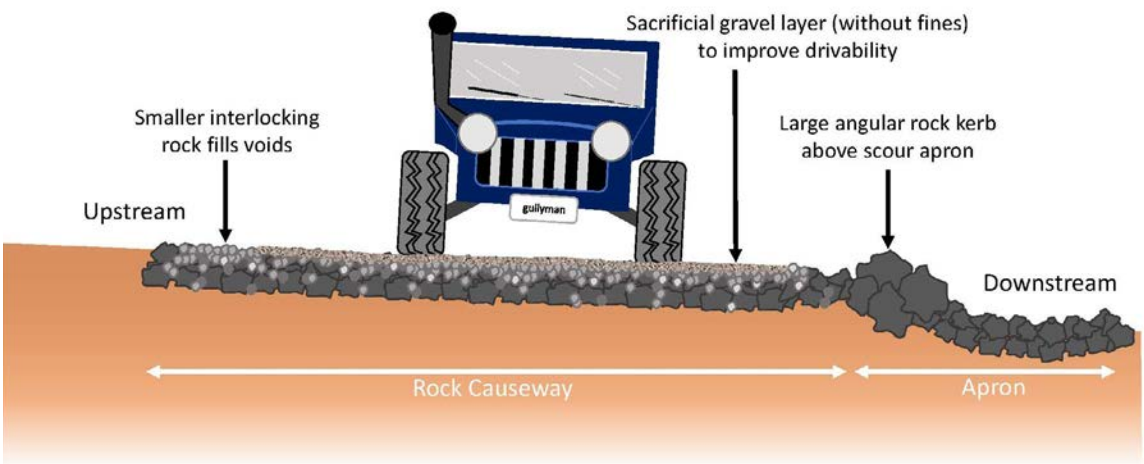


Figure 52:
Road cross-section diagram at a rock floodway crossing.

Figure 53:
The coarse base of a rock crossing of a drainage swale and trafficable dip (left), inset into the existing road surface, with a thin layer of road base capping (right) that will settle into the rock below. The surveyor is standing on a bypass track which was later stabilised with rock mulch shown on the right.

4.8.1.3 Diversion Track Erosion Avoidance and Control

The construction and use of a diversion track during the construction of a floodway should be avoided if possible. This avoids damage to the watercourse and its banks, environmental damage, escape of sediment into the watercourse and the cost of construction and rehabilitation of the track itself (Figure 53 top). If the use of a diversion track cannot be avoided, the track and cut banks must be reconstructed, stabilised and rehabilitated with rock mulch and/or revegetated using non-dispersive topsoil and native grasses (Figure 53 bottom).

Rehabilitation of a typical diversion track through a steep water course is expensive and typically uses several hundred tonnes of rock mulch, or top soil and native grass revegetation, which takes significant time and cost to complete (Figure 53).

Figure 54:
Deep rilling of a temporary bypass road crossing a creek (top) used during construction of a concrete floodway. Rock mulch placed on the same bank to mitigate soil erosion (bottom).

4.8.2 Culverts at Stream Crossings

Culverts and elevated causeways constructed at stream crossings require careful design consideration to minimise erosion both upstream and downstream of the culvert. This is particularly the case in dispersive soils commonly associated with alluvial soils and stream banks in Queensland. Culverts at stream crossings require RPEQ advice and Fisheries Act (waterway barrier works) approval or accepted development requirements (ADR). Key aspects to consider include:

- Fish passage may need to be accommodated and if required will have a significant effect on the design of the culvert.
- The culvert invert level should be as close as possible to the natural bed level (except fish passage culverts which must be buried).
- Culverts need to be installed on a suitable foundation and may require additional works in-stream to prevent subsidence.
- In dispersive soils, compaction at optimum moisture content using a vibrating roller is important to avoid tunnelling or piping erosion.
- Rock capping with underlying geofabric at inlets and outlets protects against scour (Figure 54).
- A rock apron with geofabric should be provided to the drain at the outlet of culverts. As a general guide for single pipe culverts up to 1.2 m in diameter:
  - Aprons should be constructed using a 600 mm thick layer of 350 mm rock.
  - Aprons should be about 4 to 8 m long and the full width of the outlet channel including the banks (Figure 55).
- Banks and beds of realigned channels in dispersive soils should be covered with geofabric before being rock armoured or chemically treated before being capped with stable topsoil and revegetated.
- If the culvert directs a jet of concentrated water at downstream streambanks, these banks also need to be rock armoured (Figure 55).

Figure 55:
A well armoured box culvert with rock/concrete mix (left) but a lack of rock scour protection on the outside creek bank downstream (right).

Figure 56:
Minimal erosion control measures downstream of a concrete culvert, including a lack of rock protection and collapsed grade control structure and silt fence that were inadequate for the catchment area.

Figure 57:
Inadequate rock erosion protection at the inlet of large box culvert, with associated gullying and slumping.

4.9 Road Pavement for Erosion Control

4.9.1 Pavement Maintenance

4.9.1.1 Road Base Composition and Fine Sediment Production

The pavement or running surface of unsealed roads can be a significant source of eroded sediment. This is on the order of 20% of the annual fine sediment < 20 μm generated from the road system (running surface, batters, drains) with a vertical erosion of 5 to 60 mm/year[69]. The composition of road base and its fine sediment binder are critical for resistance to erosion during heavy rainfall and flooding. Unsealed pavements have an inherent soil erodibility factor for a given rainfall erosivity, which changes with time and traffic.

Industry best practise guidelines for unsealed road pavements should be followed where applicable to address the aspects of operational demands, performance expectation, pavement configurations, suitable pavement materials, stabilised materials and binders, pavement design, drainage and erosion protection[4,1,2,3,32]. However, these industry guidelines are deficient on information on how best to reduce the production of fine sediment < 20 um from unsealed road pavements to reduce water quality pollution, beyond the pavement integrity and drivability. More experimentation is needed by local Councils and QTMR in different climates to find innovative solutions to reduce fine sediment production from pavements to local waterways and the GBR[63].

The particle size distribution of road base can vary by specification for wearing course, base, and subbase[4,3,32], climate, quarry type, geologic material and mineralogy (Figure 57). A fine sediment binder is mixed with the screened gravel at commercial quarries, whereas ridge gravel pits have more variable fine sediment composition. The 'fines component' < 0.425 mm (medium sand to clay)[32], and its distribution varies greatly by specification and source (decomposed granite/diorite, basalt, sedimentary rock). The percentage of fine silt vs. clay is controlled by Atterberg limit specifications for linear shrinkage (LS), liquid limit (LL %), plastic index (PI), along with the California Bearing Ratio (CBR). Adjusting these indicators (often beyond specifications), along with particle size, mineralogy and inclusion of binders, is key to reducing erosion of fine sediment < 20 um. Often, road performance is assessed by the shrinkage product (increasing plasticity) and grading coefficient (increasing coarseness and gap). A target zone exists for 'good' stable roads with poor performance in other zones (erodible, ravel, slippery) varying by climate Figure 58[63,4].

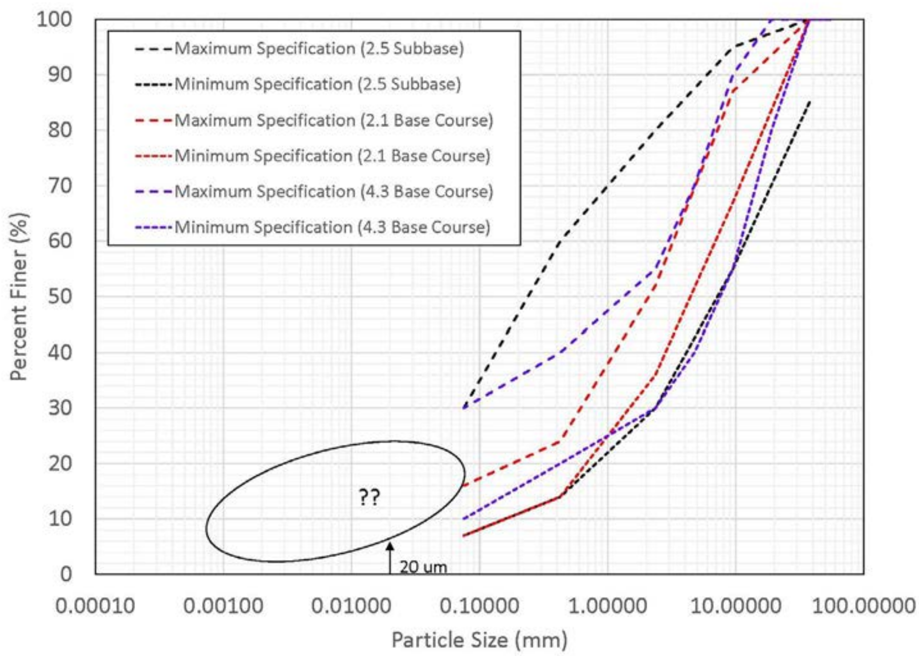


Figure 58: *Specification examples for unsealed road base particle size distributions[32], with the % < 20 um (GBR concern) dictated by Atterberg limit specifications.*

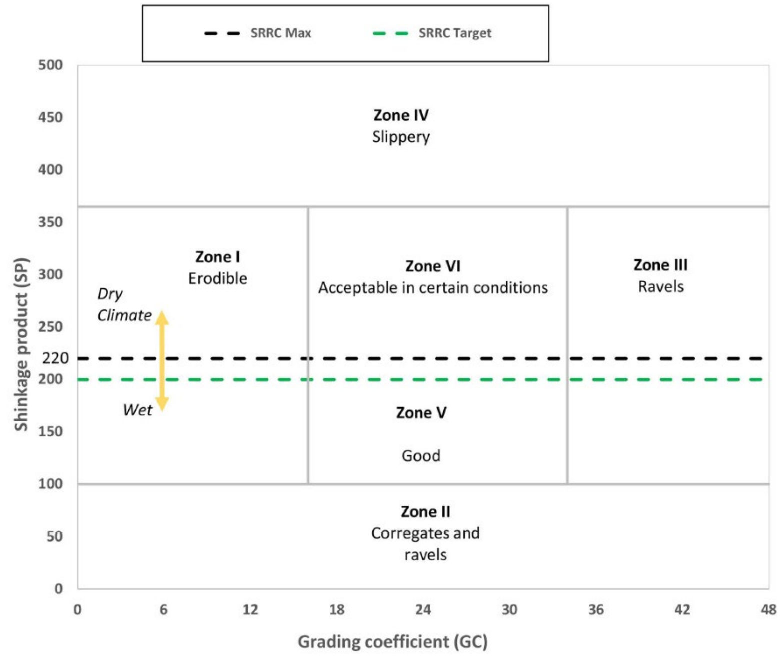


Figure 59:
Road performance base on grading coefficient (increasing coarseness and gap) and shrinkage product (increasing plasticity)[63].

Case Study: Use of Type 2.5 Road Base in Coastal Environments

In Far North Queensland, some councils use Type 2.5 'subbase' material with a decomposed diorite binder for the wearing course of unsealed roads. It is used due to its higher range of fine sediment (Figure 57) that binds better in wet environments compared to bonier Type 2.1 or 2.3. The drawback is it does not hold up as well in the dry season higher traffic (unravelling, dusty) and needs to be reapplied every year. It also results in major pollution of fine silt to local creeks and the GBR[69]. Quarry and independent sieve analyses indicate that the material passes QTMR (2022) specifications, as well as the soaked CBR (> 15) and 4 to 8% < 0.004 mm clay needed to pass the linear shrinkage (LS) and plastic index (PI) tests. However, more detailed particle size analyses (Mastersizer) indicate a much higher fine silt (4–63um) content than sieving, both at the product delivery stage and after rolling and compaction (Figure 59). This is because the silt particles are dispersible both with water and chemically.

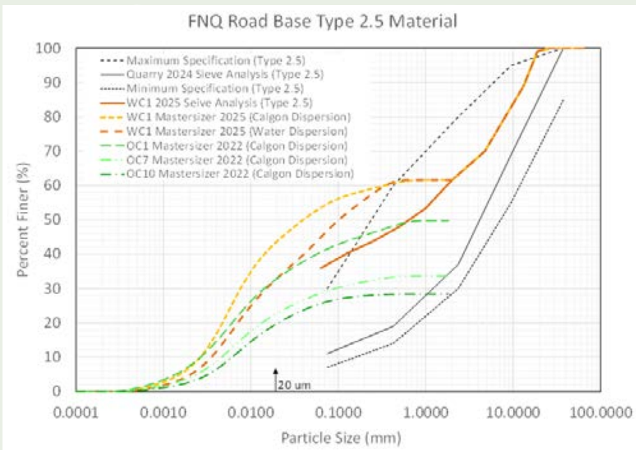


Figure 60:
Particle size distribution of Type 2.5 road base as tested by sieving and laser diffraction (Mastersizer).

More experimentation is needed to reduce the field silt content (4 to 63 um) of this Type 2.5 road base to develop a better graded and more stable product. Substituting the silt/clay mineralogy of the binder is one option. Increasing the clay content beyond specifications for the PI (3.5 to 8) is another option, as clay binders with PI of 10-15 make more stable roads over longer periods of time, as long as the soaked CBR is acceptable and the road is not too slippery when driving (Figure 58). Additionally, or alternatively, chemical binders (e.g., lime) could be used in the mix following the above industry standards. Light primer seals could also be useful on the shoulders of the road pavement where erosion is greatest.

4.9.1.2 Road Pavement Re-grading

4.9.1.2.1 Compaction

Compaction (rolling) at the OMC and rolling duration (minimum number of passes) are key to stable road base for unsealed roads. Excess moisture during compaction can lead to premature failure of granular pavements, as can inadequate moisture below OMC[32]. Grader mixing of road base on site and obtaining OMC are critical for compaction and longer-term stability. This is especially important in the hotter drier months (August-December) leading up to summer when road works are commonly conducted before the wet season.

Complete mixing of road base on-site with a grader (after transport) is important to ensure the binder and gravel are well mixed and not segregated (uneven distribution of particle sizes) by gravity during handling and unloading. Stony road patches are a sign of both poor mixing and incorrect moisture. While more mixing time may slow the job down, the compaction results will create a more durable road for the road user and the environment.

The duration and extent of rolling (minimum number of passes) has implications for compaction and pavement durability. Particularly, road shoulders near table drains are often neglected during rolling and subsequently erode. The skill and training of the roller operator(s) are important on unsealed roads. Compaction (rolling) at the OMC and rolling duration are key to stable road base of unsealed roads.

'Proof rolling' compaction tests can help ensure the compaction and integrity of the unsealed road pavements. Compaction tests are less commonly used for unsealed roads, compared to preparatory compaction before road sealing. However, 'proof rolling' of pavement layers and shoulders can detect incomplete compaction by showing perceptible surface deformation[32].

4.9.1.2.2 Loose Road Base in Drains

Waste road base material left in table drains is common along unsealed roads. This uncompacted material is readily mobilised during the first rain events and the fine sediment easily flushed into local waterways. This wasted excess material has been paid for, so waste material and overspill are also a significant inefficiency factor as well as detrimental to water quality. Road base material should be kept out of table drains by concentrating mixing on the road surface and minimising grading spillover into drains.

4.9.1.2.3 Road Shape During Re-grading

Information and guidance on road pavement construction and maintenance can be found in ARRB[2] and IPWEAQ[20]. Best Practice for unsealed road re-grading maintenance include:

- Maintaining a 5% cross fall and super-elevate as required through bends.
- Protecting the road pavement and subgrade by reducing water ingress.
- Obtaining good compaction of the pavement including the shoulders at OMC and rolling duration (minimum number of passes) as quantified with proof rolls.
- Avoiding spilling road base windrows into table drains.
- Protecting erosion sensitive areas during construction.

4.9.2 Road Surface Sealing for Erosion Control

4.9.2.1 Bitumen 'Dust Seal'

For some roads, it may be possible to apply a two-coat bitumen 'dust seal' to an existing unsealed road without changing the road alignment or pavement (Figure 60). In some cases, preparation for sealing can simply be completion of a medium or heavy formation grade and rolling to prepare the existing road base for a two-coat seal. In other cases, an additional gravel overlay will be needed before sealing. The change of a section of road from unsealed to sealed road requires the approval of an RPEQ who will consider the road alignment, geometry, safety, signage, speed control and pavement strength. Dust sealing treatment is not suitable in all situations[35].

Benefits include:

- Reduced sediment loads entering the drainage system from the road surface.
- Avoids washouts and corrugations.
- Table drains will not fill with sediment so quickly and do not need to be cleaned out frequently.
- Maintenance needs of road batters and verges also decreases.

Cons include:

- Initial sealing is costly ($110,000/km, 2024 prices), but costs less than a full upgrade ($1 million/km).
- Drains may require more erosion control measures to ensure stability to protect the investment in the dust seal (Figure 61).

Consideration should be given to dust sealing the steeper approaches to stream crossings (± 200 to 500 m) where road surface, drain and batter erosion is likely to be highest. Addressing hotspots at erosion at creek crossings will have the most significant cumulative effect on reducing erosion and improving environmental outcomes.

Figure 61:
An unsealed road and stream crossing approach before (left, 2023) and after (right, 2024) a two-coat seal on top of a heavy formation grade (batters and drains left ungraded).

Figure 62:
A bitumen 'dust seal' for community amenity on an existing alignment with sodic soils. Note untreated gully on drain outlet threatens road stability and Reef health.

4.9.2.2 Alternatives for Floodway Approaches (steep grades)

Road base at the steeper approaches (± 50 m) to stream crossings often experiences higher erosion rates due to increased slope, inability to divert water away from the road cut, and vehicle traffic climbing in and out of the crossing. While bitumen dust seals (or concrete) and rock armoured table drains are the best solutions for these situations, there are alternatives.

Cellular confinement systems use a grid geocell that can contain and stabilise road base gravel. These three-dimensional cell grids are backfilled with gravel road base and the cells improve gravel retention and interlocking of the material (Figure 62). They could significantly reduce erosion of road base material near stream crossings by retaining gravel and minimising road base unravelling. The disadvantage is that future grading of the surface would need to be conducted with attention and caution to avoid damaging the geocells. They are also made of plastic, commonly polyethylene (HDPE), which, over a 100-year lifetime, could break down, rip off and pollute local streams.

Figure 63:
A cellular confinement system (diamond shape) used to stabilise road base at an approach to a concrete floodway (Cassowary Coast Regional Council, photo Justin Fischer).

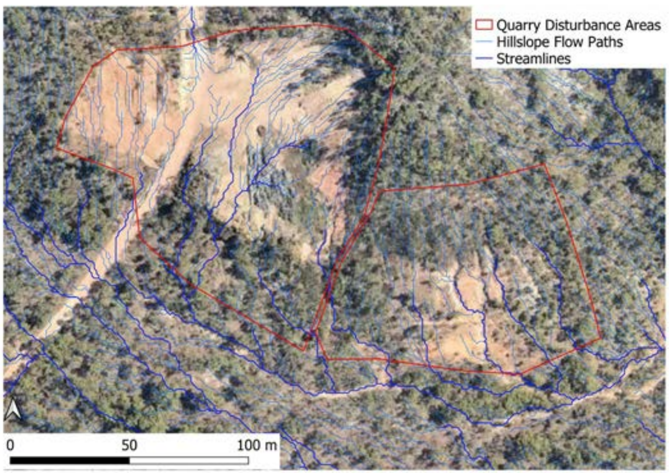
4.10 Gravel Pit Erosion, Sediment Retention, and Rehabilitation

Gravel pits (borrow pits or quarry pits) are used to win material for rural unsealed road construction and surfacing[3,4]. These gravel pits are a cheaper and practical alternative for sourcing material locally, compared to long-haul transport from commercial rock quarries, even if permission and payments need to be arranged with landowners adjacent to the road reserve. This can extend the funding available for road investment and also make available additional rock material for erosion control betterments off such as gully and batter control. However, the durability and quality of country rock varies greatly, and can impact the quality of the road running surface as well as its erodibility and run-off of fine sediment < 20 µm (see Section 4.9.1).

Figure 64:
A roadside gravel pit that drains directly to a stream in background via a gully channel outlet.

The extent of erosion and off-site pollution of gravel pits depends on their topographic position, slope, erodibility of the country rock, proximity to any stream or flow channel, access tracks and their stability, time since disturbance, extent of natural vegetation colonisation, and any progressive erosion and sediment control measures put in place to control run-off. Locations on shallow ridges, well away from streams and channels, are key to sustainability, as are the condition of the access tracks in and out of quarries. Sourcing material inside the road reserve next to unsealed roads and stream crossings is not sustainable (Figure 63). Multiple legal Acts are applicable to use and rehabilitation (see Section 2.2).

Gravel pit quarries should be rehabilitated progressively each year that they are utilised[3,4]. This will prevent progressive sheet, rill and gully erosion each wet season that become harder to address over time. Legacy un-rehabilitated gravel pits are eroding and ubiquitous across the rural landscape of Queensland, with some councils claiming they are neither responsible for nor funded to clean up past mistakes (Figure 64). Road authorities should consider including funding for progressive and functional rehabilitation in the cost of supplying material to the program and unsealed road, rather than ignoring rehabilitation or undertaking by ad hoc measures. This cost is usually around 10% of the costs of sourcing, digging and transporting the material to the site of use. The impacts of gravel pit quarries should not be externalised to the environment (weeds, sediment pollution, culture, aesthetics).



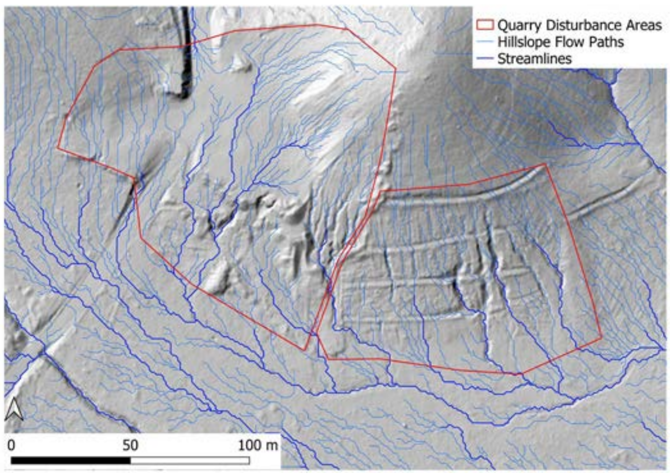


Figure 65:
Legacy gravel pit quarries that have not been properly rehabilitated remain sediment sources for decades after use and pollute local streams, as seen in aerial photo (left) and LiDAR (right).

Rehabilitation of gravel pits for erosion and sediment control should include:

- Creating a sediment trap (pit) that traps water and sediment laden run-off.
- Ensuring that the outlet flow of the gravel pit is directed to flat vegetated depositional areas that further filter water and sediment, aided by multiple functional silt fences.
- Armour gravel pit outlets channels with rock and control gully prone areas with rock chutes (Figure 47, Figure 65) to prevent incision from excess run-off and concentrated flow.
- Stabilising the hillslopes of the gravel quarry by battering to stable angle, creating retention bunds, deep ripping or constructing terraces on contour to check flow and, where needed, construction of batter rock chutes to manage concentrated flows. Revegetating the disturbed quarry area, by respreading stockpiled topsoil, adding additional organic rich topsoil where needed and seeding the area with native grass, shrub and tree species.
    - Some shrubby Acacia species and select native grasses are excellent at colonising rock substrate.
- Controlling the invasion of weed plant species brought into the quarry during use or colonised into the disturbed area. Follow up treatment over time. Weed control is a Biosecurity Act obligation.

Figure 66:
Abandoned gravel pit without proper rehabilitation and turbid rainfall run-off (top) and outflows causing downstream gully erosion and sediment pollution (bottom).

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6. Glossary

Aggradation (fill): means the increase in land elevation due to the deposition of sediment, typically bed material. Aggradation (fill) typically occurs where the supply of sediment is greater the channel's ability to transport it.

Apron, Rock Apron: means a designed layer of erosion resistant material placed at the bottom of a slope to direct water horizontally away from the slope and prevent the formation of a plunge pool close to the bottom of the slope. A rock armoured energy dissipation zone.

Floodway (ford or causeway): means a drivable structure of rock or concrete that crosses a stream at bed level and allows free passage of flood flows, sediment, debris and fish.

Check Dam: Also Grade Control Weir: means a small loose rock grade control structure within a small water course or drain which has the following features; a crest, batter protection, a downstream slope and an apron. Designs for Type 1 (well-graded rock with long scour protection) and Type 2 (poorly-graded rock with steep face) versions are available. Check dams may also include geofabric in their construction. Check dams are usually small (up to about 20 tonnes each) and usually do not have cut-off walls.

Degradation (cut): means the decrease in land elevation due to the removal, cut or scour of sediment, typically bed material. Degradation (scour) typically occurs where the supply of sediment is less the channel's ability to transport it.

Diversion Drain, Turnout Drain, Cut-Off Drain, Mitre Drain, Catch Drain: Means a drain cut into the side of a table drain on the low side of the road to direct water away from the road.

Geofabric: refers to a geofabric that complies with TMR specification MRTS27 Geotextiles Separation and Filtration for strength class C. For example, Bidim A24 meets this specification.

Grade Control Structure, Riffle: means a specifically designed loose rock structure within a water course or drain of any size which has the following features; a crest, batter protection, a downstream slope and an apron. Grade Control Structures may also include geofabric and or cut off walls in their construction. Often a plunge pool will develop immediately downstream from the Grade Control Structure, and should be rock armoured as part of the design.

Gravel lag: refers to the development of a layer of gravel (larger, harder particles) on the eroding surface of a bare soil slope by removal of the fine grains of soil by erosion under the action of rainfall impact.

Head Cut: refers to the abrupt (usually vertical) change of the bed level of a watercourse. It is more usual for this term to be used of an actively eroding watercourse.

Hillslope Drain: means a drain across a slope generally to divert overland flow away from road batters.

Levee, Training Levee, Berm, Bank: earth or rock lined earthen structure constructed to divert water to a different discharge point.

Level Spreader: Refers to an outlet structure constructed at the downstream end of diversion drain where it discharges to open ground. The structure is shaped to provide a very wide, low velocity outlet shape to discharge flows as a wide shallow flow to spread water out across natural landscape. Refer to Figure 39.

Rock Chute: means a rock lined channel constructed specifically to convey water down a slope without causing erosion to the slope (also a grade control structure). A plunge pool is constructed immediately downstream from the Rock Chute. Refer to Figure 47.

Rock Mulch: means a well-graded mix of unscreened crushed rock (often directly from a rock crusher) containing a reasonable proportion of fines (D10) to fill the pore spaces of larger rock (D90) to create a dense protective layer to a batter or soil surface to prevent erosion. Over time humus and natural debris will accumulate in the Rock Mulch providing a seed bed that will aid in the revegetation of the area.

Table Drain: Means the drain located next to the road shoulder.

Appendix A

Appendix B

Australian Government
REEF TRUST
Great Barrier Reef Foundation
South Cape York Catchments
SEEC
JosephConsulting
LGAQ Every Queensland community deserves to be a liveable one