



Office of
Environment
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Erosion and sediment control on unsealed roads

A field guide for erosion and sediment control maintenance practices

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1 Soil erosion and sediment control

Soil erosion occurs when soil particles are dislodged and transported by the action of water and/or wind. Sediment is the material produced by erosion. Long-term erosion and sedimentation from unsealed roads is inevitable. However, effective management can minimise erosion and sedimentation and in turn reduce the overall financial cost of maintenance, potential public safety risks and environmental impacts.

The aim of this field guide is to provide field staff with practical guidance on soil erosion and sediment control practices that improve asset management and minimise the amount of sediment entering waterways. Routine maintenance of unsealed roads using best practice standards is generally more cost-effective than allowing roads to deteriorate to levels requiring substantial works.

The guide is educational and advisory in nature and provides information on best management practices. Any legislative or regulatory requirements prevail. The management practices described in this guide are not the only approaches to erosion and sediment control on unsealed roads. Technically sound site-specific approaches should always be considered where they meet the relevant operational, safety and environmental outcomes.

1.1 General principles for effective soil and water management on unsealed roads

- Conduct regular inspections to check that the road formation is performing adequately.
- Ensure that drainage is working and the road and discharge areas are stable.
- Inspect sediment and erosion control structures during and after heavy rainfall and minimise traffic where possible.
- Maintain effective erosion and sediment control measures.
- Ensure road usage is commensurate with road design.
- Minimise the area of soil disturbed and exposed to erosion when conducting maintenance operations.
- Stabilise and rehabilitate disturbed soil as soon as possible.

2 Maintenance

Regular effective maintenance of roads and road drainage structures will help prevent erosion and avoid repair and reforming of substantial lengths of road.

All unsealed roads should be included in a cyclic maintenance program. Additional inspections of the road network, particularly during or after periods of heavy rain, should also be considered as part of a broader maintenance program. In particular, regular inspections of watercourse crossings and their approaches should be conducted as these represent a high risk to water quality. There are a number of indicators of road maintenance condition that may trigger remedial maintenance works. Some of these include:

- flattening out of crown or crossfall
- rills and/or scouring of the road surface (Figures 1 and 2)



Figures 1 and 2. Rilling and scouring of the road surface indicating poor drainage

- build-up of sediment or blockage of table and mitre drains (Figure 3)
- windrows preventing outfall drainage or blocking the entrance to drainage structures
- build-up of sediment and/or debris in rollover channels, culverts and headwalls
- discharge surfaces no longer stable
- deposition of road-base sediment in a watercourse.



Figure 3. A mitre drain requiring repair and reshaping

3 Shaping the road

3.1 Road profile

Maintaining the road profile is essential to effective drainage of the road surface. The road type generally determines the road profile. The following provides guidance on how to achieve crowning and crossfall drainage, including grading and compaction.

3.1.1 Crowning drainage

Crowning, also known as camber, involves raising the centre of the road profile 150–300 mm above the table drain or natural surface so that water drains from a high point in the centre to both sides of the road (Figures 4 and 5). Correct crowning reduces the chance of potholes and rutting and reduces the frequency in which re-sheeting and routine grading is required.

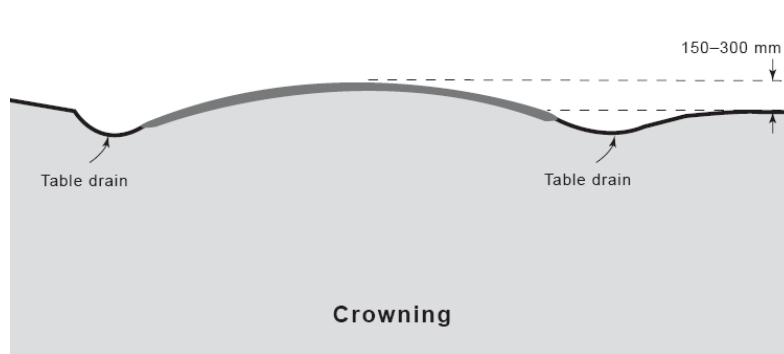


Figure 4. Crowning drainage



Figure 5. Crowning of the road surface

3.1.2 Cross slope drainage

Cross slope occurs where the road surface slopes in one continuous direction with one side of the road being the highest point. This is the preferred road profile slope where water is to be directed toward one side of the road. The types of cross slope are:

- outfall drainage – the road surface slopes away from a cut batter or hillside with water flowing evenly to the shoulder of the fill or lower side of the road (Figure 6a). This is generally used on moderate slopes for low traffic volume roads and stable soils.

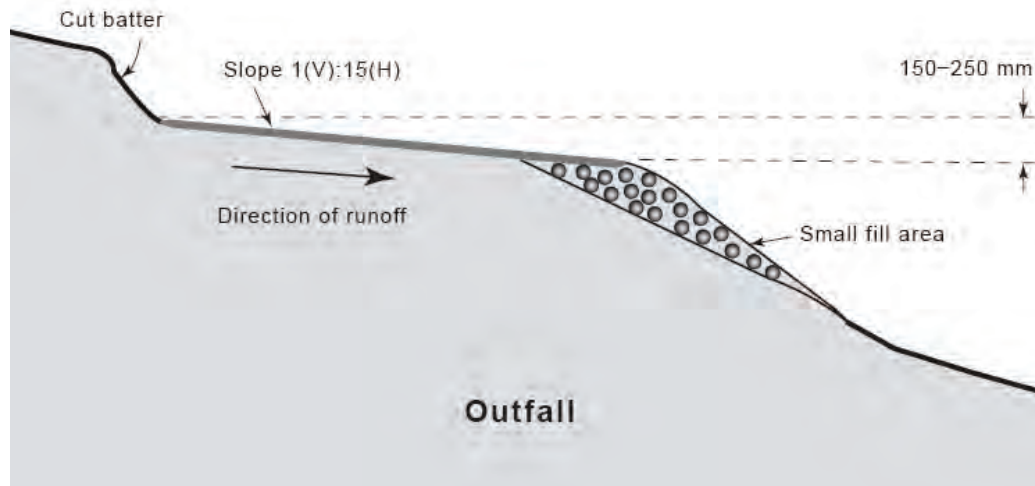


Figure 6a. Outfall drainage

- infall drainage – surface water is directed towards a cut batter or hillside to be captured by a table drain (Figures 6b and 7). This is commonly used with a table drain on steep terrain and/or where fill batters are not stable and/or exceed 1.5 m in height.

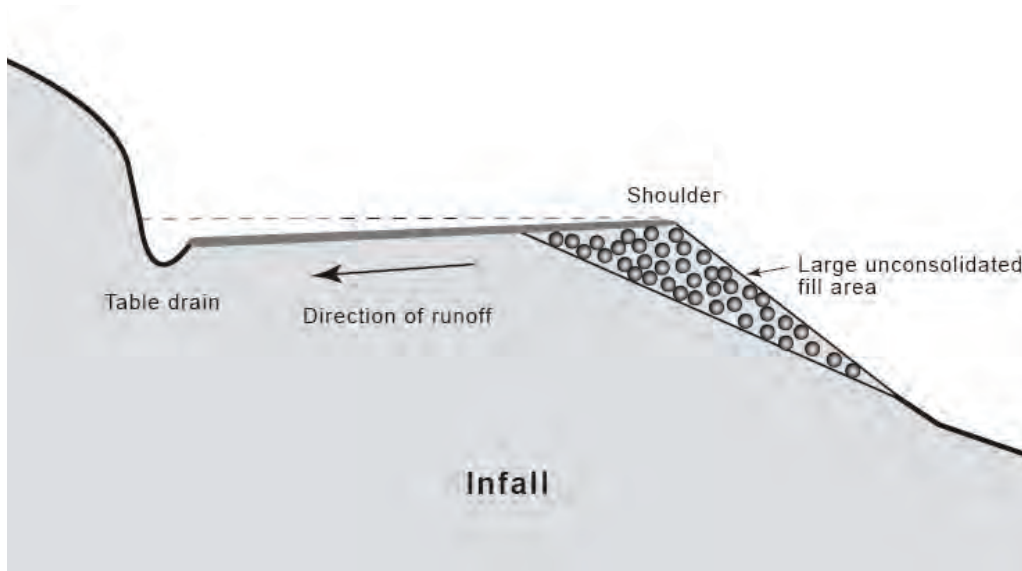


Figure 6b. Infall drainage



Figure 7. An example of effective infall drainage

3.2 Road profile maintenance

The road profile is maintained by grading the road surface and in some instances filling and compacting before grading. Table 1 contains best practice provisions that should be observed during all maintenance activities. There are generally two types of grading activities:

- light grading – used where there is no major potholing and the road profile is generally of an acceptable shape. The grader makes limited passes to reshape the surface and there is little or no compaction required. Equipment includes a grader and water cart, and production rates are about 4–6 km per day. A roller may be required depending on the material.
- heavy grading – used where there is substantial potholing and/or the road profile requires substantial reshaping. The grader makes numerous passes and the existing surface is scarified in the areas where material is to be moved from and to. Equipment includes a grader, water cart and roller (>6 tonne) and production rates drop to about 2–4 km per day.

3.2.1 Grading

On a crowned road:

- commence grading from the roadside edge and work towards the centre of the road
- material from the road edges, lost from the pavement surface due to traffic and erosion, should be bladed in and deposited beyond the centreline
- spread the windrowed material beyond the centreline back across the surface on the following passes, depositing the material on the cut surface
- try to maintain the appropriate crossfall with each successive pass and remove all surface defects
- repeat on the opposite side of the road formation
- ensure the grader does not make a final pass down the middle of the road which will remove the crown.

On a crossfall road:

- commence grading from the lower edge and work towards the upper edge of the road surface maintaining the appropriate crossfall with each successive pass and removing all surface defects
- the number of passes depends on the depth of road defects (such as potholes) and the width of the formation.

3.2.2 Compaction

To achieve sufficient compaction:

- compact in layers of 120–150 mm depth (compaction of layers less than this thickness may result in separation from the underlying layer and scaling of the material off the road surface; compaction of layers thicker than 150 mm may result in undercompaction and the development of soft spots)
- use appropriate imported material for fill, including a good range of fines through to larger particle sizes. Any imported material should be tested and recommended by a qualified road practitioner. A record should be kept of all fill material, including its performance over time – material that performs well should be favoured and used for future works.
- when material is compacted onto an existing road surface the surface should be scarified prior to compaction. Scarification breaks the shear plane and aids:
 - bonding of the compacted material to the existing surface
 - mixing of existing and new materials
 - formation of sufficient compaction depth.
- road design will specify that compaction is to occur at optimum moisture content. Testing for optimum moisture content will generally only occur for roads of higher classification. For minor trails add water to the material as compaction occurs – optimum moisture content is reached when compaction (rolling) does not produce either cracks or plastic rebound.
- sufficient compaction can generally be achieved by six passes of a 6-tonne roller or four passes of a 10-tonne roller. Compaction is generally considered sufficient when the roller no longer leaves an imprint on the surface.
- if the road surface becomes wet, or too much water is added, the material should be dried prior to compaction by either leaving the material for a period of time, or scarifying to expose to air, then regrading and rolling
- the number of passes required will depend on the depth of road defects and the width of the formation
- on crowned roads ensure that the roller does not make a final pass down the middle of the road as this will remove the crown
- start compaction on the outer edges of the road and move towards the centre.

3.2.3 Best practice provisions

Table 1 Best practice soil and water provisions to observe during all road shaping activities

Subject	Do	Don't
Grading	<ul style="list-style-type: none"> • Avoid maintenance in higher rainfall months as this may lead to erosion and poor compaction. In western NSW higher rainfall months may provide sufficient moisture content to undertake grading. • Grade under moist conditions to limit dust production and assist with compaction. As maintenance cannot generally be structured around weather patterns, a water cart should be available at all times. 	<ul style="list-style-type: none"> • Lower the road surface below the surrounding natural ground level as this will result in the road becoming the drainage path. • Undertake maintenance if there is runoff from the road surface or if rutting >3 cm of the road surface could occur. • Blade off.
Soil disturbance	<ul style="list-style-type: none"> • Confine machinery to the road formation to avoid damaging roadside vegetation and disturbing the soil. Where soil disturbance occurs use soil stabilisation techniques (Section 6). 	<ul style="list-style-type: none"> • Widen the road pavement as this will lead to a greater area of soil exposed to erosion and runoff.
Windrows	<ul style="list-style-type: none"> • Remove earth windrows from the shoulders of roads unless they are constructed to prevent erosion of fill batters or where infall drainage is used. • Cut through windrows at regular intervals to allow drainage consistent with Table 2. 	<ul style="list-style-type: none"> • Leave windrowed excess material that blocks drainage from the road surface.
Batters	<ul style="list-style-type: none"> • Ensure that batters are stable (Section 6). 	<ul style="list-style-type: none"> • Cut the toe off batters; this will reduce their stability and lead to erosion. • Use a grader blade to clean off batters, or use a slope mower.
Drainage structures	<ul style="list-style-type: none"> • Ensure that drainage structures remain open. 	<ul style="list-style-type: none"> • Damage culverts or drainage structures.

4 Road surface drainage

4.1 General guidance

Effective road surface drainage will control runoff to prevent it from concentrating and reaching erosive volumes or velocities.

4.1.1 Road drainage structures

Drainage is one of the most important aspects of road maintenance as it protects the road structure from the effects of surface water and groundwater. Water entering the road structure may affect its stability, slow traffic and contribute to accidents.

All roads should be drained at distances no greater than those provided in Table 2.

Table 2. Maximum distance of water flow along road surfaces and table drains

Road grade (degrees)	Maximum distance (metres)	Road grade (degrees)	Maximum distance (metres)
1	250	8	70
2	200	9	65
3	150	10	60
4	125	11	55
5	100	12	50
6	90	13	45
7	80	14 & 15	40

Drainage spacing may be varied, however, by a suitably qualified person to suit site-specific conditions, for example highly erodible soils requiring an increased frequency of drainage. The Soil Conservation Service categorises soil types into one of four erosion classes:

Class A – Low soil erodibility. Brown and red soils derived from finer sediments and metasediments.

Class B – High soil erodibility. Red soils on fine granites, fine sandstones and basalt.

Class C – Very high soil erodibility. Grey and yellow soils derived from granites, sediments and metasediments, especially coarse-grained types.

Class D – Extreme soil erodibility. Unconsolidated sediment. As a general rule tracks should not be built on Class D soils.

Based on these soil erosion classes, rollover spacing is then recommended as follows:

Road grade	Class A	Class B	Class C
Up to 8	70 to 90m	60 to 70m	20 to 30m
8 to 12	60 to 70m	50 to 60m	*
12 to 16	40 to 60m	*	*
16 to 20	30 to 40m	*	*
20 to 22	20 to 30m	*	*

* Tracks should not be constructed on these soil types within the slope range.

One or a combination of the following techniques can be used in conjunction with crowning or crossfall to drain roads to the distances provided in Table 2:

- table drains
- mitre drains
- rollovers
- cross drains (also known as relief pipes or culverts)
- dish drains (also known as swales or spoon drains)
- catch drains.

Figure 8 provides a schematic of some road drainage features and their general location in the landscape.

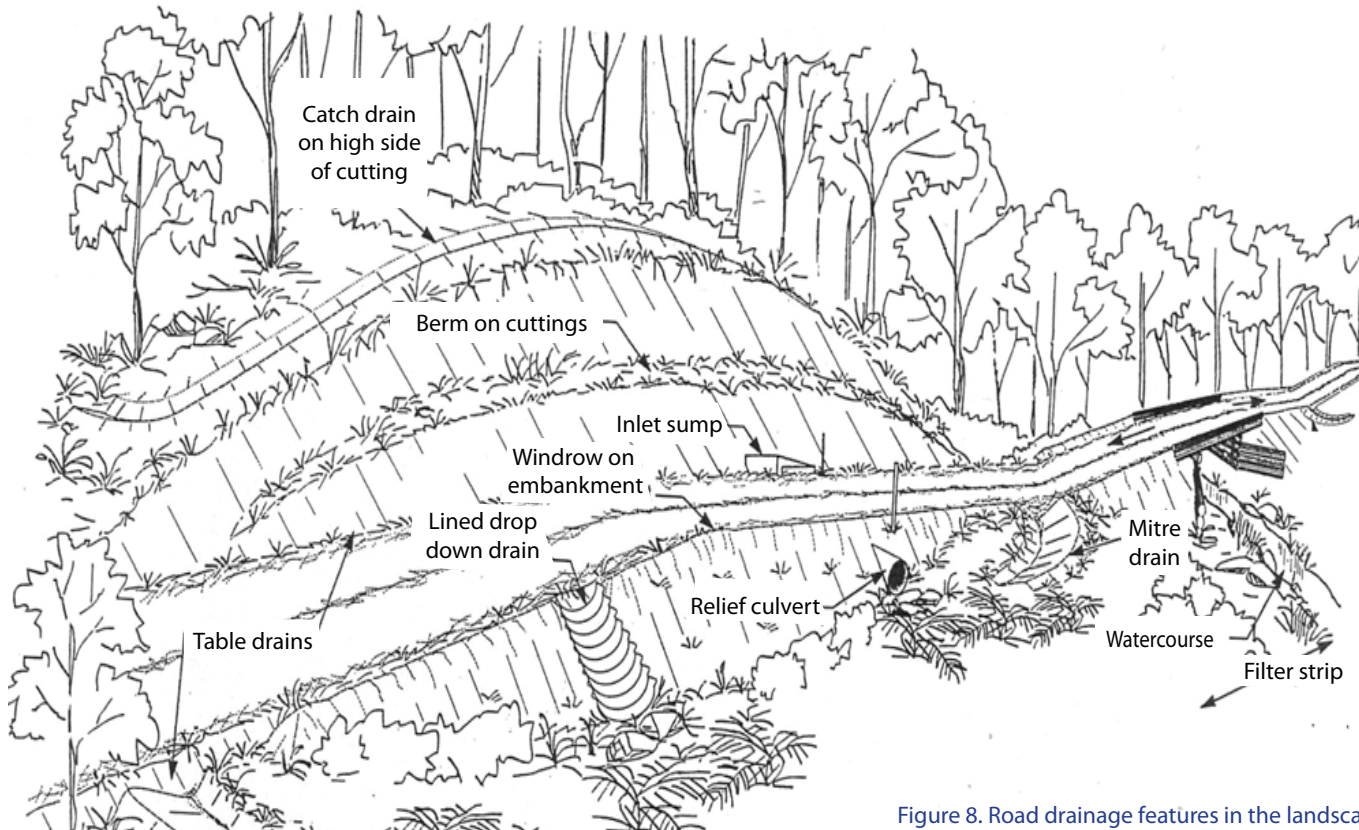


Figure 8. Road drainage features in the landscape

If the ground is steep or a road drainage structure is discharging near a watercourse, consider additional erosion protection, energy dissipation and/or sediment trapping devices at the outlet.

Where any soil disturbance occurs, stabilise and rehabilitate as soon as possible (Section 6).

Drainage structure outlets should:

- be stable and gently sloping to prevent erosion, not blocked by a stump, rock or soil debris
- spread water to dissipate erosive energy
- not discharge within 10 m of a watercourse
- not allow water to re-enter the road further downslope.

Drainage structures should discharge water onto a stable surface. This could include one or a combination of:

- undisturbed vegetation
- slash and vegetative debris
- a natural or artificial non-erosive surface
- natural or artificial sediment traps below the outlet of the road drainage structure.

4.2 Drainage structures

This section provides guidance on how to effectively install and maintain drainage structures.

4.2.1 Table drains

Regular maintenance of table drains prevents collected material from reducing their function and capacity and causing erosion.

Description

Table drains are excavated open channels that run adjacent to the road formation and are used to collect water runoff from the road surface, overland flow and cut batters (Figure 9). They are sized to reflect catchment area, soil type, slope and the distance that water flows between discharge points so that they have sufficient capacity to convey runoff without eroding. Note that a curved surface is difficult to achieve and therefore rarely used.

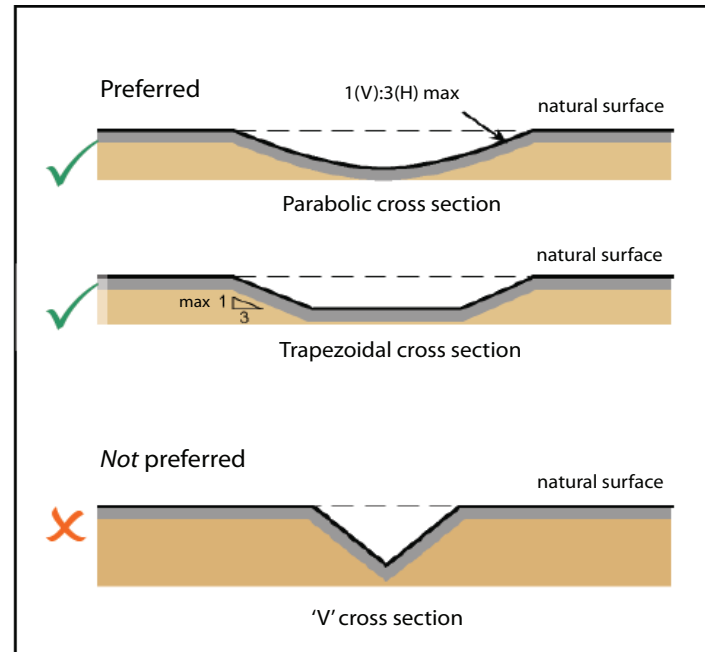


Figure 9. Table drain shaping

Operational guidance

Table 3. Guidance on maintaining table drains

Subject	Do	Don't
Profile	<p>Table drains should:</p> <ul style="list-style-type: none"> • be wide (preferably 1–2 metres where possible) with a flat-based profile • have low sloping sides, grade 1:3 (18°) • have a minimum depth of 150 mm (where the table drain invert has intercepted the water table, table drains will protect the subgrade of the road by being lower than the surrounding water table, protecting the road from saturation). 	<ul style="list-style-type: none"> • Create a 'V' cross section if possible (this will accelerate erosion).
Cleaning	<ul style="list-style-type: none"> • Only clean when necessary to restore drainage capacity (debris such as leaf litter slows runoff and allows sediment to settle). • Clean by mowing and/or raking. • Dispose of material generated from maintenance in an approved manner. 	<ul style="list-style-type: none"> • Create a smooth surface (this will accelerate erosion). • Leave loose soil material in the table drain. • Leave windrowed material that blocks drainage structures such as mitre drains. • Windrow material into roadside vegetation. • Damage or remove vegetation adjacent to the table drain.
Machinery	<ul style="list-style-type: none"> • Use a grader to achieve the required shape. 	
Erosion control	<ul style="list-style-type: none"> • If the table drain is eroding it may need to be lined with rock, jute mesh, appropriate grasses or other erosion control materials to create a stable surface (Section 6). 	

4.2.2 Mitre drains

Description

Mitre drains relieve the flow of water in table drains before it reaches an erosive volume or velocity by directing it from the shoulders of a road to a stable discharge area (Figures 10 and 11). They are simple, low-cost structures that allow the passage of vehicles without affecting their speed. They are most commonly used on ridge-top roads but provide effective drainage in a range of situations and grades and are particularly effective when used in combination with a crowned surface.

Operational guidance

- 1 Identify the spacing requirements based on the road grade.
- 2 At each location where a mitre drain is to be installed, choose an outlet point. Ensure the location of the outlet will not allow for water to re-enter the road further down-slope.
- 3 Install the mitre drain.
 - Cut from the table drain into the roadside vegetation on a slight angle to the road.
 - If possible the mitre should extend from the road to ensure runoff will not bypass the mitre. It may be necessary to dish the mitre drain entrance or construct an earthen headwall to direct runoff into the mitre.



Figure 10. A mitre drain

- Excavate to a depth of no more than 300 mm and a grade between 1:50 (1°) and 1:20 (3°) – a low grade will encourage sediment to settle and deposit.
- The mitre drain outflow length should limit disturbance to the surrounding area but be of sufficient length to adequately discharge water from the table drain.
- Attempt to keep the outlet of the mitre drain even and broad to encourage any concentrated water flow to become sheet flow.

Ongoing maintenance

- Remove sediment build-up in the mitre drain and any windrowed soil blocking the inlet.
- If the road is lower than the mitre drain inlet, reopen by either deepening the inlet or raising the surface of the road by regrading. In either case, inspect the table drain and next drainage structure downslope for any evidence of erosion.
- If a mitre drain is eroding consider:
 - additional drainage structures upslope
 - reducing the grade of the mitre
 - stabilising the structure with rock or jute mesh.
- If there is erosion at the outlet stabilise the discharge surface (Section 6).



Figure 11. A well-formed mitre drain used in conjunction with crowning crossfall

4.2.3 Rollovers

Description

A rollover (also known as a grade dip) is an earth bank with an upstream channel used to direct water flow across the road to discharge onto a stable surface (Figures 12 and 13).

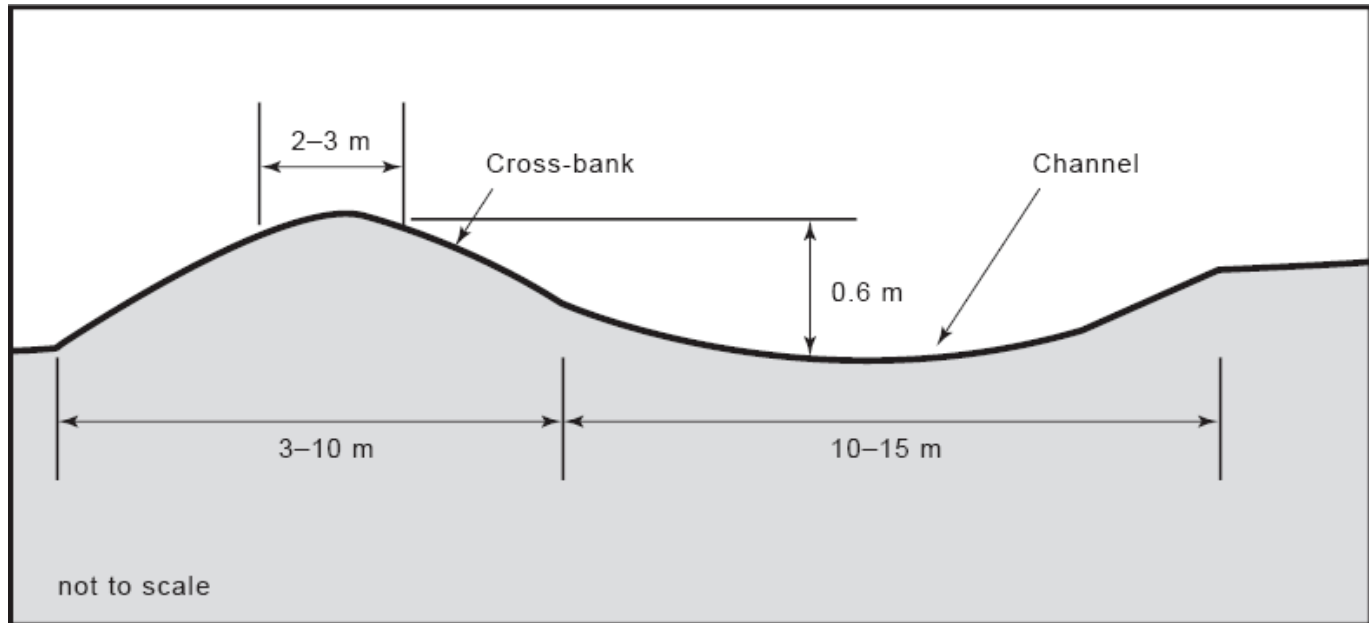


Figure 12. Rollover design and dimensions

Operational guidance

- Use natural road-base material where possible or clean imported material where the required quantity or quality is not available on site.
 - Material used for construction should be free of sticks and logs.
 - As the road grade increases consider increasing the height of rollovers with a relative increase in length.
 - The depth of a rollover should not exceed 600 mm (as shown in Figure 12) as it may become untrafficable.
- 1 From the outlet point, rip back across the road to a depth of 200–300 mm.
 - Rollovers should be perpendicular to the road and extend across the entire width of the road.
 - 2 Beginning at the uphill side of the road and working across to the outlet side, push the loose earth into a bank.
 - Enough loose earth should be used to give the required dimensions after shaping and compaction is completed (aim for a consolidated effective bank height of 300–600 mm).



Figure 13. Well-formed rollovers

- A long, shallow excavation for the bank is better than a short, deep excavation so as to allow vehicle passage while effectively collecting and diverting runoff. Ensure the channel is deep enough to prevent runoff from breaching the bank.
 - Where a rollover is installed adjacent to a cut batter it should be tied into the cut batter to prevent water from bypassing it.
 - If an eroded table drain has to be filled to build a bank, compact the bank at that point with extra earth to allow for slumping and to cope with the concentrated runoff in the table drain.
- 3 Track- or wheel-roll the entire length of the bank to get maximum compaction and a smooth, even surface.
- Adequate compaction will minimise the risk of banks breaching and maintain their capacity for vehicle use.
 - Any loose earth or other material that may block water flow off the road should be removed from the excavation.

Ongoing maintenance

- Increase the bank height or decrease the spacing between rollovers if they are being overtopped or breached.
- Repair any damage to the integrity of the bank; maintain an effective consolidated height of at least 300 mm.
- Ensure the cross-bank channel is clear of debris and/or sediment.
- If there is erosion at the outlet stabilise the rollover (Section 6).

4.2.4 Cross drains

Description

Cross drains (also known as relief pipes or culverts) are used to transfer water flow in a table drain located on the high side of a road by piping the water under the road to the low side for controlled discharge (Figure 14).

A suitably qualified person should develop the cross-drain specifications.

Ongoing maintenance

- The cross drain should have at least 300 mm of fill above the pipe.
- Signs of overflow may indicate a blockage or inadequate design size.
- Inspect for blockages and remove any debris from the pipe entrance, minimising disturbance to the ground surface.
- Inspect for evidence of erosion at the pipe inlet and outlet. In particular, ensure that the pipe outlet is not being undermined. This can be achieved by armouring or using a lined batter drain, including an energy dissipator.
- Install guide posts at pipe inlets to assist road maintenance operators identify inlet location and minimise damage and infilling.

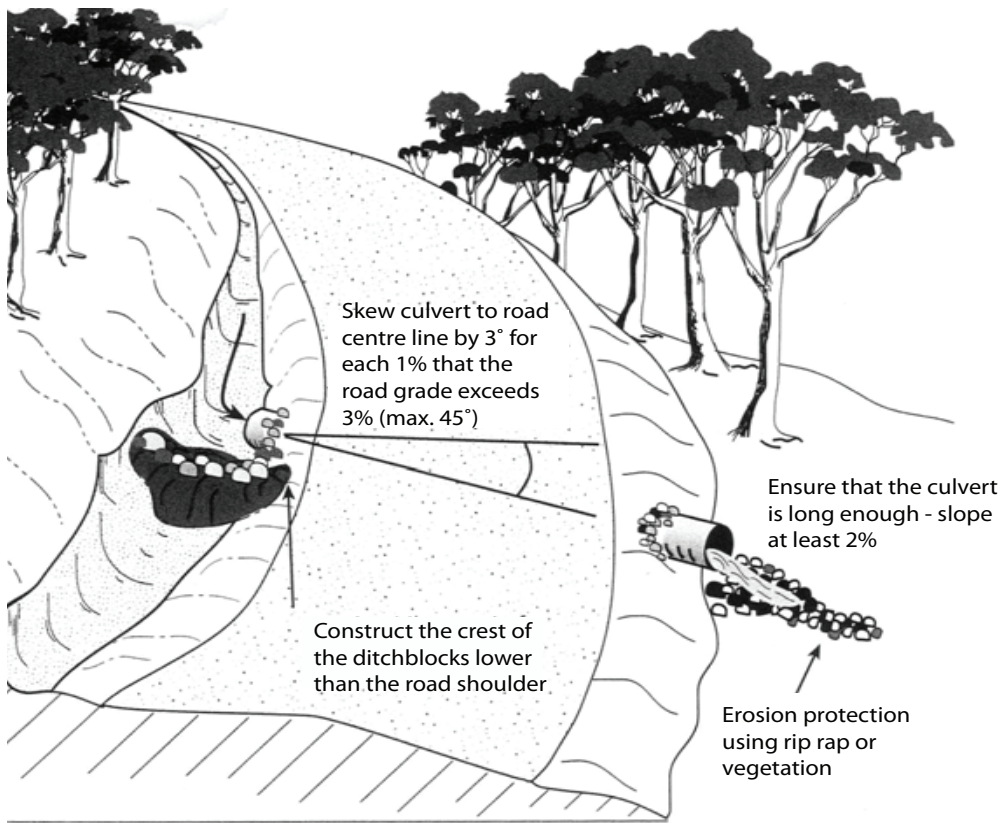


Figure 14. A cross drain

4.2.5 Dish drains

Description

Dish drains (also referred to as swales or spoon drains) are shallow depressions used to collect and direct water to a stable discharge point (Figure 15). They provide an alternative to rollovers and are generally placed where there is a natural depression in the road and where low water velocities are encountered, such as on low grade roads (generally less than 5°).

Operational guidance

From the outlet point, rip back across the road to a depth of 200–300 mm. Dish drains:

- should extend across the entire width of the road
- are most effective if constructed at least 30° to the road and a minimum depth of 150 mm.

Ongoing maintenance

- Inspect for accumulation of sediment and evidence of over-topping. Remove any accumulated sediment.
- If there is erosion at the outlet, stabilise the dish drain (Section 6).

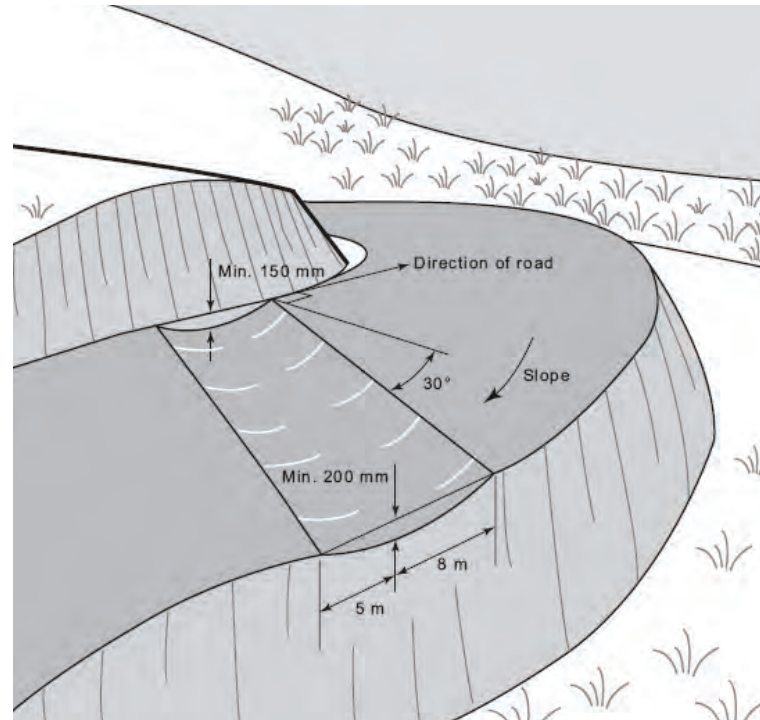


Figure 15. A dish drain

4.2.6 Catch drains

Description

A catch drain is a constructed depression above a cut or fill batter to prevent batter erosion and direct runoff to a stable discharge point (Figures 16 and 17). The size and lining of catch drains will depend on the size, slope and rainfall characteristics of the catchment above and the distance that water must flow along the catch drain before it is discharged. They are often used in conjunction with drop down structures (Section 4.2.7).

Ongoing maintenance

- Maintain catch drains to avoid runoff flowing down the batter face. Inspect for accumulation of sediment and evidence of over-topping. Remove any accumulated sediment.
- If there is erosion at the outlet stabilise the catch drain (Section 6).

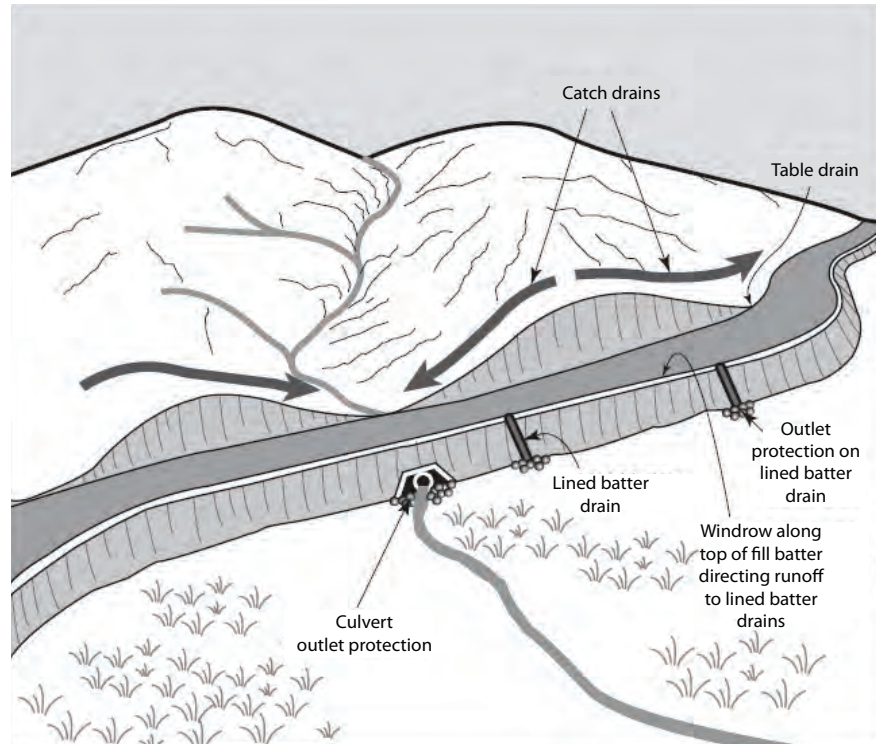


Figure 16. Location of catch drains in the landscape



Figure 17. A well-formed catch drain

4.2.7 Drop down structures

Description

Drop down structures, also known as batter drains or flumes, are used to transport water from road drainage structures down a fill batter to a safe discharge point without causing erosion (Figures 18 and 19). Depending on considerations such as catchment size, rainfall characteristics, soils and vertical fall, drop down structures can be constructed from round or half-round pipes of galvanised steel and concrete, or they can be formed using rock, cement, geotextiles, jute mesh and bitumen.

Operational guidance

Consider the use of drop down structures where:

- a road drainage structure discharges onto a newly constructed fill batter greater than 1 m in height
- an existing fill batter greater than 1 m in height has an unstable surface or less than 70% groundcover
- ground slope is greater than 1:2 (26°) (this is also dependent on the soil type).

Drop down structures should:

- consist of an inlet, chute and an outlet
- have the inlet designed to capture and direct all intended flow into the chute, including the use of diversion banks, box inlets or headwalls
- include an energy dissipator at the end of the chute.

Ongoing maintenance

If there is continued erosion of a batter face and/or slumping, investigate stabilisation through additional drainage (such as catch drains) and/or revegetation.



Figure 18. Drop down structure with rock energy dissipator



Figure 19. Energy dissipator – a riprap outlet on a steep slope

5 Road crossings

5.1 General guidance

Unsealed roads should be drained between 5 and 30 m from a crossing. Effective drainage at this distance will help prevent runoff from the road depositing sediment into a watercourse.

- 1 Unsealed roads should be drained between 5 and 30 m from a watercourse, drainage line, drainage depression, wetland or swamp crossing. This distance can be measured from the top of the bank of the incised channel or, where there is no defined bank, from the edge of the channel or depression.
- 2 Where it is not possible to install drainage structures between 5 and 30 m from a crossing, site-specific techniques should be used to help minimise the deposition of sediment in the watercourse. This could include one or a combination of the following techniques:
 - armouring the road surface and/or table drain
 - grassing the road surface and/or table drain
 - covering the surface of the table drain with an erosive resistant fabric
 - installing sediment traps and/or sediment fences.
- 3 If maintenance activities disturb the soil, the area should be reshaped to a condition that integrates the surrounding landscape and soil stabilisation measures put in place, including the efficient use of topsoil. However, if the soil is saturated, machinery should not enter the disturbed area and temporary soil stabilisation and sediment control measures be put in place. Permanent soil stabilisation measures should be put in place when the soil is not saturated. Examples of erosion and sediment control measures can be seen in Figure 20.
- 4 Any clearing associated with maintenance of crossings should be undertaken at, or as close as possible to, right angles to the flow of water unless an angled approach reduces ground and soil disturbance.
- 5 Crossing maintenance operations should restrict disturbance of vegetation and groundcover in the filter strip to a maximum length of 3 m upstream and downstream of the crossing.

- 6 Any spoil, loose material or tree debris that results from maintenance operations must not be placed inside drainage features, filter strips or drainage structures. Excess material should be removed off site or temporarily stockpiled within a perimeter sediment fence in an area at least 10 m from drainage features.
- 7 Soil erosion and sediment control measures should be used and maintained during crossing maintenance operations that require greater than one day to complete. They should prevent water from the road surface and road drainage structures entering disturbed areas and avoid the deposition of spoil into the drainage feature.



Figure 20. Erosion and sediment control measures around bridge abutments

5.2 Structures

5.2.1 Bridges

Description

A bridge is a structure, including supports, erected over a depression or an obstruction such as water, a road or railway to provide passage.

Operational guidance

- Use soil stabilisation measures to protect bridge embankments from table drain discharge (Section 6).
- Install structures to prevent soil or gravel, where it is used as the pavement for the bridge surface, from entering the drainage feature (Figure 21).
- Remove soil or gravel deposited within the drainage feature (Figure 22).
- Minimise disturbance to the bed and bank of the drainage feature and use soil stabilisation techniques if required (Section 6).



Figure 21. Soil entering a drainage feature from the pavement of a bridge surface



Figure 22. Spoil in the drainage feature beneath a bridge

5.2.2 Culverts

Description

A culvert is a conduit used for the passage of surface water underneath a road formation or other embankment (Figure 23). Culverts comprise one or more pipes or box culverts, normally fitted with headwalls.

Operational guidance

- Pipes should be covered to a depth in accordance with the pipe manufacturer's specifications and depend on the pipe material and class of pipe. As a general rule pipes of 3.6 m diameter or less should be covered by at least 600 mm of compacted fill and pipes with a diameter greater than 3.6 m should have a depth of cover of one-sixth of the pipe diameter.
- Headwalls and soil stabilisation measures should be used to protect the upstream and downstream fill batters surrounding the culvert pipe(s) (Figures 24 and 25). This should be completed within five days of crossing maintenance operations.
- Pipe outlets should discharge onto stable surfaces. Scouring at the pipe outlet should not undermine the crossing structure or initiate gully erosion (Figure 26). Armouring and/or dissipators may be required to stabilise the outlet (Figure 27).
- Check the inlet for blockages to ensure that capacity is maintained.
- Check that the bank downstream is not eroding – stabilise as required (see Section 6).
- Refer to the Department of Primary Industries for fish passage requirements if relevant.



Figure 23. An example of a culvert crossing



Figure 24. Poor stabilisation of batter



Figure 25. Culvert outlet requiring clean-out and stabilisation – head-wall placement too low resulting in erosion from the pavement



Figure 26. Scouring beneath a headwall



Figure 27. Outlet dissipation structure

5.2.3 Fords

Description

A ford, also known as a floodway, is a place in a watercourse that is shallow enough to be crossed in a wheeled vehicle (Figure 28). The pavement of a ford may consist of gravel, rock, bitumen or concrete, or of a stable natural surface. Fords are the preferred method for creek crossings as they are largely maintenance free once the site has been stabilised and are fish-passage friendly.

Operational guidance

If the maintenance of a ford results in erosion or deformation of the road surface or the bed and banks of the drainage feature, then:

- the ford crossing should be replaced with a bridge or causeway with pipe culvert(s), or
- the ford surface and approaches should be armoured with a non-erosive material.

Repair or replacement of ford crossings should include all sections of the crossing and crossing approaches where erosion or deformation has occurred.



Figure 28. An example of a ford crossing

5.2.4 Causeways

Description

A causeway is a form of trafficable floodway where the roadway is elevated above the stream bed to provide an even surface for traffic. It usually has one or more culverts for the passage of low water flows and is designed to be dry, and flooding is restricted to periods of wet weather (Figure 29).

Operational guidance

- The bed and banks of causeway crossings must consist of a stable natural surface or be constructed of erosion resistant materials.
- Repair or replacement of causeway crossings must include all sections of the crossing and crossing approaches where erosion or deformation has occurred.
- Operational guidance for culverts should be as per Section 5.2.2.



Figure 29. An example of a causeway

6 Erosion and sediment control measures

Erosion control measures either protect or reinforce the soil surface or convey runoff in a non-erosive manner. Sediment control measures capture eroded soil particles by reducing the velocity of runoff, allowing the soil particles to settle out of suspension.

It is preferable, and typically easier and cheaper, to implement erosion control measures that prevent erosion occurring in the first place. In addition to this, scheduling work during the drier months of the year will also result in less erosion than conducting the same work during the wetter months.

Selection of appropriate control measures will depend on whether the problem is erosion or sedimentation and site-specific requirements (Table 4). An extensive range of products are available, and the following table provides a number of erosion and sediment control measures that are typically available to field staff.

Table 4. Erosion and sediment control measures

	Erosion	Sedimentation
Splash	<ul style="list-style-type: none">• vegetation• soil surface mulching	
Flowing water	<ul style="list-style-type: none">• erosion mats and blankets• armouring• check dams	
Sheet flow		<ul style="list-style-type: none">• sediment fences
Concentrated flow		<ul style="list-style-type: none">• sediment traps

Field staff should also be aware of the potential for dispersible soils and slaking. Dispersible soils are structurally unstable in water and easily split into their constituent particles resulting in relatively high levels of turbidity in receiving waters. Many NSW clays are dispersible.

Slaking means the partial breakdown of soil aggregates in water due to the swelling of clay and the expulsion of air from pore spaces. Soils that slake will break down in water but not go into suspension as dispersible soils do.

The Emerson Aggregate Test can be used to identify the presence of dispersible soils and provide an indication of the conditions under which it will disperse and whether soils will slake. In both instances additional erosion and sediment control measures should be implemented. For example, areas of bare soil should be covered with erosion control matting or geofabric until vegetation is established.

The following section provides information on the erosion and sediment control measures contained in Table 4, including, where appropriate, installation instructions.

6.1 Erosion

6.1.1 Vegetation

Stabilisation with vegetation and native grasses is a relatively inexpensive and effective method as it binds the soil with roots, minimises raindrop splash and sheet flow erosion, reduces the volume and erosive velocity of runoff, and increases runoff retention time and therefore promotes infiltration. In general:

- use of topsoil will aid germination and promote long-term stability and provide a valuable seed source for plants endemic to the local area
- works requiring seeding should be conducted at the start of spring
- for long-term stabilisation it is common to use a mixture of perennial and annual species; the annual species quickly establish effective ground cover allowing the perennial species to grow and succeed them to provide more permanent ground cover
- the success of seeding will depend on a range of factors, including sunlight, temperature, soil fertility and structure, and moisture levels.

For further details regarding vegetation management and rehabilitation refer to Section 7.

6.1.2 Soil surface mulching

Mulching involves placing a cover of coarse organic material, usually vegetative debris, on an exposed soil surface to protect it from splash erosion and sheet flow. Where available, operators may consider hydromulch or hydraulic bonded fibre matrix, blown straw, hay or other crop residue with bitumen tack. Achieve at least 70% groundcover to effectively minimise erosion. For further details regarding mulching refer to Section 7. Mulch will:

- stop erosive processes and sediment losses
- protect soil and subsoil structure of batters
- inhibit weed seed germination
- provide microclimates for seed retention and germination of native species
- facilitate plant growth by inhibiting evaporation of water from the soil profile.

6.1.3 Erosion control matting

Erosion control blankets can be used on batters, embankments and other sheet-flow environments to protect against erosion and promote vegetation. They are generally temporary measures designed to degrade, being made of wood fibre, wool and jute, and generally used in conjunction with seeding. Erosion control mats are made from durable material such as coconut fibre, nylon and polypropylene and are to be used in concentrated flow environments such as table drains.

When installing erosion control blankets and mats (Figures 30 and 31):

- the ground surface should be free of grass and objects (e.g. rocks and sticks)
- spread topsoil to at least 75 mm depth, seed and fertilise as appropriate
- grade the surface to allow the matting to be continuously in contact with the soil
- lay the matting so that the upslope mat overlaps the top of the next downslope mat
- secure all matting with sufficient staples
- in the case of erosion control mats, divert water from the drainage structure until vegetation is established.

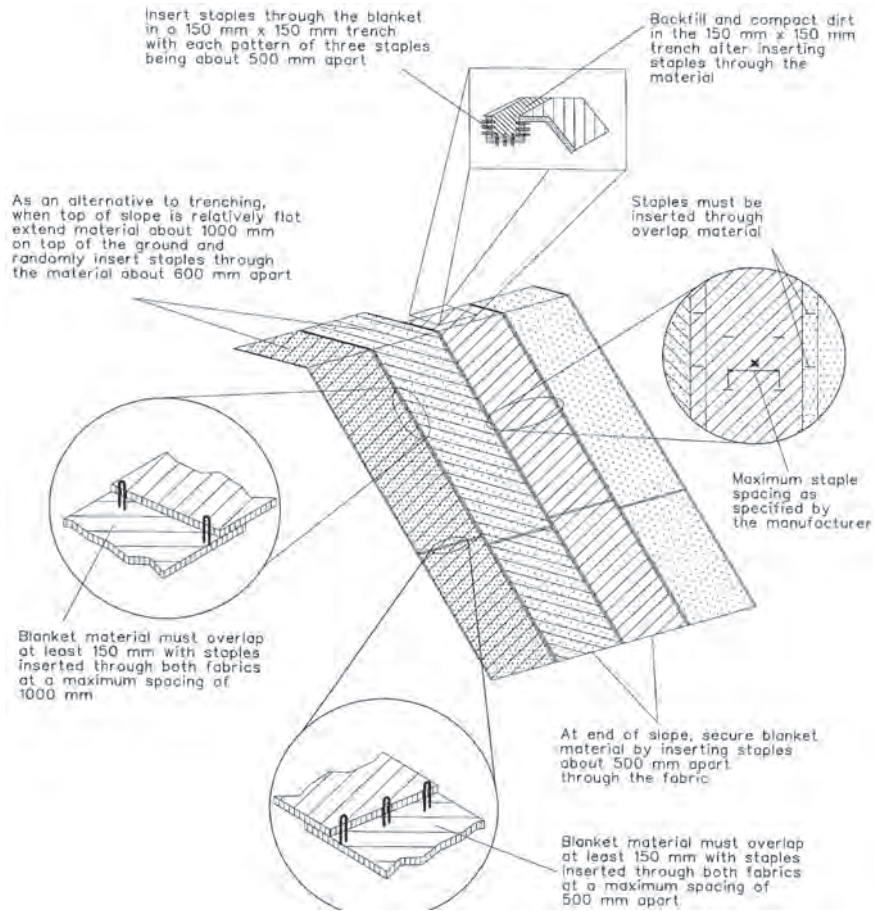


Figure 30. Installation of erosion control blankets



Figure 31. An example of erosion control matting used to stabilise a batter

6.1.4 Armouring

Rock or aggregate can be used to ‘armour’ unstable areas such as table drains and drainage structure outlets. All rockwork should be underlain with geofabric. Armouring of drainage feature crossings, including approaches, is also common.

6.1.5 Check dams

Check dams are small temporary weir structures that can be built from rocks, logs, sandbags or straw bales (Figure 32). They reduce the velocity of runoff and capture limited amounts of coarse sediment.

- Trench the dam about 200mm into the ground.
- The height of the dam should not normally exceed 600 mm above the soil surface.
- The middle of the dam should have a spillway with a height about 150 mm lower than the outer edges.
- If using multiple check dams the toe of the upslope dam should be at the same level as the crest of the next down slope dam.
- Straw bales will require regular replacement (usually every 2–4 months).



Figure 32. An example of a sandbag check dam

6.2 Sedimentation

6.2.1 Sediment fences

A sediment fence is a temporary barrier of permeable geotextile, partially installed in a trench and supported by posts (Figures 33, 34 and 35). When using sediment fences:

- don't use in areas of concentrated flow
- install as close as possible to the contour of the site, including small returns at the end
- ensure the bottom edge of the fence is adequately buried in the soil (about 150 mm) and the fence posts are on the down-slope side of the fabric
- compact the trench after installation
- ensure the geotextile is tied to the fence posts
- consider additional fences where erosion is occurring
- maintain them by checking their integrity and removing sediment build-up.

6.2.2 Sediment traps

Sediment traps are designed to capture and slow runoff containing eroded sediments and allow the coarse sediment to settle. Larger structures require design (Figure 36) while simpler, smaller structures can be constructed in the field using rocks, logs and sandbags (Figure 37).

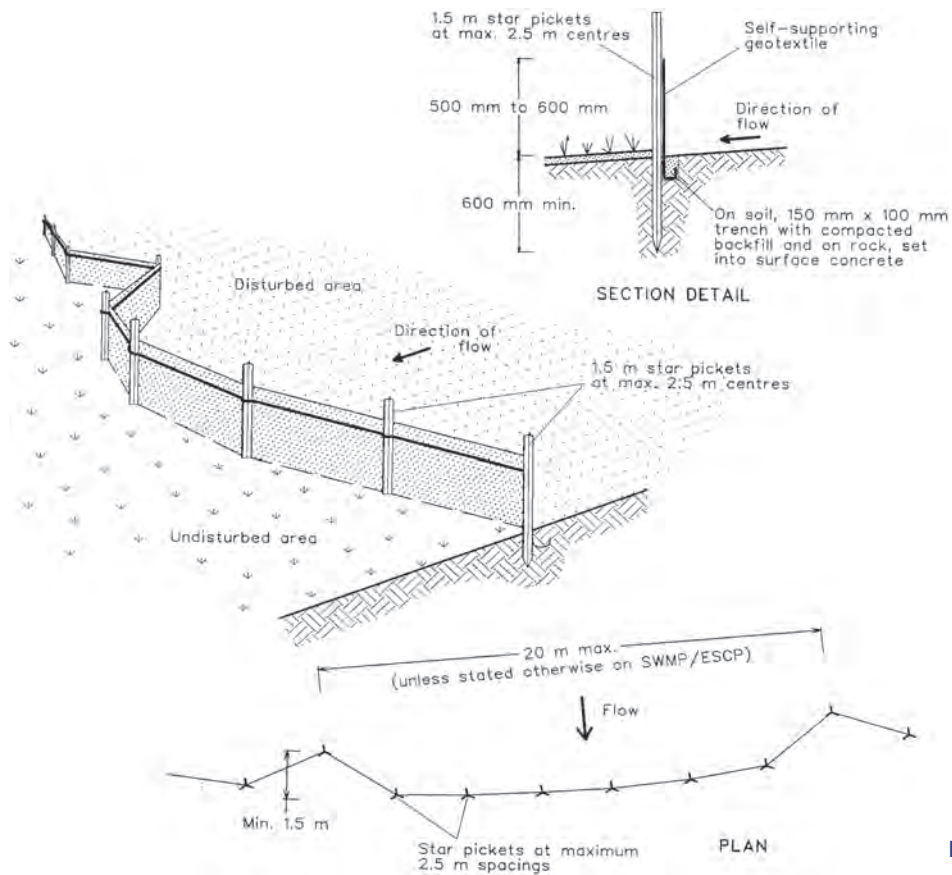


Figure 33. Installation of sediment fences



Figure 34. Sediment fencing



Figure 35. A poorly maintained sediment fence



Figure 36. A designed sediment trap



Figure 37. A sandbag sediment trap with a spillway in the outlet of a table drain

7 Site rehabilitation

This section provides information regarding the on-site rehabilitation of an area. Any disturbance should be rehabilitated as soon as possible after works, which generally includes covering the affected area in the short term and revegetation in the short to medium term. Some general principles to achieve effective rehabilitation include:

- Rehabilitation should be part of the planning for road maintenance works.
- Don't leave bare earth as it promotes erosion and degradation – cover as soon as possible.
- Each site has site-specific characteristics so rehabilitate accordingly (e.g. topography, climate and soil type).
- Use indigenous revegetation plant species.
- Monitor rehabilitation to ensure success.
- Control drainage across rehabilitated areas and deposit surface water into natural drainage depressions/lines as soon as possible and in a controlled manner.
- Stockpile and re-use topsoil and other organic materials from the site.

7.1 Stages in rehabilitation

The following are the major steps in the rehabilitation process:

- | | |
|--|------------------------------------|
| 1 weed management | 6 plant maintenance |
| 2 replace topsoil/organic matter | 7 place ground mulch |
| 3 erect fauna controls such as fencing | 8 place tree guard |
| 4 plant seedlings/seeds | 9 weed management |
| 5 watering | 10 maintain mulch and tree guards. |

The following sections provide further details on some of these steps.

7.1.1 Topsoil

Topsoil should be stripped prior to earthworks, stockpiled appropriately (including sediment control), and re-applied to the bare surface as the first step. Where there is no, or insufficient, topsoil, compost can be used to provide organic material in the soil matrix to assist the revegetation process. The basic recipe for compost production is:

- 4 parts sawdust (aged hardwood is best)
 - 1 part woodchip (hardwood or softwood)
 - 1 kg dolomite per cubic metre of material
 - 1 kg urea per cubic metre of material.
- 1 Mix all components well and ensure the material is damp but not soaking – this is very important for green sawdust as it can become hydrophobic (water repelling); if required use a surfactant to wet down the sawdust.
 - 2 Windrow in piles less than 2 m in height and a minimum length of 6–8 m (the pile needs to be large enough for bacteria to break down the sawdust).
 - 3 Turn the pile every 2–4 weeks depending on the condition of the material; the greener the sawdust the longer it will take to break down with more water and higher temperatures required – the pile needs to get to approximately 60°C for green sawdust or 40°C if aged sawdust is used.

7.1.2 Planting

Plant species

The plant families most suited to use in rehabilitation of roadside batters include:

- Poaceae (grasses)
- Asteraceae (daisies)
- Fabaceae (colonising peas)
- Proteaceae (some small attractive shrubs).

All plants used in roadside rehabilitation should:

- be 'natural colonisers' or plants that will colonise bare ground
- not grow with a single woody stem as they tend to 'fall off' batters and create a hazard
- have rapid growth rates
- be easily accessible (either through a commercial seed source or collected from a local natural reserve if permissible).

Using colonising local plants will increase the biological and aesthetic success of rehabilitation of roadside batters. When selecting which species to use, look around the site to see what species are coping. Seedlings or tubestock should be used where possible as they are dynamic, full of sugars and hormones, 'elastic' in regard to coping with environmental extremes and, once established, will grow much faster than a larger plant.

Hardening tubestock

Hardened plants have a better chance of establishment as they can moderate water loss, cope with strong winds and cold temperatures and use their available carbohydrates to establish rapidly. All tubestock should be hardened by putting them outside, lowering watering regimes and exposing them to an environment comparable to the location where they will be planted, including exposure to wind and extreme temperatures.

Planting techniques and tools

Planting tubestock

- Dig the hole at least twice the size of tubestock depth and width.
- Remove big rocks or other large material from the planting hole as too much air is caught up around these items.
- Place a handful of pre-wet water crystals, up to 5 litres of compost, and 25 g of slow release fertiliser in the hole. This will provide a suitable substrate for initial establishment of the planted tubestock. The compost principally provides an organic material that can be mixed with local soils.
- Remove the seedling and tease out the roots if the plant is pot bound; if the plant is not pot bound, don't tease out the roots as this adds to transplant stress. Woody root systems can be scored with a knife if the plant is pot bound.

- Make sure the collar (the part between the root and shoot) is at the top of the soil/compost. Planting too deeply or too high is a common reason that tubestock dies.
- Backfill with soil and compress firmly after the seedling is planted.
- Create a small depression in the soil around the plant so that water is captured when it rains or when the plant is watered.
- If planting on the side of steep slopes, use a small deep hole that has a front lip for catching water and a face at the back of the planting hole that won't collapse onto the plant.
- Creeping plants and grasses can be planted sideways or on an angle so they cascade down a slope and follow the profile of the landscape.
- Consider planting, for example, a tree and a shrub or a shrub and grass in the one hole. There are some advantages to planting a nitrogen fixing or phosphorus fixing plant with another plant type as the other plant is provided with nitrogen or phosphorus from the action of the roots of the 'fixing' plant. This can accelerate growth rates significantly.

Direct seeding

- Sites need to be weed free – consider the use of selective herbicides as a weed control measure.
- Only sow seed on slopes less than 1:4 (14°) to reduce loss through slippage.
- Only broad-leaved native species should be sown on sites that are predominantly invaded by exotic grasses; similarly, sow native grasses on sites that are predominantly invaded by broad-leaved weeds.
- Only sow seed where there is some organic layer (soil or compost) for the seedlings to establish.
- Prepare the seed bed by creating small grooves in the soil surface with a rake.
- Use a thin layer of organic mulch to cover the soil and seed.
- Water in seed once it is covered with mulch with a fine spray.
- Sow grass and forb species at 10 g/m² and shrub and tree seed at 5 grams per cubic metre. These rates can be increased by 5 grams per cubic metre at altitudes above 1500 m.

Fertiliser

Add a small amount of fertiliser (20–30 g/hole) for every planted tubestock to encourage rapid growth and establishment. Direct incorporation into the planting holes reduces the amount of available nutrients to weed species during the site rehabilitation phase. Fertiliser is best applied in the form of certified pathogen-free pelletised chicken manure and slow release trace element fertilisers. This is prophylactic practice to prevent poor or nil growth due to soil infertility. The slow release property of these fertilisers protects against phytotoxic response by the seedlings.

Tools

Good tools for planting are small sturdy trowels, short-handled mattocks for slope planting, post-hole shovels, and mattocks and crowbars for punching in holes in the side of a batter. Rakes, hoes, wheelbarrows and buckets are all essential in a rehabilitation project. Small excavators, quad bikes, mechanical augers and bobcats are also very useful.

Watering-in

Plants must be watered on the day of planting at a rate of 3-5 L/plant. The initial watering-in phase is important because lack of water is a common cause of death amongst seedlings. The water also pushes soil around the root system, preventing air pockets forming. Follow-up watering may be needed if no rain falls 4–6 weeks after planting. Only one follow-up watering is recommended, none if possible.

The logistics of watering should be resolved before planting begins. Water points can be used and pumped with a small 4-stroke pump to the planting area, or a 500–1000 L water cart will have to be transported to the site. The time taken to effectively water tubestock in (and wet down straw) is often underestimated; watering needs to begin by mid-afternoon on each planting day so that seedlings are properly watered-in on the day they are planted.

Plant establishment

A well-tended plant is sufficiently established 6–8 weeks after planting.

Grazing protection

Protecting newly planted seedlings or directly sown seed from fauna grazing is essential. Seedlings need to be protected for at least six months. Fencing is the most common method of fauna control.

7.1.3 Mulching

Organic mulches can be used to cover bare soil to limit erosion and provide an organic environment to promote plant growth. Mulch should be weed and crop free (less than 10% crop seed) straw, paper products (such as hydro mulching) and jute or coconut matting. Straw should be applied 2–5 cm thick. If applying to batters, reduce the thickness of the mulch layer as batter steepness increases.

The storage, retention and re-use of local small-gauge thatch will significantly improve roadside rehabilitation. Any herbaceous or small woody plants removed from an area for road construction can be re-used in the rehabilitation of the roadside batters. This material (grass swards, small shrubs and canopies from small trees) can be placed over revegetated batters and will:

- protect batters from grazing of tubestock
- help secure straw and organic matting to the batter surface
- slow flows of water and sediment over the batter surface.

Small-gauge woody material when used in roadside batter work can significantly improve rehabilitation outcomes. It is very important that large-gauge wood is not used as it may become a hazard to motorists.

7.2 Batters and rehabilitation

Batters require special approaches to rehabilitation dependent on their slope. As a rule, cut and fill batters should be designed to be no steeper than the in-situ soil stability permits.

Table 5A provides the recommended maximum batter slopes based on soil type or rock stability.

Tables 5B and 5C provide some approaches to batter rehabilitation.

Table 5A. Recommended maximum batter slopes

Soil or rock type	Slope (horizontal:vertical)
Rock – slip plane horizontal or dipping away from cutting	0.5:1
Rock – slip plane dipping toward cutting	1.5:1
Well-graded gravels	1:1
Poorly graded gravels	1.5:1
Clayey or silty gravels	2:1
Silts and fine sands	3:1
Clayey sands	2.5:1
Sandy clays	2.5:1
Clays	2:1

Table 5B. Batter rehabilitation

Slope	Rehabilitation
Greater than 1:3 (18°)	<ul style="list-style-type: none"> • Hydro-mulch with a herbaceous species (grasses and forbs) and cover with straw. • Offset cross logs with tube stock planted behind logs (Figures 38 and 39). • Construct small spoon drains across slope to retain water (Figures 40 and 41). • Organic matting is also suitable for steep slopes (refer to Section 6).
Less than 1:3 (18°)	Batter will rehabilitate successfully if mulched, sown and planted with local native species or cover crops.
Batter height <5 m and slope <1:3 (18°)	Batter can be left smooth – does not require a hydrological break such as spoon drains, cross logs or roughness of surface.
Batter height >5 m (of any angle)	Batter will require benching at intervals not exceeding 5 m (vertical) and hydrological breaks. Spacing recommendations for drains or cross logs is shown in Table 5C.

Table 5C. Spacing recommendations for drains or cross logs

Grade	1:20 (3°)	1:10 (6°)	1:6.66 (8.5°)	1:5 (11°)	>1:4 (14°)
Spacing	30 m	20 m	15 m	10 m	5 m



Figures 38 and 39. Offset cross logs with tubestock



Figures 40 and 41. Spoon drains on batters

8 Definitions

Armour: provide a protective surface that is resistant to erosion or displacement by machinery or vehicles.

Batter: an earth slope formed by the placing of fill material or by cutting into the natural hillside.

Batter drain: a constructed and stabilised drain to carry runoff down a batter without scouring or erosion.

Batter stabilisation: the provision of adequate vegetative, structural or mechanical measures to control erosion from batters. Measures may include the provision of catch drains, topsoil, seeding, mulching, use of geofabrics, benching, use of batter drains, retaining walls or other engineering structures.

Blade off: the use of a machine to sweep drifts of loose mud, slush or soil from the surface of the road to provide temporary access following wet weather.

Catch drain: a diversion drain excavated on the high side of the batter, embankment or road to intercept and divert surface runoff water before it reaches the batter, embankment or road.

Causeway: a form of trafficable floodway where the roadway is elevated above the stream bed to provide an even surface for traffic, usually with one or more culverts for the passage of low water flows and designed to be dry with flooding frequency restricted to periods of wet weather.

Crossbank: a hump of earth constructed across a road to baulk the flow of water so that it can be diverted.

Cross drain: a pipe used to direct water from a table drain and under the road, also known as a relief pipe.

Culvert: one or more adjacent enclosed conduits for conveying a drainage feature underneath a road formation.

Dish drain: a drain with a semicircular cross-section with no associated ridge of soil and capacity solely defined by the excavated channel dimensions. Also known as a swale or spoon drain.

Drainage depression: a level to gently inclined shallow, open depression with a smoothly concave cross-section, rising to moderately inclined hillslopes.

Drainage feature: a drainage depression, drainage line, major water storage, watercourse, swamp or wetland.

Drainage line: a channel down which surface water naturally concentrates and flows. Drainage lines exhibit one or a combination of the following features which distinguish them from drainage depressions:

- evidence of active erosion or deposition such as gravel, pebble, rock, sand bed, scour hole, nick points
- an incised channel of more than 30 cm depth with defined bed and banks.

Drop down structure: a non-erodible channel or hydrologic structure that discharges water over a fill batter. They may be constructed of gabion baskets, rock mattresses, precast concrete segments, geotextiles or half round sections of plastic, corrugated or concrete pipes. An energy dissipator should be used in conjunction with a drop down structure.

Effective bank height: the minimum height of a crossbank above the outlet.

Energy dissipator: a device in the base of a channel or running water that dissipates the energy of the flow. The dissipator reduces the velocity and depth of water flow by spreading it over a larger area. Energy dissipators may be constructed from rocks, logs, steel baffles or concrete blocks.

Erosion: wearing away of the land by running water, rainfall, wind, ice or geomorphological agent, including but not limited to processes such as detachment, entrainment, suspension, transportation and mass movement.

Fill: a previously excavated material that is used to raise the surface of an area to a specified level.

Filter strip: a strip of vegetation or groundcover along each side of a watercourse or drainage line retained for the purposes of:

- retarding the lateral flow of runoff and facilitating its infiltration into the soil, thereby causing deposition and filtration of transported material, and reducing sediment movement into the stream
- retarding sediment movement into the stream by minimising ground disturbance which may reduce infiltration and concentrate water
- reducing the risk of erosion of the channel and bank.

Ford: a place in a watercourse that is shallow enough to be crossed in a wheeled vehicle. The pavement of a ford may consist of gravel, rock, bitumen or concrete, or of a stable natural surface. Also known as a floodway.

Geotextile: a product used as a soil reinforcement agent and as a filter medium, made of synthetic or natural fibres manufactured in a woven or loose non-woven manner to form a blanket-like material.

Grade: a unit of slope measured from a horizontal plane.

Gravel: a naturally occurring mixture of coarse mineral particles 2–75 mm in diameter. Gravel is placed on the surface of a road to increase the load-bearing capacity of a natural surface.

Groundcover: material which covers the ground surface to reduce erosion. It may include existing vegetation, leaf litter, tree debris, gravel, rock, straw, mulch, geotextiles, erosion control mats, jute mesh and coconut mesh.

Gully: an open incised channel >0.3 m depth and characterised by moderately to very gently inclined floor and steep walls.

Infall drainage: a drainage method for a section of road located in steep side-slope terrain where the whole surface is in-sloped against the natural surface side-slope.

Mitre drain: a drain used to channel runoff water from the shoulders of a road to a disposal area away from the road alignment. It is often the extension of a table drain away from the road surface.

Mulch: a natural or artificial layer of plant residue or other material covering the land surface that conserves moisture, holds soil in place, aids in establishing plant cover and minimises temperature fluctuations.

Outfall drainage: drainage which occurs when the surface of a road, snig track or extraction track has cross slope causing water to flow across and off the surface. This flow of water is away from and not into the hillside.

Outlet: the point from which water discharges.

Rehabilitate: to return an area of land or a road or track surface to a stable condition. This may involve reshaping the land, spreading topsoil, constructing banks, revegetating or a combination of these methods.

Relief pipe: see cross drain.

Revegetate: to establish an effective vegetative groundcover by either natural regeneration or sowing with a seed and fertiliser mixture.

Rill: a form of erosion characterised by small channels up to 0.3 m deep which cut into the surface of a slope.

Road drainage structure: a structure designed to direct water along, across or underneath a road, and includes catch drains, mitre drains, relief pipes, rollover banks, spoon drains and table drains.

Rollover: a crossbank constructed with a smooth cross-section and gentle batters, and which is well compacted to allow permanent vehicular trafficability.

Silt fence: a fabric or mesh placed in the path of runoff which acts as a filter to reduce and detain sediment.

Soil stabilisation: the provision of vegetative, structural or mechanical measures to prevent or control erosion by providing an energy-absorbent or energy-resistant barrier on the soil surface.

Spoil: excess soil, rock or other material.

Spoon drain: see dish drain.

Stable: the physical condition of land or a flowline which experiences no appreciable soil erosion or sedimentation and is protected from erosive agents. Also means a soil conservation or hydraulic structure which is functioning effectively and is not adversely affected by erosive agents.

Stable outlet: an outlet which is protected from erosion, up to peak discharge of water flow from a storm event of less than or equal to the design specification of the structure.

Table drain: the side drain of a road adjacent to the shoulders of the road.

Toe: the bottom intersection line of two slope planes; the toe of a fill is the line formed by the intersection of a fill batter with the natural ground surface.

Topsoiling: the application of topsoil to exposed or eroded areas, including batters and earthworks, to encourage the rapid growth of vegetation, for the purpose of soil stabilisation against erosion.

Watercourse: a channel with distinct bed and banks down which surface water flows on a permanent or semi-permanent basis.

Windrow: an accumulation or mound of soil material on the edge of a road or track formed by the spillage from the edge of a blade or other similar machine during earthmoving operations.

9 Figure and table acknowledgements

Figures 1, 2, 5, 7, 11, 13: G Mead/Parks and Wildlife Group, OEH

Figure 3, 10, 17, 28: Volume 2C*, © J Caddey/Sydney Catchment Authority

Figures 4, 6a, 6b, 12, 15, 16, 35: Volume 2C*

Figures 8, 18: *Forest Soil and Water Protection – A Manual for Forestry Operators*. Forests NSW, June 2000

Figure 9: Department of Land & Water Conservation NSW, 1999. *Erosion and Sediment Control Drawings – Version '99*

Figure 14: *Unsealed Roads Manual – Guidelines to Good Practice*, 2000 edition. ARRB

Figures 19, 30, 33: *Managing Urban Stormwater: Soils and Construction*, Volume 1, 4th edition 2004, Landcom

Figures 20, 37: TREES Pty Ltd

Figures 21, 22, 24, 25, 26, 34: A Pik/OEH

Figure 23: J Miles/EPA

Figures 27, 31, 32, 36: Volume 2C*, © Tony King

Figure 29: S Hemer/Parks and Wildlife Group, OEH

Figures 38, 39, 40, 41: /Parks and Wildlife Group, OEH, SWS Region

Table 5A: Volume 2C*

*Volume 2C: *Managing Urban Stormwater: Soils and Construction. Volume 2C Unsealed Roads*. Department of Environment, Climate Change and Water NSW, 2008

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