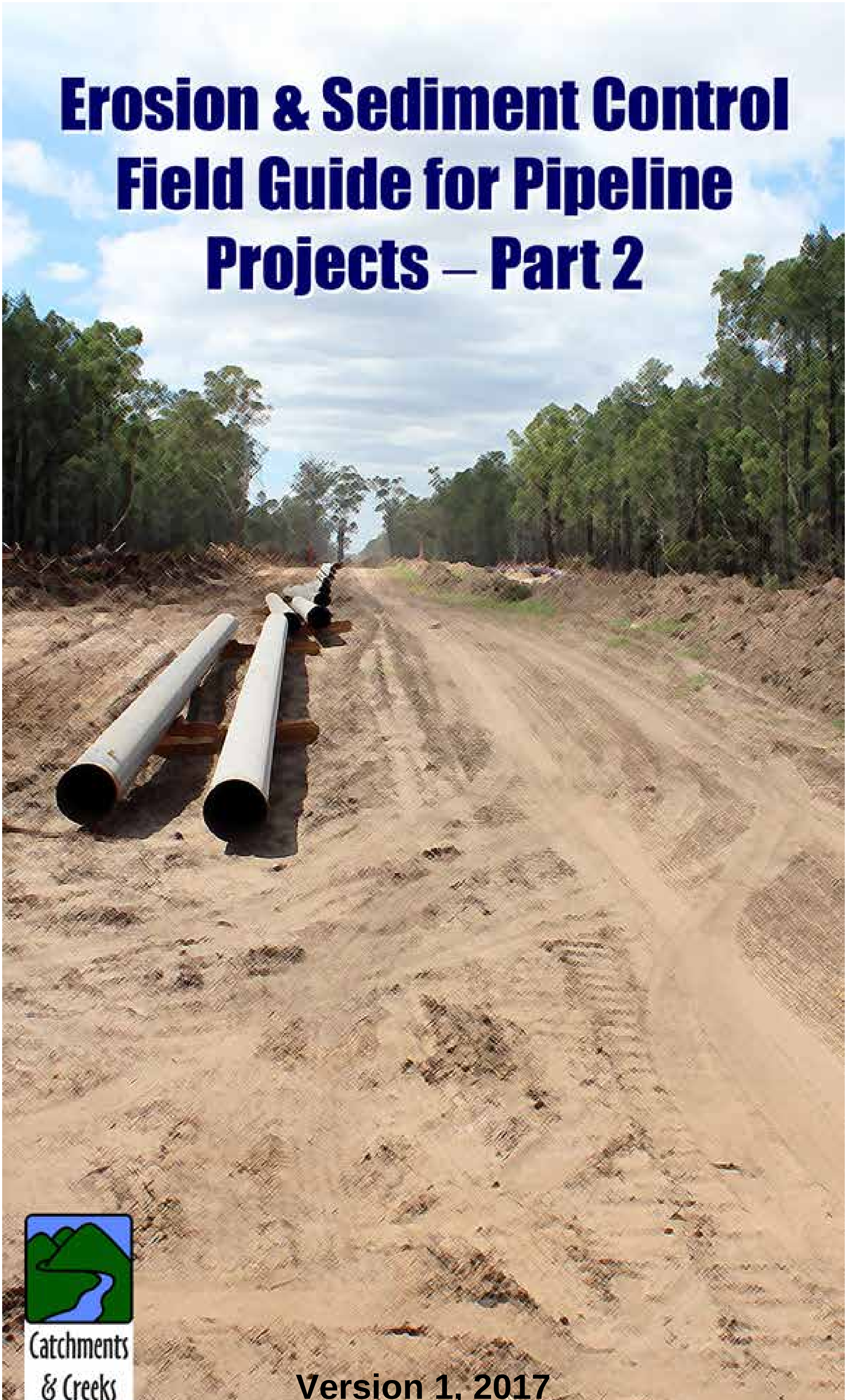
Erosion & Sediment Control Field Guide for Pipeline Projects – Part 2



Catchments & Creeks

Version 1, 2017

Erosion & Sediment Control Field Guide for Pipeline Projects – Part 2

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Significant effort has been taken to ensure that this document is representative of current (2017) best practice erosion and sediment control practice; however, the author cannot and does not claim that the document is without error, or that the recommendations presented within this document will not be subject to future amendment as techniques and knowledge improve.

To be effective, erosion and sediment control measures must be investigated, planned, and designed in a manner appropriate for the given work activity and site conditions.

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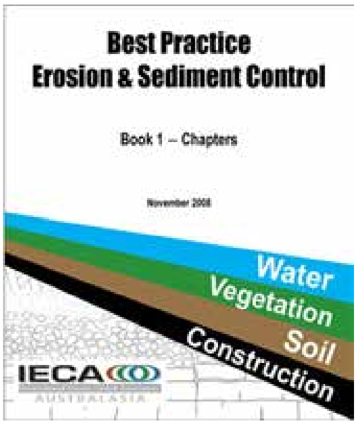
Specifically, adoption of the recommendations and procedures presented within this field guide will not guarantee:

- compliance with any statutory obligations
- compliance with specific water quality objectives
- avoidance of environmental harm or nuisance.

Principal reference documents:

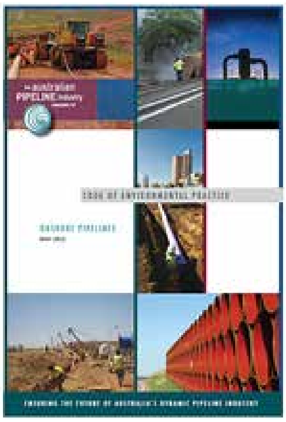


IECA (2008) – Book 1

***Best Practice Erosion & Sediment Control*. International Erosion Control Association, (IECA) Australasia Chapter, 2008**

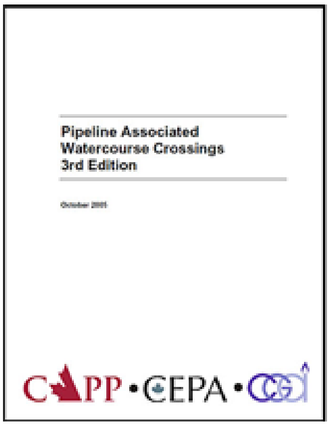
Specifically, reference is made to:

- Chapter 2 (Principles of ESC)
- Chapter 4 (Design standards)
- Chapter 6 (Site management)
- Appendix C (Soils and revegetation)
- Appendix I (Instream works)
- Appendix K (Tracks and trails)



APIA Code of Environmental Practice

Code of Environmental Practice – Onshore pipelines, the Australian Pipelines Industry Association Ltd (APIA), May 2013



Canadian Pipeline Watercourse Crossings

Pipeline Associated Watercourse Crossings, October 2005

Canadian Association of Petroleum Producers, Canadian Energy Pipeline Association and Canadian, Gas Association.

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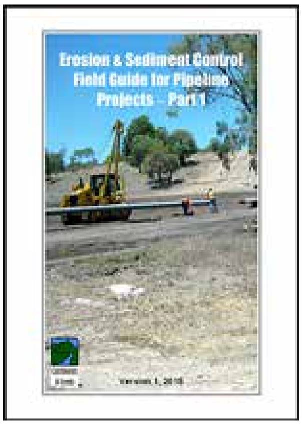

ESC Field Guide for Pipelines, Part-1

Erosion & Sediment Control Field Guide for Pipeline Projects – Part 1, May 2017

Witheridge 2017, Catchments and Creeks Pty Ltd., Brisbane, Queensland.

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Contents

Purpose of field guide

This field guide (Part 2 of a two-part series) has been prepared specifically to:

- Provide the pipeline industry with general guidelines on the management of their construction sites with respect to erosion and sediment control, and the management of waterway crossings.
- Provide construction personnel working on pipeline crossings of waterways with general guidelines on the selection of appropriate construction practices and erosion and sediment control measures in the circumstances where an appropriate Erosion and Sediment Control Plan does not exist, or does not adequately address the current site conditions.

The field guide has **not** been prepared for the purpose of being a site's primary guide to erosion and sediment control. As such, the recommendations provided within this field guide should **not** be used to overrule advice obtained from suitably trained experts, or the recommendations and/or requirements of locally adopted ESC guidelines/manuals.

This field guide has been prepared specifically for use on large rural pipeline construction projects. Only parts of the document will be relevant to small domestic pipeline installations.

It is noted that 35% of the photos presented within this field guide have originated from pipelines projects. The majority of waterway rehabilitation photos have originated from general creek rehabilitation projects in South East Queensland.

About the author

Grant Witheridge is a civil engineer with both Bachelor and Masters degrees from the University of NSW (UNSW). He has over 35 years experience in the fields of hydraulics, stormwater management, creek engineering and erosion & sediment control, during which time he has worked for a variety of federal, state, local government and private organisations.

Grant is the principal author of such publications as the revised *Queensland Urban Drainage Manual* (2007, 2013 & 2017) and IECA (Australasia) *Best Practice Erosion and Sediment Control (2008)* documents. In 2010 Grant was presented with the IECA (International) *Sustained Contributor Award*.

Introduction

Pipeline crossings of waterways are complex construction activities that can pose a high risk to the environment, as well as a significant financial risk to the pipeline contractor. Each waterway crossing can present a unique set of site conditions to the pipeline contractor, which often prevents the adoption of generic solutions and construction practices.

This field guide, which represents Part-2 of a two-part series, attempts to provide general advice and guidance on the construction of pipeline crossings of drainage lines and waterways with respect to erosion and sediment control (ESC) issues. However, it should be noted that ESC issues represent only one of the many issues that need to be considered at any waterway.

To a limited extend, guidance is also provided on related topics such as fish passage considerations during the construction phase, and the rehabilitation of waterways disturbed by construction activities.

The application of this field guide to a particular waterway crossing will depend on the type of pipeline and the type of waterway. The appropriate application of this field guide requires the reader to have experience in pipeline construction. The recommendations presented within this field guide **must** be tailored to the conditions known to exist at a particular site, and **must** represent an appropriate balance between theory, past experience, and common sense.

The Erosion and Sediment Control industry relies on the combined experience of several professions, including construction personnel, soil sciences, hydraulic engineering and revegetation specialists. The design and construction of pipeline crossings of waterways introduces into the design team experts from a number of other professions, including river morphology, biology and geotechnical engineering.

It should always be remembered that waterways are mobile and ever-changing features of our landscape. The waterway profile that exists at the time of the pipeline construction may be very different from that which exists at the end of the pipeline's working life.

Defining waterways, watercourses and drainage lines

Introduction

- The official classification of waterways, watercourses and drainage lines is usually a matter for the state, and some states have taken the step to map all waterways.
- In comparison to drainage lines and overland flow paths, waterways can be identified by the existence of a channel with well-defined banks.
- This means the 'channel' needs to be visible, and the 'banks' are not just an extension of the valley's side-slopes.

Example of a drainage line (not waterway)

Ephemeral waterway

- In many locations within Australia, dry ephemeral waterways can look remarkably similar to 'drainage lines'.
- Even experts can disagree on what is a 'dry creek', and what is a 'drainage line'.
- The term 'ephemeral' simply means the waterway occasionally stops flowing, but could still contain permanent pools.
- It is noted that an ephemeral waterway may contain sub-surface groundwater flows even though the bed appears dry.

Example of a dry, ephemeral waterway

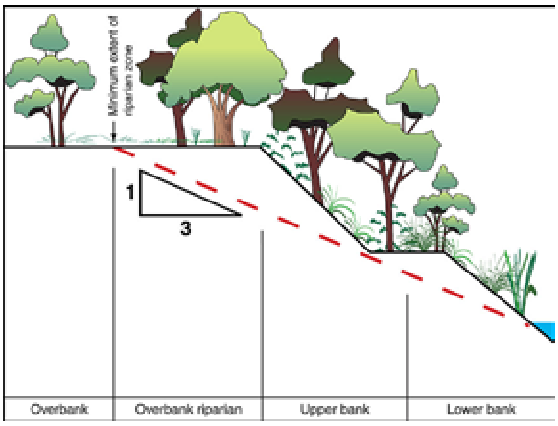
Waterways and watercourses

- Historically, the term 'waterway' referred only to a navigable watercourse.
- In farming communities, a 'waterway' is a shallow constructed drainage line that crosses either pasture or cropping land.
- In the construction industry it is common for the terms 'waterway' and 'watercourse' to be interchangeable.
- Within this publication, the terms waterway and watercourse are considered to have the same meaning.

Navigable waterway

Riparian vegetation

- The riparian zone is that part of the landscape adjacent to a waterway that influences, and is influenced by, the processes that occur within the waterway.
- This usually includes instream habitats, and the bed, banks and floodplains of a waterway (or parts of the floodplains).
- Ideally, the riparian zone (measured from the water's edge) should be wider than the top-of-bank width of the waterway channel, or three times the bank height, whichever is the greater.



Minimum desirable riparian width

Types of waterways

Clay-based waterway

Clay-based waterways

- There are many types of waterways, and descriptions are often given based on the channel shape.
- Clay-based waterways contain clayey soils across the bed and banks.
- These are 'fixed bed' waterways, that should not have significant quantities of 'natural' sediment flow
- Mature woody vegetation can often appear close to, or even on the channel bed.

Sand-based waterway

Sand-based waterways

- Sand-based waterways contain deep, loose sand across the channel bed.
- The depth of the sand typically exceeds the depth of the root systems of some bed and lower bank vegetation.
- These are 'alluvial' waterways that experience significant sand flow during both minor and major stream flows.
- There is normally a clearly defined change in plant species from those growing on the bed (if any) and those on the banks.

Gravel-based waterway

Gravel-based waterways

- In gravel-based waterways, the bed material is made-up of well-rounded gravels and boulders.
- These are also alluvial waterways that usually contain pools and riffles, which can completely reform during severe floods.
- The channel bed of both sand and gravel-based waterways is usually 'flat', as compared to the U-shaped bed of clay-based waterways.
- Woody vegetation can struggle to form on the channel bed.

Rock-based waterway

Rock-based waterways

- The bed material of rock-based waterways is made-up of exposed rock outcrops often separated by sections of clay, sand or gravel-based channels.
- These are fixed-bed 'spilling' waterways usually containing waterfalls or riffles followed by deep pools to help dissipate water energy.

Vehicular Crossings of Waterways

Temporary vehicular crossings of waterways

Mud generated by vehicular traffic

Clay-based waterway crossings

- The design of temporary vehicle crossing is strongly influences by the of bed material found within the watercourse.
- Clay-based waterways are almost impossible to cross at bed level if the bed is damp because the bed will quickly turn to mud.
- Temporary vehicle crossings of clay-based waterways normally require a temporary culvert, or possibly a rock-lined ford or causeway if the bed is dry.

Sand-based ford crossing

Sand-based waterway crossings

- Sand-based waterways can experience significant sediment (sand) flows during both minor and major floods.
- These waterways can often be crossed by vehicles at bed level (ford crossing) with minimal sediment release or damage to the waterway, even if the bed is wet.
- These bed-level crossings can also be temporarily reinforced with a cellular confinement system, but this synthetic material **must** eventually be removed.

Gravel-based ford crossing

Gravel-based waterway crossings

- Gravel-based waterways usually contain a series of pools and riffles along the channel bed.
- The channel bed is typically flat, and bed-level crossings (fords) are normally located at riffles where flows are shallow.
- It is **important** to avoid sand and fine sediments entering the riffle, so drainage and sediment controls are usually required on the approach roads.

Rock-based ford crossing

Rock-based waterway crossings

- The waterway bed is normally very stable on rock-based waterways, and few restrictions apply to the location of vehicle crossings other than to avoid disturbance to important riparian vegetation.
- In between the individual rock outcrops, these waterways may contain sections of clay, sand or gravel-based channels, in which case the above rules apply as appropriate for the type of substrate.

Temporary vehicular crossings of waterways

Vehicle access across a waterway

Vehicle access across waterways

- Vehicle access is required along the pipeline RoW in order to:
  - access the construction site
  - deliver pipes and materials.
- The type of vehicle crossing depends on a number of factors, including:
  - type of watercourse
  - flow conditions within the watercourse
  - expected operational life of the watercourse crossing.

Temporary bridge crossing

Temporary bridge crossings

- A temporary bridge crossing is used when it is important to maintain fish passage during the construction period.
- Pre-cast culvert bridging slabs (left) can be used to form a temporary bridge deck for light vehicles.
- Traditional log bridges can also be formed from felled timber.

Temporary culvert crossing

Temporary culvert crossings

- Temporary culvert crossings are typically used on wide stream crossings.
- Long-term culvert crossings are best used when fish passage is not critical.
- If the culvert is to remain for permanent maintenance access, then fish passage will need to be considered when designing the culvert.
- Recycled steel pipes (left) are often used to form temporary culvert crossings.

Ford crossing of an alluvial waterway

Temporary ford crossings

- A ‘ford’ is a bed level crossing.
- Ford crossings are used to cross drainage lines and dry creek beds when stream flows are not expected.
- The bed-level crossing of wet flowing streams by construction vehicles should be avoided.
- The surface of the ford crossing can be reinforced with various geo-synthetic materials.

Temporary vehicular crossings of waterways

Permanent maintenance access bridge

Permanent maintenance access bridge

Crossing of a sand-based watercourse

Alluvial waterway crossings

- Bed-level ford crossings can only be formed across alluvial waterways; that is a waterway with either a predominantly sand-based or gravel-based bed structure.
- Bed-level crossings of clay based waterways quickly turn to mud, and become impassable.
- Alluvial waterways can be identified by the type and depth of loose bed material, and the relatively flat bed; however, the bed is unlikely to be 'flat' at pools.

Concrete sealed 'ford' crossing

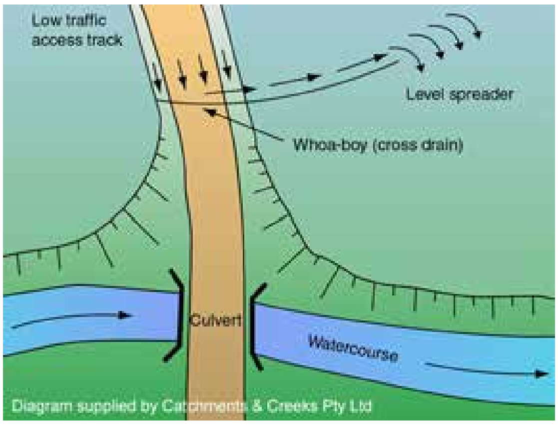
Alluvial waterway crossings

- A key geomorphological feature of alluvial waterways is that the bed material (i.e the sand or gravel) migrates (flows) down the waterway during flood events.
- This means that 'fixed' surfaces (such as concrete capping) should **not** be placed across the channel bed—otherwise the result will be an accumulation of bed material upstream of the crossing, and a scouring (displacement) of bed material downstream of the crossing; thus forming a barrier to fish passage.

Ecoflex 'E-pave' stabilisation system

Cellular confinement system stabilisation

Design of approach roads



Diversion of road runoff

Drainage control

- Critical to the management of vehicle crossings of waterways is the appropriate management of road runoff adjacent to the waterway.
- Road runoff must be diverted off the approach roads such that sediment-laden water does not discharge, untreated, into the waterway.
- Typically, cross drainage berms (cross banks) are used to divert runoff into a sediment trap or the adjacent bushland to filter sediments from the runoff.

Flows diverted off access track

Cross bank placed at top of descent

Recessed approach road

Rock stabilised vehicle crossing

Alignment of approach roads

- Preference is normally given to aligning approach roads perpendicular to the waterway.
- Recessing the approach road into the channel bank can provide both positive and negative outcomes for the waterway.
- The exposed banks formed by recessing the approach roads must be appropriately stabilised against the erosive forces produced by eddies formed when floodwaters pass over these channel features.

Stabilisation of the road surface

- The need to stabilise the road surface with rock or gravel depends on:
  - the intended service life of the road
  - the weight and number of vehicles
  - the likelihood of wet weather.
- Ideally, hard engineering structures should be avoided within the waterway and riparian zone, especially if the waterway is unstable or mobile (i.e. subject to natural lateral movement).

Vehicular crossings of dispersive soil gullies

Dispersive soil gully

Dispersive soil gullies

- Rural pipelines often encounter deep gullies that have cut through highly-erodible dispersive soils.
- In most cases, these gullies will represent recent geological features (i.e. less than 50 years old) that have resulted from past land management practices rather than natural forces.
- Vehicular or even pipeline crossings of these gullies can be **very** unstable if not appropriately designed and constructed.

Lateral bank erosion

Controlling lateral bank erosion

- Lateral bank erosion is the formation of new gully lines that cut laterally into the banks of the main gully.
- Lateral bank erosion is normally caused by overland flows spilling into the gully.
- Drainage systems associated with a roadway crossing often initiate such bank erosion, which in turn can damage the approach roads for the crossing.
- Ideally, road drainage should enter the gully well away from the road crossing.

Unstable gully banks (fluting erosion)

Stabilising the banks and inflow drains

- The key to managing dispersive soils is to over-excavate all surfaces by at least 500 mm and then to cap the exposed dispersive soil with a 500 mm thick layer of non-dispersive soil.
- In most locations along a pipeline RoW, dispersive soils only need to be capped with a minimum 200 to 300 mm layer of non-dispersive soil; however, when working in a gully or watercourse, an allowance must be made for additional soil disturbance by animals and stream flows.

Tunnel erosion

Managing tunnel erosion

- Drainage systems associated with roadway crossings of dispersive soil gullies can easily be damaged by tunnel erosion.
- Tunnel erosion <u>cannot</u> be repaired by simply filling the tunnel with treated soil; instead, consider the following options:
  - excavate the full length of the gully and fill with compacted, treated soil, or
  - excavate a trench 'across' the tunnel and backfill the trench with treated clayey-soil of low permeability.

Pipeline Crossings of Drainage Lines

Pipe crossings of drainage lines

Natural drainage line

Boggy drainage line crossing

Rock stabilised vehicle crossing

What is a drainage line

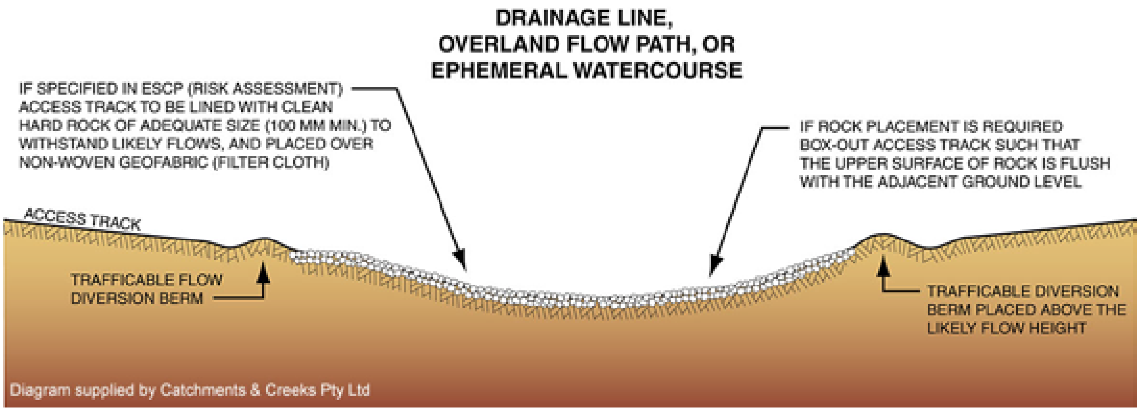
- A 'drainage line' is a natural or constructed stormwater drainage path that:
  - carries 'concentrated' rather than 'sheet' flow
  - is likely to flow only during periods of rainfall, and for short periods (hours) after rain has stopped
  - is a drainage path that cannot be classified as a 'watercourse' based on a locally or state-adopted classification system.

Potential for causing environmental harm

- When wet or damp, drainage lines can 'appear' as significant pollution hazards, but this may not always be the case.
- The potential environmental harm caused by the temporary crossing of drainage lines can often be overstated.
- If a risk assessment process does identify potential harm, then the width of the RoW can be reduced in the region of the crossing, and soil disturbances can be stabilised with erosion control mesh if deemed necessary.

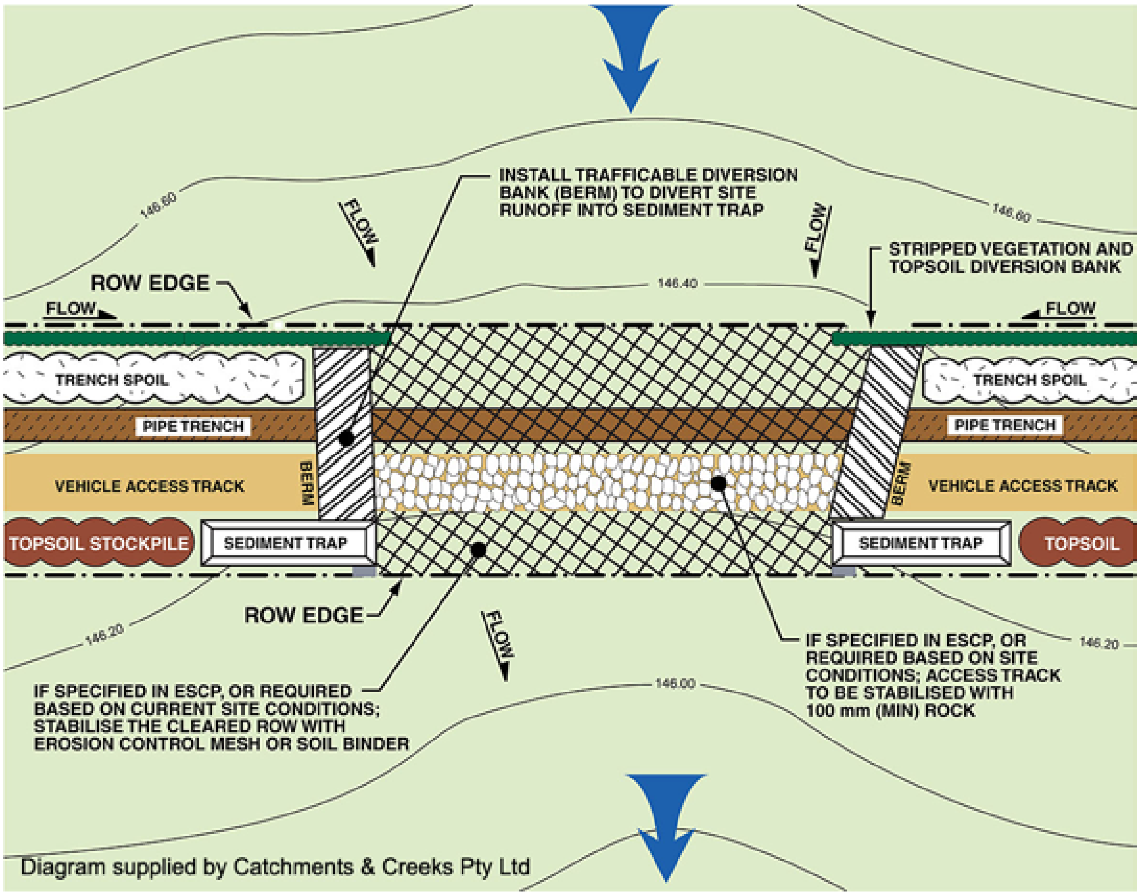
Rock stabilisation of vehicle crossings.

- In most cases, temporary vehicle crossings of 'dry' drainage lines do not require rock stabilisation.
- However, rock stabilisation of vehicle crossings may be required if:
  - the crossing is likely to turn into a 'bog'
  - surface flows are likely to occur during the construction phase
  - rock is required to provide the necessary traction for vehicles.



Stabilised vehicle crossing of a drainage line

Pipe crossings of drainage lines



Example crossing of a low gradient drainage line

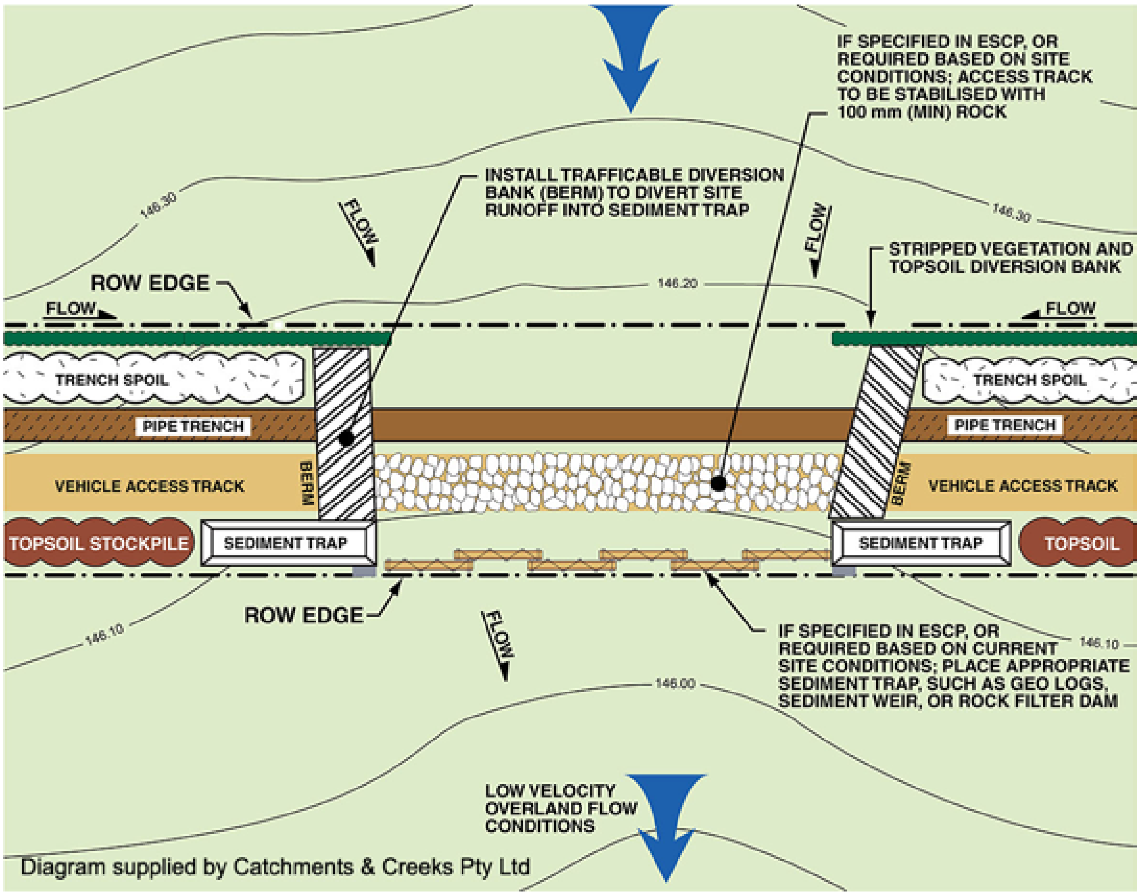
Geo log

Erosion and sediment control

- The degree of erosion and sediment control applied to a drainage line crossing depends on the site's risk assessment:
  - the likelihood of rainfall while the RoW is exposed
  - the gradient of the drainage line and the likelihood of erosive flow velocities
  - likely impacts of sediment-laden runoff on downstream environments
  - ability of the downstream environment to filter and clean any runoff.

Example of a pipeline crossing a drainage line

Pipe crossings of drainage lines



Example crossing of a medium to steep gradient drainage line

Erosion control mesh

Sediment control weir

Effects of drainage line gradient

- As the gradient of the drainage line increases, there is an increasing need to control soil erosion within the RoW.
- In general, if the fall across the RoW exceeds the height of the down-slope sediment control system (i.e. a *Geo Log*, *Sediment Weir* or *Rock Filter Dam*), then the surface of the RoW should be stabilised with erosion control mesh or soil binder if rainfall is possible/likely during the construction phase.

Selection of sediment control system

- **Geo logs** provide the advantage of low cost, quick installation, and reuse if rainfall does not occur during its previous use.
- **Rock filter dams** are better suited for use when crossing constructed drainage channels, or deep/steep drainage lines.
- **Sediment weirs** provide the advantage of high stability during overtopping flows; however, the high cost of installation restricts their use to only high-risk locations.

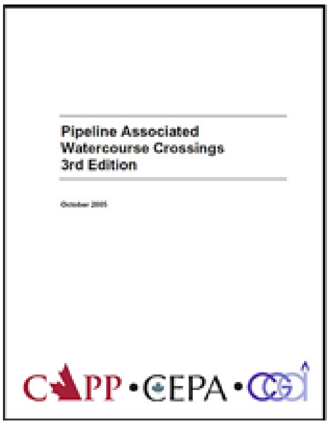
Assessing Options for Pipeline Crossings of Waterways

Introduction

Instream construction works

Use of a long-reach excavator

Use of sheet piling isolation barrier



Canadian Pipeline Watercourse Crossings

Introduction

- The list of design options presented in this section is not comprehensive, and other construction methods do exist; for example, attaching pipelines to a bridging structure.
- In some cases a combination of techniques may be required.
- The diagrams provide only one example of how each construction process can be applied, and the demonstrated site layout should be considered a guide only.

Objectives of waterway crossings

- Minimise overall environmental harm.
- Minimise the duration of instream works.
- Minimise potential long-term impacts on fish habitats and fish passage.
- Zero impact on essential fish migration.
- Use of best practical and affordable construction methods.
- Minimise impacts on waterway navigation.
- Minimise sediment releases to the waterway.
- Minimise disturbances to the waterway's bed and banks.
- Stabilise the waterway in a manner compatible with the waterway's hydraulic and geomorphology attributes, and the long-term protection of the pipeline.
- Rehabilitate disturbed areas in a manner compatible with the waterway's 'values' (aesthetics and aquatic & terrestrial habitats) and the long-term protection of the pipeline.
- Maximise the restoration of riparian values adjacent to the pipeline.

Source of information

The following content was primarily developed from the Canadian publication:

- **'Pipeline Associated Watercourse Crossings', 2005**, Canadian Association of Petroleum Producers, Canadian Energy Pipeline Association and Canadian, Gas Association.
- The above document was prepared by TERA Environmental Consultants and Salmo Consulting Inc. Calgary, AB.
- Most diagrams were adapted from those presented in this Canadian publication.

Issues for consideration

Project financing

Cost

- Construction costs remain a primary factor in the choice of construction method.
- Costs include:
  - site survey and data collection
  - crossing design
  - obtaining approvals for instream works
  - pipeline construction
  - stream rehabilitation
  - initial maintenance of revegetation measures.

Dry-bed waterway crossing

Stream flow

- The choice of construction method is critically dependent on the expected stream flows.
- Open pipe trenching is obviously much easier and cost effective if the trenching can occur during periods when ephemeral streams are either:
  - wet but not flowing (trench de-watering will be required), or
  - dry (preferred condition).

Elevated stream flow conditions

The risk of elevated stream flows

- Elevated stream flows can result from local or distant rainfall.
- Many parts of Australia experience only seasonal rainfall and stream flows, so different construction methods will need to be employed during the dry and wet seasons.

Construction of a pipeline crossing

Available land area (Right-of-Way)

- Each of the pipe construction options discussed here have different land area requirements.
- The selection of the preferred installation method may be governed by:
  - the existence and width of riparian vegetation
  - the allowable RoW width outside the riparian zone
  - the allowable RoW width within the riparian zone.

Issues for consideration

Gravel-based alluvial waterway

Flood damage to bridge & buried pipes

Pipeline exposed by migrating waterway

High, unstable river bank

Type of channel substrate

- The channel bed or substrate may consist of clayey earth, sand, gravel, fractured rock or solid (impermeable) rock.
- Alluvial (sand or gravel-based) waterways can experience significant migration of the bed material during flood events.
- In most cases it is **essential** that the pipe is positioned **below** any bed material that is likely to migrate during the life of the pipe.
- Further discussion on this topic is provided in the next section.

Likelihood and extent of bed erosion

- 'Head-cut' erosion is a form of severe bed erosion that migrates up a gully or waterway.
- Head-cut erosion is most commonly associated with gullies and drainage lines; however, this form of bed erosion also occurs in waterways.
- A river engineer or fluvial morphologist may be required to estimate the likely extent of long-term bed movement.

Mobility of the waterway channel

- Most waterway channels experience some degree of lateral movement.
- Rocky gorges may be considered an exception to this rule.
- Low-gradient waterways that cut through wide open floodplains are the types of waterways that are most likely to experience significant lateral movement.
- Pipe trenching **must** allow for the likely movement or expansion of the waterway channel.

Stability of the channel banks

- The preferred pipeline installation method may be governed by the sensitivity of the waterway's banks to ongoing bank erosion.
- Constructing a pipeline crossing by open trenching means the waterway banks will need to be cleared of vegetation and disturbed by machinery.
- In some cases it may not be practical to rehabilitate the channel banks back to a suitable 'pre-disturbance' condition.

Issues for consideration

Instream channel disturbance

Sediment releases

- The potential release of sediments into a waterway during pipeline installation greatly depends on the construction method.
- The sensitivity of a waterway to sediment releases depends on many factors, which will need to be assessed by appropriately qualified experts.
- A critical factor in assessing the potential impacts of sediment is the degree of turbidity immediately upstream of the works (i.e. background levels).

Freshwater fish migration

Fish passage

- Potential impacts on fish passage can vary significantly across the country.
- The best option is to approach the local Fisheries Office for guidance on fish passage sensitivity and the critical periods of fish migration.
- Some states may have specific legislation or construction codes.
- Issues include: time of year, duration of works, the extent of the fish barrier, and proposed bank rehabilitation measures.

Navigation maintained around works

Navigation

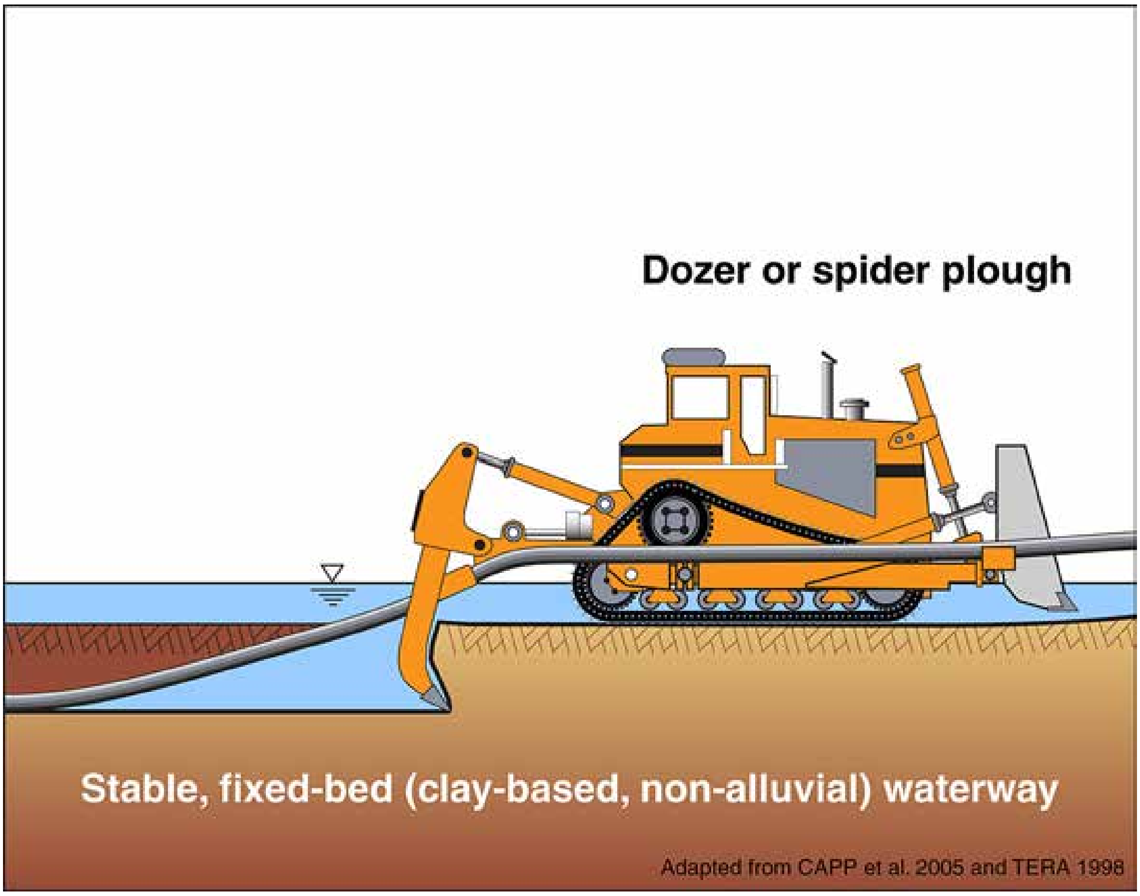
- The selection of pipeline installation method may be governed by the need to maintain navigable conditions along the waterway.

Long reach excavator

Other factors

- The selection of the construction method may also be determined by:
  - public and worker safety
  - the potential release of other pollutants (e.g. directional drilling fluids)
  - the availability of specialist construction equipment
  - the size and type of pipeline
  - the required depth of cover over the pipeline.

Dozer or spider plough



Example of dozer plough

Typical application:

- Placement of small diameter (typically < 150 mm) pipes across drainage lines, dry fixed-bed waterways, and non-flowing shallow (typically, < 1 m) water bodies.
- Installation of telecommunication cables in clay-based waterways.
- Not suitable for the crossing of alluvial (sand or gravel-based) waterways where the plough cannot embed the pipe below that part of the substrate that is likely to migrate (move) during severe floods.
- Not suitable if the waterway bed contains large boulders or shallow bedrock.

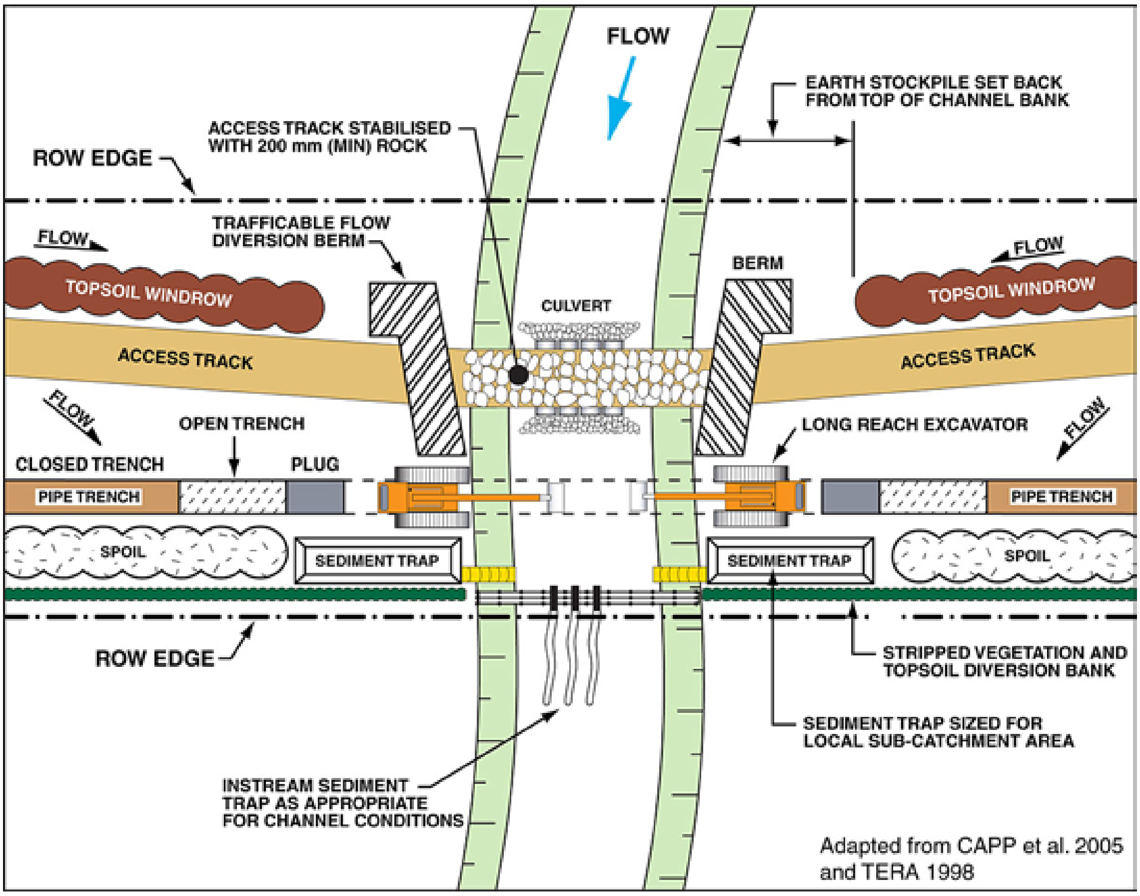
Advantages:

- Rapid, low-cost construction method.
- Sediment releases to the waterway can be minimised (relative to other construction methods) in some circumstances.

Disadvantages:

- Trafficable access required up and down adjacent waterway banks.
- Limited cover is achieved over the pipeline.
- Highly problematic in dispersive soil regions due to inadequate placement and compaction of backfill.
- Requires specialist equipment.
- This installation method can cause excessive sediment releases to the waterway in some circumstances.

Open cut across of a small waterway



Possible layout of an open cut waterway crossing

Typical application:

- Crossing of drainage lines, dry-bed waterways, and non-flowing shallow (typically, < 1 m) water bodies.
- Suitable for alluvial (sand or gravel-based) waterways where the excavator can reach well below that part of the substrate that is likely to migrate (move) during severe floods.
- May not be suitable if the waterway bed contains large boulders or shallow bedrock.

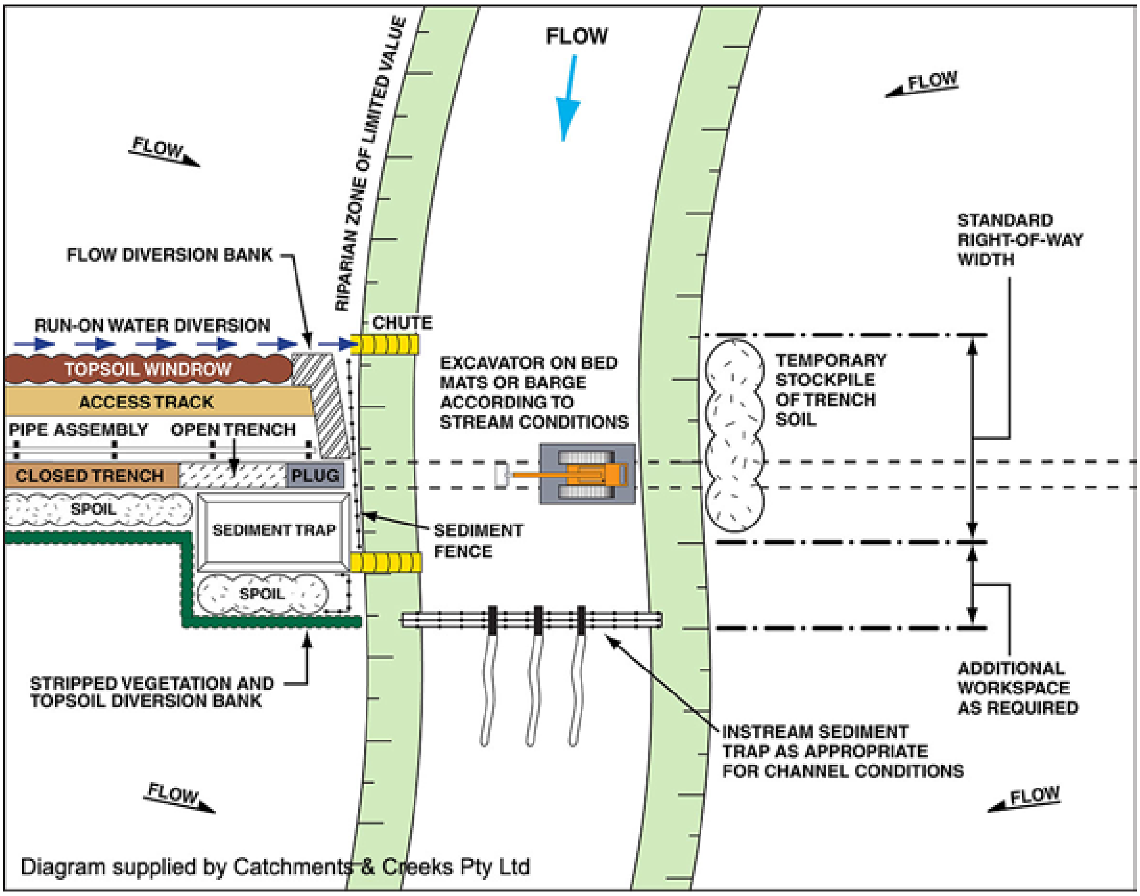
Advantages:

- Rapid, low-cost construction method.
- In narrow waterways, construction equipment may not need to access the waterway bed (use of long reach excavators).
- No specialist equipment required.

Disadvantages:

- The open pipe trench can be subject to slumping.
- Possible need to bench the pipe trench across the waterway bed to reduce the risk of bank slumping, which will increase the extent of disturbance to the channel bed.
- The disturbed waterway banks may need to be battered flatter than ‘natural’, which could adversely affect stream flows and the risk of ongoing bank erosion (site specific issue).
- Excavators may have insufficient reach to place the pipeline at the required depth (sometimes dictated by the depth of the mobile bed substrate).
- Can cause excessive sediment releases to the waterway in some circumstances.

Open cut across of a large ephemeral waterway



Possible layout of an open cut waterway crossing

Typical application:

- Crossing of large dry-bed waterways, and non-flowing shallow (typically, < 1 m) water bodies.
- Suitable for alluvial (sand or gravel-based) waterways where the excavator can reach well below that part of the substrate that is likely to migrate (move) during severe floods.
- May not be suitable if the waterway bed contains large boulders or shallow bedrock.

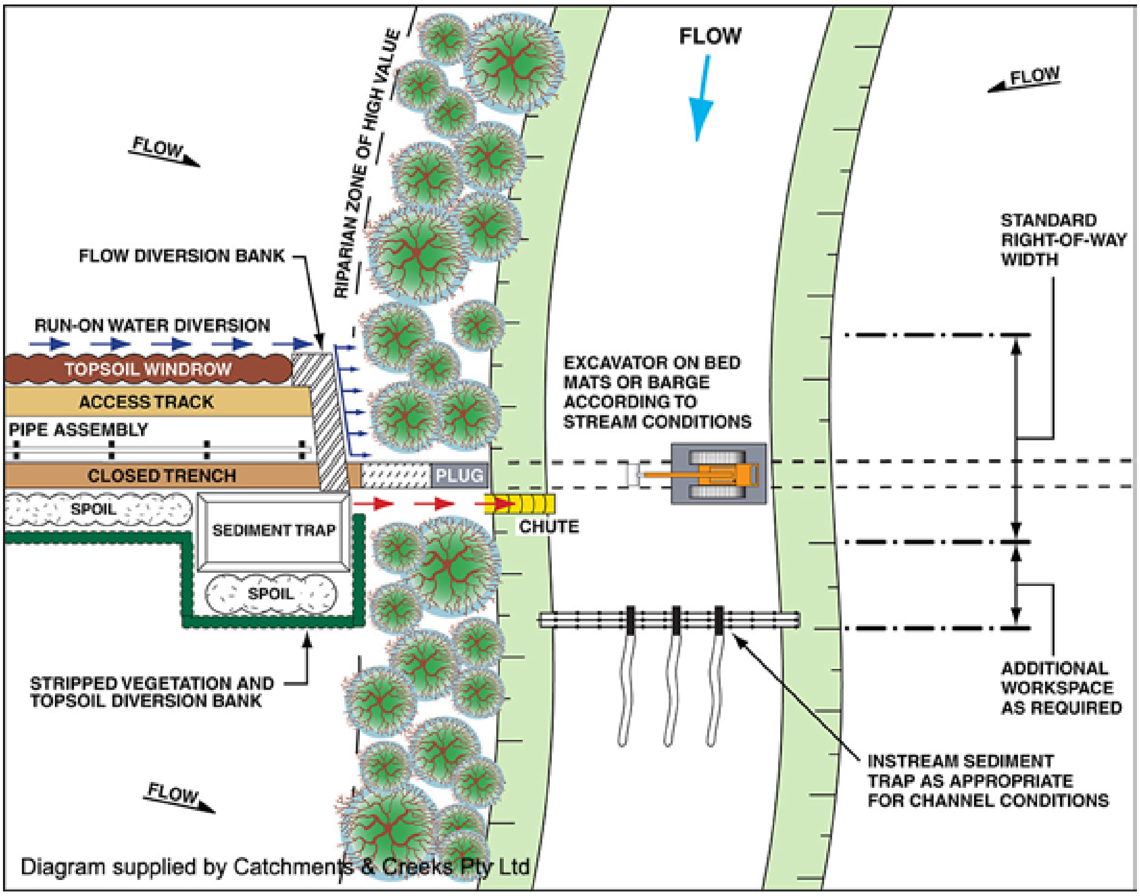
Advantages:

- Fast, low-cost construction method.
- Limited specialist equipment required (large cranes may be required to lift and install the pre-fabricated pipeline segment).

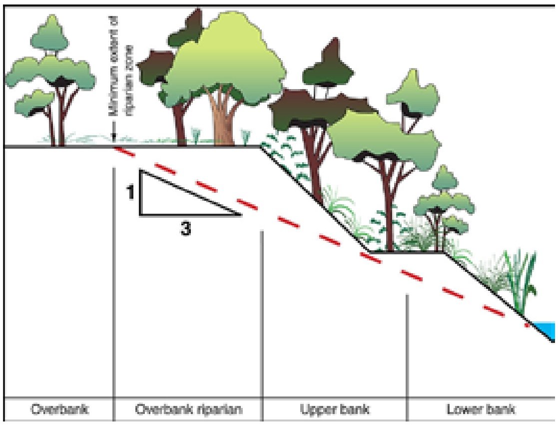
Disadvantages:

- Typically the full trench must be excavated and remain open before the pre-assembled pipeline can be craned or winched into place.
- The open pipe trench can be prone to slumping.
- Possible need to bench the pipe trench across the waterway bed to reduce the risk of bank slumping, which will increase the extent of disturbance to the channel bed.
- The adjacent waterway banks may need to be battered flatter than ‘natural’, which could adversely affect stream flows and the risk of ongoing bank erosion (site specific issue).
- Excavators may have insufficient reach to place the pipeline at the required depth (sometimes dictated by the depth of the mobile bed substrate).
- Can cause excessive sediment releases to the waterway in some circumstances.

Open cut across of a waterway with existing riparian vegetation



Possible layout of an open cut waterway crossing



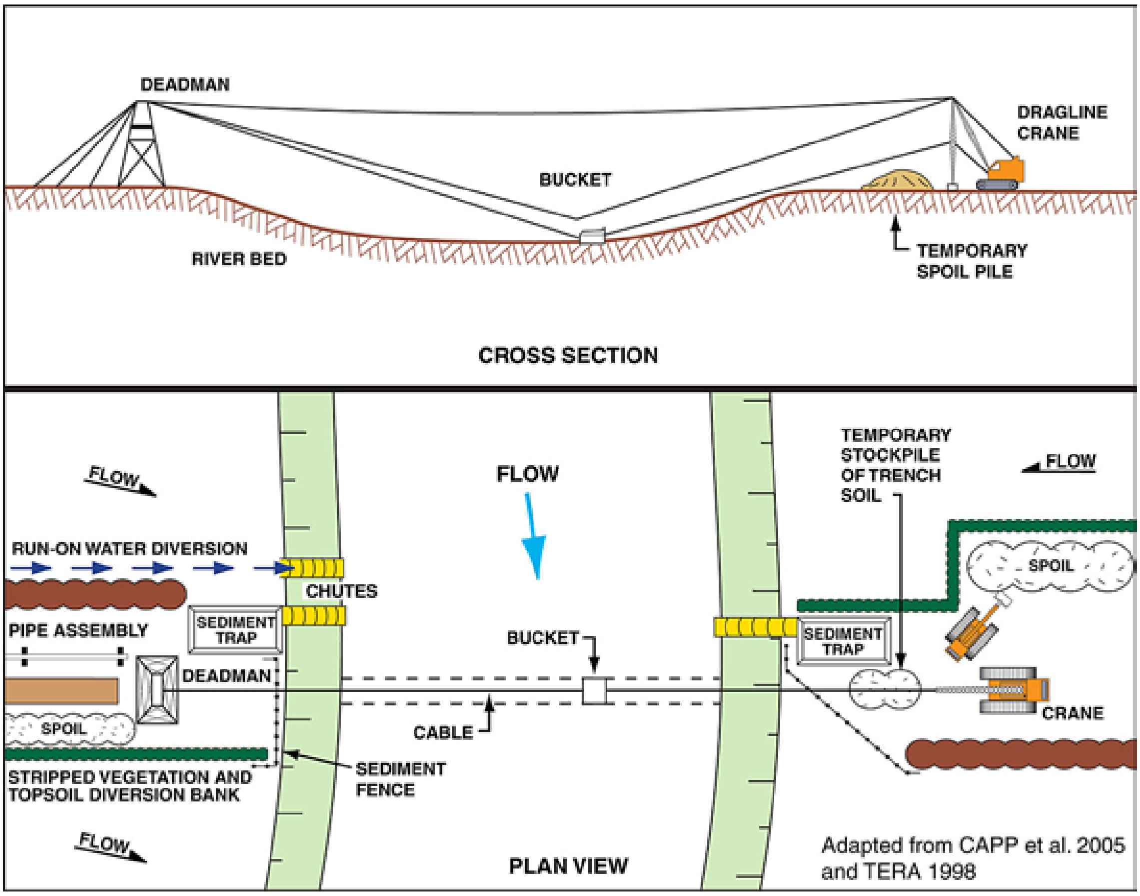
Minimum width of riparian zone

Protection of riparian 'values'

- Riparian vegetation plays an important role in the function of natural waterways, including bank stability, terrestrial habitat, and fish passage during flood events.
- The above diagram demonstrates (in comparison with the previous diagram) how the construction site layout could vary in a manner that helps to minimise disturbances to the riparian zone.
- The critical width of the riparian zone varies from waterway to waterway—refer to local guidelines.

Construction of pipeline crossing of a waterway with riparian 'values'

Dragline



Possible layout of a dragline pipe-trenching operation

Typical application:

- Suitable for wide and deep waterways with soft substrate and limited navigational traffic.
- Not suitable if the waterway bed contains large boulders or shallow bedrock.

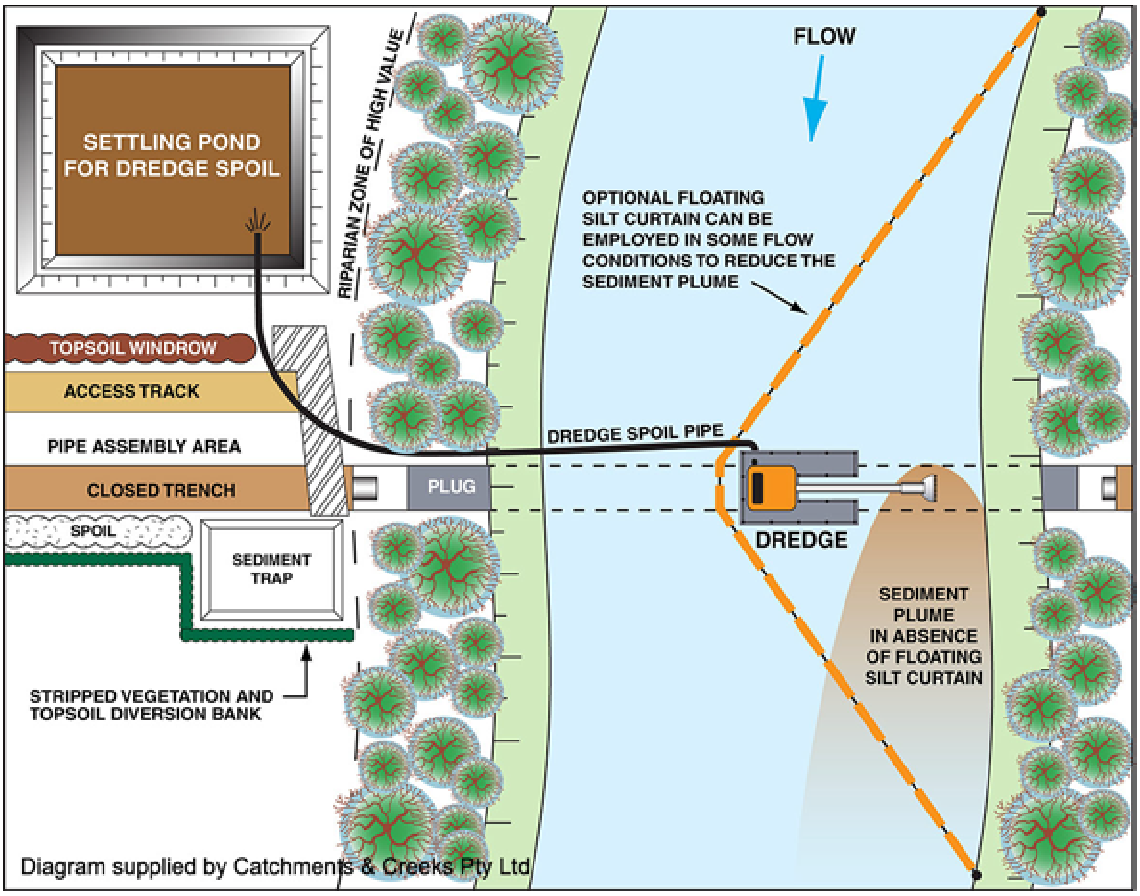
Advantages:

- Mechanical equipment does not need to enter the waterway channel.
- Disturbance to river banks can be minimised.
- Maintains stream flow and fish passage.

Disadvantages:

- Potentially high sediment releases into the waterway, including long-term turbidity plumes during the construction phase.
- Significant disturbance to the overbank areas.
- The open pipe trench can be prone to slumping.
- Unexpected elevated stream flows can damage the open trench.
- Difficult to compact the trench backfill.
- Slow construction method.
- Specialised equipment is required.
- Cables can interfere with the navigational use of the waterway.

Dredging



Possible layout of a dredging operation with optional floating silt curtain

Typical application:

- Suitable for wide and deep waterways with soft substrate.
- Not suitable if the waterway bed contains large boulders or shallow bedrock.

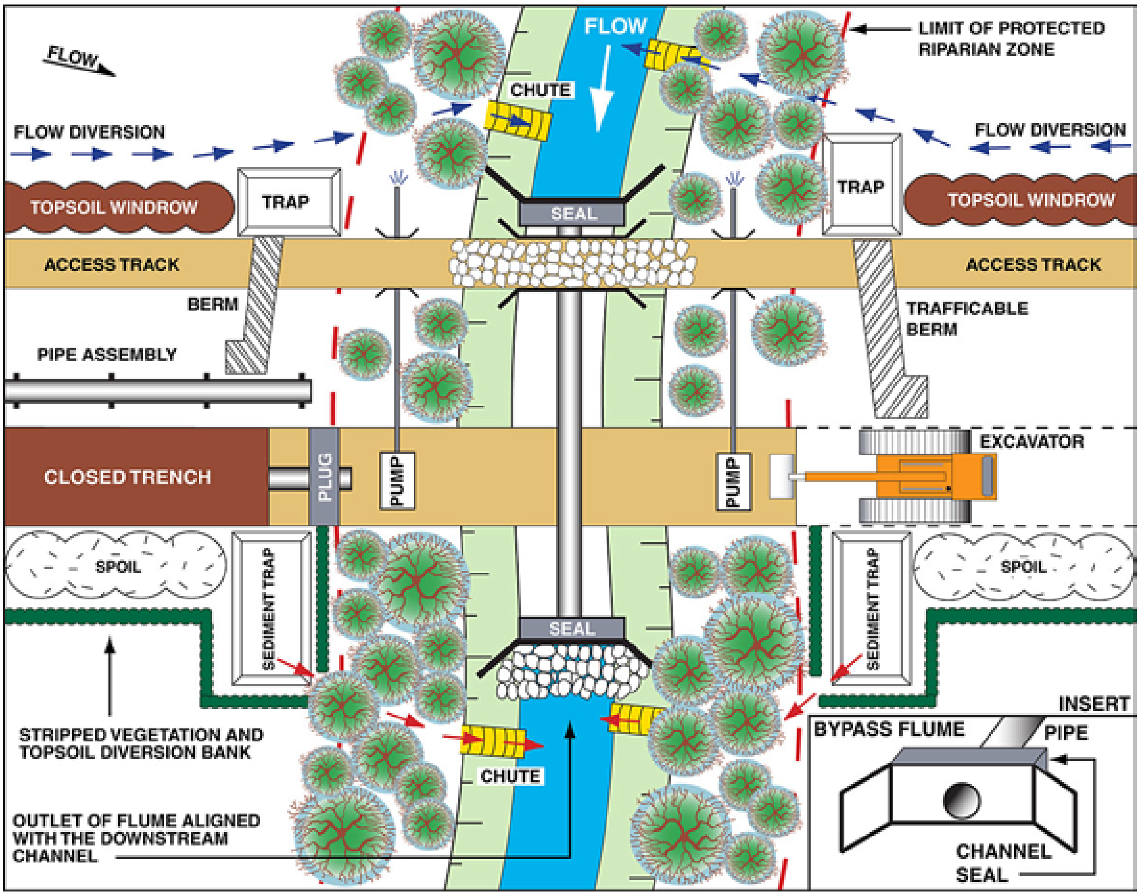
Advantages:

- Only the floating dredge needs to enter the waterway channel.
- Disturbance to river banks can be minimised.
- Maintains stream flow and fish passage.
- May benefit from natural sediment transport to backfill the trench.

Disadvantages:

- Maximum dredging depth could limit the degree of cover over the pipe.
- Potential sediment releases into the waterway, which may be reduced in some circumstances through the use of a floating silt curtain.
- Significant disturbance to the overbank areas to form settling ponds for the dredge spoil.
- The open pipe trench can be subject to slumping.
- Unexpected elevated stream flows may damage the open trench.
- Difficult to compact the trench backfill.
- Slow construction.
- Specialised equipment is required.
- Dredging pipes can interfere with the navigational use of the waterway.

Gravity bypass flume



Possible layout of a gravity bypass flume

Typical application:

- Suitable for minor, narrow waterways with minimal base flows, and during those periods when flood flows are unlikely to occur and fish passage is not critical.
- Typically requires a relatively straight channel reach.
- The bypass flume may be augmented with a pumped bypass.

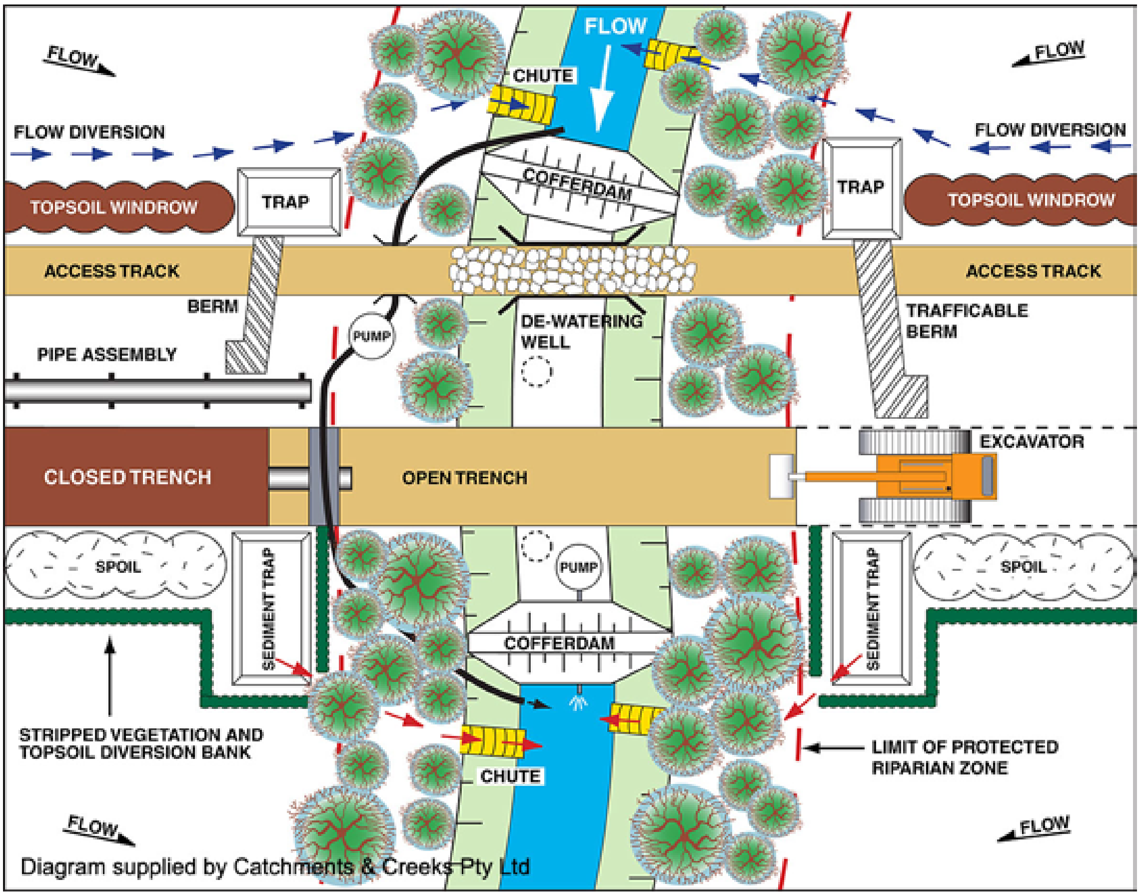
Advantages:

- Minimal sediment releases to the waterway.
- Allows ideal benching, backfilling and compaction of the pipe trench.

Disadvantages:

- Flows in excess of the flume's design discharge can cause damage to the open trench.
- Significant short-term impacts on fish passage during the construction phase.
- Potential damage to the waterway during installation and removal of the flume.
- The flume pipe can interfere with the placement of the pre-fabricated pipe segments.
- The flume can be blocked by natural sediment flows during flood events.
- The open trench and the isolated channel will need ongoing de-watering during the construction phase.

Cofferdam with pumped bypass



Possible layout of cofferdam operation with pumped flow bypass

Typical application:

- Suitable for waterways with minimal base flows, and during those periods when flood flows are unlikely to occur and fish passage is not critical.
- Can be applied to meandering waterways.

Advantages:

- Minimal sediment releases to the waterway.
- Allows ideal benching, backfilling and compaction of the pipe trench.

Disadvantages:

- Susceptible to mechanical failure of the pumps.
- The pumps need ongoing maintenance (fuel supply, blockage removal) during their operation (including non-work days).
- Bypass pump hoses can interfere with the construction process.
- Flows in excess of the pumped bypass capacity can cause damage to the open trench.
- Significant short-term impacts on fish passage during the construction phase.
- Potential damage to the waterway during installation and removal of the cofferdams.
- Bypass pumps can be blocked/damaged by natural sediment flows during flood events.
- The open trench and the isolated channel will need ongoing de-watering during the construction phase.

Types of cofferdams

Sandbag cofferdam in concrete drain

Types of cofferdams

- Cofferdams can be formed from a variety of materials, including:
  - sandbags
  - earth
  - water-filled rubber dams
  - sheet pilling
- The preferred construction materials will depend on the type of waterway.

Construction of a cofferdam

Structural integrity

- In urban areas, the failure of a cofferdam could lead to a loss of life, as such, their design and construction will need to be appropriately regulated and supervised.


Floodgates prior to their installation

Managing inflows

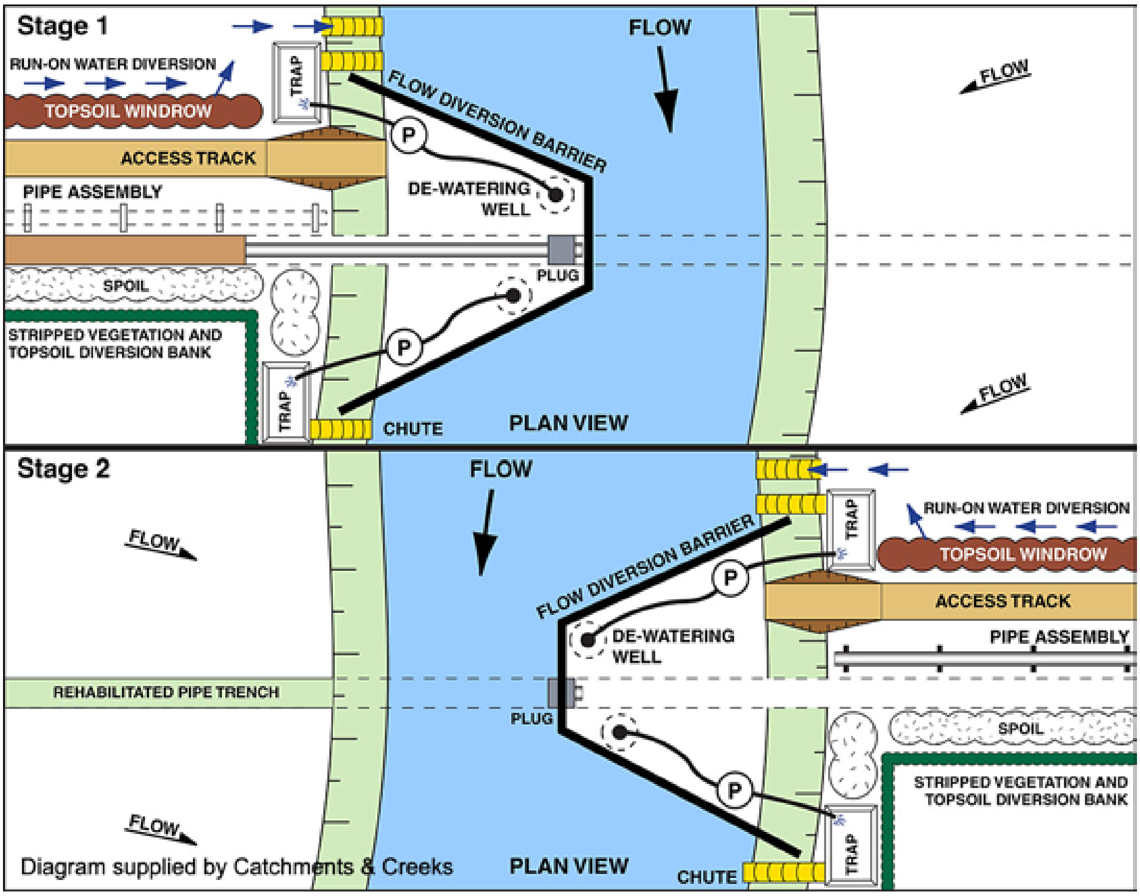
- A de-watering system will usually be needed to manage both groundwater and local stormwater inflows.
- In some circumstances, floodgates can be incorporated into the cofferdam to allow the work area to drain in the event of heavy local rainfall or elevated stream flows.

Works within a tidal waterway

Tidal waters

- Working in tidal waterways can introduce additional complexities.
- In most cases, different state legislation will apply to works within tidal waters as compared to freshwater streams.
- It is also common for specific legislation to apply to the damage and/or removal of marine plants.

Two-stage open cut crossing of a waterway



Possible layout of a two-stage open cut operation

Typical application:

- Applicable to the larger waterways, and waterways where maintaining fish passage is critical.
- May be difficult to apply to some gravel-based (alluvial) waterways due to the difficulty of anchoring/punching the barrier into the gravel bed, and creating a watertight seal.
- Flow diversion or isolation barriers may be constructed using either floating or land-based machinery.
- The degree of de-watering depends in part on the type and depth of unconsolidated substrate.

Advantages:

- Maintains stream flow and fish passage.
- Minimal release of sediment except during the installation and removal of the isolation barrier.
- Can produce a relatively dry work area behind the isolation barrier.
- Allows significant time for pipeline installation and replacement of backfill.

Disadvantages:

- Can be expensive depending on the type of isolation barrier.
- Elevated stream flows may cause bed and bank erosion within the open waterway.
- Requires a large right-of-way adjacent to the waterway.
- Potential damage to isolation areas (i.e. areas isolated by barriers) during elevated flood flows.

Types of isolation barriers

Sheet piling isolation barrier

Sheet piling

- Steel sheet piling is a traditional instream isolation barrier.
- This technique can be used in relatively deep water.

Water-filled dams

Transportable water-filled dams

- Transportable water-filled dams can be used to isolate large areas at low cost.
- Generally limited to relatively wide and shallow waterways.

Earth bund

Earth bunding

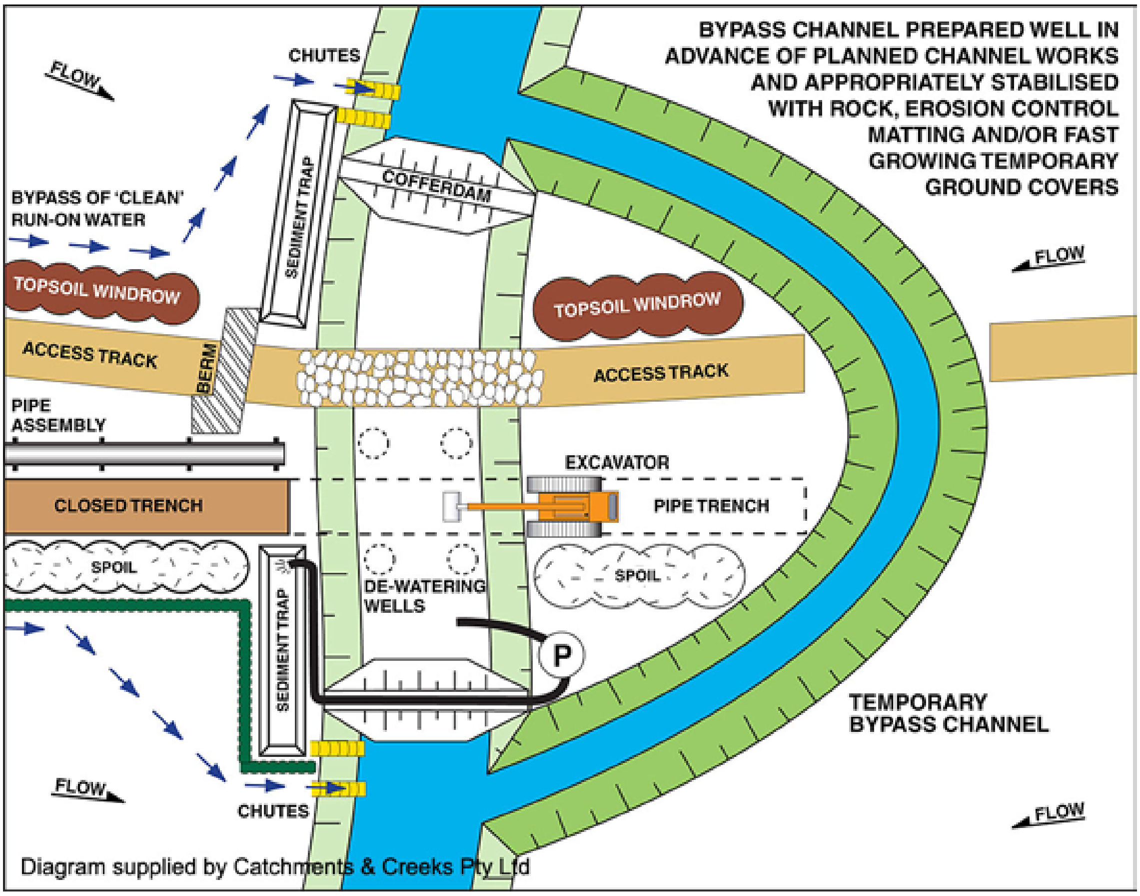
- Earth bunding can be a slow and expensive construction method.
- Can cause significant sediment disturbance during installation and removal.

A-frame Aqua Barrier

A-frame water barriers

- Various commercial products are available.
- These techniques are generally limited to shallow water bodies.
- Possibly best used when working within concrete lined drainage channels.

Constructed bypass channel



Possible layout of a constructed bypass channel

Typical application:

- Best suited to waterways with a wide, low floodplain.
- Can be applied to a wide range of waterway types.
- Extreme care must be taken if the bypass channel is to be constructed through unconsolidated sandy soil because ongoing channel erosion can occur, even after the bypass channel is backfilled and rehabilitated.
- The bypass channel may need to be lined with erosion control mats, unless the channel can be constructed (off-line) well in advance of the pipe installation.

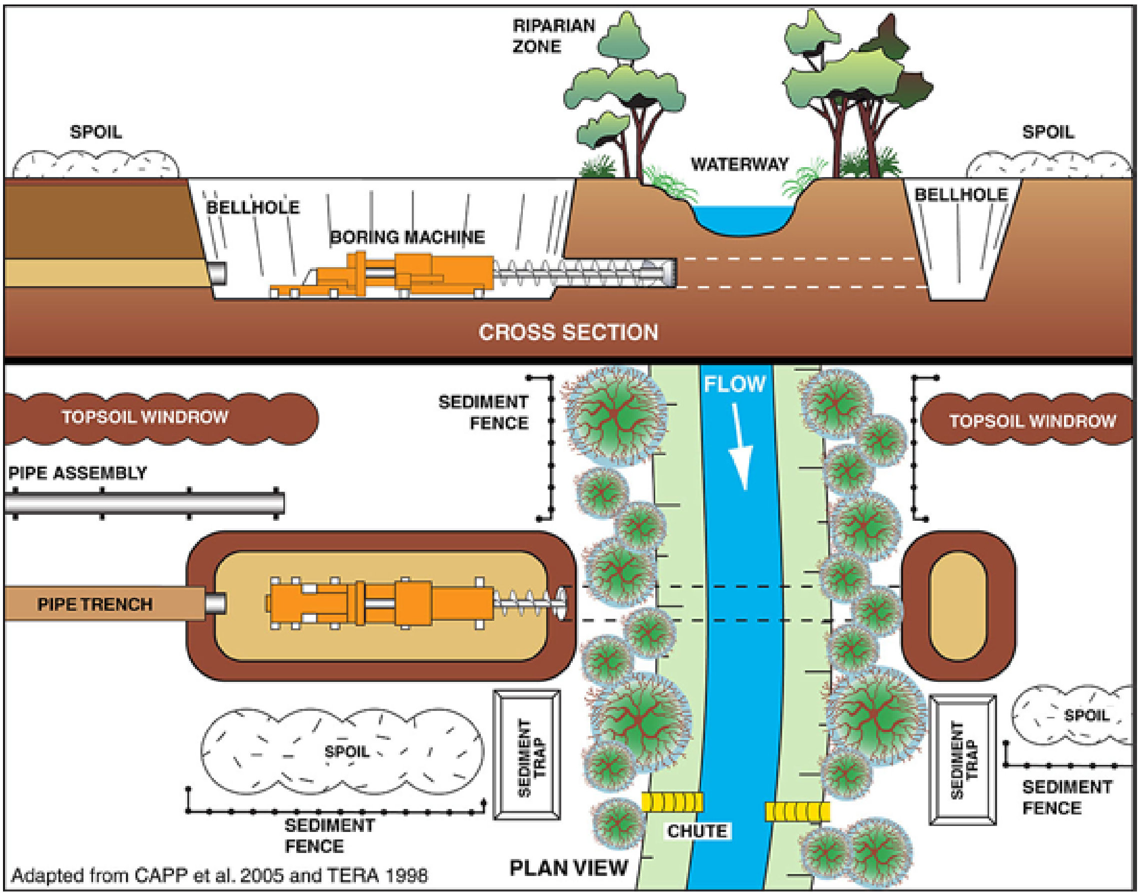
Advantages:

- Maintains stream flow.
- The bypass channel can be constructed off-line, thus reducing sediment releases.
- The bypass channel can be constructed and stabilised well before the pipe installation.
- Fish passage may occur along the constructed bypass channel.
- Ample time provided for pipeline installation and replacement of backfill (depending on the fish barrier permit timeline).

Disadvantages:

- In most cases, fish passage will be reduced below natural conditions during the construction phase.
- Potential flood damage to the cofferdams, bypass channel and work site.
- Can cause significant damage to riparian zones.

Horizontal bore and punch, or pipe jacking



Typical layout of a bore and punch operation

Typical application:

- Best suited to passing pipelines under narrow, sensitive waterways containing impermeable substrates.
- The process is not suited to all waterway substrates due to excessive borehole slumping and water seepage.
- Borehole length possible limited to around 100 m (boring) or 50 m (pipe jacking).
- Before adopting trenchless technique, the substrate material along the pipeline path should be evaluated to determine whether it is appropriate for such a method.

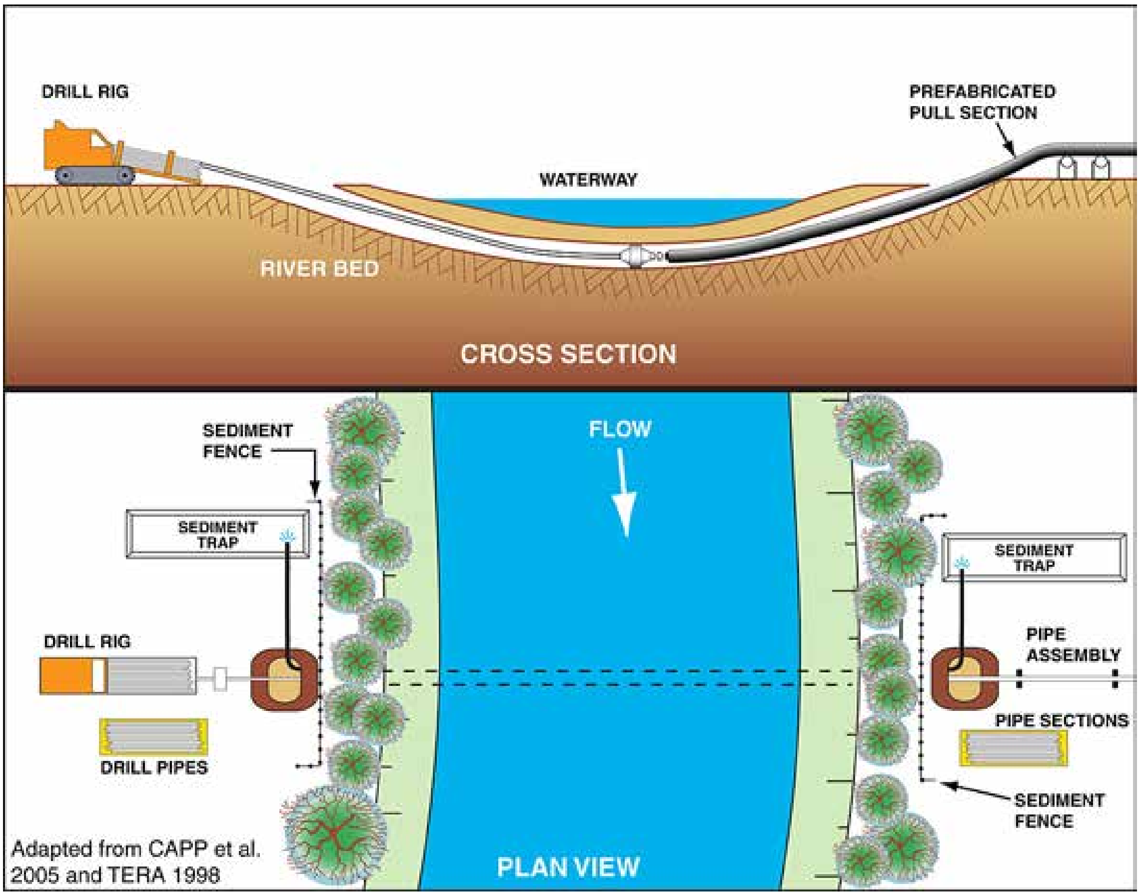
Advantages:

- Potentially zero sediment releases.
- No disturbance to the waterway channel.
- Maintains stream flows and fish passage.
- Minimal damage to riparian zones.
- Reduces the need to rehabilitate the waterway banks, and the risk of ongoing bank erosion as a result of bank disturbances.

Disadvantages:

- Potential worker safety issues.
- Can be an expensive and slow construction process.
- Potential for borehole slumping.
- Can increase the cost of the deeper approach segments of the pipeline.
- Requires specialised equipment.

Horizontal directional drilling



Typical layout of a horizontal directional drilling operation

Typical application:

- Best suited to passing pipelines under sensitive waterways.
- The maximum approach angle of the pilot hole is around 10–20 degrees.
- Success depends on the type and consistency of the substrate (bed material).
- Before adopting trenchless technique, the substrate material along the pipeline path should be evaluated to determine whether it is appropriate for such a method.

Advantages:

- Potentially zero sediment releases.
- No disturbance to the waterway channel.
- Maintains stream flows and fish passage.
- Minimal damage to riparian zones.
- Reduces the need to rehabilitate the waterway banks, and the risk of ongoing bank erosion.

Disadvantages:

- The need for disposal of drilling fluids.
- Potential release of drilling fluids into the waterway through fractured substrate.
- Can be an expensive and slow construction process.
- Requires specialised equipment.
- May damage the pipe coating.

Construction Practices at Waterway Crossings

Impact of waterway type on pipeline design

Clay-based waterway

Clay-based waterways

- The type of waterway not only influences the choice of construction technique, but also the desired depth of the pipeline under the channel bed.
- Clay-based waterways contain clayey soils across the bed and banks.
- These are 'fixed bed' waterways, and mature vegetation can often appear close to, or even on the channel bed.
- Trench stability and trench de-watering requirements will be related to soil type.

Sand-based waterway

Sand-based waterways

- Deep, loose sand dominates the make-up of the stream bed on sand-based waterways.
- These are 'alluvial' waterways that experience significant sediment (bed) flow during both minor and major stream flows.
- The bed material can become 'fluid' during floods, and consequently can quickly slump and backfill an open pipe trench.
- Shoring and constant de-watering are usually required to form an open trench.

Gravel-based waterway

Gravel-based waterways

- The bed material of gravel-based waterways is made-up of well-rounded gravels and boulders.
- These are 'alluvial' waterways often containing pools and riffles that completely reform during severe flooding.
- The bed material can be highly mobile, but usually only during severe floods.
- In most cases it is **essential** that the pipe is positioned well below any mobile bed material contained within both sand and gravel-based waterways.

Rock-based waterway

Rock-based waterways

- The bed material is made-up of exposed rock outcrops separated by sections of clay, sand or gravel-based channels.
- These are fixed-bed 'spilling' waterways usually containing riffles and waterfalls followed by deep pools.
- Trenching, tunnelling, or drilling through such bed material can be slow and expensive; thus 'bridging' techniques may be preferred in many cases.

Impact of waterway type on pipeline design

Timber bridge prior to 1996 flood

Flood-induced bed sediment migration

- Left is an image of Brookbent Road bridge prior to the May 1996 flood.
- Below are two images of the flood damage caused, in part, by the natural migration of bed material (sand) during this flood.
- Significant damage occurred to both the bridge-attached and buried pipelines.
- The bottom image is an example of the type of channel expansion/erosion that can occur within gravel-based waterways during severe floods.

Sand-based Oxley Creek at Brookbent Road in May 1996 (flow from right to left)

Flood damaged Brookbent Rd bridge abutment and attached pipe work

Gravel-based Buaraba Creek, Queensland after 2011 flood

Pipe crossings of dry ephemeral waterways

Dry-bed, sand-based watercourse

Sub-surface groundwater flows

- Pipe crossing of dry creek beds generally do not cause significant environmental problems.
- Trench de-watering may be required if sub-surface groundwater exists below the dry bed.

Rock stabilisation above pipeline

Placement of rock

- If the pipeline crossing is to be stabilised with rock, or other hard surfacing material, it is important to consider the likelihood and consequences of natural bed sediment flows.
- Alluvial waterways (sand-based and gravel-based systems) are subject to the significant ongoing migration of bed sediments.
- If rock stabilisation above the buried pipe is required, then ensure this rock is placed <u>under</u> the natural bed sediments.

Gravity bypass pipe (flume) system

Management of stream flows

- Unexpected stream flows can occur during the construction phase as a result of local or distant rainfall.
- If stream flows are possible, then a risk assessment procedure should be employed to assess the need for a flow diversion system, such as:
  - gravity bypass pipe (flume)
  - cofferdams with pumped bypass (?)
  - flow diversion barriers.
- It is unlikely that a pumped bypass will be able to manage such sudden storm flows.

Ephemeral creek with permanent pools

Consideration of fish passage

- It can seem inconceivable that fish passage could be a consideration in some dry inland waterways, but freshwater fish can and do survive in numerous inland waterways.
- In the absence of official fisheries advice, the following rule can be applied to inland Australia: If there are permanent natural water bodies (not dams) upstream of the site, then fish migration should be expected during periods of flow within ephemeral waterways.

Pipe crossings of flowing waterways

Wet, ephemeral waterway

Flow diversion systems

- If flows are occurring within the waterway, then some type of flow diversion system may be required.
- Typical flow diversion systems include:
  - gravity bypass pipe (flume)
  - cofferdams with pumped bypass
  - sheet piling
  - water-filled rubber dams
  - earth bunding.

Works within a sandy waterway

Exceptional cases

- There are exceptions to the need for flow diversion, such as:
  - clean, sand-based waterways where only natural bed sands are disturbed, and minimal potential environmental impacts exist
  - highly turbid waterways where the instream works will not increase instream turbidity levels by more than 10% (exceptions do exist).

Deepwater tidal waterway

Deepwater channels

- Typical options for the construction of a pipeline across deep water include:
  - bridging
  - dragline open cut
  - dredging open cut
  - pipe jacking
  - directional drilling.
- Sediment controls may consist of floating silt curtains, which are used to isolate the disturbance area rather than filter the water.

Inappropriate instream sediment control

Instream sediment control

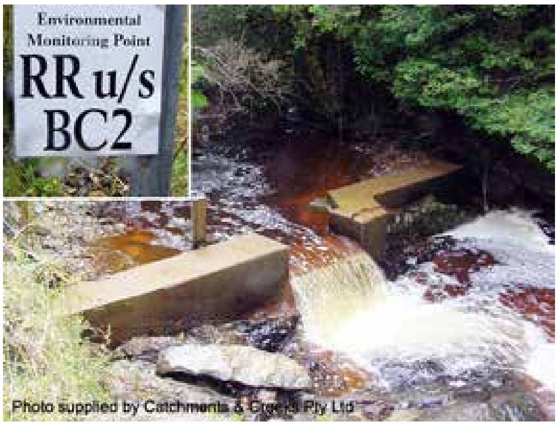
- The use of instream sediment systems can be controversial.
- Only **very minor**, shallow flows can be treated within ephemeral streams.
- These systems also create fish barriers.
- The key principle is to design the instream sediment trap to treat **only** the dry weather trickle flow, not elevated stream flows.
- Woven fabrics, such as ‘sediment fences’ should NOT be used in waterways.

Assessing the potential impacts of sediment released into waterways

Sand deposited into a wetland

Coarse sediment v fine sediment

- The potential impact of sediment on aquatic environments depends on the type of water body and the type of sediment.
- Coarse sediment, that being sands and silts, many cause adverse impacts to wetlands and small waterways, such as creeks.
- Fine sediment, such as fine silts, clays and 'turbidity', can cause adverse impacts to almost all waterways, including bays and estuaries.



Permanent discharge monitoring site

Background levels

- In some cases, the allowable discharge conditions from construction sites will be either linked to:
  - long-term average background levels
  - the immediate upstream water quality conditions at the time of discharge.
- However, most construction projects have discharge conditions set independently of the background turbidity (NTU) and suspended solids (TSS) levels within the receiving waters.

Smaller turbid waterway entering a river

Catchment wide approach

- In some drainage catchments, natural turbidity levels can vary significantly from location to location down the waterway.
- In such cases it may not be appropriate to set water quality objectives (WQOs) based on the immediate receiving water; instead, WQOs are based on a catchment-wide objective.
- An example of this would be waterways that flow into a bay, where WQOs may be based on the needs of the bay, rather than the needs of the immediate waterway.

Wawirra Creek in central NSW

Inland waterways

- In Australia, many waterways that pass through arid or semi-arid regions are naturally highly turbid.
- Typically the countryside is arid or semi-arid, and the soils often have dispersive properties.
- When working in such regions, authorities must set appropriate WQOs, usually a maximum of 10% above natural background levels.
- Conversely, most coastal streams have traditionally had very clean base flows.

Instream sediment control systems

Instream rock filter dam

Rock filter dams

- Rock filter dams are in-effect, large rock check dams used to slow and filter waters passing through the dam.
- Instream rock filter dams are normally wrapped in filter cloth, which is used as the primary filter.
- Aggregate-based filters are generally not employed on instream rock filter dams.
- Fine aggregate, however, can be used to control the rate of flow passing through the rock dam.

Instream sediment weir

Sediment weirs

- A sediment weir is similar in structure to a gabion wall.
- Sediment weirs are formed from two or more parallel wire mesh fences (staked perpendicular to the flow) in between which aggregate (preferred) or straw bales are placed to control the rate of through-flow.
- Fine aggregate and/or filter cloth is then placed on the upstream face to act as the primary filter (which can be removed and replaced after elevated flows occur).

Rock filter dam with filter tubes

Filter tube dams

- A filter tube dam is a rock filter dam, into which ribbed drainage pipes are set, onto which non-woven, geotextile filter tubes (below) are attached.
- Instream sediment traps are only suitable for use within constructed drainage channels, natural drainage lines and ephemeral waterways, and are designed **only** to treat dry weather trickle flows.
- Elevated stream flows should be allowed to pass untreated over the sediment trap without causing damage to the trap.

Elevated stream flows at work site

Filter tube connected to ribbed pipe

Fish passage considerations

Freshwater fish migration

Signage at in-stream works

Retention of tree root system

Natural bank vegetation

Fish passage

- Fish passage considerations and management strategies need to be discussed with the local Fisheries office.
- Some states may have specific legislation or self-assessable codes that address issues such as:
  - the maximum allowable duration of instream works and the existence of temporary fish barriers
  - the time of year when works can occur
  - required bank rehabilitation measures.

Notification and signage of works

- Requirements for on-site signage of approved works vary across the country.
- In some states, all instream works will require both pre-works and post-works notification with the local Fisheries office.
- In Queensland such requirements also apply to works conducted under their self-assessable codes.
- It is important to note how rules can change during periods of fish 'migration' as compared to general fish 'passage'.

Vegetation clearing on bed and banks

- If it is necessary to remove vegetation (marine, aquatic or riparian) from the bed and banks; then wherever practical, this vegetation should be cut no lower than ground level, with the roots left in the ground to aid bed and bank stabilisation.
- Ideally, roots should only be removed within the region of the pipe trench.
- However, in reality, the application of environmental requirements such as this will vary from site to site.

Bank rehabilitation

- In some cases it may be a requirement to reinstate the channel's bed and banks to their natural profile, and to re-establish natural vegetation cover.
- However, this may be inconsistent with achieving a stable channel surface over the buried pipeline, and protection of the pipeline from root damage.
- In many cases, a **critical** component of maintaining fish passage is to reinstate natural vegetation along the toe of bank.

Rehabilitation of Waterway Crossings

Introduction

Rehabilitated pipeline crossing

Introduction

- In most cases there will be requirements for the rehabilitation of the bed and banks of the waterway following installation of the pipeline.

Minor waterway in a semi-arid area

Arid and semi-arid waterways

- The rehabilitation needs of the waterway will depend of the 'natural' waterway conditions.
- An existing harsh landscape does **<u>not</u>** mean that no site rehabilitation is required.
- Native grasses may need to be established across the banks, even though these grasses will quickly fall dormant after work activities leave the area.

Gravel-based waterway

Replacement of natural bed material

- Natural bed material (substrate) must be returned to the channel surface above the pipeline.
- The replacement of the natural substrate is important for:
  - fish passage
  - maintaining the natural boundary layer flow conditions along the bed.
- If rock stabilisation of the buried pipeline is required, then this rock should be placed well below the natural bed material.

Natural bank vegetation

Bank rehabilitation

- The re-establishment of natural bank vegetation over pipelines is a controversial topic.
- In many cases the pipeline owner will insist that deep-rooted vegetation cannot be established over the pipeline.
- In just as many cases Natural Resource and Fisheries officers will insist that natural conditions need to be reinstated.
- Critical to fish passage needs is the reinstatement of edge plants along the bank toe or water's edge.

Potential problems caused by <u>not</u> reinstating natural bank vegetation

Failure of bank stabilisation works

Concentration of lateral inflows

- It is only natural that stream rehabilitation measures will focus on the erosive potential of in-bank flows; however, all waterways experience lateral inflows resulting form local rainfall.
- Natural riparian vegetation can intercept and maintain these inflows as 'sheet flow'.
- Pipeline installations normally remove or modify riparian vegetation causing the concentration of local stormwater runoff down the banks of the waterway.

Bank erosion adjacent pipe alignment

Bank erosion

- Woody tree and shrub species can help push high-velocity flows away from stream banks.
- Non-woody species, such as grasses, fold flat during flood flow, thus allowing high-velocity water to move closer to the stream banks.
- Establishing only non-woody grasses over the pipeline can cause bank erosion to occur immediately downstream of the pipeline corridor.

Non-vegetated rock stabilisation

Blockage to fish passage

- Natural bank vegetation is ideal for producing suitable boundary layer conditions (water velocity profiles) adjacent to waterway banks to aid fish passage during elevated stream flows.
- Failing to re-establish suitable woody vegetation and channel roughness along stream banks can result in unfavourable fish passage conditions, as well as ongoing bank erosion problems.

Non-vegetated rock stabilisation

Blockage to fish passage

- In some circumstances, plain, non-vegetated, rock-lined surfaces can also represent a barrier to fish passage.
- Such surfaces may not be able to produce desirable boundary layer flow conditions, or desirable plant establishment adjacent the water's edge.
- In permanent streams, open voids <u>below</u> the water line can provide additional fish habitat; however, <u>above</u> the water line it is generally preferable for vegetation to be established over the rock protection.

Erosion control and bank stabilisation measures

Bank stabilisation measures

Replacement of tree debris

- Felled trees and wooden debris can be placed over the pipeline corridor to:
  - increase bank roughness
  - increase the anchorage of erosion control mats
  - provide a source of native seed
  - reduce the risk of concentrated lateral inflows passing down the bank (caution, poor placement of logs can have the reverse effect).

Erosion control jute mesh

Use of erosion control mats

- Preference is typically given to the use of jute or coir 'mesh' as a form of erosion control matting on disturbed waterway banks.
- The mesh can also be used to anchor loose mulch and small quantities of organic matter recovered from the land clearing phase.
- Rocks and tree debris can be used to provide additional anchorage to the mesh.

Use of synthetic reinforced mats

Synthetic reinforced mats

- Synthetic (plastic) reinforced erosion control mats should **NOT** be used to stabilise waterway banks.
- Such materials can be fatal to terrestrial wildlife, such as lizards and snakes, that try to move through the plastic mesh.
- This is a real problem that should not be ignored.
- Preference, wherever practical, should always be given to the use of jute or coir mesh.

Failed erosion control mat

Placement of erosion control mats

- All erosion control mats MUST be placed on waterway banks such that the upstream mat overlaps the immediate downstream mat.
- Failure to place the mats correctly will increase the risk of the mats being displaced by stream flows.

Toe stabilisation of waterway banks

Erosion along toe of bank

Toe erosion on channel banks

- Toe erosion is common along the base of disturbed waterway banks.
- Rock protection along the toe of disturbed channel banks is usually necessary to provide short-term bank stabilisation during the plant establishment phase.
- Without such rock protection, elevated stream flows can cause bank erosion before the plants are fully established.

Rock stabilised pipe crossing

Toe stabilisation using rock

- If flow velocities are low enough to allow the use of vegetated banks, then the rock stabilisation of the toe usually only needs to extend about 0.5 to 1.0 m above the bed within ephemeral streams.
- The toe rock should integrate well into the bank soil and toe vegetation.
- The rock should not sit on the bank, but rest within the bank soil.

Natural bank vegetation

Toe vegetation

- The selection of plant species usually depends on its location within the waterway, such as:
  - bed
  - toe of bank
  - lower bank
  - upper bank
  - overbank
- The choice of toe vegetation can be critical for both bank stability and fish habitat.

Coir 'geo-log' temporary toe protection

Alternative toe stabilisation measures

- Coir or jute 'geo logs' can be used as an alternative to rock stabilisation along the toe.
- These geo logs typically provide only temporary (less than 2-years) protection of the toe.
- These temporary protection measures are only successful if suitable vegetation is incorporated into, or around, the logs.
- It is important to ensure that bank erosion does not occur behind the logs during elevated stream flows.

Use of flow deflection systems

Bank erosion exposes sewer pipe

Bank erosion at channel bends

- If the pipe crossing is located at a sharp channel bend, then there may be the risk that ongoing bank erosion/migration could result in exposure of the pipe.
- Ideally, the pipe depth and alignment should have allowed for the expected migration of the channel banks.
- In rare cases it may be necessary for flow deflection systems to be installed to reduce the risk of bank erosion.

Rock flow control groyne

Rock groynes

- One of the simplest ways of deflecting minor flows away from the base of recently stabilised waterway banks is to establish short rock groynes:
  - on the outside channel bank just upstream of the bank rehabilitation
  - at regular intervals (approx 3 to 5 times the length of the groynes) along the base of the disturbed bank if it is judged that a single rock groyne will not be sufficient to deflect flows away from the bank.

Pile filed in sand-based waterway

Timber groynes and pile fields

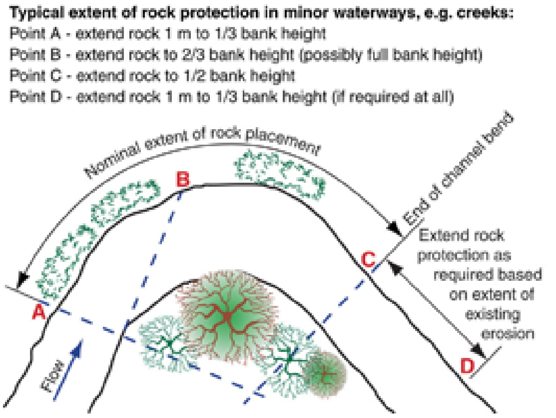
- Timber posts can also be used to control flow movement near the base of disturbed channel banks.
- The posts can be placed in the form of 'groynes' (below) or placed as 'pile fields' (left) along the base of the bank as a form of toe protection.

Log groynes

Log groynes

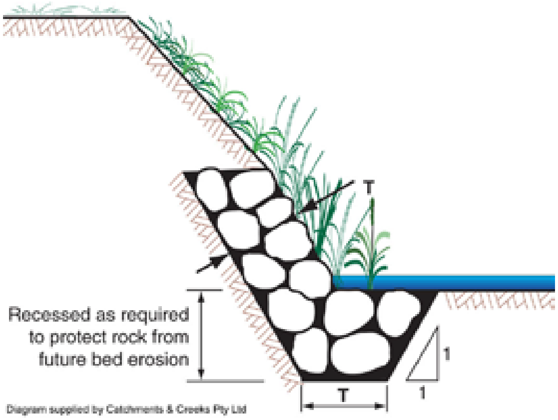
- Felled trees can also be used to form timber flow deflection groynes.
- It is essential that the logs are adequately anchored with wire cables and suitable earth anchors to prevent the groynes being displaced during floods and becoming damaging flood debris.

Use of rock in bank stabilisation



Placement of rock on channel bends

Partial vegetated bank stabilisation



Typical rock placement at toe of bank

Rock stabilisation on channel bend

Design velocity (V_{design}) adjacent banks

- In grass-lined channels with a uniform cross-section, adopt a design velocity equal to the calculated average flow velocity ($V_{design} = V_{average}$).
- In irregular, natural, woody/scrubby waterways, adopt a design velocity of two-thirds (67%) the average flow velocity.
- In all cases, on the outside of significant channel bends, adopt a design velocity adjacent to the outer bank of 133% of the average flow velocity ($1.33\ V_{average}$).

Rock type and grading

- Crushed rock is generally more stable than natural rounded stone.
- A 36% increase in rock size is recommended for rounded rock.
- The rock should be durable and resistant to weathering.
- Neither the breadth nor the thickness of a given rock should be less than one-third its length.
- In waterways the nominal rock size is usually between 200 mm to 600 mm.

Recessing rock below the toe of bank

- In most cases, rock stabilisation only needs to extend **below** the bed level if:
  - the rock is placed on a steep bank, and there is a risk of the rocks slipping down the bank during floods
  - deep movement of bed material is likely to occur during floods, or
  - long-term lowering of the bed level (bed erosion) is likely to occur.
- Otherwise, the toe protection can rest on the channel bed.

Elevation of rock placement on banks

- Rock placement often does not need to extent to the top of the bank.
- A simple guide to rock placement is:
  - straight reaches: 1/3 to 1/2 bank height
  - channel bends: 2/3 lowest bank height on outside of bends; and 1/3 the lowest bank height on the inside of bends.
- In most cases the upper bank area only needs to be stabilised with suitable vegetation.

Use of rock in bank stabilisation

Larger rocks forming toe protection

Rock placement over filter cloth

Stacked boulder wall

Rock placed on a dispersive soil bank

Thickness of rock protection

- The thickness of the armour layer should be sufficient to allow at least two overlapping layers of the nominal rock size.
- The thickness of rock protection must also be sufficient to accommodate the largest rock size.
- It is noted that additional thickness (i.e. placing more then two layers of rock) will **not** compensate for the use of undersized rock.

Backing material or filter layer

- Non-vegetated armour rock must be placed over a layer of suitably graded filter rock, or geotextile filter cloth.
- The geotextile filter cloth must have sufficient strength, and must be suitably overlapped, to withstand the placement of the rock (which normally causes movement in the fabric).
- Armour rock that is intended to be vegetated by appropriately filling all voids with soil and pocket planting, will generally not require an underlying filter layer.

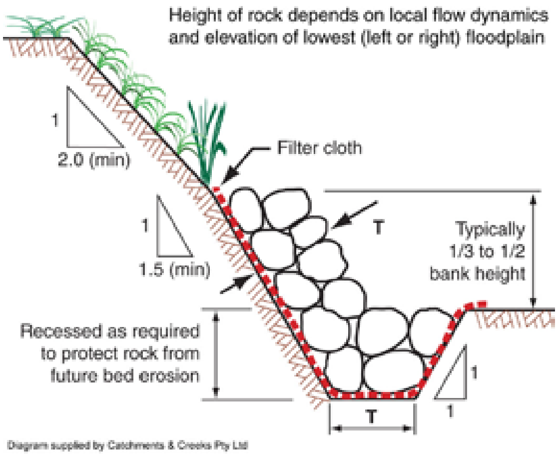
Maximum bank slope

- Maximum batter slope is typically 1:2 (V:H) for non-vegetated, and 1:2.5 (V:H) if vegetated—the flatter slope being desirable (but not essential) to provide safe conditions for planting operations.
- Steeper banks can be achieved with the use of slacked boulders, but the rocks must sit on a stable bed.
- Steep high banks can represent a safety hazard to revegetation teams—seek advice from revegetation contractors.

Rock placed on dispersive or slaking soils

- Rocks should **not** be placed directly onto a dispersive, sodic or slaking soil.
- If the subsoils are dispersive/slaking, then the work area (e.g. a batter chute) should be over-excavated, then topped with a 100 to 300 mm (min) layer of non-dispersive soil and covered with filter cloth prior to placement of the amour rock.
- The thickness of the non-dispersive soil layer depends on the likelihood of future bank disturbances.

Rock placement on waterway banks



Rock placement with open voids

Advantages:

Reduced quantity of rock.

Disadvantages:

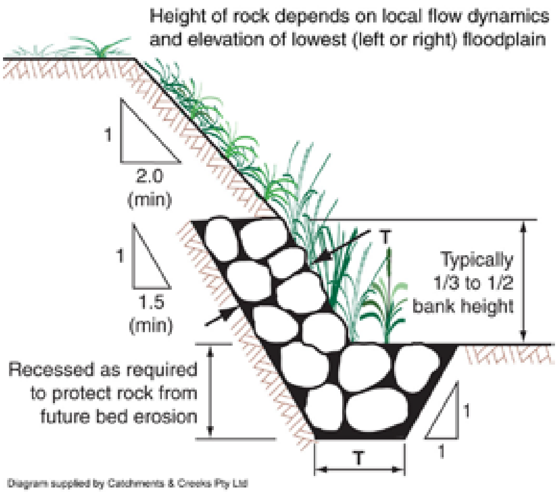
Problems can occur with lateral inflows (i.e. local stormwater runoff) entering into, or passing under, the rock.

Can result in reduced aquatic habitat values in the absence of vegetation.

Use:

Ideally, the use of this rock placement method should be limited.

Used on the inside face of fully shaded, high-velocity channel bends.



Rock placement with soil-filled voids

Advantages:

Improved aquatic habitat values.

Retention of riparian values.

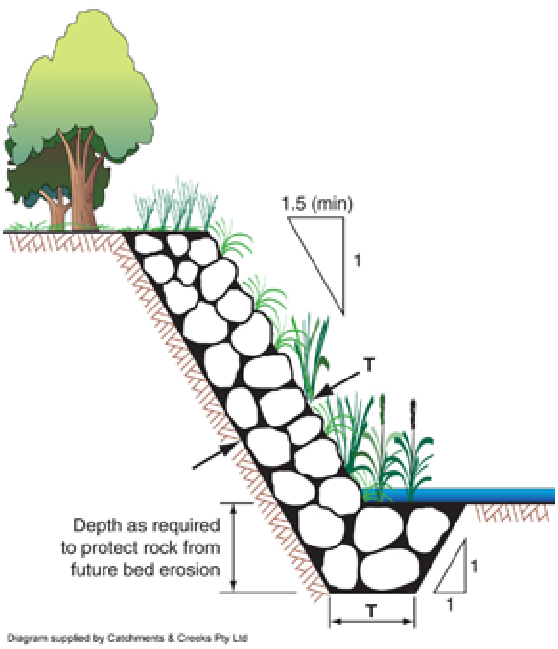
Disadvantages:

Care must be taken to ensure all voids are filled with soil to prevent loss (seepage) of the upper bank soil into the rock layer.

Use:

Toe protection of channel banks in regions of high flow velocity, or areas where the channel bed may experience scour.

Generally the preferred method of rock placement within waterways.



Full-height rock placement

Advantages:

Can provide very high scour protection once vegetation is established.

Retention of aquatic habitat values.

Retention of riparian values.

Banks can be steeper than vegetated banks that do not contain rock protection.

Disadvantages:

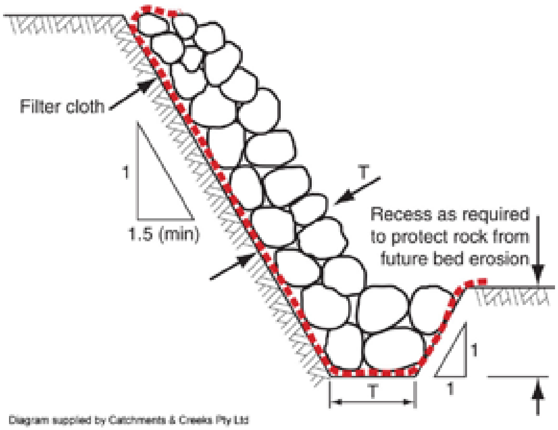
High installation cost.

Use:

Outside face of high velocity or sharp channel bends.

Also, used in areas where both the channel velocity and over-bank flow velocities are likely to be very high and thus erosive.

Rock placement on waterway banks



Full-height with open voids

Advantages:

Cheaper installation cost compared to vegetated rock protection.

Disadvantages:

Poor aesthetics.

Poor aquatic habitat and fish passage.

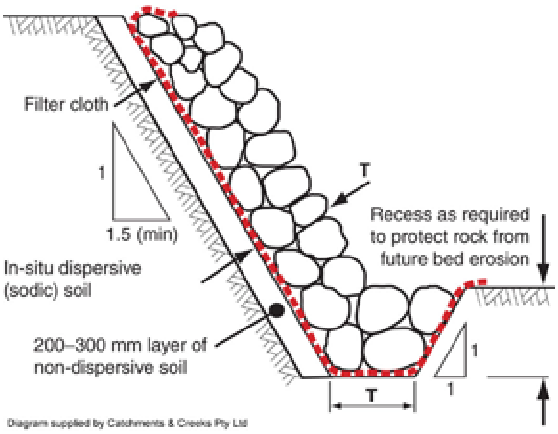
High risk of weed invasion unless fully shaded.

Use:

Heavily shaded, high velocity areas.

Outside face of fully shaded channel bends.

Very high velocity regions where vegetation is not expected to survive.



Rock placement over dispersive soils

Advantages:

Long-term protection of highly erodible soils.

Disadvantages:

Poor aesthetics.

Poor aquatic habitat and fish passage.

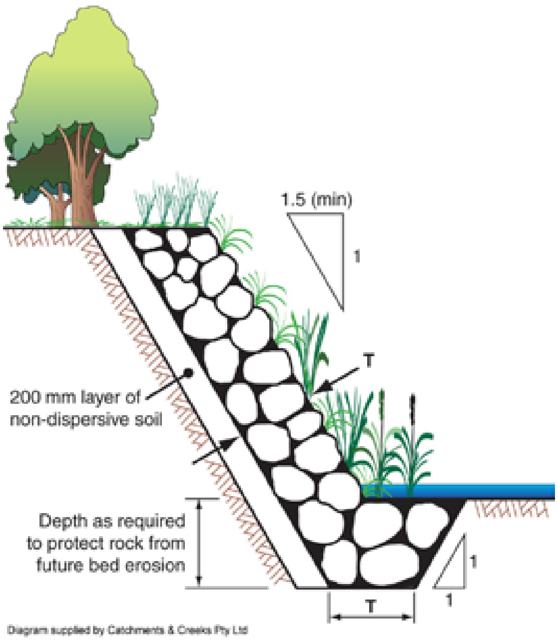
High risk of weed invasion unless fully shaded.

Use:

Heavily shaded areas containing dispersive soils.

Outside face of fully shaded channel bends.

Very high velocity regions where vegetation is not expected to survive.



Vegetated rock placement over poor soils

Advantages:

Retention of aquatic habitat values.

Long-term protection of highly erodible soils.

Reduced maintenance costs.

Disadvantages:

Higher installation cost compared to non-vegetated rock protection.

Use:

Outside face of high velocity or sharp channel bends in dispersive soil regions.

Dispersive soil areas where both the channel velocity and over-bank flow velocities are likely to be very high and therefore erosive.

Generally the preferred method of rock placement within dispersive-soil gullies and waterways.

Vegetated rock stabilisation

Planted rock-stabilised creek bank

Introduction

- Wherever practical, rock protected areas should be lightly covered with soil (to fill all voids) and pocket planted to encourage the preferred plant growth across the bank and along the water's edge.
- In areas where revegetation is not desired (i.e. when hydraulically efficient channels are required for flood control) then the establishment or retention of an effective canopy cover (i.e. shade trees) is generally the preferred means of controlling weed growth.

Voids filled with soil ready for planting

Infill soil

- Experience has shown that minimal soil is lost from the rock voids during flood events.
- The image presented left shows a recently planted bank that experienced a bankful flow just weeks after planting—all plants were lost from the bank, but most of the soil remained.
- **Important:** In order to allow proper plant growth, the infill soil needs to be placed progressively as the layers of rock are added to the bank.

Planting along the water's edge

Planting along the water's edge

- Wherever practical, vegetation should extend to the water's edge to increase the value and linkage of aquatic and terrestrial habitats.
- Plants that branch over the water's edge can provide essential shading of the water to provide pockets of cool water for aquatic life.
- Edge plants also assist aquatic life to shelter from predators.

Planted rock covered with jute mesh

Use of erosion control mats

- During plant establishment it may be necessary to mulch around newly placed plants to control soil moisture loss.
- Covering such areas with a jute or coir mesh can help to reduce the loss of mulch by wind and minor flows.
- However, it is noted that the compete loss of the matting during high flows can cause damage to, or the total loss of, recently established plants.

Common problems associated with rock stabilisation of waterways

Bank erosion at d/s end of rock work

Bank erosion at d/s end of rock work

- In the absence of a vegetative cover, rock-lined surfaces can act as 'hydraulically' smooth surfaces that can induce high flow velocities to exist adjacent the rock-lined surface.
- These same high velocities can cause erosion on the unprotected waterway bank immediately downstream of the rock-lined surface.
- Erosion along the toe of the rock is also common.

Tunnel erosion under rocks

Rock placed on dispersive or slaking soils

- Rocks should **not** be placed directly onto a dispersive (sodic) or slaking soil.
- Tunnel erosion is a common outcome when rocks are placed directly on dispersive soils.

Collapsed dispersive soil bank

Placement of rock over dispersive soils

- If the rock is placed on a dispersive (e.g. sodic) soil, then **prior** to placing the filter cloth, the exposed soil **must** first be covered with a layer of non-dispersive soil, typically minimum 200 mm thickness, but preferably 300 mm.
- It is noted that filter cloth, no matter how thick, cannot seal a dispersive soil, and thus should not be relied upon as the sole underlay for rock placed on a dispersive soil.

Poorly placed rocks on creek bank

Rock not integrated into the bank

- Rocks should not be placed on a creek bank in a manner that detracts from the natural aesthetics of the waterway.
- Wherever possible, the rocks should be recessed into the soil, and appropriately vegetated.
- The exception being when the establishment of vegetation would adversely affect the channel hydraulics or damage the underlying pipe.

Management of inspection chambers

Bank erosion exposes sewer pipe

Exposure of pipe surcharge and inspection chambers

- Pipe inspection chambers should be located well away from channel banks, especially the outside bank of channel bends.
- Exposure of these structures can cause further bank erosion as discussed below.

Bank erosion downstream of chamber

Turbulence generated by exposed inspection chambers

- Partially exposed 'round' inspection chambers cause large-scale eddies to form when floodwaters move around the chamber.
- These eddies then migrate downstream of the chamber causing significant bank erosion as seen in the image (left).

Bank erosion adjacent access pit

Erosion caused by lateral inflows

- Partially exposed inspection chambers can also cause a local acceleration of lateral inflows (local stormwater runoff) which can lead to significant bank erosion.

Rock-lining adjacent access pit

Rock stabilisation around inspection chambers

- If it is essential for an inspection chamber to be located near the waterway channel, then:
  - where practical, locate the chamber on the inside bank of channel bends
  - rock stabilise the bank immediately downstream of the chamber, and if possible, establish stiff grasses within this rock protection and immediately downstream of the chamber.

Rehabilitation of Pipeline RoW

Introduction

Disturbed pipeline RoW

Site rehabilitation

- The best way to control soil erosion is to promptly revegetate all disturbed areas.
- In some locations, reliable all-year rainfall means that revegetation can commence immediately after works have finished.
- In areas of strong seasonal rainfall it may be impractical to establish plants until just before the 'wet' season commences.
- On high risk sites, such as slopes exceeding 5%, early site revegetation may be essential.

Establishment of grass cover over RoW

Establishing sufficient soil cover

- The required surface cover depends on the 'natural' surface conditions, or the needs of the land owner (e.g. pipes crossing farmland).
- A typical construction specification is to achieve at least 70% ground cover (combined plants and mulch) however, it is noted that soil erosion will usually not cease until 100% cover is achieved.
- A quick way to achieve 70% cover is to establish a cover of fast-growing grasses, and then to mow the grass.

Placement of woody debris

Use of woody debris

- Woody tree debris collected during land clearing can in some cases be used to:
  - anchor loose mulch and leaf litter
  - provide a source of native seed.
- Care must be taken to ensure the woody debris does not concentrate overland flows (i.e. the local stormwater runoff).
- Natural leaf litter collected during land clearing can provide good ground cover.

Mature corridor revegetation

Final site rehabilitation

- In all cases, site rehabilitation is a site-specific task that requires:
  - the guidance of local experts
  - an appreciation of the ongoing maintenance needs of the pipeline
  - an appreciation of the 'natural' vegetation cover and climatic conditions
  - an appreciation of the financial viability, or impracticality, of providing water to establishing plants outside natural rainfall.

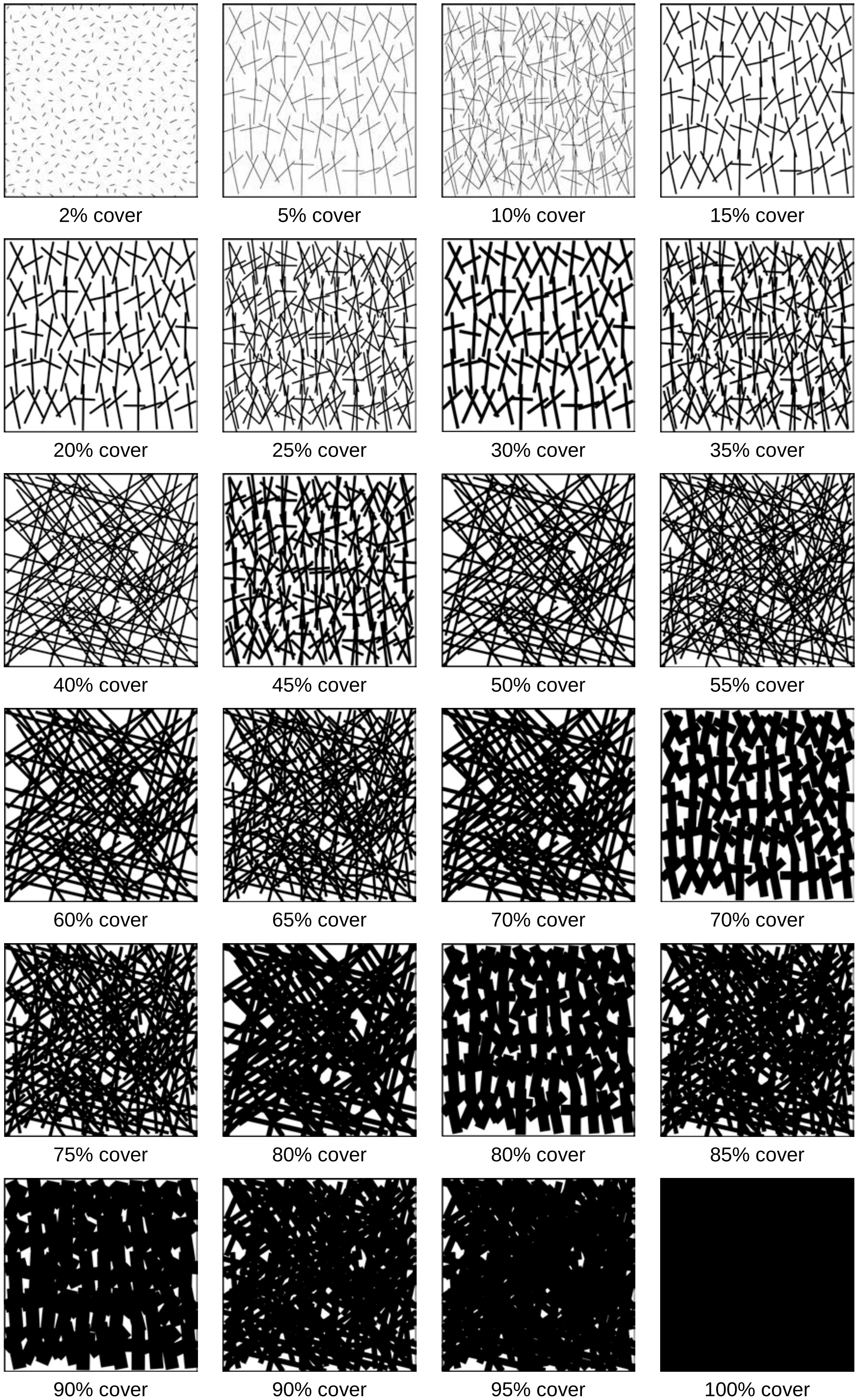


Figure 1 – Visual cover estimation guide

Site stabilisation practices

On-site training in plant establishment

Plant species

- Plant species need to be appropriate for the site conditions, including compatibility with local environmental values, and anticipated erosive forces.
- Selecting the most suitable plant species, establishment techniques, seeding rates, planting densities, fertilisers, watering rates, and maintenance techniques, requires the guidance of experts.

Soil adjustment

Soil preparation

- The long-term success of a revegetation program depends more on what happens to the soil **before** the seed is spread, than any soil modifications applied after placement of the seed.
- Subsoil surfaces that have experienced excessive compaction during the construction phase must be suitably scarified/ripped prior to spreading topsoil.
- Ideally, soil testing should be used to determine any soil amelioration.

Roughened earth batter

Surface roughening

- On recently vegetated or exposed earth surfaces, erosion protection can be increased by roughening the soil surface to increase water infiltration and delay the formation of rilling.
- Surface roughening can also reduce dust.
- Surface roughening can be applied by walking a tracked vehicle up and down the slope (other methods do exist).
- In general, soil surfaces should not be 'smooth' at the time of planting.

Mulching of plants

Maintenance of plants

- It is important to monitor planting activities to ensure that the vegetation is controlling erosion and stabilising soil slopes as required.
- In high-risk and steep-slope areas:
  - check and maintain protective fencing
  - re-firm plants loosened by wind-rock, livestock or wildlife
  - replace dead or poor-growth plants
  - control weeds, especially within a 1 m radius of immature trees.

Site revegetation techniques

Straw mulching

Hydromulching

Bonded fibre matrix

Compost blanket

Straw mulching over seeded soil

- Compared to many other forms of grass seeding, surfaces treated with straw mulch generally require less water to achieve seed germination and growth.
- Straw mulching is best used in rural and semi-arid areas where water supplies may be limited, and in urban areas during periods of water restrictions.
- Straw mulches may require the application of a tackifier to reduce the risk of their displacement by wind or water, particularly when applied to steep slopes.

Hydromulching

- Hydromulching can be used for grass establishment and the protection of newly seeded areas.
- Best used on slopes <10% and slopes with a vertical fall of less than 3 m.
- Hydro-mulched surfaces generally have higher watering requirements than surfaces treated with straw mulch.
- Tackifiers incorporated into the mix are normally water soluble and thus easily disturbed by heavy rainfall and concentrated overland flows.

Bonded fibre matrix and soil binders

- Bonded fibre matrices are effective for revegetating steep batters.
- Typically it is a highly successful grassing technique, but it requires strict control of application rates and choice of tackifier.
- Often used in wet environments (e.g. the tropics during the wet season, and drainage channels) due to the use of non re-wettable tackifiers.
- Various *Soil Binders* can also be used to seal and protect seeded soil surfaces.

Seeded compost blankets

- Compost blankets are typically used in association with the revegetation of steep slopes using grasses and/or woody species.
- Particularly useful if:
  - the slope is too steep for the placement of topsoil
  - there is insufficient topsoil, or the stripped topsoil cannot be used due to excessive weed content.
- Can be expensive, but usually highly successful.

Site Maintenance

Common maintenance repairs

Tunnel erosion above pipeline

Tunnel erosion along the pipeline

- Tunnel erosion is one of the most common maintenance issues in low gradient, semi-arid landscapes.
- In theory, regular trench breakers should prevent the establishment of tunnel erosion along the buried pipeline, but in reality problems can still exist.
- Tunnel erosion is also common along pipes that have been installed with spider ploughs.

Outlet of above tunnel erosion

Repairing tunnel erosion

- There are few successful techniques for treating tunnel erosion other than excavating the tunnel and re-compacting the soil, possibly with additional trench breakers installed.
- Additional trench breakers may also be the solution to tunnel erosion along spider plough installations.
- If excavation and re-compaction is not practical, then filling the hole with fine organic litter may (in some cases) slow the rate of erosion.

Erosion along the pipeline RoW

Trench damage caused by surface flow

- Surface scour should be repaired by:
  - backfilling and re-compacting the trench
  - consideration given to the establishment of recessed rock check dams (rock weirs recessed into the ground such that the crest is at natural ground level) along the pipe corridor
  - a redesign of the surface drainage system such that high-velocity surface runoff is directed away from the pipe trench.

Gully erosion in slaking soil

Gully erosion

- Gully erosion can be common in sandy, dispersive and slaking soils.
- Gully erosion may be repaired using the options presented above for minor surface erosion; however, this would require the gully to be backfilled to natural land level.
- If complete backfilling is not practical, then a drainage engineer will be required to design an alternative surface drainage system that directs flows away from the gully.

Glossary of terms

Acid sulfate soil	A soil type containing significant amounts of iron sulfide (usually pyrite, FeS_2) which generates sulfuric acid when exposed to oxygen; typically associated with coastal lowlands (< 5 m AHD) and estuarine floodplains.
Aggregate immersion test	A simple soil test performed in the field that is similar to the *Field Emerson Aggregate Test*, except undisturbed samples of the soil are tested rather than a formed 'bolus'.
Alluvial waterway	A natural waterway formed primarily from flood-laid deposits of sand, silt and gravel, or a constructed channel primarily lined with alluvial material extracted from a waterway or floodplain. Typically represented by sand-based and gravel-based waterways.
Bankful elevation	A water surface elevation estimated by various procedures that describe the channel flow condition preceding significant overbank flow. If benches are well established within the channel, then significant overbank flows might occur prior to the inundation of the floodplain. To avoid erroneous and/or highly variable results, bankful elevation should not be determined by the shape of a single cross-section, but with observations made along a length of the channel.
Bankful width	The width of a watercourse when it completely fills its channel and the elevation of the water reaches the upper margins of the bank.
Causeway	A raised road or path constructed across low, wet ground or across tidal water.
Clay-based waterway	In these waterways, clayey soils dominate the make-up of the stream bed. Channel stability is most commonly governed by the strength of the bed and bank vegetation. Often referred to as 'fixed-bed' waterways—the relative stability of the bed allows for increased longevity of bed vegetation. In their natural condition, minor clay-based waterways often have little if any measurable sediment flow. There is usually a gradual change in plant species from the bed to the lower bank, to the upper bank, to the over-bank areas.
Clayey soil	A soil that contains at least 20% clay. These are fine-grained soils that readily form a clod when compressed in the hand, feel very smooth and sticky when wet, and are very difficult to shovel or break-up when compacted.
Clean water	Water that either enters the property from an external source and has not been further contaminated by sediment within the property; or water that has originated from the site and is of such quality that it either does not need to be treated in order to achieve the required water quality standard, or would not be further improved if it was to pass through the type of sediment trap specified for the sub-catchment.
Coarse sediment	That part of sediment consisting of sands and the coarser fraction of silts.
Cross bank	A longitudinal earth mound with low vertical curvature placed diagonally across an unsealed road or track to collect and divert stormwater runoff across the road or track to a table drain or suitable discharge point.
Cross ditch	A shallow ditch cut into the surface of the right-of-way. Cross ditches run parallel to and are located on the up-slope side of diversion berms.

Cross drain	A drain of various forms (e.g. cross bank or sub-surface pipe) that collects the flow of water on a road, trail or other access way and diverts it across the road surface. Typically required where runoff cannot be controlled by crossfall drainage.
Deposit	Means any discharging, spraying, releasing, spilling, leaking, seeping, pouring, emitting, emptying, throwing, dumping or placing.
Dirty water	Water not classified as clean water.
Dispersive soil (dispersible soil)	A structurally unstable soil that readily disperses into its constituent particles (clay, silt and sand) when placed in water. Moderately to highly dispersive soils are normally highly erodible and are likely to be susceptible to tunnel erosion. Most sodic soils are dispersive, but not all dispersive soils may be classified as sodic. Some dispersive soils are resistant to erosion until mechanically disturbed.
Diversion berm	An erosion control structure installed on slopes to divert surface water from the right-of-way.
Drainage line	A natural or constructed stormwater drainage path that carries 'concentrated' rather than 'sheet' flow, and is likely to flow only during periods of rainfall, and for short periods (hours) after rain has stopped, and is a drainage path that cannot be classified as a 'watercourse' based on a locally or state-adopted classification system.
Dry gully	Gully erosion that does not contain permanent water.
Emerson aggregate class	A classification of soil aggregates based on their coherence in water. Soil aggregates are classified into 8 types according the conditions in which they slake, swell and disperse, in which Class 1 is the most stable through to Class 8 which is least stable. Classes 2 and 3 may be further subdivided according to the degree of dispersion.
Ephemeral waterway	A watercourse that flows during and for short periods after storms.
Erosion control blanket	A blanket of synthetic and/or natural material used to cover and protect soil against erosion caused by wind, rain, and minor overland flows.
Erosion control mat	A mat of synthetic and/or natural material that is primarily used to protect soil against erosion caused by concentrated surface flows.
Erosion control mesh	An open weave blanket formed from synthetic or natural twine such as hessian rope (jute) or coconut fibre (coir), primarily used to protect soil against erosion caused by concentrated surface flows.
ESC	Means 'erosion and sediment control'
ESCP	Means 'Erosion and Sediment Control Plan'
Fine sediment	That part of sediment consisting of clay-sized particles and the finer fraction of silts.
Fish	Includes: parts of fish; shellfish, crustaceans, marine animals and any parts of shellfish, crustaceans or marine animals; and, the eggs, sperm, spawn, larvae, spat and juvenile stages of fish, shellfish, crustaceans and marine animals.
Fish barrier	Means any weir, dam, non-natural vegetation condition or other obstruction impeding the free passage of fish.
Fish habitat	Spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes.

Fluting	A series of vertically elongated grooves (flutes) down gully sides caused by rill erosion. Most commonly experienced in dispersive soils. In severe cases the rills may become isolated from the gully walls to form narrow tapered pinnacles.
Ford	A shallow place where a river or other body of water may be crossed by wading or otherwise passing through the water.
Freshet	Rapid temporary rise in stream discharge and water level, caused by heavy rains.
Gravel-based waterway	Bed material is made-up of well-rounded gravels and boulders. These are 'alluvial' waterways usually containing pools and riffles that completely reform during severe flooding. Bank stability is governed by the strength of the bank vegetation. The bed material can be highly mobile during severe floods, but generally stable during minor floods. Bed vegetation may consist of mature woody and non-woody species, but significant loss of vegetation can occur during severe floods. Bank vegetation can be similar to clay-based waterways.
Grubbing	A construction activity that involves removing vegetation, tree roots and stumps and surface soil from the pipeline right-of-way or other areas that will be under development.
Gully erosion	A complex of processes in which soil removal is characterised by large incised channels, usually deeper than 30 cm. The severity of gully erosion may be recorded as minor, moderate, severe or very severe.
Inland waterway	A waterway located well away from a coastline, such as waterways that ultimately discharges to a trapped water body, or most of the tributaries of the Murray–Darling rivers catchment.
Mitigation	Actions taken during the planning, design, construction and operation of works and undertakings to alleviate potential adverse effects on the productive capacity of fish habitats.
Plug	See 'trench plug'
Raindrop impact erosion	The splattering of soil particles caused by the impact of raindrops on the soil surface. The loosened particles may or may not be subsequently removed by runoff. Raindrop impact erosion is a component of sheet erosion.
Right of way	That part of a pipeline construction corridor over which the pipeline owner and/or contractor have the right to access.
Riparian zone	That part of the landscape adjacent to a watercourse that influences, and is influenced by, watercourse processes. Usually includes the instream habitats, beds, banks and floodplains of watercourses, or their parts.
Riprap	Loose, medium to large rock or stone used to protect earth surfaces against erosion by flowing water or wave action, as in a revetment.
Rock-based waterway	Bed material is made-up of exposed rock outcrops separated by sections of clay, sand or gravel-based channels. Bank stability is governed either by bank vegetation or exposed rock walls. These are fixed-bed 'spilling' waterways usually containing riffles and waterfalls followed by deep pools. The waterway bed is normally very stable; however, significant sediment flows can still occur during floods. Within vegetated sections of the bed, plant species are usually governed by the type of bed material (clay, sand or gravel).

RoW	Mean 'right of way'
Sand-based waterway	Deep, loose sand dominates the make-up of the stream bed. The depth of the sand typically exceeds the depth of the root systems of some bed and lower bank vegetation. These are 'alluvial' waterways that experience significant sediment (sand) flow during both minor and major stream flows. The bed material can be highly mobile during floods, thus bed vegetation is normally dominated by quick-response species. There is normally a clearly defined change in plant species from the bed to the channel bank. Upper bank vegetation can be similar to clay-based waterways.
Sandy soil	A soil that contains at least 50% sand. These are coarse-grained soils that are easy to shovel and break-up when compacted. It is very difficult to form a clod when sandy soils are compressed in the hand.
Sediment	Any clay, silt, sand, gravel, soil, mud, cement, fine-ceramic waste, or combination thereof, transported from its area of origin.
Sheet flow	Flow that passes evenly over the ground as a thin sheet of water as opposed to concentrated flow. Normally occurs on plan surfaces (ground not heavily concaved), and on uniformly grassed areas when the depth of flow is not significantly greater than the blade length of the grass.
Slaking	The process of natural collapse of a soil aggregate in water where its mechanical strength is insufficient to withstand the swelling of clay and the expulsion of air from pore spaces. It does not include the effects of soil dispersion. Slaking aggregates readily break down when immersed in water, but do not disperse. Clouding of the water, if any, is limited to just around individual aggregates. Slaking soils are highly erosive and structurally unstable, but readily settle in water.
Sodic soil	A soil containing sufficient exchangeable sodium to adversely affect soil stability, plant growth and/or land use. Such soils are dispersive and typically contain a horizon in which the exchangeable sodium percentage (ESP), expressed as a percentage of cation exchange capacity, is 6 per cent or more. Strongly sodic soils are considered to be those with an ESP of 15 per cent or more.
Substrate	The material, whether organic and inorganic, found on the bed of the watercourse.
Trench breaker	An erosion control device consisting of impermeable material that is placed within the trench after the pipe has been lowered in and before backfilling. Trench breakers are designed to block the water movement along the trench line and direct it to the surface where it is directed away from the trench line.
Trench plug	A small portion of the ditch line that is left unexcavated, to block water flow along the trench or allow wildlife to cross the trench at known and used wildlife trails.
Tunnel erosion	An erosion process involving the removal of sub-surface soil by water while the surface soil remains relatively intact. Water seeps through soil causing the dispersion and/or slaking of soil particles. The dispersed soil is then removed by seepage until the seepage path takes the form of a tunnel.
Turbidity	A measure of the clarity of water. Commonly measured in terms of Nephelometric Turbidity Units (NTU).

Type 1, 2 & 3 sediment traps	A classification system used to rank sediment control measures based on their ability to trap a specified grain size.
Watercourse	A channel with defined bed and banks, including any gullies and culverts associated with the channel, down which surface water flows on a permanent or semi-permanent basis or at least, under natural conditions, for a substantial time following periods of heavy rainfall within its catchment.
Waterway	A term commonly interchangeable with the term 'watercourse'. The legal definition may vary from state to state, and region to region.