# Erosion Control for Unsealed Roads

## A Practical Guideline to Minimise Sediment Discharge

**Version 1.1** January 2025

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Great Barrier Reef Foundation
South Cape York Catchments
LGAQ Every Queensland community deserves to be a liveable one

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## Authorship

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## Disclaimer



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

# 1 Introduction

## 1.1 Scope and Purpose of this Guideline

Queensland has approximately 39,000 kilometres of unsealed formed roads that Local Government directly manages, with an additional 600 km 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 fewer road users. However, unsealed roads are a significant source of sediment to freshwater streams and marine ecosystems, including the Great Barrier Reef (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 (Waterhouse et al. 2024). 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 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.

The purpose of this document is to provide roads asset managers with a practical guide to better understand best practice management of unsealed roads to minimise the generation and discharge of fine sediment. Minimising the erosion of road pavements and associated table drains and embankments will reduce maintenance time and costs, in addition to reducing fine sediment discharged to local waterways and ultimately the reef.

This guideline draws on erosion control trials and insights gained from collaboration with seven Queensland Reef Councils from 2021-2024 (Johnson et al. 2024; Klye et al. 2024; Shellberg et al. 2024a). Detailed methodologies and study results are reviewed in Section 2.5. Additional studies and guidelines have been used as listed in the references.

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

## 1.2 Limitations of this Guideline

The guideline 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 Great Barrier Reef.

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, engineering advice and design can only be provided by a Registered Professional Engineer of Queensland (RPEQ) where significant changes are proposed to the road or drainage infrastructure. Seek expert advice, particularly for high-risk sites.

# 2 Background

## 2.1 Unsealed Roads in Queensland

Unsealed roads are typically formed from local materials and capped with gravel road base from local quarries and borrow pits. Standards for design, construction, and maintenance vary across the state, and road authorities face challenges due to insufficient resources to construct and maintain roads to acceptable standards. Standards for unsealed roads are typically based on traffic loads and available maintenance funds with minimal consideration given to runoff water quality and downstream impacts. Generally, unsealed roads are built to meet a specific level of service, formed and gravelled with a layer of imported quarried material, and maintained periodically. Locations can be remote and suitable materials can be scarce. Unsealed roads are often constructed using materials obtained from within the road reserve.

There are also many unformed, non-engineered roads and tracks across Queensland that are used for private access; but these roads are *not* the focus of this guideline. Guidelines for erosion control on unformed, non-engineered roads and tracks can be found elsewhere (Jolley 2009; QDERM 2010abc; Shellberg et al. 2024b).

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

## 2.2 Legal Responsibilities

**Everyone in Queensland** has a general environmental duty to not cause environmental harm, this includes sediment pollution runoff from unsealed roads. Unsealed roads, if not managed well, have the potential to generate significant sediment loads and cause environmental harm. The design, construction and maintenance of unsealed roads must be managed to limit harm. Minimising sediment loads is a legislated requirement for all road managers.

Key environmental legislation relevant to the construction and maintenance of unsealed roads include:

**The Queensland Environmental Protection Act (1994):**

- Mandates to all persons a General Environmental Duty (Section 319) to minimise environmental harm.
- Disturbing the soil and releasing sediment from worksites without taking measures to protect the environment is considered causing environmental harm.
- 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).
- A person who caused or permitted an incident involving contamination of the environment that results in unlawful environmental harm must, as soon as reasonably practicable after the incident happens, take measures, to rehabilitate or restore the environment to its condition before the harm (the duty to restore the environment) (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 and do not lose soil due to sheet, rill or gully erosion, or lead to sedimentation or 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 the Great Barrier Reef catchment.
- Relevant activities must avoid a residual impact defined as "the presence of fine sediment, or DIN (dissolved inorganic nitrogen), in Great Barrier Reef catchment waters that a) was released to the water because of the relevant activity; and b) remains, or is likely to remain in the water despite mitigation measures for the relevant activity".

**Fisheries Act (1994)**

- Mandates the management and protection of fish resources and habitats, including minimisation of impacts to fish and their habitat. Regulates "waterway barrier works" that may inhibit the free movement of fish along waterways and onto floodplains.
- 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 if the barrier limits fish access to, or movement within, a designated waterway (Queensland Government 2018).
- The accepted development requirements (ADR) state that "impacts on water quality are to be minimised by undertaking the works to the standard set out in the current version of the Best Practice Erosion and Sediment Control, published by the International Erosion Control Association, Australasia" (Queensland Government 2018).

**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 applies to all land in Queensland (tenure blind) and is still applicable to land where Native Title has been extinguished (i.e., road reserves).
- Aboriginal cultural heritage is anything that is a significant Aboriginal area or an area/object that is particularly significant because of Aboriginal tradition or history.

**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).

There are wide variations in the application and enforcement of the Qld Acts and Policies by Local Governments (Healthy Land & Water 2022). 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 (Healthy Land & Water 2023).

## 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.

**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).

**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 Great Barrier Reef 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.

Minimising the financial cost of road maintenance is well understood and is typically factored into road design and maintenance. This guideline 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 (see below; Erlandsen et al. 2024).

## 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 Great Barrier Reef (GBR) Lagoon (Waterhouse et al. 2024). 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 (Queensland Government and Australian Government 2018). Unsealed roads are an increasingly appreciated, but poorly measured or modelled, source of anthropogenic fine sediment in GBR catchments (Bartley and Murray 2024).

Key impacts of fine sediment on downstream ecosystems include:

- Reduced water quality and increased turbidity that can cause the water to become clouded, reducing light penetration and photosynthesis.
- Sediment can settle on the beds of rivers, lakes, and coastal areas, smothering habitats critical for fish spawning, macroinvertebrates, and benthic organisms.
- Sedimentation can change water flow patterns, leading to changes in the distribution of aquatic plants and altering habitats.
- Fish and other aquatic animals can experience gill irritation, clogging and damage, making it difficult for them to extract oxygen from the water.
- Sediment can affect the ability of filter feeders, such as shellfish and some invertebrates, to obtain food, impacting their growth and survival.
- Sediment often carries other pollutants, such as heavy metals and nutrients. High levels of nutrients can lead to excessive algal growth, depleting oxygen levels.
- In marine environments, sediment settling on coral reefs can block sunlight and suffocate corals, preventing them from performing photosynthesis and building their calcium carbonate structures.
- Persistent sedimentation can make corals more susceptible to stress and diseases, impairing growth and resilience.
- Degraded water quality and habitats can affect industries that rely on healthy ecosystems, such as fisheries and tourism, such as the Great Barrier Reef.
- Craik and Dutton, 1987; Hopley et al. 1990; Ayling and Ayling 1991; Waters 1995; Ramos Scharron et al. 2023; 2024; Waterhouse et al. 2021; 2024; Howley et al. 2024.

*Figure 3 Sediment laden runoff from a road into a creek (left) and a typical river sediment plume in the GBR lagoon (right).*

## 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. Unsealed roads create persistent bare ground exposed to rainfall and runoff, alter water runoff processes, increase gully frequency, and increase coarse and fine sediment supply to the stream network (Reid and Dunne 1984; Montgomery 1994; Ziegler and Giambelluca 1997; Croke and Mockler 2001; Nyssen et al. 2002; Lane and Sheridan 2002). International data on unsealed road erosion rates range from 2.4 to 273 t/ha/yr (gravel, sand, silt, clay), with median values around 22 t/ha/yr (Fu et al. 2010). The variability in erosion rates depends on rainfall, slope, parent soils, road surface material, drainage design, management regime, time since construction or grading, vegetation cover, and traffic (Fu et al. 2010; Alvis et al. 2022). This range of road erosion values is commonly at least an order of magnitude (10x) higher than background rates in surrounding less disturbed catchments (Ramos Scharron et al. 2023; 2024). Application of effective erosion control Best Management Practices (BMPs) can significantly reduce unsealed road erosion (Turton et al. 2009; Shellberg et al. 2024a).

In Queensland, limited spatial and temporal data exist on erosion rates from unsealed roads in catchments draining to the Great Barrier Reef. Hopley et al. (1990) documented that suspended sediment concentrations (SSC) on average were 22 times higher downstream of road crossings compared to upstream during and after road construction through the Cape Tribulation rainforest. Gleeson (2012) measured SSC 2 to 4 orders of magnitude (100 to 10,000 times) higher in streams downstream of unsealed road crossings compared to upstream grazing land in the Normanby Catchment on central Cape York Peninsula. Road cut batters, table drains, V-drains, and associated gullies were deemed the major sources of eroded sediment. In the Bowen-Burdekin Catchment, Claussen and Telfer (2021) measured high SSC > 3000 mg/L (< 20 μm) during the first flush rainfall event, with slightly lower concentrations in flat-bottom drains compared to V-drains. For a 1 km road section, they estimated 2 tonnes per rain event were being flushed from the road on average.

### 2.5.2 Cleaner Road Runoff Project – LGAQ Case Study

LGAQ in partnership with the Great Barrier Reef Foundation, launched the Cleaner Road Runoff 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 (Johnson et al. 2024). 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 runoff to be undertaken and highlighted that unsealed roads can generate a significant volume of sediment during runoff events, between 1.8 t/ha/yr and 11.5 t/ha/year. Although not all of this fine sediment will make its way into local waterways or the reef lagoon, reducing the fine sediment load from unsealed roads will improve the health of local waterways and the reef. This guidance document is based in part on the testing and knowledge gained from working collaboratively with the five Reef Councils (Johnson et al. 2024).

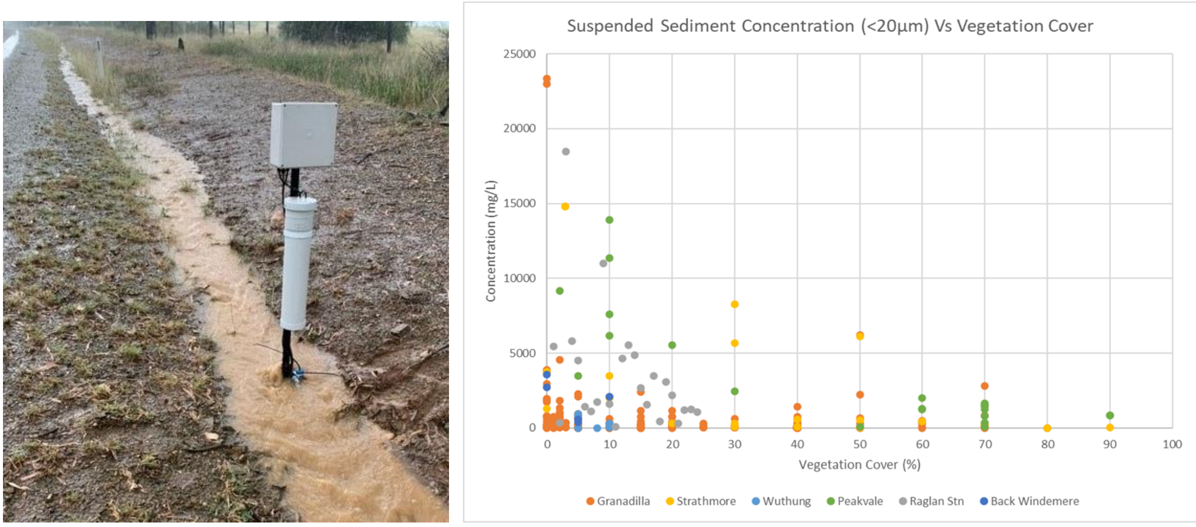



*Figure 4 LGAQ sediment sampler (left) and inverse relationship between sediment concentration and vegetation cover (right).*

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

South Cape York Catchments (SCYC) partnered with Cook Shire Council (CSC) 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) (Shellberg et al. 2024a). The goals were to assess 1) baseline erosion from status quo maintenance, and 2) reductions in erosion from applying Best Management Practices (BMPs) to reduce fine sediment loads delivered to the Great Barrier Reef (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 (Klye et al. 2024) and this guidance document is based in part on that work.

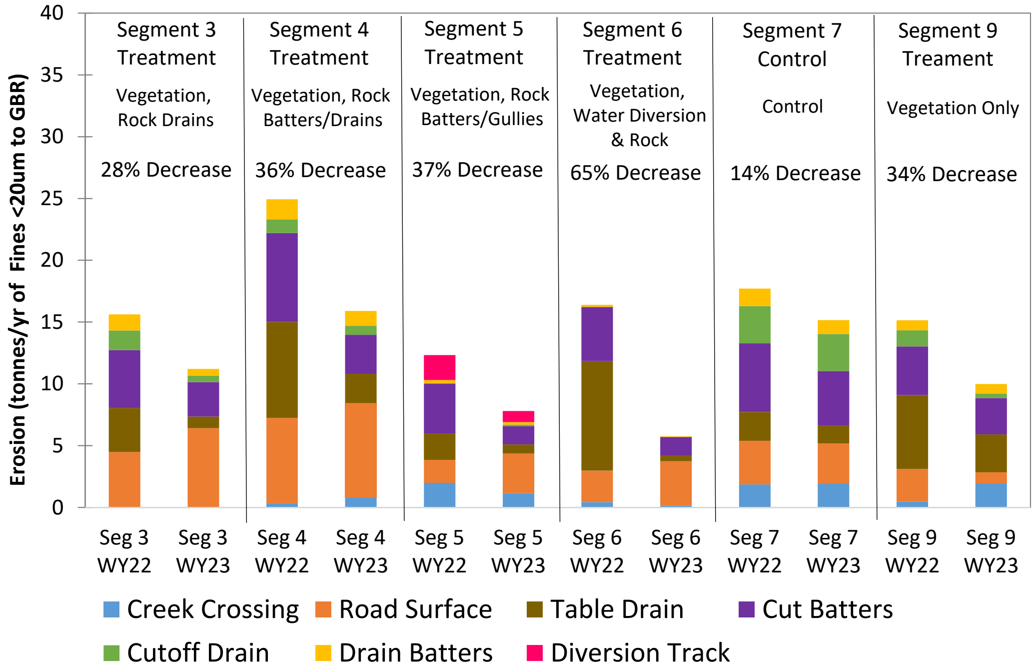



*Figure 5 Erosion rates by road element over two years at treatment and control sites.*

A Cost-Benefit Analysis (CBA) of alternative management practices was conducted by Erlandsen et al. (2024) using erosion data from Shellberg et al (2024a). Four different scenarios of road maintenance and betterment were analysed, inclusive of sediment abatement costs externalised to the environment. These included 1) Business-As-Usual (BAU), 2) Vegetation Management, 3) Major Erosion Control, and 4) Full Betterment (Figure 6). 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.

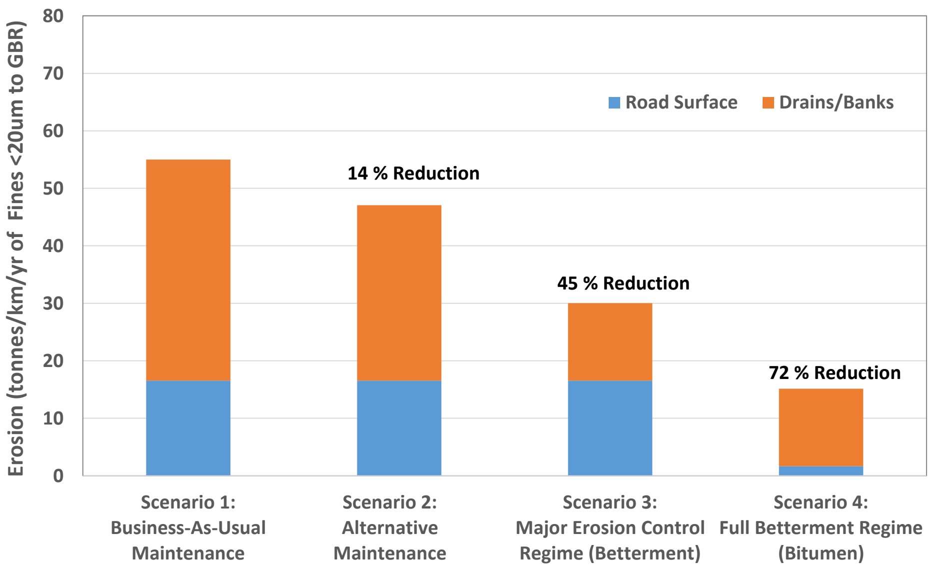



*Figure 6 Scenarios of erosion used for the cost-benefit analysis (CBA) by Erlandsen et al. (2024).*

# 3 Unsealed Road Design and Maintenance Standards

## 3.1 Existing Unsealed Road Design Standards

Current unsealed road design standards are reviewed below and should be adopted where applicable. However, most of these standards 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 standards.

### 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 (AUSTROADS 2016). The guide includes design processes and formula necessary to design effective drainage systems and infrastructure.

### 3.1.2 ARRB Unsealed Roads Best Practice Manual

The 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 (ARRB 2020). The guide reflects current global best practice and information to effectively manage unsealed roads across Australia to improve mobility and safety. The manual does include an environmental considerations section with important erosion control guidance. ARRB (NTRO) also provides training on unsealed road management.

### 3.1.3 IPWEAQ Lower Order Road Design Guideline

The 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 (IPWEAQ 2016).

### 3.1.4 QTMR Road Drainage Manual

The Road Drainage Manual (RDM) sets out a multi-disciplinary approach to the provision of drainage infrastructure for State controlled main roads (QTMR 2019). 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-reference the Australian Rainfall and Runoff (ARR) 2019, the Queensland Urban Drainage Manual (QUDM) and Austroads Guide to Road Design.

### 3.1.5 Local Standards

Each Council has design guidelines they reference for new engineering works. They typically include key references for recognised national and state guidelines such as AUTROADS 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 (QRA 2018) 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' (SP_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)(QRA 2018). By default practice, diversion V-drains are cleaned of sediment and vegetation, and road batters and verges are graded to remove grass and trees (Figure 1; Figure 7; Figure 14).

## 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 the 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 fast 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 during maintenance.
- 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 is 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.

*Figure 7 Typical maintenance work and medium formation grading on an unsealed road.*

## 3.4 Existing Erosion Control Guidelines and Gaps in Existing Standards

Best Practice for road construction and management are often different and not always inclusive of erosion control Best Management Practices (BMPs) for preventing erosion or reducing non-point source pollution along roads (e.g., Skorseth et al 2015; IPWEAQ 2016; ARRB 2020). For example, Queensland's Lower Order Road Design Guidelines (IPWEAQ 2016) mentions erosion just once.

The Australian Road Research Board (ARRB) report on *Unsealed Roads Best Practice Guide* (ARRB 2020) was created for Local Government Councils in Australia to "*expand their understanding and capacity to manage road infrastructure effectively and to fulfil their obligations to the community while also improving mobility and safety*". The ARRB report focuses on Assets, Design, Construction and Maintenance. It does have a useful Appendix A that covers Environmental Considerations including Sediment and Erosion Risk, but most of these examples are targeted at Victoria and NSW temperate environments.

Many standard environmental considerations for unsealed road erosion control do not adequately address the erosion issues associated with highly dispersive and erodible sodic soils or regolith commonly found near stream crossings in Queensland and in Great Barrier

Reef Catchments. Other erosion control BMPs need to be drawn upon to address this gap (Shellberg and Brooks 2013; Wilkinson et al. 2022).

The key Erosion Control BMP references familiar to road engineers for unsealed roads in Queensland are:

- Australian Road Research Board (ARRB) Unsealed Roads Best Practice Guide (ARRB 2020).
- International Erosion Control Association (IECA) Best Practice Erosion and Sediment Control (Witheridge 2009).
- NSW OEH Erosion and Sediment Control on Unsealed Roads (NSW OEH), 2012.
- NSW RMS Guideline for Batter Surface Stabilisation Using Vegetation (Machar et al. 2015).
- TMR Road Drainage Manual (QTMR 2019).
- TMR Erosion and Sediment Control Technical Specification MRTS52 (QTMR 2021).
- TMR Managing Slaking and Dispersive Soil Risks in Transport Infrastructure Projects: Technical Note (QTMR 2023).
- Wet Tropics Road Best Practice Guidelines (Goosem et al. 2010; WTMA 2017).

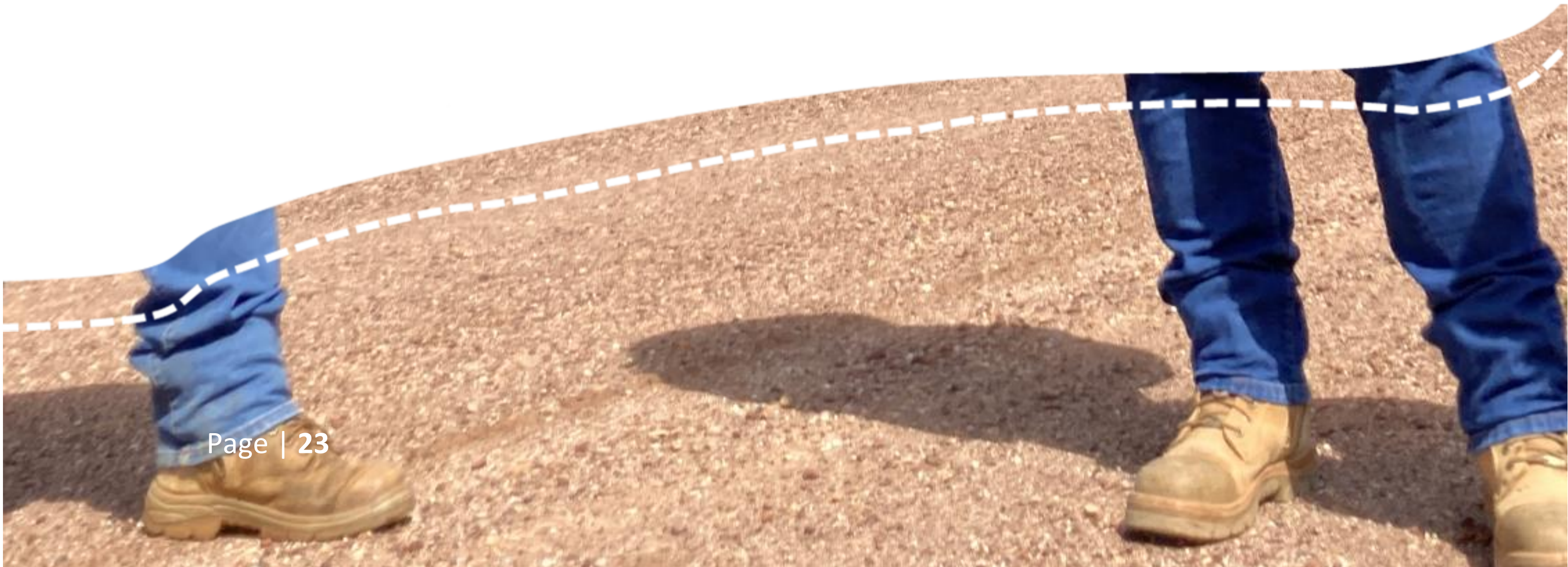
All of these references have valuable information that can be drawn upon for potential field application. These references rely on each other in many ways. The ARRB Unsealed Roads Best Practice Guide (ARRB 2020) relies on erosion and sediment control work by Kemp (2012), NSW OEH (2012), and QPWS (2014) on unsealed roads in Victoria, NSW, and QLD respectively. The TMR Erosion and Sediment Control Technical Specification (QTMR 2021), and Road Drainage Manual (QTMR 2019) refer the reader in detail to seek out and apply the IECA Best Practice Erosion and Sediment Control manual (Witheridge 2009), as does the Fisheries Act accepted development requirements (ADR)(Queensland Government 2018). Additional visual guidance is also provided by a more recent update for Erosion & Sediment Control at Road Construction sites in SE Qld (Witheridge 2017), but these are not always applicable to rural roads or tropical Queensland. Furthermore, the use of some of these reference guidelines may not be appropriate for dispersive or highly erodible soils.

Many other road erosion control BMPs also exist for unsealed roads internationally (Johansen et al. 1997; Copstead et al. 1998; Rashin et al. 1999; BRPC 2001; Bloser et al. 2012; Ice and Schilling 2012; Skorseth et al 2015; Edwards et al. 2016), some of which have been validated with rigorous monitoring of erosion rates over time (e.g., Turton et al. 2009).

This detailed guideline (Section 4) for "*Erosion Control for Unsealed Roads: A Practical Guideline 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 2

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



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

## 4.1 Scope

This section of the guideline 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. 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 Great Barrier Reef.

These BMPs are intended for application in the improvement of unsealed roads where there is an opportunity to change 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 (Erlandsen et al. 2024).

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.

Any change to current road management practices or to the road itself will inevitably attract comment from the public. It is important to provide some form of public information or education explaining why changes are being implemented.

## 4.2 Erosion and Sediment Control Principles and Risks

### 4.2.1 Basic Principles of Soil Erosion and Sediment Control Along Unsealed Roads

The following principles should be adopted in all management aspects of unsealed roads.

- Minimise Soil Disturbance

Avoiding all unnecessary soil and vegetation disturbance 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

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. This is particularly the case for steep batter slopes and cut banks, and dispersive soils. Apply surface treatments such as re-vegetation, mulching (including gravels), or hydromulch to reduce exposure to rainfall and runoff erosion.

- Treat and Cover Dispersive Sub-Soils

Dispersive sub-soils are prone to rapid erosion and should be identified, ameliorated and covered under stable soil. Dispersive sub-soils should be treated chemically (e.g. gypsum) where appropriate. Dispersive sub-soils should be covered with non-dispersive top-soil or rock mulch, and revegetated. Organic or rock mulch will aid revegetation.

- Reduce Water Flow or Discharge

Reducing flow volume within drains minimises the erosive power of runoff. This can be achieved by turning water away from table drains into diversion drains more frequently. Diversion drains must 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 must 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. Runoff 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 the Slope, Increasing Width and Roughness

Slower flow velocities on flatter slopes with more roughness (vegetation or rock lining) have less ability 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. 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. Steep channels may require drop structures or rock lining.

- Reduce the Direct Connectivity to Streams Crossings and Gullies

Most sediment delivery to streams happens 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 like rock lining are warranted.

- Control the 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 rock chutes or grade control structures, and revegetated.

- Bed Level Stream Crossings

Road bed level stream crossings can be protected from scouring by constructing rock or concrete floodways at the natural stream bed level to prevent undercutting and bank erosion and allow 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 crossing 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 the channel bed and banks downstream experiencing concentrated flow and scour.

- Maintain road shape

Table drains are required to efficiently collect runoff from unsealed pavements to improve safety and prevent scour and damage. Maintain road crossfall of between 4%-6% (ARRB, ARRB 2020) to direct runoff into table drains. 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) mixing of road base to avoid segregation, 2) compacting at optimal moisture content (OMC), 3) ensuring complete compaction with a minimum number of passes, particularly along shoulders, 4) avoid losing road base into table drains as waste, 5) providing stable non-dispersive fine material in road base from quarries, 6) minimising the breakdown of fines on site into particles < 20 µm from handling, transport grading, rolling and traffic.

### 4.2.2 Erosion Risk

#### *4.2.2.1 Key Risk Factors*

Soil erosion, sediment runoff, 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 Great Barrier Reef.
- 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).

#### *4.2.2.2 Erosion Risk Scores*

A risk score has been developed to assist 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).

*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 to 100 km | 3 | |
| | | < 10 km | 5 | |
| 9 | Annual Rainfall (mm/year) | < 600 mm | 1 | |

| Item | Description | Selection | Score | Adopted |
|---|---|---|---|---|
| | | 600 to 1200 mm | 5 | |
| | | > 1200 mm | 3 | |
| 10 | Roughness of road<br>(RACAS Roughometer Score or Number of Complaints) | Low | 1 | |
| | | Medium | 3 | |
| | | High | 5 | |
| 11 | Pavement Erodibility and<br>Binder % Fines < 20 µm<br>(Section 4.8) | 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 runoff 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 like 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 soils) and can be diagnosed via laboratory testing or by undertaking a simple field test (Emerson Aggregate Test). Place small pieces of DRY soil (about 5 mm across) 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.

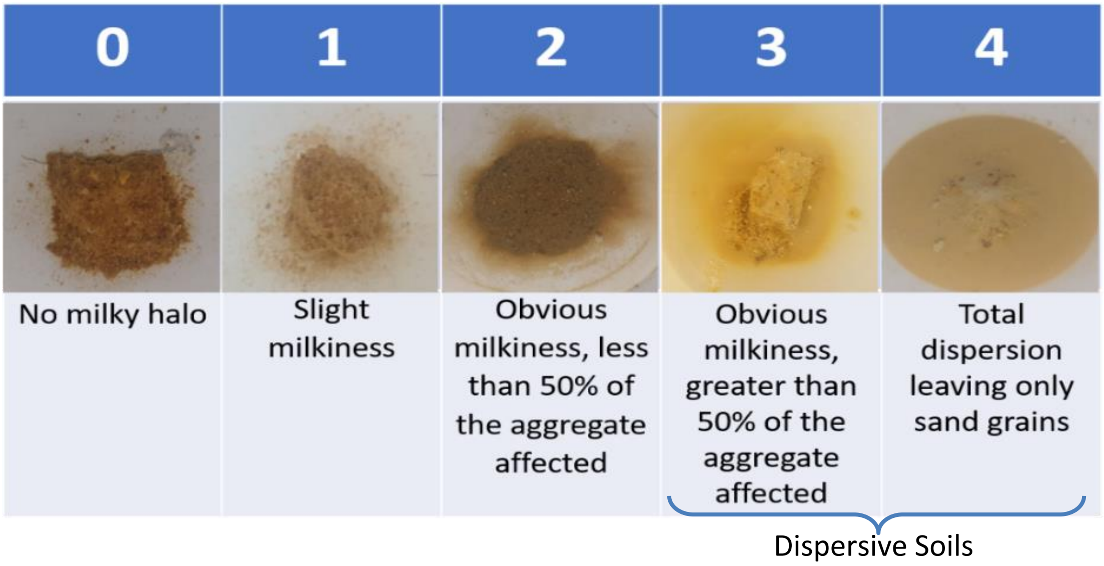



*Figure 8   Dispersion Index class upon wetting of dry soil aggregates.*

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 top-soil and revegetate with suitable grass species (native preferred). OR
- Cover dispersive sub-soils with unscreened rock mulch armour.

*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 Minimise Soil Disturbance

### 4.3.1 Work Site Footprint

To effectively reduce erosion, it is essential to minimise the overall work site footprint and 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. 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.

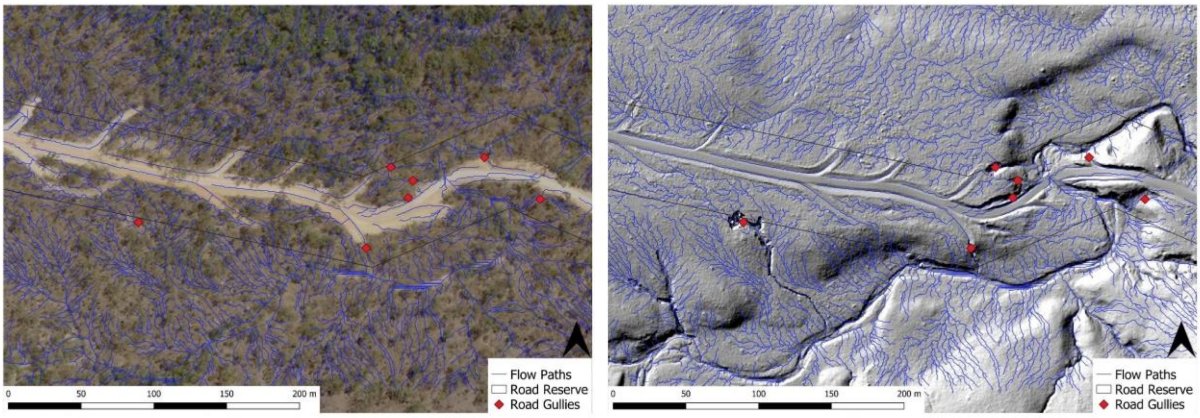



*Figure 10 Unsealed road disturbance area shown in Air Photo (left) and LiDAR hillshade (right).*

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

### 4.3.2 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 wash off. Treatments can include organic mulching, rock mulching, gravel cover, revegetation, soil binders etc.

Imported road-base (gravel and binder) watered and compacted generally resists erosion to a greater degree, but still produces fine sediment runoff < 20 µm (see Section 4.8).

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 if 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).

#### 4.3.3 Vegetation Management

Roadside vegetation is typically “managed” by grading (and removal) before the wet season resulting in large areas of exposed soil. This causes significant soil disturbance through the 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 the following.

- Maximise vegetation cover (particularly grass) along road verges.
  - Leave vegetation in place where stable and not a hazard.
  - Slashing or herbicide spray vegetation to leave organic mulch cover.
- Slashing vegetation should be a first preference.
  - 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 re-growth.
  - Roundup (glyphosate) to manage invasive grasses (e.g., grader grass) before seed set.
  - Don’t mix herbicides. Follow directions on the label. Avoid spraying near water.
    - 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:
  - 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 (left) that needed either slashing with a tractor (middle) or broadleaf herbicide application to avoid soil disturbance from grading.*

*Figure 13   Grader grass (Themeda quadrivalvis) invasion of an annually disturbed road corridor (left) and after management with two rounds of slashing during the early dry season (right)*

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.

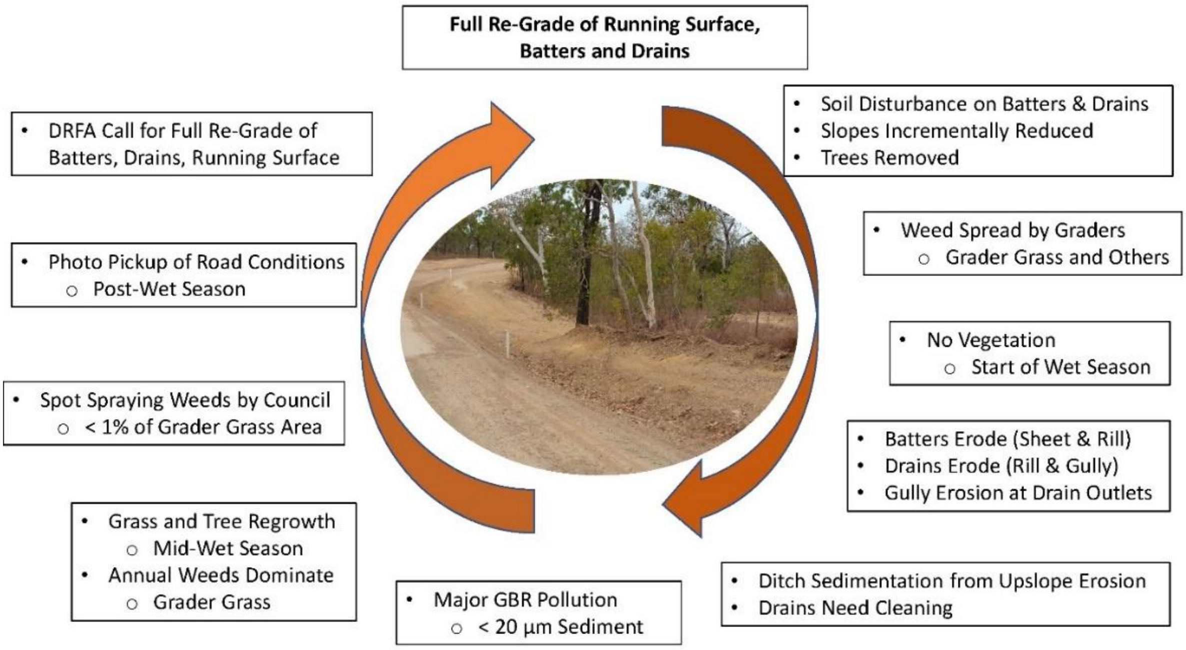



*Figure 14 Status quo current management of roadsides with full grading.*

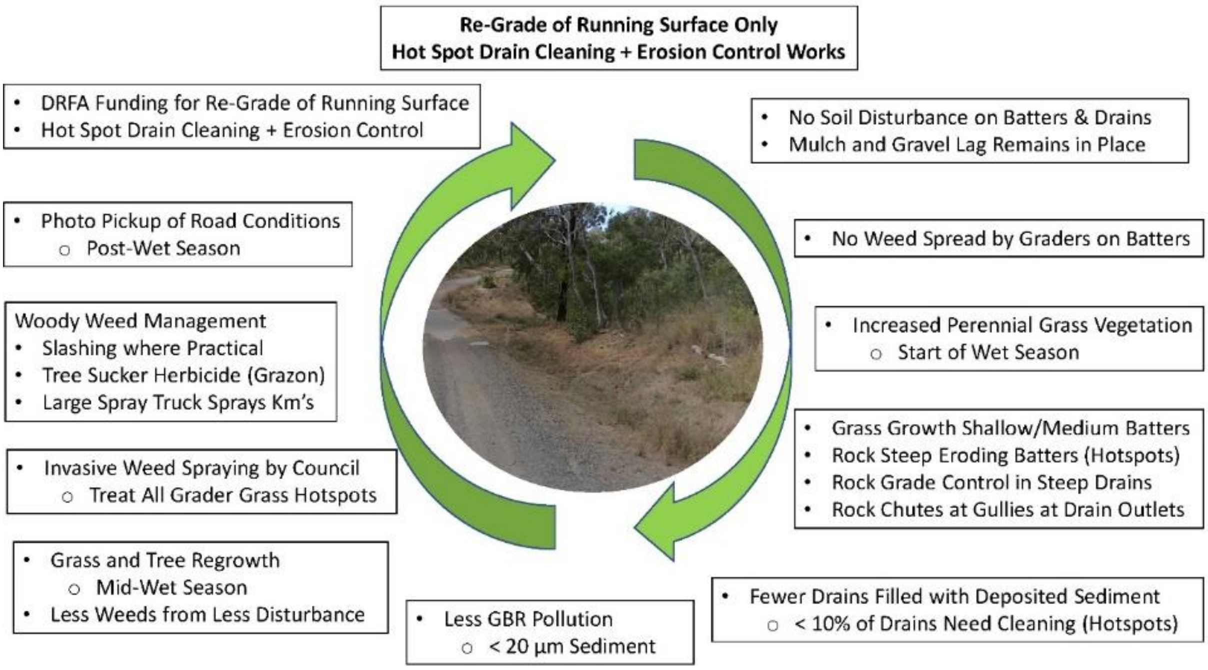



*Figure 15 Alternative management of roadsides with vegetation retention and slashing or herbicide.*

## 4.4 Batter Erosion Control

### 4.4.1 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 the following:

- 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 top-soil 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 (left) will be more stable than if annually graded (right).*

### 4.4.2 Batter Improvements

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

*4.4.2.1 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, maximize vegetation growth, and allow maintenance machinery to access the batter where needed (e.g., slashing).
- Always seek expert geotechnical / soil science advice for steep or high batters that pose environmental risks or safety risks to maintenance crews (Figure 17).

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

#### *4.4.2.2 Surface Stabilisation*

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

Factors to consider before adopting any embankment protection include:

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

*Figure 18 A stable grassed batter with native grass (left), 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 colonization.*

#### 4.4.2.2.1 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 stabilization in remote areas.
- 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 top-soil seed bed, and track roll on contour. Do not sow grass seed on the surface of compacted bare ground.
- Soil binders (polymers) can be sprayed over seeded surfaces to prevent erosion during first rain storms before vegetation establishment. The addition of gypsum aids revegetation in sodic soils.
- Hydromulch solutions can be applied by contractors in difficult revegetation areas.

#### 4.4.2.2.2 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 ($D_{10}$) to fill the pore spaces between larger rocks ($D_{90}$) 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 colinisation 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 to accelerate vegetation recovery.
- The size of the rock mulch ($D_{90}$ 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.

*Figure 19 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 20 Rock mulch over sodic dispersive soils after 10 year of vegetation colonisation (left), and the same untreated soils (right).*

#### *4.4.2.3 Clean Water Diversion*

Limiting off-site hillslope runoff from entering batters and table drains will reduce on-site erosion. Diversion drains can be put in place to re-route and divert hillslope runoff 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 4.6 on Gully Erosion).

- For table drains, excess hillslope runoff 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.

Refer to AUSTROADS for details on diversion drain design.

*Figure 21 A clean water diversion drain re-entering the road batter and table drain causing gully erosion (left), and a small batter chute to control scour where clean water diversion re-enters the road system (right).*

## 4.5 Drainage Erosion Control

### 4.5.1 Drain Maintenance (Existing Drains)

#### *4.5.1.1 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 left). If the drain is unstable, then apply appropriate erosion control measures rather than just re-grading it (Figure 22 right).

*Figure 22 A functional semi-stable drain that does not need grading maintenance (left) compared to an unstable drain needed erosion control (rock) maintenance rather than just re-grading (right).*

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 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 Hotspot of drain sedimentation (gravel, sand, and coarse silt > 20 µm) before (left) and after (middle) the wet season, with subsequent silt removal with a backhoe along a 10 m drain length (right).*

#### 4.5.2 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 requiring less maintenance.
- **Lining**: Adopt an appropriate drain lining that can cater for the expected flow volume and velocity (i.e. larger catchment areas draining to steeper table drains will experience higher velocities).
- **Slope:** Reduce 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.

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

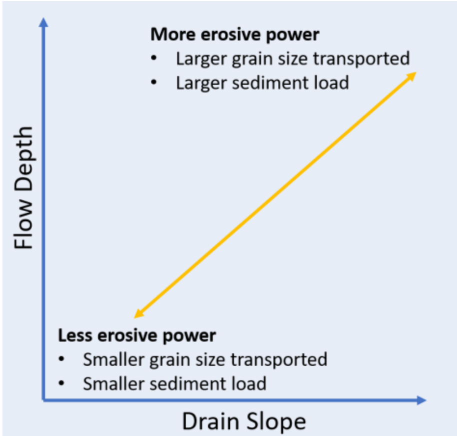



*Figure 24   The relationship between flow depth, drain slope and erosion.*

### *4.5.2.1   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 25   A V-Shaped Table Drain with erosion (left) versus a Flat-Bottom Table Drain (Trapezoid-Shaped) (right).*

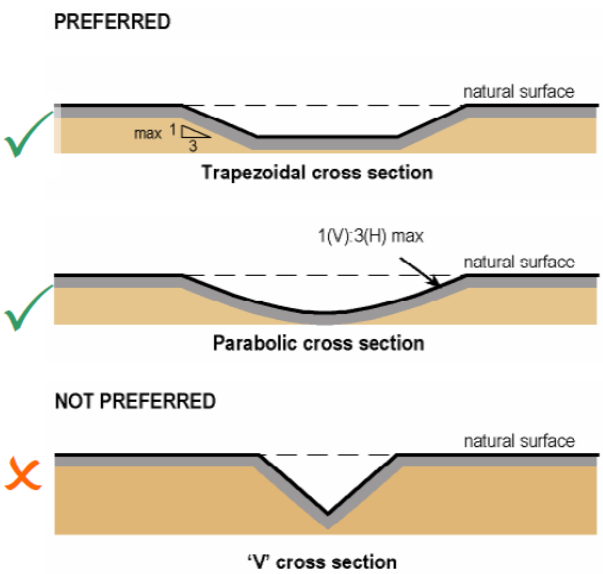



*Figure 26   Preferred drain shapes.*

#### 4.5.2.2 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.

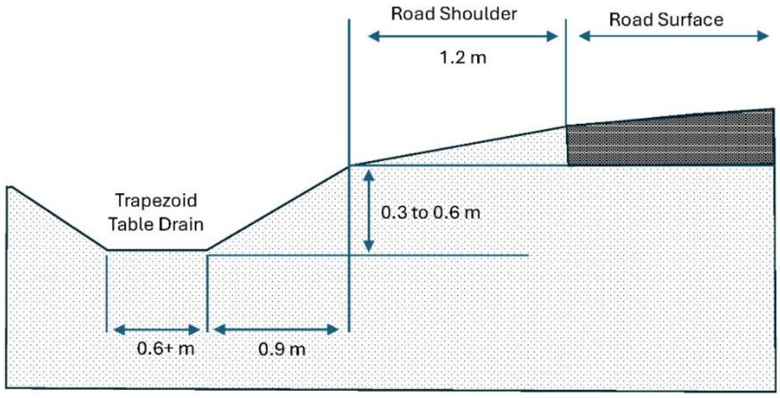



*Figure 27 Minimum drain depth and width (ARRB, ARRB 2020).*

#### 4.5.2.3 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 runoff. 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 4.6).

#### *4.5.2.4 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 (Adapted from Source: IECA 2008)*

| Type | Description | Expected Flow Velocity | Comments |
|---|---|---|---|
| Open Earth (unlined) | Extremely erodible soils | Very Low (0.3 m/s) | • Dispersive clays are highly erodible even at low velocities.<br>• Highly erodible soils may include: Lithosols, Alluvials, Podzols, Siliceous sands, Soloths, Solodized solonetz, Grey podzilics, some Black earth, fine texture-contrast soils and Soil Groups ML and CL.<br>• Erosion resistant soils may include: Xanthozem, Euchrozem, Krasnozems, some Red earth soils and Soil Groups GW, GP, GM. GC, MH and CH. |
| | Moderately erodible soils | Very Low (0.6 m/s) | |
| | Stiff clay very colloidal soils | Low (1.1 m/s) | |
| Established Grass | Easily erodible soils | Low-Medium (1.0-1.5 m/s) | • Easily eroded soils include: black earths and fine surface texture-contrast soils (dispersive).<br>• Long establishment time when seeded. |
| | Erosion resistant soils | Medium (1.5 – 2.0 m/s) | • Erosion resistant soils include: Krasnozems and red earth soils.<br>• Long establishment time when seeded. |
| Turf | Turf slabs laid perpendicular to the flow direction | Medium (1.5 – 2.0 m/s) | • Newly laid turf should be anchored with wooden pegs if medium to high flow velocity is possible on the first two weeks. |
| Soil Binder | Polymer spray | Medium (1.5 - 2.5 m/s) | • Binds dust and soil particles to limit erosion.<br>• Typically applied to unsealed roads and haul roads and embankments but can assist to stabilise drains, particularly during vegetation establishment).<br>• 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 | • Used mainly as a liner for chutes and steep drains.<br>• Rock must be recessed below the surrounding ground to allow flow to freely enter the drain.<br>• Requires an underlying filter cloth.<br>• Larger sized rock is required for higher velocities.<br>• Requires detailed design from a Registered Professional Engineer of Queensland (RPEQ). |

| Type | Description | Expected Flow Velocity | Comments |
|---|---|---|---|
| Concrete | Concrete floodways | Very High (7.0 m/s) | • Used to provide a stable major water crossing.<br>• Needs upstream and downstream protection (cut of walls, rock armouring etc)<br>• Requires detailed design from a Registered Professional Engineer of Queensland (RPEQ). |

#### 4.5.2.4.1 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.

#### 4.5.2.4.2 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 shapeize. Typical examples of acceptable rock sizing for various drain shapes are provided below (Table 4; Table 5). 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 28 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 $D_{50}$.*

| Drain Slope % | $D_{50}$ (mm) Rock Size Table — 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 | 50 | 75 | 75 | 100 | 100 | 200 | 200 |
| 1 | 50 | 50 | 75 | 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 | 500 | 600 |
| 7 | 100 | 200 | 250 | 300 | 350 | 400 | 500 | 700 |
| 8 | 100 | 200 | 250 | 300 | 350 | 400 | 600 | 700 |
| 9 | 100 | 200 | 250 | 300 | 400 | 500 | 600 | 700 |
| 10 | 100 | 200 | 250 | 300 | 400 | 500 | 600 | 800 |

*Adapted from Catchments and Creeks (2010b), Rock Linings, Table 13A.*

*Table 5 Rock sizing selection table, $D_{50}$ (mm), based on drain slope and width, assuming a 300 mm depth of trapezoid channel (3:1). Use well-graded rock with the $D_{90}$ < 2x the $D_{50}$ and $D_{10}$ of 5% of $D_{50}$.*

| Drain Slope (%) | Drain Base Width | | | | |
|---|---|---|---|---|---|
| | 0.6 m | 0.8 m | 1.0 m | 1.2 m | 1.5 m |
| 0.5 | 100 | 100 | 100 | 100 | 100 |
| 1.0 | 100 | 100 | 100 | 100 | 100 |
| 2.0 | 100 | 100 | 100 | 100 | 100 |
| 3.0 | 100 | 100 | 150 | 150 | 150 |
| 4.0 | 150 | 150 | 150 | 150 | 150 |
| 5.0 | 150 | 150 | 150 | 150 | 150 |
| 6.0 | 150 | 150 | 150 | 200 | 200 |
| 7.0 | 150 | 200 | 200 | 200 | 200 |
| 8.0 | 200 | 200 | 200 | 200 | 200 |
| 9.0 | 200 | 200 | 200 | 200 | 300 |
| 10.0 | 200 | 200 | 300 | 300 | 300 |

*Adapted from Catchments and Creeks (2014).*

#### 4.5.2.4.3 Check Dams in Drains

Check dams can stabilise steep eroding drains by slowing water velocity, reducing local bed slope, trapping coarse sediment, and promoting revegetation (Figure 29). However, they are not a fine sediment collection measure. Any fine sediment collected is a bonus. The main purpose of check dams is to control the grade (slope) of the drain and prevent future channel incision (cutting). Check dams should be constructed using well graded, unscreened crushed rock sized in accordance with Table 4 or Table 5 above. Check dams made out of thin rock walls, coir logs or sand bags are almost always ineffective and are not recommended.

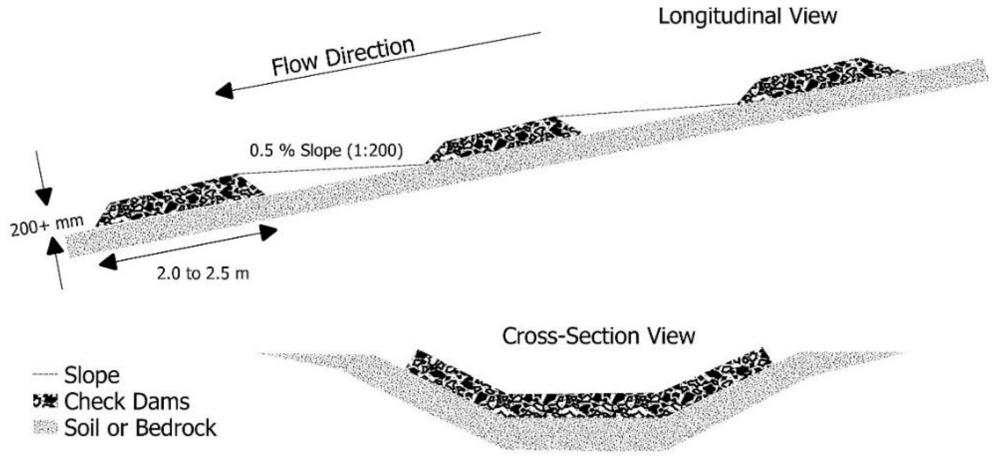



*Figure 29   Longitudinal section and cross-section of a table drain with check dams.*

As a general guide, small check dams in drains from unsealed roads 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 (Table 4 or Table 5).
- 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.
- The check dam 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.
- 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.
- Sequential low-profile check dams are more 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 30 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 (left) and after (right) a major cyclone. Note dumpy level on left used in construction.*

*Figure 31 Sequential low-profile rock check dams in V-drains can control the slope and channel erosion without blocking drains or backwatering the road.*

*Figure 32 Failed check dams in non-dispersive soils due to outflanking (left) or excessive plunge pool scour (right) due to insufficient width up the drain batter (left) or insufficient frequency of check dams (right), note absence of check dams in the upstream direction.*

#### 4.5.2.4.4 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 4.6). Grade Control Structures need to be constructed to a site-specific design undertaken by a Registered Professional Engineer (Figure 44).

### 4.5.3 Reduce Connectivity to Gullies and Stream Crossings

#### *4.5.3.1 Diversion Drain Frequency (Cutoff or Turnout)*

Roadside table drains collect and convey stormwater before discharging runoff 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 runoff 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 (2009) equation can be a useful guide:

$$Spacing\ (m) = \frac{300}{\%\ Slope\ of\ Drain}$$

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 6.

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, per TMR (2021; 2023) Type B catch drains as shown in IECA Standard Drawing CD-01: 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 runoff rates and erosion potential (Kyle et al. 2024; Shellberg et al. 2024a).
- 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 33).
    - 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 4.5.3.2). Where possible culvert frequency should be similar to diversion drain spacing.

*Table 6 Diversion drain frequency in relation to slope and soil erodibility.*

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

** Source: modified from Jolley (2009); Johansen et al. (1997); Copstead et al. (1998) and field experience with operators on Cape York Peninsula (Kyle et al. 2024 and Shellberg et al. 2024a).*

*# Source: modified from ARRB (2009).*

*Figure 33 Diversion drain with an earth bund to turn runoff away from the road (left) and a breached earth bund due to drain sedimentation from a large drain catchment and inadequate drain slope and flow capacity (right).*

#### *4.5.3.2 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 34). Floodways installed as trafficable dips can also be used to relieve flow in long-sections of table drains.

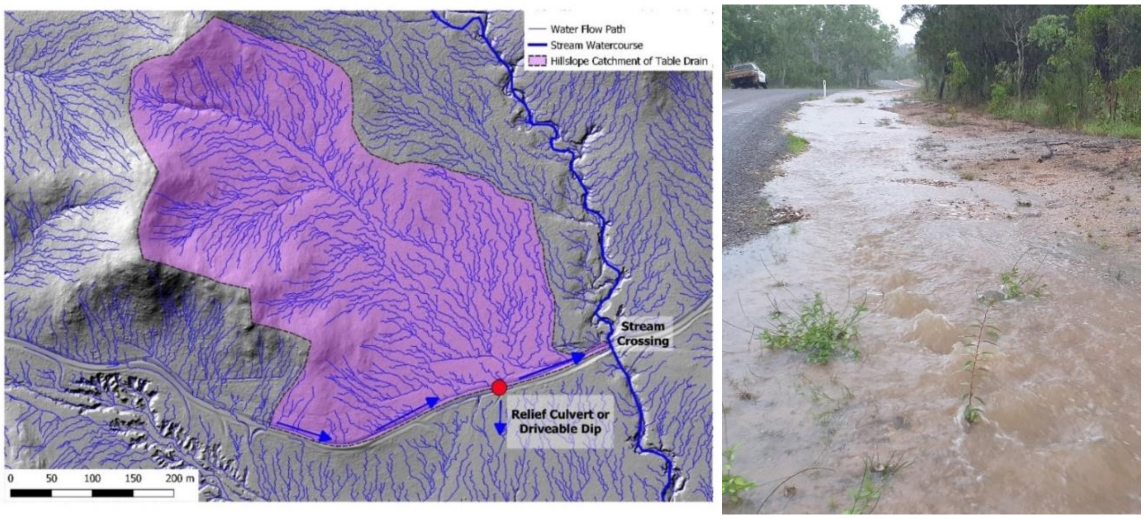



*Figure 34 A hillslope catchment (16 ha) captured by a road table drain (> 500m) and discharged to a stream, with the location of a constructed rock floodway (driveable dip) (Figure 49) to relieve water along a stable flow path. Alternatively, a large relief culvert could have been used.*

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 6) 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 drainage 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 4.7.2.

#### *4.5.3.3 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 37), or
- Stabilise steeper slopes with rock chutes or grade control structures to prevent gully erosion (Figure 44).

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 38) (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 37),
- If drain connectivity cannot be reduced, consider other erosion control measures such as rock armour or rock chutes to minimize erosion (Figure 36; Figure 43; Figure 44; see Gully Section 4.6).

*Figure 35 Table drains well connected to streams with few places to divert sediment laden water from bare batters.*

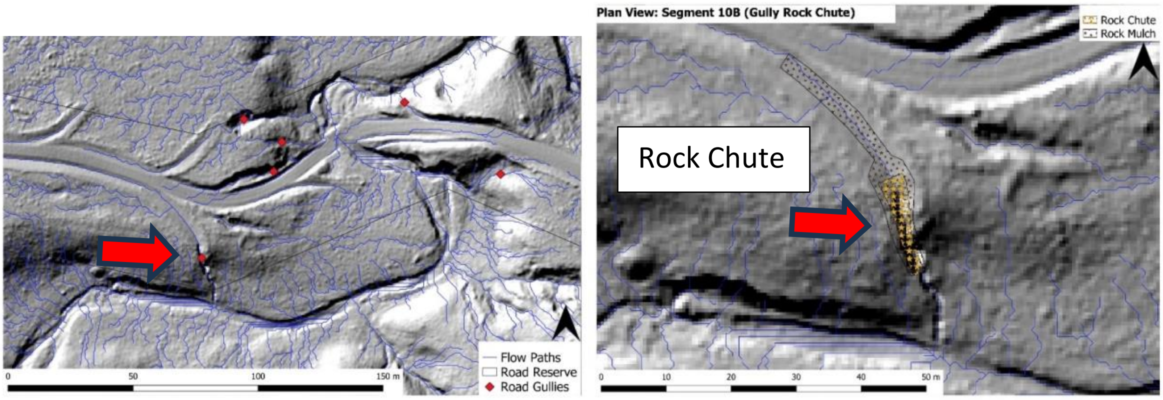



*Figure 36   Poor drain placement (left). Drain placement is important to avoid discharging onto gully prone areas near creek crossings. If no drain placements alternatives exist, then rock chutes may be needed in gully prone areas (right).*

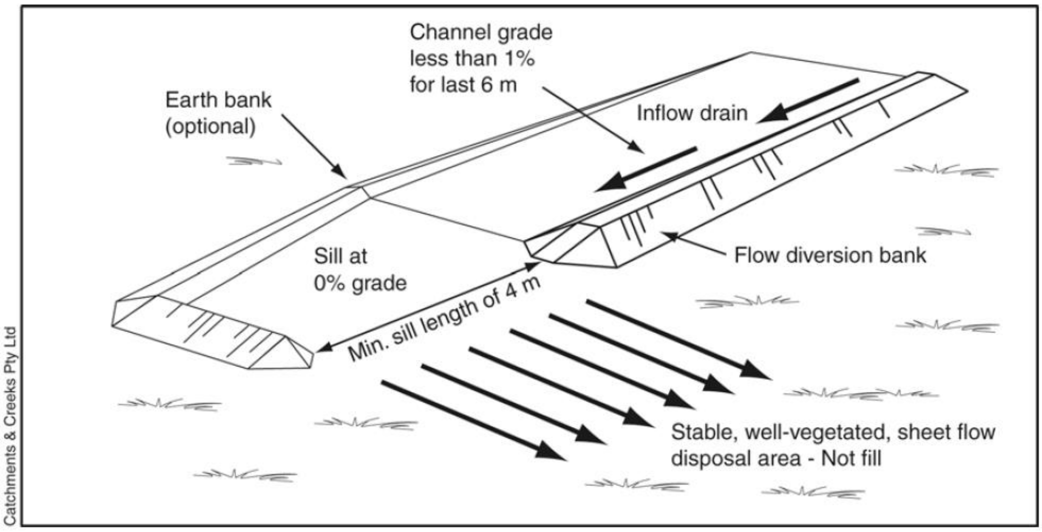



*Figure 37   Level Spreader (Source: Catchments and Creeks Pty Ltd).*

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

### 4.6.1 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 38). 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 39).

*Figure 38 A gully at the bottom of road diversion drain looking upstream (left) and downstream (right).*

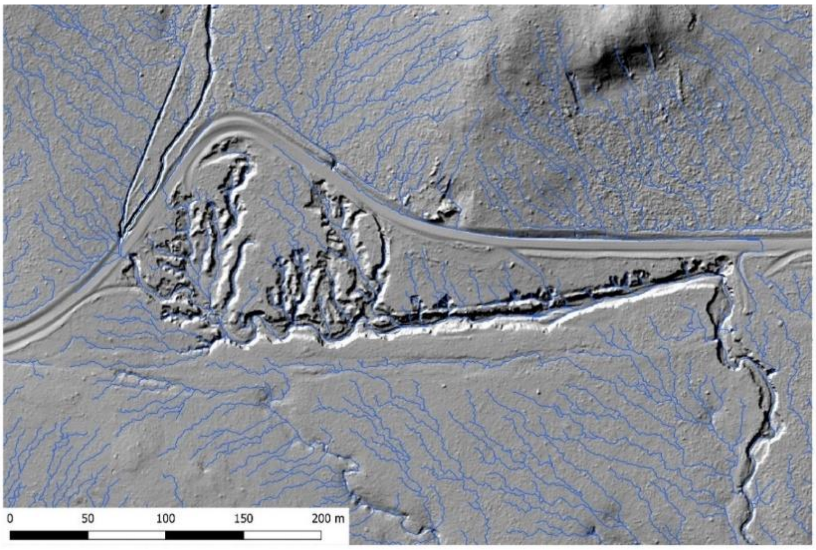



*Figure 39 Legacy roadside gully erosion (LiDAR hillshade) created along an old, straight road alignment and affecting current drainage and road configuration.*

### 4.6.2 Preventing Gully Erosion

Prevention of gullies caused by road drainage runoff 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.

### 4.6.3 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.

### 4.6.4 Small Rock Chute Construction

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 $D_{50}$ 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 44).

*Figure 40 An incising V-drain outlet (left) and rock chute (right) at the same location to control erosion incision.*

*Figure 41 Small rock chutes at diversion drain outlets can prevent gully head-cutting upstream into drains.*

*Figure 42 Failed rock stabilisation due to use of porous coarse rock (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 44).*

### 4.6.5 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. 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 44).
- Adjust rock size to the catchment area, peak water discharge, and chute slope following standard hydraulic calculations (Keller 2003; Catchments and Creeks 2010).
- Cover the side walls of the rest of the gully with rock mulch and leave to revegetate (Figure 43).
- 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 and geomorphology design advice from a Registered Professional Engineer or qualified expert should be sought for large rock chute design and control of larger gullies (Figure 45).

*Figure 43   Rock chutes constructed at the outlets of road diversion drains to control gully erosion.*

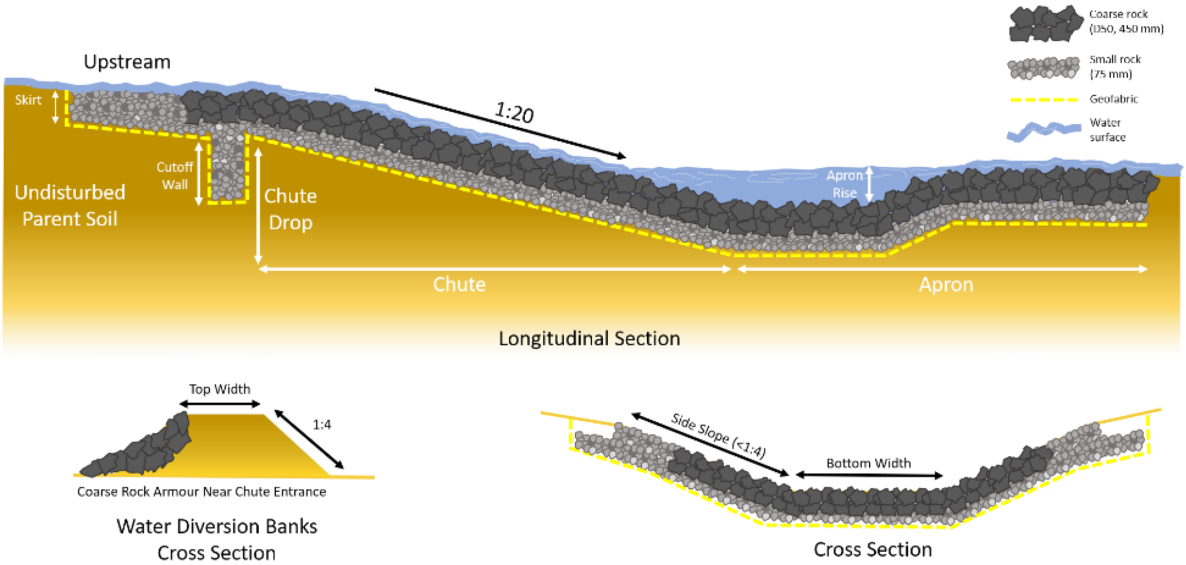



*Figure 44   Design of a rock chute (grade control structure) for gully control.*

*Figure 45   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).*

## 4.7 Floodway and Culvert Improvements

### 4.7.1 Floodways and Bed Level Creek Crossings

#### *4.7.1.1 Concrete Floodways*

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 46).

- 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 Registered Professional Engineer 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 3m/s.
- 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 47).
    - 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.
    - The increased construction costs, e.g., additional traffic control, are offset by reduced costs associated with not constructing and then rehabilitating a diversion track.

*Figure 46 A concrete floodway installed at a creek crossing to reduce bed scour, but with associated erosion at the diversion track (Figure 50). Note downstream scour below concrete due to lack of rock protection; and rill erosion on batters.*

*Figure 47 A concrete floodway poured in two (2) sections side by side to avoid the need for a temporary diversion track and associated erosion disturbance.*

### *4.7.1.2 Rock Floodways*

Rock floodways are a cost-effective alternative to concrete floodways for low volume roads (< 50 average daily traffic).

- For low volume, low speed roads, rock floodway pavements can be constructed using clean well-graded unscreened rock with a $D_{50}$ 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 48).
- 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 48; Figure 49).

- Use of 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 49). Depositing fine sediment into a streambed knowing that it will be washed further downstream is illegal.
- 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 49). 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 48).

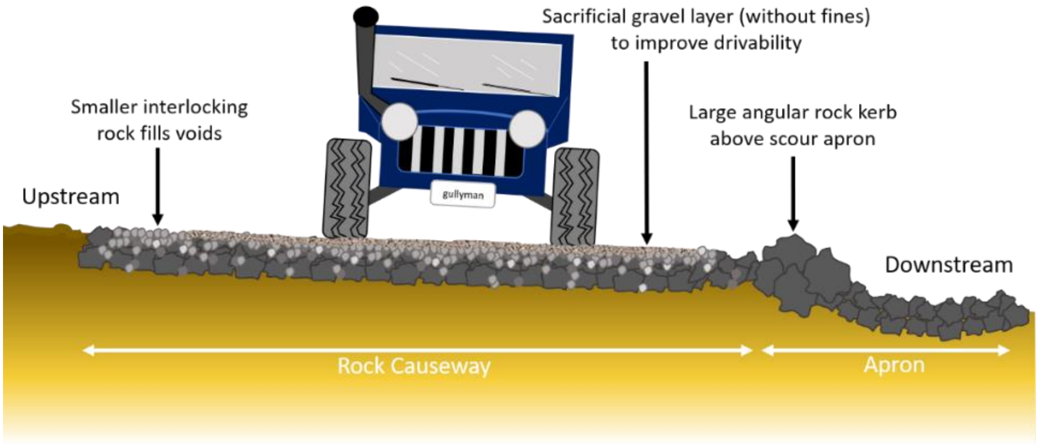



*Figure 48   Road cross-section diagram at a rock floodway crossing.*

*Figure 49   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.*

### *4.7.1.3   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 50 left).  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 top-soil and native grasses (Figure 50 right).

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 50).

*Figure 50 Deep rilling of a temporary bypass road crossing a creek (left) used during construction of a concrete floodway. Rock mulch placed on the same bank to mitigate soil erosion (right).*

### 4.7.2 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 Fisheries Act approval and should be designed by a Registered Professional Engineer. 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 51).
- 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 1.2m 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 52).
- 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 52).


*Figure 51   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 52   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 53   Inadequate rock erosion protection at the inlet of large box culvert, with associated gullying and slumping.*

## 4.8 Road Pavement for Erosion Control

### 4.8.1 Pavement Maintenance

#### *4.8.1.1 Road Base Particle Size Distribution and Fine Sediment Production*

The quality and composition of road base and its fine sediment binder are critical factors in resistance to erosion during heavy rainfall. This is particularly important in Great Barrier Reef catchments for fine sediment < 20 µm originating from road base binder. Essentially each road base layer and its compaction integrity have a soil erodibility factor (K), which is the collective effects of the detachment susceptibility and sediment transportability under a given rainfall erosivity (RUSLE). This K factor changes with time and traffic, but is inherent to the material placed and compacted on the road.

Most road base material contains a fine sediment binder mixed with the screened gravel. QTMR (2022) defines the 'fines component' as the fraction of the material passing the 0.425 mm test sieve. This < 425 µm material is in the size range from medium sand to clay. For subtype 2.5 road base often used on unsealed roads, the target fines component < 0.425 mm is 14-60%, which is a wide range. The target for fines < 0.075 mm (silt and clay) is 7 to 30%. A clay content < 0.004 mm from 4 to 8% is usually acceptable for 2.5 road base. Anything higher can fail the linear shrinkage (LS) and plastic index (PI) tests.

The particles size distribution of road base can vary by quarry and source material type (Figure 54). Decomposed diorite, granite, or sedimentary rock are commonly used as a binder with metamorphic or basalt gravel. Very fine silt is more common than clay particles in binder. However, for Type 3 or 4 gravel ridge quarries in more remote locations, a higher clay content is often used due to availability.

One example (Figure 54) from a Type 2 quarry for subtype 2.5 road base with a decomposed diorite binder, the sieve analysis indicated that 37% was < 2.36 mm, 19% < 0.425 mm, and 11% < 0.075 mm, all withing the QTMR (2022) specifications. However, field samples from the same material after loading, transport, mixing, and rolling indicated that 22% was < 20 µm (0.020 mm, fine silt) and 7% was < 2 µm (0.002 mm, clay). These data confirm two things: 1) that loading, transport, mixing, and rolling can significantly break down particle sizes compared to the material at the quarry, and 2) that gentle sieving does not disaggregate the fines component as effectively as full dispersion in the laboratory, or disaggregation after rainfall impact and sediment transport. These differences do not include the impacts of particle breakdown due to traffic over time. In conclusion, the field availability of fine particles < 20 µm after road base placement can be much greater than quarry tests would indicate, leading to pollution of waterways and the Great Barrier Reef.

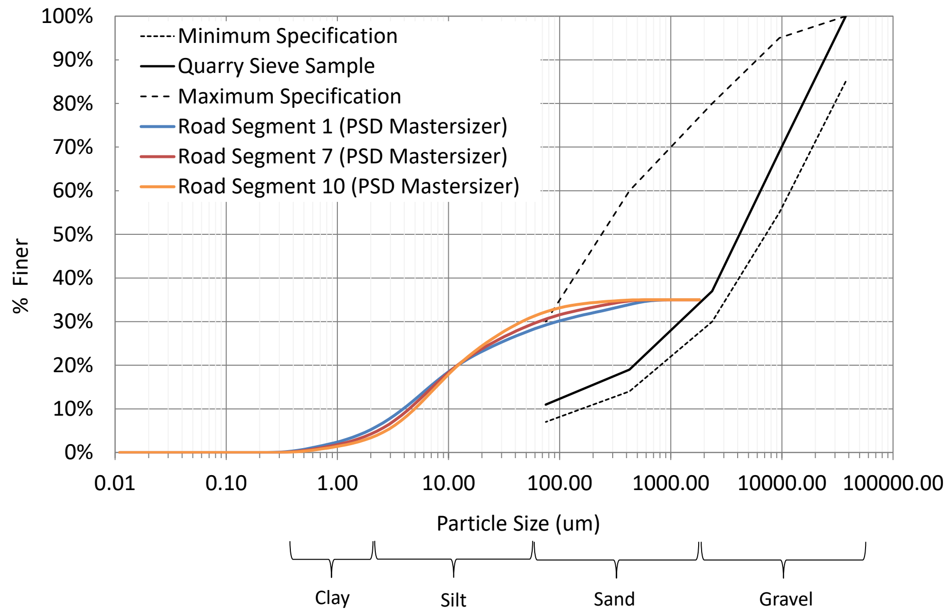



*Figure 54 Particle size distribution of road base as tested with sieving at the quarry (black) and tested with laser diffraction (Mastersizer) for material less than 2000 µm (2mm) on road surfaces.*

Fine silt dominated road base materials have less long-term cohesion and generally disaggregate faster than clay dominated road base, and potentially pollute streams more readily. However, clay road bases are often too slippery in wet conditions for safe driving. If rutted by tyres when wet, clay road bases can become greater sources of fine sediment erosion and counteract their additional cohesion. For this reason, wet season road closures are important for remote roads with native rock and high clay content. Traffic management is key.

While the content and quality of the binder of road base cannot always be adjusted, regionally there are often alternative choices that could be made for increased road base stability and cohesion for specific traffic, rainfall, or high erosion risk situations. For example, depending on the area, binders with increased calcium content can be more stable due to stronger bonds between clay particles. It is well known that lime-based roads hold up better than others.

### *4.8.1.2 Road Pavement Re-grading*

#### **4.8.1.2.1 Compaction**

Compaction (rolling) at the optimum moisture content (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 (QTMR 2022; MRTS05). 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 (Aug-Dec) 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 by gravity during handling and unloading. Segregation is the uneven distribution of particle sizes, and compaction is heavily dependent on the particle size distribution. 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 major implications for compaction and pavement durability. This is particularly the case for road shoulders near table drains that 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 optimum moisture content (OMC) and rolling duration are key to stable road base of unsealed roads.

Compaction tests are less commonly used for unsealed roads, compared to preparatory compaction before road sealing. However, “proof rolling” of pavement layers of traffic lanes, shoulders and other areas can detect incomplete compaction by showing perceptible surface deformation (QTMR 2022). Proof rolls can help ensure the compaction and integrity of the unsealed road pavements.

#### 4.8.1.2.2 Loose Road Base in Drains

Waste road base material in 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.

#### 4.8.1.2.3 Road Shape During Re-grading

Information and guidance on road pavement construction and maintenance can be found in ARRB (2020) - ‘Unsealed Road Best Practice Guide’ and IPWEAQ (2016) – ‘Lower Order Road Design Guideline’. 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 optimal moisture content (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.

### 4.8.2 Road Surface Sealing for Erosion Control

*4.8.2.1 Bitumen 'Dust Seal'*

A bitumen 'dust seal' over an existing unsealed road can be applied to some roads without changing the road alignment or pavement depth (Figure 55). Sealing simply requires a medium or heavy formation grade to prepare the road base for a two-coat seal. This treatment is suitable in many but not all situations (QTMR 2015).

*Figure 55 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).*

Benefits include:

- Reduced sediment loads entering the drainage system from the road surface.
- Avoids wash outs 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:

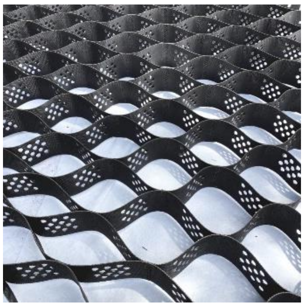
- Initial sealing is costly ($110,000/km, 2024 prices), but costs less than a full upgrade ($1 million/km).
- Drains may require more erosion control measures to ensure stability to protect the investment in the dust seal (Figure 56).

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 56 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.*

*4.8.2.2 Alternatives for Floodway Approaches (steep grades)*

Road base at the steeper approaches (± 50 m) to stream crossing 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 57). 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 57 A cellular confinement systems (diamond shape) used to stabilise road base at an approach to a concrete floodway (Cassowary Coast Regional Council, photo Justin Fischer).*

## 4.9 Gravel Pit Erosion, Sediment Retention, and Rehabilitation

Gravel pits (borrow pits or quarry pits) are used by Councils to win material for rural unsealed road construction and surfacing. These gravel pits are a cheaper and a practical alternative for sourcing material locally compared to long-haul transport from commercial rock quarries, even if permission and royalties need to be arranged with freehold 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 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 runoff of fine sediment < 20 µm (see Section 4.8.1).

The extent of erosion and offsite 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 runoff. 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 crossing is not sustainable (Figure 58). The Cultural Heritage Act, Vegetation Management Act, and other Acts are applicable to new quarry development.

*Figure 58 Roadside gravel pit with runoff directly connected to a stream (behind).*

Gravel pit quarries should be rehabilitated progressively each year that they are utilised. 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 Councils claiming no funding or responsibility to clean-up the past mistakes (Figure 59). 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, aesthetics).

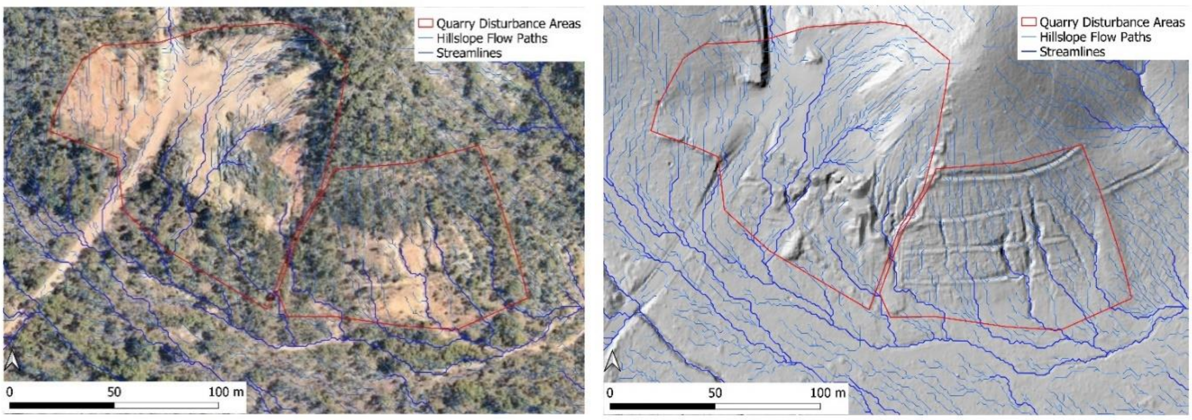



*Figure 59 Legacy gravel pit quarries that have not been properly rehabilitated remain sediment sources for decades after use and pollute local streams, as seen in air photo (left) and LiDAR (right).*

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

- Creating a sediment trap (pit) that traps water and sediment laden runoff.
- Ensuring that the outlet flow of the gravel pit is directed to flat vegetated depositional areas that further filters 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 44) to prevent incision from excess runoff 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 top-soil where needed, and seeding the area with plants native to the area.
    - Some shrubby *Acacia* species and some native grasses are excellent at colonizing rock substrate.
- Controlling the invasion of weed plant species brought into the quarry during use or colonized into the disturbed area. This is a Biosecurity Act obligation.

*Figure 60 Abandoned gravel pit without proper rehabilitation and turbid rainfall runoff (left) and outflows causing downstream gully erosion and sediment pollution (right).*

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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 to prevent the formation of a plunge pool close to the bottom of the slope.

**Floodway (ford)**: 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 construction within a small water course or drain which has the following features; a crest, batter protection, a downstream slope and an apron. 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 construction 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.

**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 37.

**Rock Chute**: means a rock lined channel constructed specifically to convey water down a slope without causing erosion to the slope. A plunge pool is constructed immediately downstream from the Rock Chute. Refer to Figure 44.

**Rock Mulch**: means a well-graded mix of unscreened crushed rock (often directly from a rock crusher) containing a reasonable proportion of fines ($D_{10}$) to fill the pore spaces of larger rock ($D_{90}$) 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.