Saving Soil

A landholder's guide to preventing and repairing soil erosion

Northern Rivers CMA CATCHMENT MANAGEMENT AUTHORITY

NSW DEPARTMENT OF PRIMARY INDUSTRIES

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NRCMA Region

This publication was developed for the Northern Rivers Catchment Management Authority (NRCMA) whose area covers most of the NSW North Coast and some of the Northern Tablelands. Throughout the publication we use the term 'region' to refer to this geographic area. While much of the information will apply to areas outside this region, significant variation in soil types, geology, climate and topography may occur in other areas and advice should be sought from local authorities.

Where the source of an image is not noted the source is NSW Department of Primary Industries (NSW DPI).

Saving Soil – A landholder's guide to preventing and repairing soil erosion brings together current information from a variety of sources that will provide the reader with a useful resource to:

- understand techniques to prevent and remedy erosion
- apply these techniques to their landscape and soil type
- integrate erosion control in their routine land management
- fix minor erosion problems
- know when to seek technical expertise
- know what to ask experts.

This guide is designed for new and long time landholders, community support officers, extension officers, Landcare groups, and agricultural industry bodies. We have used the terms landholder and land manager interchangeably, as in many cases the individuals concerned with erosion issues may not be the legal owners or occupiers of the land, or identify as farmers.

Saving Soil is available online at NSW DPI's website and in print through the Northern Rivers Catchment Management Authority.

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Contents

Eroded soil in Richmond River floodwaters at Ballina, 2004. Source: Colin Cooksey

Introduction

Soil erosion is one of the world's major environmental issues. Each year wind and water erode 75 billion tons of soil, most of it from agricultural land. Erosion is a natural process but is accelerated by practices such as land clearing, overgrazing and soil cultivation. It removes fertile topsoil that contains most of the soil's plant nutrients and soil microorganisms that contribute to soil health. The subsoil that remains is less fertile.

Why we need to protect soil


Lost topsoil means reduced fertility.

Soil is essentially a non-renewable resource because it erodes much faster than it forms. In NSW soil forms at a rate of 0.04 to 0.4 tonnes per hectare per year, but losses from grazed pastures can be around 1 tonne per hectare per year.

Cultivated paddocks commonly lose 1 to 50 tonnes per hectare per year. These rates of soil loss may not be obvious – a 1 mm loss of topsoil per year represents a loss of around 14 tonnes per hectare per year.

The loss of soil through erosion has been implicated in the downfall and destruction of many civilisations. The loss of fertile land can lead to economic disruption, food shortages and dislocation of rural populations. In the last 40 years over 30% of the world's farmland has become unusable because of soil erosion.

Due to its high rainfall, high rainfall intensities and steep topography, the Northern Rivers CMA region has a high risk of soil erosion. This risk will increase if predicted climate changes such as hotter, drier seasons and more severe summer storms occur.

Financial losses incurred by soil erosion, and the cost of fixing it, mean that erosion prevention is a much better option than remediation.


An eroding dam spillway

For instance, stabilising a gully headcut can easily cost over $10,000 in earthworks and materials, and that is before the gully is fenced off or remediated. Fencing off a watercourse as soon as erosion is noticed may avoid the need for any other gully works. Gullying in macadamia orchards reduces the efficiency of machine harvesters, requires expensive manual harvesting, and increases the trees' needs for fertiliser. Implementing erosion control works in a mature orchard is much more difficult and expensive than in a new orchard.

A 1 mm loss of topsoil from a 1 hectare cropping paddock means a loss of over 14 tonnes of soil, including nutrients and organic matter. If the soil continues to erode, nutrient requirements will continue to increase. Minimising erosion maintains soil fertility and keeps input costs low.

Look, investigate, and act to protect your soil

Look


Exposed tree roots

Take time to walk over your land, especially after heavy rain, checking for changes that might indicate soil erosion. Look out for bare soil, exposed tree roots, soil pillars, rills (shallow gullies), muddy runoff water, sediment fans and silted dams.

Check where water collects and flows on your land as these areas are vulnerable to erosion. Take photos of the same locations at regular intervals to help you pick up changes. Use monitoring tools like erosion pegs to get an idea of the rate of soil loss.

A line on an erosion pin shows the original soil level.

Monitor your soil health with the Northern Rivers Soil Health Card (www.dpi.nsw.gov.au/agriculture/resources/soils/testing/health-card) because erosion removes the finer soil fractions that contain most of the nutrients and enhance water-holding capacity.

It's also important to check farm infrastructure including tracks, banks, constructed waterways and dams for any signs of damage.

Investigate

When you see erosion occurring think about what is causing the problem, and how you can fix it. There may be more than one factor to consider and manage.

A sediment fan means erosion upslope.

The cause of the erosion may be higher in the catchment, resulting in downstream damage to pasture or cropping areas. For instance, upslope land clearing can lead to mass movement lower in the catchment.

Consider the timing of any actions to reduce erosion. Often it's best to make any changes or complete works during drier winter months to avoid having bare soil in the summer storm season.

Act

Act on any erosion when it's a small problem. Addressing the problem means both repairing erosion damage and treating the cause, so that erosion does not re-occur. Make soil erosion management part of your routine activities. Evaluate the erosion risks and impacts of your regular activities and make changes where appropriate.

Sediment build-up in a watercourse indicates there is major erosion in the catchment.

When starting a new land use or activity, design the site to cope with water flows so that erosion never becomes a problem. Seek advice and plan major erosion rehabilitation projects carefully to get the best value from your efforts.

1 Farming to reduce soil loss

The basic principles of erosion management are the same for all farming enterprises, but management techniques vary according to the enterprise. This section looks at groundcover, the crucial element in erosion prevention in all farming enterprises, and specific erosion management practices for the three main agricultural enterprises on the NSW north coast: grazing, orchards and plantations, and cropping.

Groundcover

Sloping land needs contact and canopy cover.

Groundcover is any material that protects the soil. The most efficient groundcovers for large land areas are living plants because

- foliage reduces the impact of raindrops
- foliage and stems reduce the speed of overland flow
- roots bind the soil
- soil organisms feeding on dead vegetation produce gums that aggregate soil particles, making them less erodible.

Plants protect the soil by providing canopy cover (more than 5 cm above the soil surface) and contact cover (up to 5 cm above the soil surface). Canopy and contact cover both protect the soil against raindrop impact, but contact cover is more effective in protecting soils because it slows runoff so that water infiltrates the soil and deposits any dislodged sediment around the plants. Good contact cover is crucial on sloping country.

Without groundcover the soil erodes.

A complete and permanent cover will usually reduce erosion to a negligible level. Any activity that disrupts vegetation cover on the land usually results in accelerated erosion rates. On cultivated soils, the nature of the canopy, the proportion and time of the year that the soil is covered and the amount and nature of residues left on the soil between crops are all significant.

Groundcover is a good indicator of farm productivity and sustainability. Without it, up to 85% of rainfall from storms can run off into creeks and streams rather than soak into the soil and be available for plant growth. When groundcover is thin, patches of bare soil provide a path for runoff to build up speed and erode the soil.

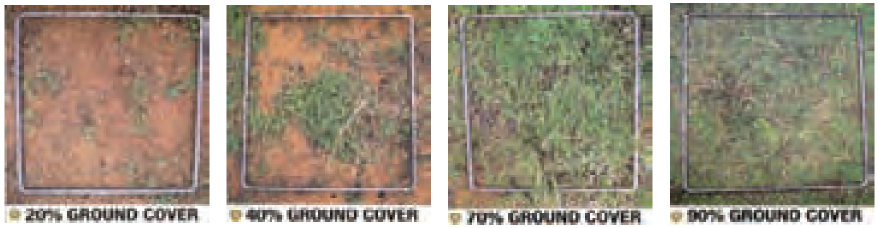
Groundcover levels

Generally groundcover is adequate when there is minimal runoff and no soil is being eroded. Runoff and erosion indicate the need to improve groundcover. The amount of groundcover needed depends on

- the amount of rainfall
- the intensity and seasonality of the rainfall
- the soil moisture
- the slope gradient and length
- the soil characteristics.

There is more detail on how these factors affect erodibility in the Erosion basics section, see page 146.

Groundcover is measured as the percentage of plant material covering the ground, including crops, stubble, pasture plants and their residues, leaf litter, bark and twigs. Research by the Department of Natural Resources (DNR) in the Hunter Valley found that at least 70% groundcover is needed to prevent excessive runoff and erosion on red clay soil with a gentle slope of 10% and average rainfall of 625 mm.



Source: Greg Lodge NSW DPI

Estimates of minimum groundcover (%) required to reduce erosion for a range of slope gradients and soil erodibility classes and soil types.
Source: NSW DPI Agfact P2.1.14 January 2005. Maintaining groundcover to reduce erosion and sustain production.

Erodibility	Typical soil types	Flat	Gentle	Moderate	Steep
Low	deep sands	60	80	90	100
Low to moderate	sandy loams, light clays, ferrosols	60	85	95	100
Moderate to high	dermosols, vertosols	65	90	100	100
High	kandosols, sodosols	70	90	100	100
Low to high	drainage lines (all soil types)	100	100	100	100

On the NSW north coast 90-100% groundcover is recommended because of the region's sloping country and intense rainfall events, especially in the storm risk period from October to May.

In drainage lines where water runs with considerable force, 100% groundcover is required to prevent erosion and formation of gullies. This means drainage lines may need to be fenced, with regular slashing or selective grazing of the groundcover to maintain plant growth.

Groundcover assessment

There are many ways to assess groundcover. Several methods are described in the worksheets at the end of this publication (see page 176).

Types of groundcover

The best way to maintain good groundcover is to select plants that are well adapted to the climate, the soil and the farming system, so that they persist without a lot of attention.

Grasses

Grasses with fibrous roots systems are preferable to tap-rooted plants because the roots increase soil organic matter, provide habitat for microorganisms, improve soil structure and encourage water infiltration.

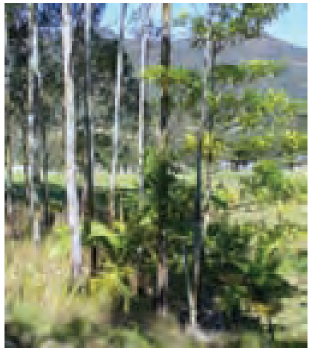

Dense pasture

Perennial grasses are preferred because of their greater potential to provide year round cover. Species with above ground runners or stolons, such as kikuyu (*Pennisetum clandestinum*) and couch (*Cynodon dactylon*), are good for drainage lines because of their ability to spread and provide good contact cover. Smothergrass (*Dactyloctenium australe*) is proving a useful groundcover in low-light conditions such as macadamia orchards.


Smothergrass

Shrubs and trees

Shrubs and trees provide additional canopy and protection from rainfall. Plant species need to be suited to the soil and climate. Local species will have a higher survival rate. Information about the best species to plant is available from local native vegetation specialists.



Trees and shrubs

Mulch

Biodegradable organic mulches such as woodchips, straw and compost provide short term protection from raindrop impact, hold moisture in the soil, and enrich the soil with organic matter. Mulch can help bare, degraded soils recover and support plant growth. It can also be a good 'band-aid' for small bare patches in pastures, to allow time for grass to recolonise before weeds invade. But unless suitable materials are available on site, mulching can be expensive, so it is mainly used to protect new plantings and suppress weeds on rehabilitated erosion areas.

Leaf and twig mulch

Grazing

Animal grazing is the largest agricultural land user on the north coast. As such it has the greatest potential to cause soil erosion, so good grazing management techniques are crucial. This section focuses on grazing management practices that can reduce erosion.

Other sections of this book that may be useful to graziers include:

» **Dams that minimise erosion (page 65)**
» **Stable roads and tracks (page 89)**
» **Erodibility of northern rivers soil types (page 152)**

How grazing causes erosion

Any erosion problem on grazing land almost always starts with a break in pasture cover. The most common causes of erosion on pastures are overgrazing and high wear in specific areas. Erosion risks intensify on steep land, in areas with soils of high erosivity, and in areas with a lot of stock movement such as cattle tracks.

A good land manager will have a sound understanding of the impact of stocking rates and grazing techniques on soil and be able to respond to changing conditions.

How to avoid erosion

Maintain healthy pastures

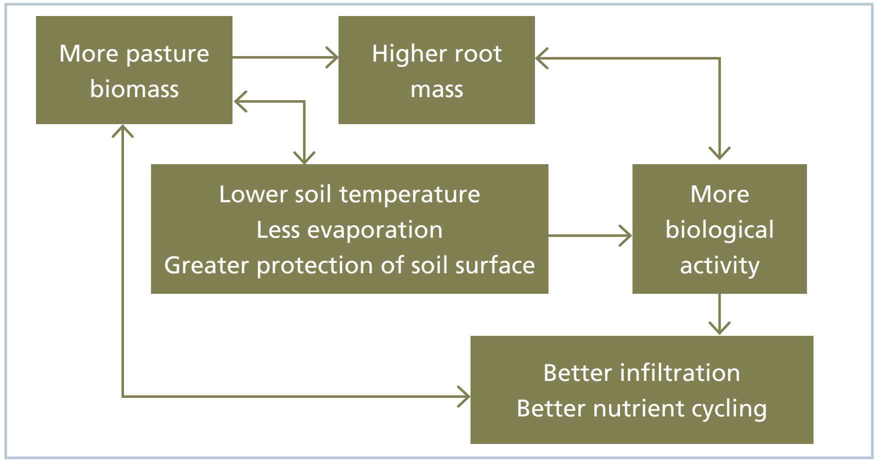
Healthy, actively growing pasture plants cover the soil and protect it from the erosive forces of wind and rain. In addition, the roots hold soil particles and make them less easy to erode. Any rain that falls is more likely to soak into the soil, rather than flow along the soil surface. This reduces the likelihood of erosion from surface runoff and increases soil moisture levels to prolong the plant growing season.

Deep-rooted perennial grasses are better able to survive dry periods, recover quickly after rain and reduce the likelihood of wind erosion in droughts. Land managers should aim for at least 70% pasture cover on flat country and close to 100% cover on slopes.

Stoloniferous or running grasses are more suited to sloping land and erosion-prone situations than tufted species. They are also better able to maintain groundcover in dry times.

Biomass flowchart - How better pastures help the soil.

Adapted from Keeping it in place – controlling sediment loss on grazing properties in the Burdekin River catchment, Meat & Livestock Australia, 2004



Encourage plant roots

The size of a plant's root system is proportionate to its size above ground. Pastures kept continuously cropped short have shallower root systems, and are less productive, more susceptible to drought and at risk of developing bare patches. Pastures that are allowed to periodically grow higher develop deeper and larger root systems. When plants are grazed the roots die back to balance the smaller above-ground size of the plant.

As this root material decomposes, it feeds soil organisms whose activities make more nutrients available to plants and so improve plant growth. The activities of soil organisms improve soil structure, encourage water to enter the soil, and make soil less erodible. The more diverse the pasture species, the more diverse the habitat they provide for soil organisms.

Match stock numbers to pasture availability

Pasture condition determines how many stock it can feed. Land managers wanting 100% groundcover 100% of the time will usually carry less stock per hectare than someone aiming for 70% groundcover. There is usually higher production per head when stocking rates are low, as the animals have more feed, but there is higher production per hectare with higher stocking rates. At excessive stocking rates, production is at the expense of soil resources so soils will degrade over time. Whatever the groundcover goal, the actual number of animals that a pasture can sustain varies from season to season.

Rest pastures from grazing

Continuous or set stocking of pastures is not generally recommended because of the potential for overgrazing and erosion. Research has found that resting pastures from grazing has enormous benefits for both pasture and soil. It allows pastures to develop diversity, and encourages plant growth, reducing the likelihood of erosion. Resting allows soils to recover from compaction so that soil structure and water infiltration improve and runoff is minimised. Resting periods can vary from weeks to months, depending on stock numbers and the growing season.

Minimise compaction

Some degree of soil compaction from the impact of hooves is inevitable with livestock production. Compaction compresses air spaces in the soil, making it difficult for water or plant roots to move in the soil, so pasture growth slows, leading to reduced groundcover and increased erosion.

Compaction severity varies with soil type, being worst on wet soil with a high clay content. If possible move stock onto lighter soils when heavy rain is likely. After rain, avoid grazing clay soils when they are wet, especially when stock numbers are high. Where possible, avoid mustering when soil is wet.

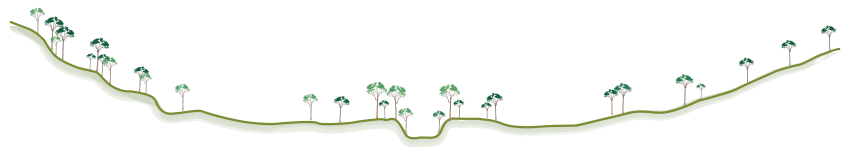
Compacted soils can be slowly restored with appropriate grazing management of deep-rooted perennial grass pastures that contain persistent productive legumes. Where there is a compacted layer within the subsoil, deep ripping along the contour can break up compacted layers and improve infiltration. Deep cracking clay soils that swell and shrink have the greatest ability to recover from soil compaction by livestock. However, these soils do require very careful management with rest periods and moderate grazing pressures to ensure minimal long term impact.

Fence paddocks according to erodibility

Fencing paddocks according to their susceptibility to erosion makes it easier to prevent erosion. Traditional 'square' paddocks that contain more than one soil type or slope make erosion management difficult. Try to fence land so that each paddock has similar characteristics, for example all flat, all slope, all sandy soil, or all heavy clay.

Where paddocks have varied conditions, manage them to minimise erosion in the most vulnerable areas. It may be worth constructing temporary electric fencing around these areas. Grazing management becomes difficult in paddocks larger than 40–50 ha, so subdivision into smaller paddocks should be considered even if soil and slopes are consistent. Some areas of a property may not produce good pasture cover at any time. These areas are best fenced off and used for timber production or nature conservation.

Fence paddocks according to the landscape.
Adapted from Keeping it in place – controlling sediment loss on grazing properties in the Burdekin River catchment, Meat & Livestock Australia, 2004



Have several shaded areas

On hot days, stock prefer shade to sun and will gather under any tree available. These camps lead to trampled groundcover and denuded soil, making the soil very prone to erosion. By planting several shade areas, the impact of the cattle camps is spread over a wider area, and there is less chance of severe erosion.

Prevent stock tracks forming

Stock often form tracks in paddocks and these need to be monitored because once a track is worn lower than the pasture, it can concentrate runoff and scour out quickly. The sooner stock are stopped from using an eroding track, the smaller the problem that needs to be fixed.

Management options include placing obstacles across the track, fencing it off, or moving watering points.

This cattle track has become a gully.

Reduce the impact of dairy cattle movements

The regular movements of dairy herds tend to trample groundcover, making the soil more prone to erosion, particularly around the dairy. Below are some ideas for reducing the erosion potential on dairy farms.

- Make laneways as narrow as practicable, as this reduces the amount of ground subject to the pressures of cattle movement.
- Avoid sharp corners in laneways or fence lines used to guide stock movement, as stock will tend to mill around at the corner and this increases the wear and disturbance to the ground. Consider fencing off and planting out sharp corners.
- Install gateways in well-drained areas, and don't allow water to pond in or flow through a gateway.
- Use concrete pathways near dairy buildings.
- Install feeding pads for wet periods so cattle don't pug up the wet soil on the farm. Pugged soil becomes very prone to erosion once it dries out.

Fencing narrower laneways can reduce erosion.

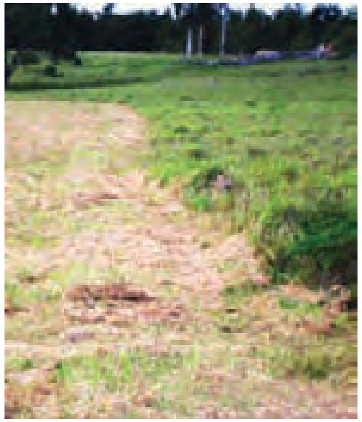
Manage weeds carefully

When controlling weeds, try not to leave soil bare. Have pasture seed on hand to sow in the bare areas as soon as possible (observing replanting recommendations when using herbicides), otherwise these areas are vulnerable to erosion and recolonisation by weeds. When using earthmoving or cultivation equipment, exclude stock from the disturbed area until pasture cover is re-established.

Slash rather than burn

To promote a green pick, slash and mulch pasture rather than burn it, because the cut vegetation contributes to protective groundcover and adds organic matter to the soil as it breaks down. Regular burning depletes groundcover, organic matter and plant nutrients and leads to long term soil degradation.

Burning off leaves the ground bare and vulnerable to erosion.
Source: Michel Dignand NSW DPI



Slashing leaves groundcover in place and adds organic matter to soil. Source: Joshua Quinn

Minimise cultivation when improving pastures

There is a high risk of erosion when soil is cultivated for new pastures. Direct drilling into existing pasture carries much less risk of erosion and, in many situations, over-sowing existing pastures with legumes and topdressing with fertiliser is the lowest risk and most cost-effective pasture improvement method. Earthworks that disturb soil or remove groundcover need to be carried out in drier months when there is low risk of intense rainfall events. Only cultivate when the soil moisture is right to avoid damaging the soil structure, and work across, not up and down slopes. Erosion rates increase dramatically on slopes above 10%.

For more information on when soil is at the right moisture content for cultivation go to: http://www.dpi.nsw.gov.au/agriculture/resources/soils/structure/compaction

The Native Vegetation Act 2003 restricts some pasture improvement practices where existing pasture contains native species.

Note: Pasture improvement may be associated with an increase in certain livestock health disorders. Livestock and production losses from some disorders are possible. Management may need to be modified to minimise this risk. Consult your veterinarian or adviser when planning pasture improvement.

A coulter, tine and press wheel mechanism for direct drilling seed minimises soil disturbance.

Source: Natalie Moore NSW DPI

Destock in drought

Once groundcover is below 70% on flat country or 85–90% on slopes, there is an increased risk of severe erosion. When this point is reached landholders need to decide whether to sell or agist stock, or hand feed them in one paddock where pasture is 'sacrificed' to save the other paddocks. Confining animals to a 'sacrifice' area allows destocked areas to recover quickly when rain returns, and minimises the cost of re-establishing pastures. Letting animals wander in search of scarce feed wastes their energy, increases erosion and threatens the survival of remaining pasture.

Further information on drought grazing management is available from http://www.dpi.nsw.gov.au/agriculture/emergency/drought/managing

Orchards and plantations

This section is relevant to horticultural enterprises such as macadamias, low chill stone fruit, avocados, custard apples, coffee, blueberries and bananas. It focuses on orchard management techniques that can reduce erosion.

Other areas of this book that may be useful to orchardists include:

» **Managing water flow (page 43)**
» **Dams that minimise erosion (page 65)**
» **Stable roads and tracks (page 89)**
» **Erodibility of northern rivers soil types (page 152)**

Develop orchard drainage plans

The most efficient and cost-effective way to reduce erosion risk in orchards and plantations is to determine where water naturally flows, ascertain slope lengths and grades, and design an appropriate drainage management plan before any trees are planted. 'Retrofitting' drainage plans in established orchards is more difficult and expensive and may entail removal of trees.

An orchard drainage plan should include:

- drainage and discharge of excess runoff
- problem areas such as waterlogged spots and steep areas
- location of planting areas
- tree row orientation (planned and existing)
- windbreak location
- design and location of access tracks
- location of existing infrastructure.

The space left for the natural drainage line in this newly planted orchard may not be enough to maintain a grassed waterway when the trees mature.

A contour plan at 1 m intervals is very useful when developing drainage plans and could well pay for itself in avoiding the need for future remediation works. Many local councils now have accurate topographic maps, with 1 m contour intervals, that can be purchased at a reasonable price.

The orchard drainage plan will identify where erosion control measures may be needed and where planting should be avoided or trees removed. Trees should not be planted in or near drainage lines, even ephemeral ones, or gullies. The minimum recommended planting distance from drainage lines is generally 15–20 m to allow adequate grass cover when the trees are established and to allow a small buffer to filter runoff before it enters the concentrated flow.

Breaking the site into a series of smaller subcatchments using an integrated system of well-planned drains, banks, waterways and roads can reduce both the volume of water and the length of the slope over which it flows, and will reduce the erosive potential of runoff waters. Excess water can be directed to safe discharge areas such as watercourses retained for this purpose, or broad, flat, well-vegetated basins.

Divert water

A diversion bank directs water between blocks of macadamia trees.
Source: Ian Clapham

Banks, waterways and roads can all be used to divert water from erosion risk areas to safe areas, but poorly-designed structures and poorly-executed works can increase the risk of erosion. All diversion works require establishment of adequate groundcover (living or non-living). Under existing legislation, redirection of water from one catchment to another is not permitted. Under common law the construction of drainage features to dispose of excess water into a neighbour's property is not permitted without their consent. So when directing water off your property you may need to work with neighbouring landholders. Specialist consultants with qualifications and experience in erosion management can assist with the design of diversion works. Possibly the easiest diversion technique is to install a bank and/or a channel to direct runoff water from further up the slope to a 'safe' disposal area. This could be a flat well-grassed basin with 100% groundcover and/or a farm dam, or it may be possible to direct water into an existing natural waterway.

Another useful diversion technique is to break up long slopes with banks or drains. Long slopes allow water to build up speed and become erosive. Cross slope drains divert water collected in the interrow drain before it reaches the end of the row. The spacing of cross slope drains will be determined by characteristics such as slope grade, soil type and groundcover present. On slopes between 5–10%, low profile banks are needed to cope with a 1 in 10 year rainfall event. On steeper slopes, banks need to be higher or closer together.

Use the worksheet to estimate slope (see page 175)

A cross bank breaks up long rows of blueberries running downslope.

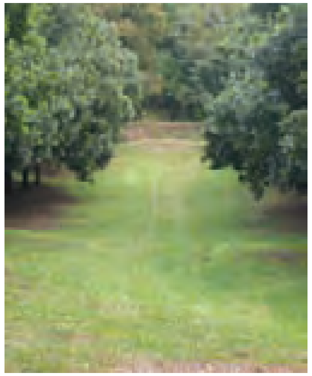
Shallow dish drains are preferable to V-shaped drains because they spread the water flow, and are easier to grass and maintain. V-shaped drains channel water along a narrow path, increasing erosion risk, and are more difficult to maintain.

A low, broad dish shape is the best drain profile.

Roads can be incorporated with diversion works, but need well-designed drains and stable, vegetated discharge areas. Waterways and roads need to be able to cope with a 1 in 20 year rainfall event. Roads should be on ridges and higher slopes. Minor access tracks can be located at the upslope end of tree rows, or can incorporate grassed waterways.

Repair small scale eroded flowlines

Many orchards or plantations have small scale gullies and washouts. Profiling of the interrow may be necessary to achieve the correct shape to prevent further washouts, or these can be rehabilitated to some extent by placing check structures (see page 57) across the path of the flowing water.



A grassed waterway

In areas that experience significant concentrated water flows, even periodically, specialist structures/works may be required. Appropriate professional advice should always be sought for the design and construction of such works.

Trap sediment

Sediment traps prevent eroded soil from leaving the property and/or entering a permanent watercourse. Once a trap reaches 60% capacity, the sediment has to be removed and stabilised at an appropriate site. Sediment traps need to be designed by a professional to ensure they are sized and positioned correctly. Dams can be used to collect sediment (see page 62).

A sediment pond at the farm's lowest point allows this plantation to discharge cleaner water.

Reduce the erosion risk of drainage works

Newly formed surfaces, banks and drains are vulnerable to severe erosion if they are hit by heavy rainfall before groundcover is established. There are several techniques to reduce erosion risk at these times.

Carry out earthworks when there is less risk of intense erosive rainfall, but enough warmth and moisture to allow rapid groundcover establishment once works are complete, ie, around September. Retain all topsoil for respreading on the surface of all excavated drains, as it will encourage groundcover growth.

Leave grass in existing watercourses, but if these are being reshaped, plant a quick-growing groundcover immediately after reshaping. Seed and fertilise immediately to provide rapid groundcover. Where works cannot immediately sustain a permanent level of more than 70% groundcover, then sow quick germinating annuals, such as oats, ryegrass or Japanese millet. Slower growing perennial groundcovers can be sown into this rapid cover. Alternatively, turf can be laid or erosion matting used to protect soil where it may have to carry fast flows immediately following works before vegetation can establish from seed.

Use groundcovers

The best orchard groundcovers are stoloniferous (with runners) such as kikuyu (*Pennisetum clandestinum*) as they provide better cover than clumping grasses such as paspalum (*Paspalum dilatatum*) and ryegrass (*Lolium perenne*). It is also important to choose species that will survive machinery traffic used for spraying and harvesting. Establishing groundcovers is relatively easy in open orchards but more difficult in dense plantings where there is little light. Shade-tolerant species are available but these will not grow in dense shade.

Macadamias pose a difficult case for erosion control. The crop needs to be picked up from the orchard floor, so harvesting has favoured bare ground. This practice, coupled with the region's rainfall pattern, steep slopes and soil types, has combined to produce a high erosion risk for the industry. However, many successful growers have found that a bare orchard floor is not a prerequisite for reliable harvesting operations.

This orchard has good groundcover. Source: Rex Harris

Groundcovers such as smothergrass (*Dactyloctenium australe*) protect the soil from pre-harvest blowing and sweeping, and surface water flow.

In banana plantations, contour strips of groundcover help reduce erosion. The interval between removing old plants and replanting new ones is a high risk erosion period so groundcover needs to be planted among the old banana plants before their destruction and then sprayed off before new plants are put in the ground. Choice of groundcover needs to consider its weed or fire hazard potential.

Use mulch and compost where appropriate

Mulch and compost can protect the soil to some degree, but do not provide the binding action of a living groundcover. They benefit areas where low light levels prevent any living groundcover establishing. Both mulch and compost need to be applied thickly (50–100 mm) to eliminate raindrop impact and prevent concentrated flow, and need to be replaced, particularly after intense rainfall events when they are washed away.

Compost can be washed away by concentrated stem flow.

In heavily shaded macadamia plantations where nothing will grow, a 5 cm mulch cover may be needed to protect bare soil. Mulch can also be used where groundcover is discouraged because of its perceived competition with trees.

Banana trash is good mulch.

In banana plantations, trash from the plants themselves provides good mulch. Heaping the trash on the contour in every alternate row is also beneficial. Mulching materials for avocado tree mounds include straw, interrow slashings or chipped wood from prunings. Slightly 'hayed off' and coarsely cut crops such as oats, sorghum, setaria mixed with legumes such as lablab, soybean or lupins provide an open mulch that decomposes gradually. Finely cut materials such as sawdust and bagasse are undesirable because they tend to pack down and induce root rot.

Prune trees for more light

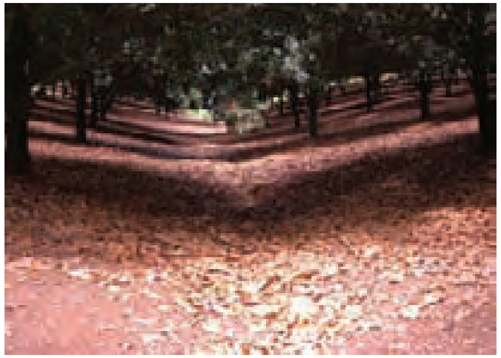
In older orchards where row spacings and cultivar selection cannot be altered, pruning and removal of branches will provide light to allow groundcovers to grow on the orchard floor. Pruning techniques depend on the fruit or nut crops being grown.

Further information on pruning is available from your local NSW DPI horticulturalist or http://www.dpi.nsw.gov.au/agriculture/horticulture

Hedging of macadamia trees

Remove trees where necessary

Tree removal may well be the only option where trees are planted too closely or are growing in ephemeral waterways. In most cases, trees that need to be removed are not healthy or productive because there is too much competition or soil around the tree roots has washed away due to concentrated water flow. Removing these trees disturbs soil in high risk erosion areas so quick-growing groundcovers need to be sown immediately after tree removal or the area needs to be covered with an appropriate erosion matting. If necessary, the area can be oversown later with more permanent grass cover species.



Removing trees may be the only way to get enough light to grass this watercourse.

Grassed waterways reinstated by the removal of trees can be used as drains and disposal areas for excess runoff water from other parts of the orchard.

Cropping

Sugar cane fields. Source: John Gasparotto NSW DPI

The region supports broadacre and intensive cropping. Broadacre cropping enterprises include sugar cane, soybeans and cereals, mostly grown on coastal and river floodplains where there is low risk of soil erosion. Intensive cropping enterprises include sweet potatoes, potatoes and beans grown mainly on the fertile volcanic soils of the Comboyne, Cudgen, Dorrigo, Alstonville and Acacia plateaus. Landholders cropping in these areas have to contend with more intensive rainfall and steeper slopes.

Other areas of this book that may be useful to croppers include:

» **Managing water flow (page 43)**
» **Dams that minimise erosion (page 65)**
» **Stable roads and tracks (page 89)**
» **Erodibility of northern rivers soil types (page 152)**

Since the early 1990s, there has been a marked swing to cropping techniques that conserve soil and water and reduce runoff and erosion. Conservation farming techniques minimise cultivation by planting crops and pastures directly into soil protected by a mulch of stubble or dead vegetation. The direct drill planter is very popular with growers because it places seed and fertiliser precisely with minimum soil disturbance.

Plan to prevent erosion

The main considerations when controlling erosion in cropping paddocks are slope, management of water flow within individual paddocks and farm/paddock management practices. Croppers need to know where the water flows, the location of steep slopes and permanent and intermittent watercourses, and the slope and erosion risk of both individual paddocks and the farm. With this information they can determine row direction and length and design and locate headlands and access tracks to minimise erosion.

Maintain groundcover

Retain crop stubble

Retained stubble protects bare soil from erosion after harvest by absorbing raindrop impact, increasing infiltration and slowing the speed at which water runs over the land, thereby reducing soil movement. Fitting a trash chopper or straw spreader to the header at harvesting helps to produce a more evenly spread blanket of crop residue on the soil surface. Alternatively, graze the crop.

Retained stubble protects the soil.

Double crop

Double cropping involves growing a summer and a winter crop each cropping year.

Sowing a winter crop such as oats into the stubble of a summer crop such as soybean ensures there is enough groundcover to protect the soil from erosion all year. The north coast's mild climate and relatively high rainfall makes double cropping an option in most years.

Seed by air

Land managers in the region commonly use planes to sow oats or ryegrass into soybeans before harvest. The pasture germinates during harvest and uses the residual nitrogen in the soybean root nodules. This process ensures the soil is never bare.

Avoid bare fallow

Bare fallow is used to store soil moisture for the next crop, but leaves the soil vulnerable to erosion in high intensity rainfall events.

Cultivate carefully

Use low till techniques

There are now several cultivation techniques that maintain groundcover: reduced tillage, direct drill, no till and zero till. These techniques retain stubble, maintain groundcover, control weeds with herbicides and rotations, and sow seed into stubble with equipment designed to handle the harder soil conditions. As organic matter builds up and soil health improves the soils become easier to handle.

On virgin ground, it may be necessary to cultivate once or twice to create an even ground surface. Otherwise direct drill sowing is preferred. A pioneer crop can be direct drilled into sprayed-off pasture.

Choose appropriate machinery

Tined and non-inverting implements are preferable to discs and mouldboard ploughs. Tined implements open the soil up without pulverising it. Coulter and tine combinations have proven to be the most successful implements for direct drilling into pastures and stubble in the region.

This John Deere precision planter uses a coulter and tine mechanism.
Source: Natalie Moore NSW DPI

Cultivate at correct moisture content

If cultivation cannot be avoided, work the soil at the correct moisture content. Cultivating soil when it is too wet or too dry damages soil structure and compacts the soil. Heavy clay soils are best cultivated when the soil is dry. If a handful of clay topsoil from mid-cultivation depth can be rolled between the hands into a rod that is less than 3 mm in diameter without crumbling, then the soil is too wet to plough. Light sandy, silty, or loam soils should be cultivated only when a handful can be squeezed into a coherent ball, but does not feel wet.

Avoid cultivating through natural drainage lines

Cultivating natural drainage lines makes these areas prone to soil erosion and the development of gullies. Natural drainage lines in a cultivation paddock are best kept grassed for safe disposal of stormwater runoff.

Avoid cultivating steep slopes

Cropping is best restricted to the flattest available sites, as the risk of soil erosion increases dramatically when slopes exceed 10% (6°). Slopes greater than 20% (9°) should never be cultivated.

Avoid cultivating for weed control

Control weeds with herbicides or crimp rolling rather than cultivation. The use of herbicides is usually cheaper than cultivation, and soil structure is not damaged. A crimp roller can be towed behind a tractor to flatten and kill weeds or a standing crop. The roller is a drum generally 0.6–1 m in diameter with water or oil for additional ballast, with a series of 10–12 blades or blunt knives running around the drum approximately 15–16 cm apart and 6-8 cm tall. The roller flattens vegetation and crimps it every few centimetres, breaking the stems and killing the aboveground plant structures. Crimp rolling produces a mulched layer of several centimetres thick on the soil surface, suppressing weed germination, improving water infiltration into the soil and reducing evaporation.

Rolling a crop leaves a thick mulch cover.
Source: Eric Koetz NSW DPI

A crimp roller can reduce the need to cultivate for weed control.
Source: Eric Koetz NSW DPI

Manage water flow

Maintain natural watercourses

A permanent grassed waterway at Woodford Island. Source: Natalie Moore NSW DPI

Permanent and semi-permanent flowlines should be maintained and not disturbed. Natural drainage depressions need to be kept as permanent grassed waterways for safe disposal areas for runoff from elsewhere. Any activity within the bed and banks or within 40 m of the top of the bank of any stream or waterbody requires approval under the Water Management Act 2000.

Crop in strips

Strips of crops planted on the contour break up sloping land and prevent surface water flow building up speed and eroding soil.

Cropping in rows across the slope. Source: Summit Organics

Keep paddock access in good condition

Paddock access for heavy machinery is important in cropping enterprises, so farm roads and tracks (see page 89) need to be well constructed and maintained so they can be used in all conditions.

A graded bank breaks up the slope, reducing erosion from the lower part of the field.

Use banks to slow water flow

Contour and graded banks (see page 47) are used on sloping land to intercept surface water and divert it away from the paddock to safe stable disposal areas. Waterways behind the banks are broad and shallow to ensure that they do not erode. The banks and waterways need to be designed so that farm machinery can cross without damaging machinery or the earthworks.

Build organic matter in soils

Cultivation breaks down valuable organic matter in the soil and makes it more prone to erosion, so it's particularly important to build up organic matter in cropping soils using some or all of the following techniques.

A pasture phase follows soybeans at Tabulam. Source: Natalie Moore NSW DPI

Include a pasture phase in the cropping cycle

Pasture phases are the most effective way of increasing organic matter levels in cropping soils. On the region's fragile hill soils the recommended phase is a minimum five years of pasture and a maximum three years of double cropping. On the better soils, the cropping phase can be longer.

Retain stubble

A significant portion of stubble left on the surface after harvesting becomes incorporated in the soil and increases the organic matter content. Stubble also protects the soil surface from wind and water erosion.

Grow green manure crops

Green manure crops are usually grown specifically to be slashed and incorporated into the soil. However, while they provide organic matter, they also require cultivation, so in the region they are only really suitable for flatter alluvial soils where erosion is unlikely.

Use organic fertilisers

Organic fertilisers such as animal and poultry manures provide nutrients and organic matter, but transport and spreading costs can make their use prohibitive.

Rotate crops

Crop rotations help vary the types of organic matter (roots and plant material) in the soil. The NSW cane industry is increasingly using soybeans and triticale as rotation crops to break disease cycles. In the past cane growers cultivated during the wet season, but now use crop rotations, permanent raised beds and precision agriculture techniques to reduce compaction and increase productivity.

Re-establish groundcovers after harvest

When vegetable crops are harvested in summer there is a high risk of erosion from summer storms. This risk is reduced by quickly re-establishing groundcover, improving infiltration and ensuring all erosion control works are in good condition.

Post harvest techniques on the Dorrigo Plateau

Post harvest considerations

» All land must be stabilised within 7 days of post harvest cultivation by:
  » seeding with appropriate pasture/crop and agronomic practices to encourage strike
  » immediate deep ripping on contour at maximum spacing of 2 m and mininimum depth 30 cm

and with
  » maintenance of existing or installation of new in-paddock sediment control filters/barriers.

» All works maintained and inspected and repaired following rainfall, and sediment removed when it reaches above 50% of the measure's capacity.
» Temporary measures not removed until 70% groundcover established.

Source: Cultivation management on the Dorrigo Plateau: Code of practice and guidelines, 2005, J Clerke and P Parbury

2 Managing water flow

From the moment rainfall hits the land it has the potential to cause soil erosion. Raindrops hit the soil surface with some force, and the impact can dislodge soil particles. Once dislodged, the particles move with the water. Understanding how movement of water causes erosion is essential to managing water for the greatest benefit to soil and plants. This chapter outlines management strategies to reduce the erosion potential of overland and concentrated water flows.

Overland flow

Water moving as overland flow through a paddock.

Overland flow is visible as a thin layer of water flowing over the soil surface. It occurs when rain falls faster than the soil's capacity to absorb it. If the soil is bare the water picks up and carries soil particles from the top of the soil, creating a thin layer of erosion known as sheet erosion. Overland flows and sheet erosion can be reduced by increasing the soil's capacity to absorb water, and slowing water flow.

Increase soil moisture capacity

The most effective way to improve soil moisture capacity is to increase groundcover. Vegetation intercepts and slows water so that it has time to soak into the soil and infiltrate through the soil profile where it becomes available to plant roots. Higher and denser vegetation encourages more infiltration. Vegetation also improves soil health and structure, further improving soil moisture capacity.

Other ways to improve infiltration include reducing soil compaction, and ripping along slope contours to encourage infiltration and prevent build-up of surface water. However, on land prone to mass movement where soil is already waterlogged, attempting to increase infiltration could increase the potential for land slips.

Contour ripping promotes infiltration. Source: Peter Solness NSW DPI

Slow down water flow

As overland flows speed up they become more erosive, so it is important to slow down overland flows to minimise erosion. Flow speed is determined by:

- surface roughness
- slope steepness
- slope length.

A rough surface intercepts flowing water, breaks up its force and slows it down. Roughness is best achieved with dense vegetation close to the ground. Slope steepness has a major effect on soil erosion because water runs faster down steep slopes. It is difficult to change the natural slope so it is important it is to use other techniques such as groundcover and banks to slow water speed. On long slopes, water flow builds up speed and volume, so slopes need to be broken up into shorter sections to keep water flows manageable. This can be done by planting vegetated strips across the slope to slow the flow, or building banks to intercept the water and convey it to a water course or storage area.

Install interception structures

There are a range of options for intercepting and conveying water. The choice depends on the purpose, site and enterprise. Expert advice on layout, design and spacing of interception structures may be needed, but all property drainage plans need to follow these basic principles.

- Use stable, naturally occurring flowlines where possible.
- Use constructed waterways where natural flowlines are unstable or do not exist.
- Avoid using flowlines or areas with active gully headcuts.
- Keep flows within their natural catchment. Don't divert water from one catchment to another, even if both catchments areas are within the property.
- Obtain a written agreement from all affected neighbours before altering the point at which water leaves the property.

Types of interception structures

Vegetation strips

Vegetation strips are bands of permanent, dense, low vegetation, usually grasses, planted across slopes to intercept runoff before it develops into a concentrated flow and trap sediment before it has a chance to move into watercourses. The strips are most useful where the land use precludes permanent groundcover.

Subsurface drains

These are trenches filled with gravel and a perforated pipe, often called 'ag drains'. While they are expensive to construct, they are useful for intercepting groundwater seepage and for making land trafficable.


This subsurface drain manages low flows to allow vehicle traffic through.

They are usually designed to carry a proportion of water flow within the gravel media and pipe, and to carry additional surface flow during heavy rain events.

Constructed banks

Banks are the most common structures used to direct water flows on farms. They break up slopes into shorter lengths to reduce depth and speed of runoff flow, and convey water to a stable watercourse, water storage or water absorption area.

They reduce peak runoff flows from catchments by slowing the speed of the water and forcing it to travel longer distances to move through the property.

The shape and type of the bank depend on the situation and land use and the need for trafficability by different types of machinery, but there are some basic principles.

- Choose the correct type of bank for the job it has to do.
- Make the channel created by the bank large enough to carry runoff from heavy rain.
- Design the bank outlet so that it discharges water without causing more erosion.

Contour banks

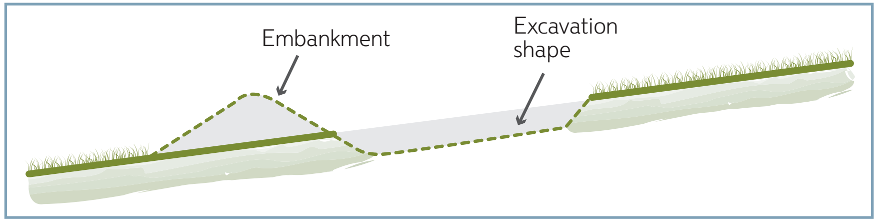
Contour banks run across the slope along the contour to intercept water and pond it behind the bank to increase infiltration and trap sediment. The banks are not generally used in cropping enterprises as the ponded water makes farming difficult. Care must be taken to ensure water overflowing the bank can be redirected without causing more erosion. Contour banks should not be constructed in dispersible soils because of the risk of failure through tunnel erosion.

Graded banks

Graded banks run across the slope on a slight grade so that water can drain to a more stable area or watercourse. The grade is designed so that water flows quickly enough to carry sediment with it, but not so quickly that it causes erosion in the channel. The grade is up to 0.3% for bare earth channels, and can be steeper if the channel is well vegetated.

A graded bank breaks up a long slope of blueberry rows.

How soil is moved in constructing a graded bank. The dashed line shows the shape of the finished graded bank and channel.
Adapted from Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Graded banks are constructed by ripping along the intended channel and pushing the loosened soil into a bank downslope of the channel excavation. On long slopes there are often several graded banks that divide the slope into smaller catchment areas so that the runoff can be safely intercepted and drained. The further apart the banks, the larger the catchment for each bank, so larger banks with greater channel capacity are required. Smaller banks spaced more closely require less channel capacity.

Diversion banks

Diversion banks are graded banks built to intercept and convey concentrated runoff water. They are usually higher and wider and need to be grassed to carry the high speed flows safely.

A diversion bank stops water from the upslope orchard from causing erosion in the block below. Source: Ian Clapham

Back-push diversion banks

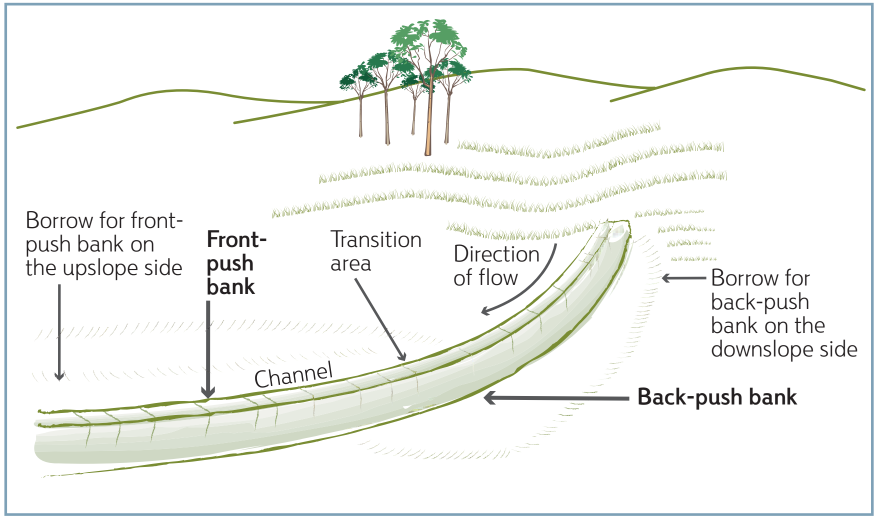
Back-push diversion banks intercept water from natural drainage lines on low sloping land. Soil is pushed up from the downslope to form a bank across the natural flowline.

The water then flows along undisturbed ground and is guided by the bank into natural drainage depressions. This type of bank is not suitable on steeper slopes as the force of the flowing water tends to undercut the bank.

Back-push trainer banks

Back-push trainer banks intercept concentrated flows of water on steeper slopes. The bank initially runs along the natural flowline and gradually cuts across the flowline to guide the water into a flatter diversion bank.

A back-push trainer bank catches and directs runoff from a natural drainage line into a channel formed by a graded bank.
Adapted from Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Bank design

Bank shape

The shape of the earth bank depends on the situation and land use. Generally, the flatter the slope the broader the bank. Broad banks are more stable and require the least maintenance. They take the most space, but can be cultivated and driven over.

A semi-broad bank can be driven over by some vehicles (usually 4WD), and some or all of the bank can be farmed.

A peaked bank takes up the least space but should not be driven over or disturbed. Peaked banks are less stable and more prone to failure, so should only be used where the slope is too great for a broader bank.

Type of bank shape recommended for different slopes.
Adapted from Earthmovers Training Course, Soil Conservation Service of NSW, 1992

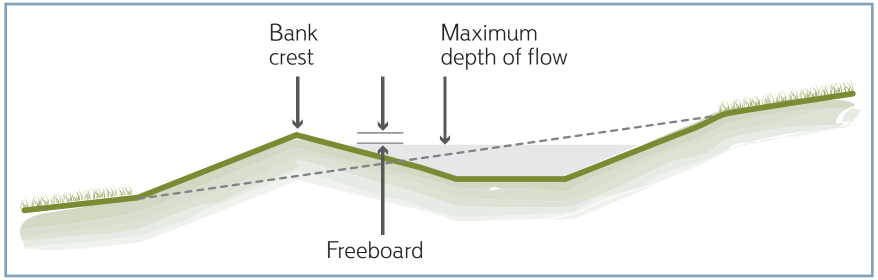
Bank shape	Land slope	Slope of bank batter to channel	Example
Broad	0–3%	1 : 6 or flatter	
Semi-broad	3–8%	1 : 4	
Peaked	8–20%	1 : 1.5	

Channel capacity

The channel capacity must be greater than the peak discharge from the bank outlet, with a minimum freeboard on the bank of 0.2 m or 50% of the depth of flowing water in the channel – whichever is greater. Freeboard is the space between the top of the bank and the water level.

Profile of a bank with enough freeboard to reduce risk of overtopping the bank.

Adapted from Earthmovers Training Course, Soil Conservation Service of NSW, 1992



The catchment area and peak discharge for the outlet of a bank can be estimated using the worksheets at the end of this handbook. See page 168, 172.

Channel shape

Least erodible channel profiles are either a broad curve (parabolic) or a flat bottom with tapered sides (trapezoidal). Steep V-shaped profiles have a high erosion risk. The sides of the channel should not be steeper than a 1:3 slope.

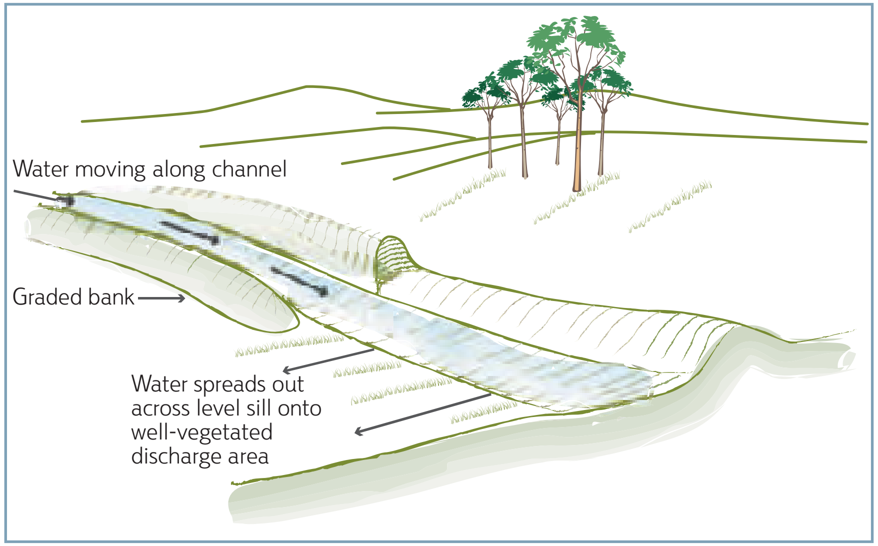
A broad curve is the most stable shape for a channel. Source: Grant Witheridge

Water discharge

The bank needs to discharge to a stable watercourse or well-vegetated disposal area via a level sill. Level sills spread the water out to slow the water before it runs onto the disposal area.

A graded bank ending at a spreading sill.

Adapted from Earthmovers Training Course, Soil Conservation Service of NSW, 1992



The length of sill will vary according to volume of water to be discharged, grade of the disposal slope and vegetation cover. In most circumstances a flow rate of 1.5 m³/s onto a well-vegetated disposal area will not cause erosion. Sometimes it may be necessary to construct trainer banks to ensure the discharge water does not run into unstable areas.

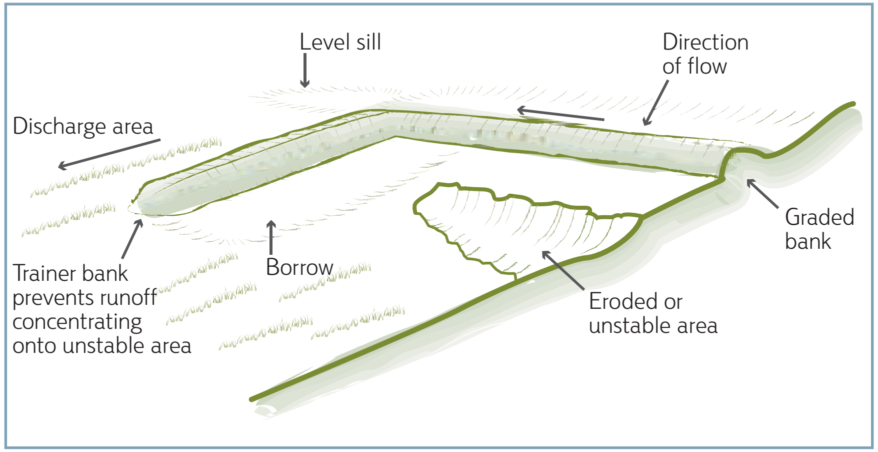
Length of sill required (in metres) to achieve various flow rates onto the disposal area.

Adapted from Earthmovers Training Course, Soil Conservation Service of NSW, 1992

		Slope of the disposal area (%)					
		1	2	5	10	15	20
Peak discharge (m^3/s)	**0.25**	0.5	0.7	1.1	1.7	1.9	2.1
	0.5	1.0	1.3	2.3	3.4	3.7	4.2
	1.0	1.9	2.6	4.5	6.7	7.4	
	2.0	3.8	5.2	9.0	13.4		
	5.0	9.5	13.0	22.5			

A trainer bank ensures that water discharged from the graded bank does not cause further erosion to an unstable area.

Source: Earthmovers training course - Contour and graded banks, p14



Troubleshooting banks

Below are remedies for common problems that landholders experience with interception banks.

Water overtopping the bank

- Check the bank for low points and build up where necessary.
- Check channel for high points and remove them.
- Check for obstacles or sediment build-up in the channel and remove.

Insufficient channel capacity for water flow

- Check that channel capacity is adequate for the expected flow of water by estimating catchment area and peak discharge for the bank.
- Increase channel capacity or bank height if necessary.

Protect persistently scouring channels with rock.

Erosion of channel

- If the velocity of the water flow is too high, it will scour the channel. Slow down water flow by widening the channel, reducing the grade or placing check structures in the flowline.
- If there is inadequate groundcover, seed or nutrients may be insufficient. Check the soil for major nutrient deficiencies and pH, rectify soil problems and resow seed. Prune or remove overshadowing vegetation that inhibits grass growth.
- Protect persistently scouring areas with hard surfaces like rock or concrete.

Erosion of sill or discharge area

- Check that the sill is level and remove any dips causing concentrated flow.
- Repair any minor erosion of the sill.
- Ensure good vegetation cover on the sill and discharge area, revegetate as necessary, and fence to exclude stock if grazing or tracking is a problem.

Water should be discharged onto well-vegetated areas.

Source: Michael Frankcombe IECA

Concentrated flow

Concentrated flow occurs when overland flow forms a single flowline or a number of connected flowlines. Concentrated flows occur naturally or are constructed to direct flows into dams or other areas. Most erosion problems associated with constructed flowlines can be addressed using options outlined in the troubleshooting section above. Naturally occurring flowlines require greater intervention to reduce their erosivity.

The erosive power of concentrated water flows is a function of water volume and velocity. Agricultural land experiences greater volumes and velocity of storm runoff compared with unmodified landscapes, and this can lead to erosion in previously stable watercourses.

Manage overland flows

The first step in managing erosive water flows is to manage overland flows upslope of watercourses to reduce the volume of water that accumulates as concentrated flow.

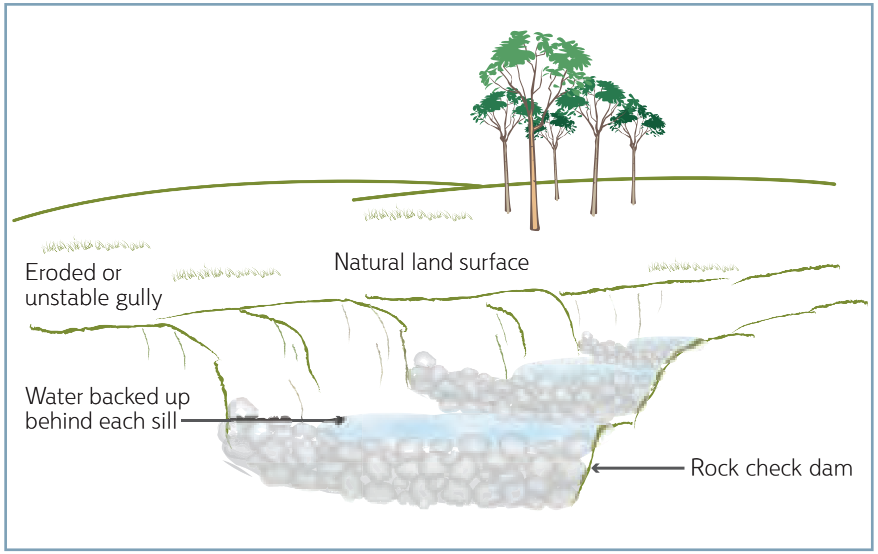
Install check structures and ponds

If overland flows are managed well, but concentrated flows are still causing erosion, it may be necessary to install check structures and ponds in the flowlines to reduce velocity and prevent soil losses and downstream sedimentation.

A check structure is an obstacle, usually permeable, placed in a watercourse to slow water velocity down and reduce scouring of the channel. In high flows, water will back up behind the structure, allowing a small degree of ponding and sedimentation. The structure spans the entire watercourse, so that the intended overflow point is the lowest point in the channel.

Check structures are not intended to hold or store water after high flow events, and should only be used in small watercourses.

In a rapidly eroding flow line, space the check structures so that ponded water backs up to the base of the upslope structure.



The number of check structures needed to reduce erosion depends on the grade of the watercourse and landholder needs. The lower the grade of the watercourse, the fewer check structures required, and more stable flowlines may need less frequent check dams. Ideally, the base of each structure is at the same level as the overflow of the next one downstream, so that in high flows ponds form between the structures. The ponds protect the downstream side of structures from scouring out. Where ponding is impractical, the downstream scour area can be armoured with rock or other hard material.

Most check structures are temporary, and constructed from degradable materials. Even when constructed with durable material such as rock, their lifespan is limited to the time it takes for the pond area to fill with sediment. The choice and location of structures and materials is determined by the design limitations of the material and site.

Types of check structures

Natural debris

Debris structures form when a branch or other material lodges in a channel, collecting other debris to create a small check dam. The usefulness of these dams depends on how the water overflows. If the debris narrows the channel, it can divert water to one side of the channel and cause scouring.

Vetiver grass

Vetiver grass is a thick, clumping grass with an unusually robust root system. Lines of the grass established across a watercourse can form long-lasting check structures.

Vetiver grass can form living check structures. Source: Michael Frankcombe IECA

Straw or hay bales

Bales need to be placed on their narrow side, dug 10 cm into the channel surface to prevent water flowing underneath them, and secured with two stakes per bale.

Hay bale check structures

Sandbags

Sandbags can be used to build low walls. Pegs on the downstream side may be required to support the wall if several layers of bags are used.

Check structure made from sandbags
Source: Michael Frankcombe IECA

Flexible log/sock

A flexible tube is pinned into place across the channel or slope. Various products are commercially available, made from coir, hay, compost etc. The tube follows the shape of the channel well, with a natural low point in the centre of the flowline. Stakes are needed on the downstream side to prevent it being washed away in high velocity flows.

Biodegradable log
Source: Michael Frankcombe IECA

Mesh

Wide metal mesh supported by stakes will trap debris and form a check dam. The mesh needs to be set into the sides and base of the channel. Where the mesh is >1 m high it will need support from guy wires anchored upstream to prevent collapse.

Rock

Loose rocks can be placed across the channel with a low point at the preferred overflow point. Generally these structures include geofabric (a synthetic textile that does not allow fine soil particles to pass through it) underneath the rock. It is important to select geofabric in accordance with manufacturer's guidelines.

A rock check dam
Source: Michael Frankcombe IECA

It is best to use a mixture of rock sizes, with a large proportion in the 75–150 mm diameter range (like the rock used in gabions). Large rocks on their own are less effective as they tend to create turbulent water flow and concentrated flow through irregular gaps, which may increase erosion downstream. Small rocks and gravel on their own are likely to be washed away in high flows.

A small rock check structure

Troubleshooting check structures

Several common problems reduce the effectiveness of check structures.

Sediment build-up behind the structure

- Determine the source of sediment and take measures to prevent it accumulating.
- Remove sediment regularly to maintain the water-holding capacity of the structure.
- Increase the water-holding capacity of structure.

Sediment needs to be removed to maintain the effectiveness of this structure. Source: Michael Frankcombe IECA

Tunnelling under the structure

- Check the material under the structure for stability and add ameliorant (see page 75) or geofabric as required.

Water bypassing / outflanking the structure

- Make sure that the intended overflow point from the check structure is the lowest point in the channel.
- Check that the sides of the structure are higher than the intended overflow point.

This rock check dam is failing because the rock does not extend far enough up the channel sides, and the lowest point is not in the centre.
Source: Michael Frankcombe IECA

Ponds

Ponds differ from check structures in that they are designed to hold water, are constructed from impermeable materials and usually have a constructed outlet to the side rather than over the top of the structure.

Ponding water slows the rate at which water moves through the watercourse, reduces its power to erode, and traps sediment. As the water stills, soil particles sink to the bottom (except in dispersible soils, where a chemical flocculant or coagulant needs to be added) and the cleaner water can be discharged or harvested.

Ponds are commonly small dams with earth walls, so care is needed to ensure that the outlet or spillway does not cause new erosion (see page 67).

Ponds can be designed to store water for short periods (detention ponds) or extended periods (retention ponds). Both types increase water infiltration of water and reduce the rate and volume of runoff. Detention ponds catch and store storm flows for days to weeks while the water drains slowly into the soil or is discharged by a pipe. These ponds are mostly empty or have substantial freeboard (height between a pipe inlet and emergency spillway) to catch and store runoff. They reduce peak flows by storing runoff and releasing it slowly.

Retention ponds store runoff permanently, but can have temporary storage incorporated in their design by increasing the height interval between a trickle pipe and the spillway. Retention ponds are limited in their capacity to reduce peak flows because once full they will not catch any additional runoff.

Sediment ponds should be long, rather than broad.

Ponds can trap more sediment if they are long rather than wide between the inlet and outlet. To achieve specific targets for sediment control in runoff water, seek technical advice on the design of the sediment pond. Bear in mind that reducing erosion upslope is much cheaper and more effective than trapping sediment.

Dams that minimise erosion 3

Farm dams are important water sources for stock, irrigation and domestic use on rural properties. Well-designed and constructed dams are farm assets and require little maintenance. Poor design and construction methods can lead to excessive construction costs, severe downstream erosion and a short-lived dam.

All farm dams must comply with NSW Government's Farm Dams Policy. Unlicensed dams may only be built off-stream, or on first or second order streams, and their water storage capacity must fall within the harvestable rights for the property. All other dams require a licence. Water contained in dams licensed for erosion control does not have to be included in a property's harvestable rights storage volume.

You can get more information about the regulations for farm dams from the NSW Department of Water and Energy at http://www.naturalresources.nsw.gov.au/water/dams.shtml

When estimating the size of the dam required, land managers need to consider the purpose of the dam and how much water the particular land use/enterprise will require and over what period. Information in this chapter applies only to small earth dams, and may not be appropriate for major structures or large catchments. Professional advice should be sought where the catchment area is greater than 5 ha, where the dam will store more than 4 m depth of water against the wall, where more than 5,000 m^3 of earth is used in the dam wall, or where material to be used for construction is unsuitable (see page 73).

Dam structure

All dams have three essential features.

- The **excavation** (borrow pit) provides a source of soil for the embankment and becomes the storage basin for the water.
- The **embankment** (dam wall) prevents excessive water seeping through or underneath. All farm dam embankments should have a core trench below the wall that extends into the ground the wall is built on. The embankment needs to be strong enough to hold the water resting against it. A wider embankment is stronger than a high narrow wall. The outside batter slope should be no more than 2.5:1.

A newly constructed gully dam, showing the excavation, embankment, spillway and a trickle pipe for low flows.

- The **spillway** allows excess water to pass through the dam without overtopping or causing damage to the embankment, and discharges excess water from the dam without causing erosion of the area onto which it flows. The spillway width depends on the rainfall intensity of the area, and the peak discharge likely from the catchment. The table below gives minimum spillway widths for locations around the region. A dam with a catchment area of 5 ha should have a spillway of at least 3 m for low rainfall intensity areas (eg Guyra) and up to 9 m for the highest rainfall intensity sites (eg Coffs Harbour, Murwillumbah).

The worksheets (page 165) at the end of this book can help you estimate the peak discharge for your dam.

Minimum spillway widths (in metres) required for dams with catchments up to 5 ha, based on a 1 in 20 year risk interval. These spillway widths assume that the spillway is well grassed, and discharges water onto a well-vegetated area.

Table developed from information provided by Graeme Goldrick, NSW Dept of Environment and Climate Change.

Location	2.5 ha catchment area	5.0 ha catchment area
Armidale	3.0 m	4.5 m
Casino	3.0 m	4.5 m
Coraki	3.0 m	4.5 m
Coffs Harbour	5.0 m	9.0 m
Comboyne	3.0 m	6.0 m
Coopers Shoot	5.0 m	9.0 m
Dorrigo	3.0 m	5.0 m
Drake	3.0 m	4.5 m
Guyra	3.0 m	3.0 m
Legume	3.0 m	3.0 m
Macksville	3.0 m	4.5 m
Maclean	3.0 m	6.0 m
Mallanganee	3.0 m	6.0 m
Murwillumbah	5.0 m	9.0 m
Nimbin	3.0 m	6.0 m
Nymboida	3.0 m	4.5 m
Tenterfield	3.0 m	4.5 m
Tyringham	3.0 m	3.0 m
Uralla	3.0 m	4.5 m
Walcha	3.0 m	3.0 m

Types of dams

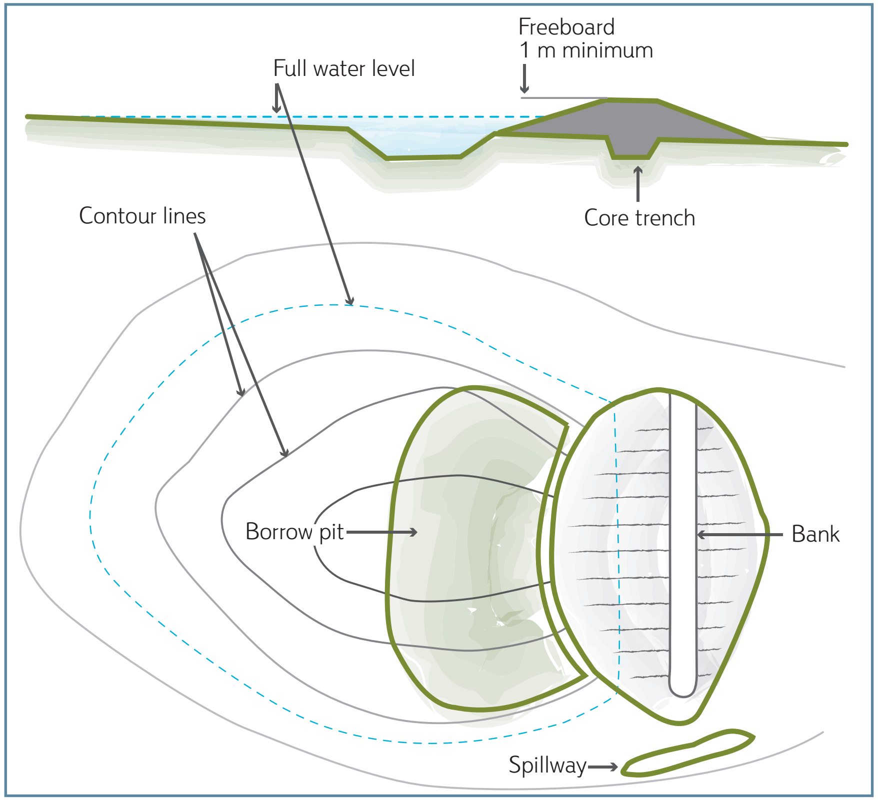
There are three types of dams commonly used on the north coast. The type of dam depends on site conditions.

Gully dam

A gully dam is an earth embankment built across a natural drainage line. These are generally the cheapest dams to build to store a large volume of water. The natural catchment above the dam channels runoff to the dam site.

Gully dam

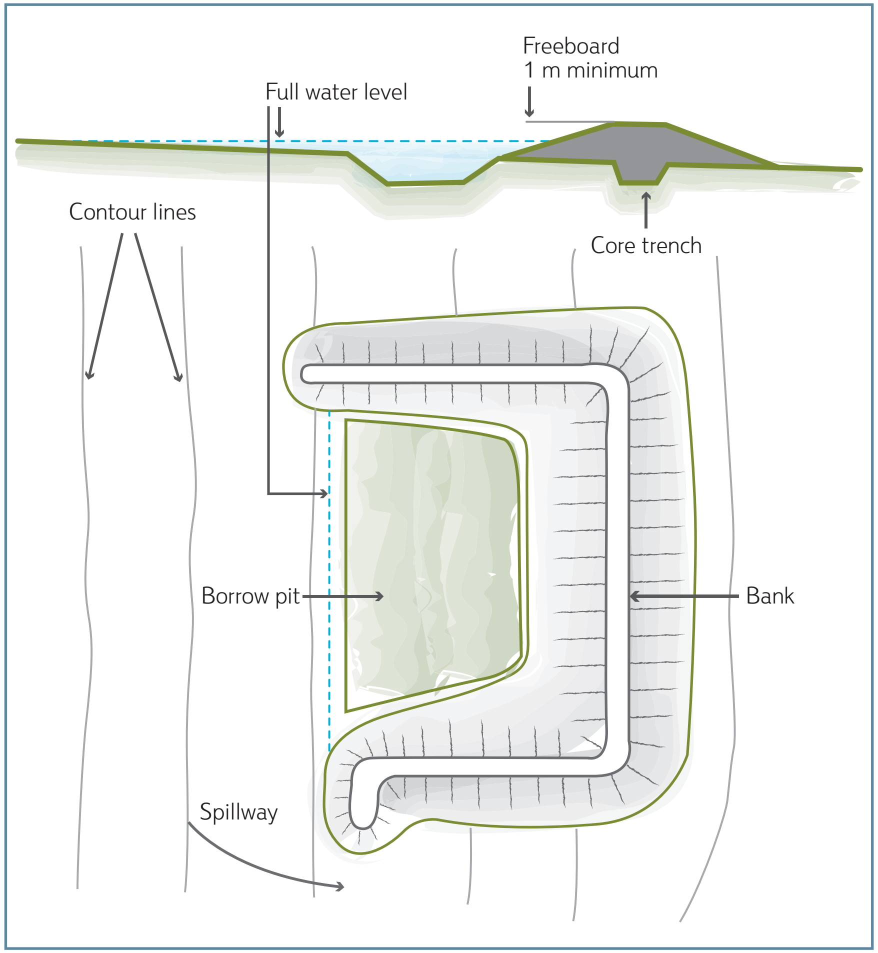
Adapted from Farm dams – planning, construction and maintenance, Barry Lewis, Landlinks 2002.



Hillside dam

A hillside dam is built on a low to moderate slope without a significant natural depression. It will generally have a three-sided or curved bank and will often have catch drains to ensure sufficient runoff makes its way to the dam. Hillside dams are also built to capture flows from natural springs.

Hillside dam
Adapted from Farm dams – planning, construction and maintenance, Barry Lewis, Landlinks 2002.



Excavated tanks

Excavated tanks are used on flat or low sloping country. The dam is dug below the natural ground surface and filled by runoff collected by catch drains or by groundwater seepage if the watertable is near the surface. When the dam excavation intercepts the watertable the dam is considered to be a well, and a groundwater use licence is required. These dams are generally the most expensive to build by volume of water stored and are uncommon in the region.

Excavated tank Source: Graham Johnson NSW DPI

Site selection

Slope

Ground slope is important in the selection of dam sites as it determines how large the embankment will need to be, and how much earth will be available from the excavation for the embankment. On flat sites, the excavation volume is the same as the water storage volume, so there is usually soil available for the embankment. As the slope increases, excavation provides less material for the embankment.

Where the slope is greater than 5%, there may not be enough earth to construct the embankment with sufficient freeboard, crest width and batter grade for stability and strength. In this case professional advice is needed.

Use the worksheet at the end of the book (see page 175) to assess slope.

Runoff

Dams fill with runoff and/or groundwater seepage. If the dam depends primarily on surface runoff, it will come from the catchment area upslope of the dam. The amount of runoff depends on the area of the catchment, rainfall, and infiltration rates, the latter determined by groundcover and soil type. To estimate runoff water available for a particular dam site you need to know:

- the average annual rainfall for the area (page 167)
- the size of the catchment (page 168)
- the annual runoff of the catchment (page 171)

Groundwater

Approval to construct any dam that intercepts groundwater is required from the NSW Department of Water and Energy. Groundwater-fed dams will only fill as far as the watertable level. The watertable must remain high enough to keep water in the dam when needed, particularly during dry spells. If the dam has a porous bottom, water will drain away when the watertable drops.

If the watertable is near enough to the surface to fill a dam, groundwater movements need to be monitored with a piezometer for some time before building the dam. These records will show how the watertable moves over the seasons and when groundwater is available to supply the dam.

A piezometer is a perforated pipe dug vertically into the ground. The height of the watertable relative to the ground surface can be measured using a tape measure and a torch.

Slotted pipes for use as piezometers. In the ground only the top of the pipe is visible. Source: Keith Bolton

Spring-fed dams are built so that the top water level of the dam is below the level of the spring. These dams do not need a licence as they do not intercept groundwater. When the spring is flowing, the dam will fill from the surface runoff from the spring. All spring-fed dams should be constructed with a trickle pipe to carry low flows, to avoid persistent wet soil on the spillway (see page 84).

Soil

Not all soils are suitable for dam embankments so soil at potential dam sites must be assessed to determine whether it will hold water (see page 155). A test hole is needed to evaluate the subsoil, as topsoil is not suitable for embankments. Formal soil tests are strongly recommended if there are no nearby dams, or existing dams in the area have unstable walls or spillways.

Some soils can cause problems or increase the costs of dam construction. If a dam has to be built in these soils, expert advice is needed in both the design and construction of the dam.

Sodic soils

Sodic soils occur in clay soils where a high percentage of sodium cations are attached to each clay particle. The cations make the particles separate and disperse when wet. This characteristic means the soils are highly erodible in water, which can lead to tunnel erosion and dam wall failure. Sodic soils are often a bleached grey or yellow in colour and should be avoided when building dams. If a dam has to be constructed in these soils professional advice is needed. The following precautions reduce the risk of dam failure in sodic soils.

- Keep the dam as small as possible, with a maximum wall crest height of 3 m.
- Increase the effort and time taken to compact the wall during construction.
- Keep soil at optimum moisture content during construction.
- Reduce batter grades to less than 3:1.
- Increase the amount of freeboard in the dam.
- Incorporate gypsum in the soil during wall construction.
- Use a dam liner.

For more information on sodic soils go NSW Department of Primary Industries website.
http://www.dpi.nsw.gov.au/agriculture/resources/soils/sodic

Well-aggregated soils

Well-aggregated soils such as the volcanic red ferrosols found on the Alstonville, Dorrigo and Comboyne plateaus have the opposite problem to sodic soils. The soil clods are so stable when wet that they retain their porous texture and do not form a good seal despite a high clay content. A dam liner or soil ameliorant may be required.

Cracking clay soils

Cracking clays such as the heavy black clays found on the Richmond River floodplain swell when wet and shrink as they dry out which leads to large cracks in the soil profile. If the cracks extend far enough into a dam wall, they can cause the dam to fail.

Low clay soils

Dam soils need a high level of clay to seal the soil from water infiltration. Clay content can be assessed by wetting a handful of soil, rolling it into a thread about 5 mm thick, and bending the thread into a 5 cm diameter ring. If the thread forms a ring without breaking it may have enough clay to form a suitable seal for the dam. If the thread breaks, the soil may be unsuitable for dam building and should be investigated further with laboratory tests.

Gravel and sand seams

Gravel and sand seams occur in the ancient flowlines of old river beds. If these seams are encountered they need to be dug out and plugged with at least 60 cm of clay material.

Rocky soils

Rocky sites can make construction of the dam more difficult. If the rocks are porous or fractured, seepage may occur through the rocks or along the soil rock interface.

Acid sulfate soils

Acid sulfate soils (ASS) produce sulfuric acid when they are excavated below the watertable and allowed to dry. This acid can affect water quality in a dam and downstream. ASS are most common in low lying coastal areas, and acid sulfate hazard maps identify areas of risk. In addition to the environmental concerns, works in ASS areas are regulated by councils under Local Environmental Planning provisions (LEPs), and may require consent and special precautions.

Soil ameliorants

When alternative dam sites are not available, soil ameliorants can be applied during dam construction to improve the performance of a problem soil.

- Gypsum and hydrated lime (NOT ag lime) reduce tunnelling in sodic soils.
- STPP (sodium tripolyphosphate) induces dispersion in well-aggregated soils that will not form a seal.
- Bentonite (engineering grade) is used in soils with insufficient clay content.

Other things to consider

When building a new dam, it is important to recognise that it will become a long term part of the infrastructure of the property and will influence how the property is managed on a day to day basis.

The following factors will influence the size and location of the dam.

- impact on access for vehicles, heavy farm machinery and stock
- impact on fencing and other infrastructure
- safety considerations (ie the location in relation to roads and houses)
- requirements of the Dam Safety Committee http://www.damsafety.nsw.gov.au
- how the water will be extracted and used (ie pumping, reticulation, troughs)

Troubleshooting

Lack of groundcover

Embankments need a good vegetative cover to protect them from erosion. Grasses, either native or introduced, are best because tree roots can create channels that cause dam walls to leak. Trees should not be planted on embankments and must be removed if they establish naturally. When dams are constructed, topsoil is stockpiled and then spread over disturbed areas that will not be covered by water when the dam is full.

When earthworks are finished, these areas are sown with heavy applications of seed (and fertiliser if required), at up to ten times the normal rate of seed application recommended for pasture establishment. In high rainfall areas, turf can be laid in strips to protect the soil until seeds shoot. Turf is most effectively used in spillways or drainage lines, where the cost of turf is less than the cost of erosion repairs.

If groundcover fails to establish, it may be due to nutrient deficiencies or pH imbalance in the soil. Soil testing can help identify these conditions. Other actions that may help include:

- sow and fertilise suitable grass species for the locality and season
- exclude stock until good cover is established
- remove trees, saplings or shrubs.

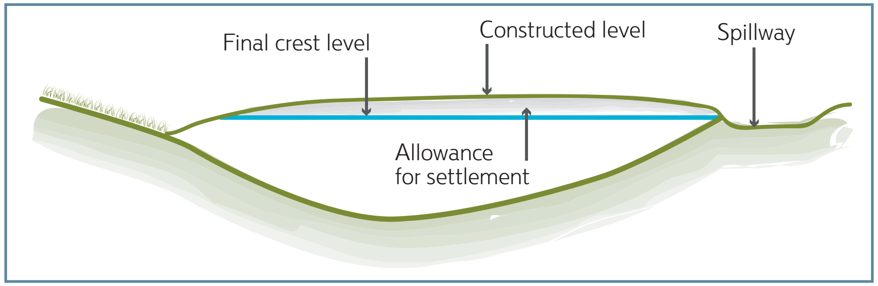
Overtopping

Water overtopping a dam wall is a serious problem that often results in dam failure. A newly constructed farm dam is most vulnerable to overtopping when groundcover has not established. Overtopping can occur for four reasons.

Insufficient freeboard

There may be insufficient freeboard between the height of the wall and the spillway to allow for wave action and storm surcharge. Ideally, a new dam embankment is constructed of adequately compacted soil with enough freeboard to allow for settling while maintaining sufficient freeboard between the height of the embankment and the height of the spillway (see diagram below). If the wall is too low to allow sufficient freeboard, it may be more effective to widen or lower the spillway height than to raise the level of the entire embankment.

A dam wall needs to be initially constructed to a higher level than required to allow for settlement.
Adapted from Farm dams – planning, construction and maintenance, Barry Lewis, Landlinks 2002.



Slumping

All new embankments settle to some extent, but excessive or uneven settling can lead to slumping of parts of the embankment. This can happen when the material at the bottom of the wall is unable to support the weight of the material above. This most commonly happens where the embankment material is poorly consolidated, is excessively wet due to seepage, or is high in organic matter, for example when topsoil is accidentally incorporated. If a large proportion of a dam embankment is affected by slumping, professional advice is needed. If only a small section is affected, it can be built up to provide at least 1 m freeboard height between the lowest point of the embankment and the spillway.

This embankment has overtopped because of insufficent freeboard between the embankment crest and the spillway (to left). Source: Mark Stanton-Cook NSW DPI

Inadequate spillway

If there is sufficient freeboard between the height of the embankment and the spillway and overtopping still occurs, it indicates that the spillway is too small to carry the peak discharge required. If the spillway is too small you may need to widen it to prevent further overtopping of the embankment.

Use the worksheet to estimate peak discharge of your catchment (see page 172).

Blocked spillway

If the spillway is obstructed by vegetation, fallen timber or other material, less water can flow over it, which may cause overtopping elsewhere on the dam wall.

Several options are available to remedy overtopping.

- Remove large debris from the spillway.
- Maintain vegetation height at 10–30 cm on the spillway.
- Check that all parts of the embankment are high enough to allow 1m freeboard between the height of the embankment and the spillway.
- Remove topsoil from low sections or breaches of the embankment, fill with clay and compact before respreading with topsoil and revegetating.
- Lower the spillway level if necessary to provide adequate freeboard.

Embankment collapse

The usual causes of collapse of an embankment are slumping and overtopping. If the damage is severe, the entire dam wall needs to be reconstructed.

Leaking, seepage and tunnelling

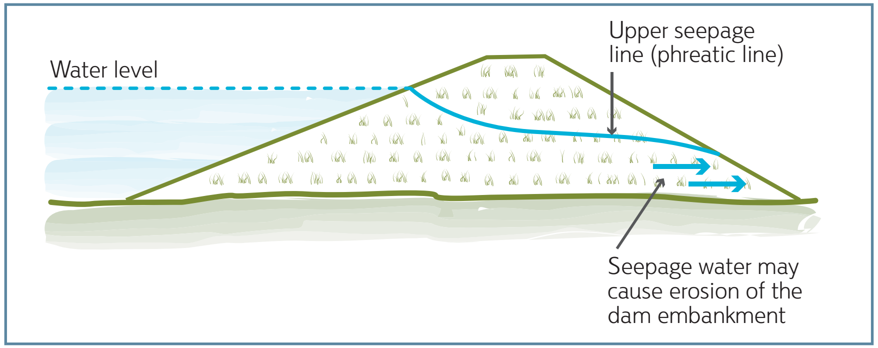
All dams leak to a degree but excessive seepage through a dam wall can lead to slumping or collapse of the wall. Indicators of excess seepage are damp spots or greener areas of vegetation in the downstream wall or below the dam. A trickle of muddy water could mean a tunnel is forming. Leakage in the bottom or upslope sides of the dam is not a structural danger to the embankment, or likely to cause soil erosion. The decision to treat the problem depends on the economic value of the stored water and the reliability of runoff to refill the dam.

The following section presents options for resolving leaking dam walls, in order of increasing cost and effort. If the leakage is not easily resolved, it is worth weighing up the cost of fixing the problem compared with the cost of building another dam in a more suitable location.

Check around the waterline for tunnels

Seepages and tunnels usually start just below the waterline. A large tunnel will be obvious by a whirlpool forming in the dam. Other tunnelling can be checked by probing the soil around the waterline with a steel bar to a depth of 40 cm. Any soft spots need to be filled and rammed with suitable clay to seal the leak.

Seepage occurring on the downstream side of dam wall.
Adapted from: http://www.worldagroforestry.org/sites/relma/relmapublications/PDFs/TH%20 29%2080-140.pdf



Compact the soil

If the dam continues to leak, further compaction may break up the soil aggregates and compact the finer particles to form a better seal. The dam will need to be emptied and then stocked heavily with cattle, or rolled with a sheepsfoot roller or, if very dry, ripped, scarified, watered and rolled.

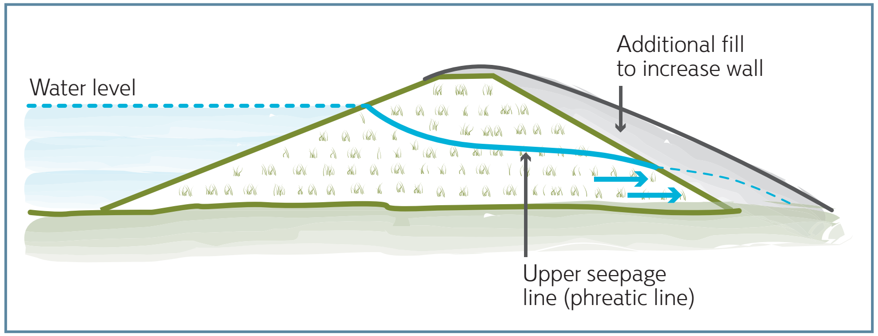
Broaden the embankment

When an embankment holds back water, a line of seepage can be imagined running through the embankment from the top water line. This line of seepage is called the phreatic line. It needs to reach natural ground level within the embankment or a zone of seepage will emerge in the face of the dam wall, making it vulnerable to erosion. This may be occurring if seepage is observed where the slope of the downstream side of the dam wall is steeper than 2.5:1.

If it does occur:

- remove and stockpile topsoil from the embankment
- add and compact more suitable earth to increase the width of the embankment and reduce the slope of the outer dam wall
- respread topsoil and revegetate.

Seepage controlled by additional fill placement.
Adapted from: http://www.worldagroforestry.org/sites/relma/relmapublications/PDFs/TH%20 29%2080-140.pdf



Line the dam

Another option is to line a leaking dam wall with an impermeable material. If suitable clay is available within the dam site, a 30–50 cm thick layer can be applied in a sequence of thin layers over the inside surface of the dam wall, rolling and watering each layer to ensure good compaction. This treatment is only viable if suitable clay can be obtained from within the dam site. Otherwise plastic membranes can be used but expert advice is needed as to which material is appropriate for the particular situation.

More detailed information on dealing with a leaking farm dam can be found in NSW DPI's Agfact AG 24 Leaking Farm Dams. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/164038/leading-dams.pdf

This eroding spillway needs repair.

Spillway erosion

Spillways need a dense cover of grass to prevent the water scouring the soil and changing the shape of the spillway, making it less effective in disposing of excess water without damage.

Spillways are designed to carry occasional large flows of water spread over a wide level sill. Prolonged low flows, such as those that occur in spring-fed dams will cut a channel in the spillway. When high flows occur, the force of the water will scour out this channel and over time this will lower the top water level or cause dam failure. Stock or vehicle traffic on the spillway will accelerate the problem. The following actions will fix an eroding spillway.

- Reshape the spillway to form a level sill.
- Establish dense cover of a local grass.
- Clear out existing trickle pipes.
- Install a trickle pipe to carry low flows through the dam wall.
- Exclude stock and vehicles until dense groundcover is established and prolonged water flow across the spillway surface is redirected.

Trickle pipes

Trickle pipes discharge small flows through the dam wall. Installed during dam construction, they are commonly 150–300 mm pipe, with the inlet installed 300 mm below the height of the spillway. The outlet for the trickle pipe is extended to the floor of the downslope flowline, as if the pipe extends through the dam wall out into the air, it is likely to create an erosion problem in the 'drop zone' below, potentially undermining the dam wall. The area at the outlet of large pipes may need to be lined with rocks to prevent erosion.

Trickle pipes can be fitted with an anti-seepage or cut-off collar, or set of collars along their length to stop water seeping or tunnelling through the dam wall along the outside of the pipe. Seepage can reduce the strength of the dam wall and should be fixed immediately if seen. Trickle pipes often become blocked by debris. A coarse screen over the entrance to the pipe can prevent this.

To maintain trickle pipes:

- check and clear out pipes annually
- repair leakage around pipes by excavating near the inlet and installing additional collars on the pipe. Before replacing soil add ameliorants to improve its seal, and compact it strongly into place.

Exposed subsoil of the back batter is difficult to revegetate.

Back batter erosion

When a dam is built on a steep slope, the excavation may be extended beyond the area covered by water to obtain enough material to build the embankment. The excavated face, known as the back batter, is usually a steep slope of exposed subsoil and prone to erosion, so deep-rooted vegetation should be established as soon as possible, using imported soil if necessary.

Stock should be kept off the batter. It is also important that concentrated water flow does not enter the dam across an excavated batter. Where this could occur, the water needs to be diverted around the batter, or the flowline armoured with rock or concrete.

Dam cleaning

Sediment eroded from the catchment area of a dam often accumulates in the dam and reduces its storage capacity, so periodic desilting is required to maintain the storage volume. Desilting is carried out with earthmoving equipment. Bulldozing is impractical because the silt is often wet and heavy, if not submerged.

For small dams an excavator is positioned beside the dam, where it buckets out sediment onto the dam wall. On larger dams, a combination of dozer and excavator may be used to bucket out and spread the silt. Silt from dams is prone to erosion as it is a fine material easily transported by water so must not be stored or spread in drainage lines. When spread thinly across grassed areas below the dam's catchment, grass will grow through it quickly and surrounding grass will catch any moving sediment. Mounded silt can be sown to grass or planted with other vegetation.

To manage a silted dam:

- reduce erosion from upslope
- remove silt from the dam
- spread the removed silt away from flowlines
- establish groundcover.

Silt spread across pasture will quickly revegetate.

Stable roads and tracks

4

Construction and maintenance of on-farm roads and tracks are high erosion risk activities. Roads and tracks can erode badly in heavy rains and quickly become untrafficable or unsafe. The erosion is usually due to poor design or lack of maintenance. If the track becomes a drain, it will quickly scour, with the soil ending up as sediment in drains and waterways. Eroding tracks can be a significant contributor to soil loss.

Track design

Lack of drainage and use in wet conditions have eroded this track.

Good track design minimises erosion potential. The first step is to consider all possible routes. Topographic maps and aerial photographs are useful, but it is essential to inspect potential routes and walk along them. A track on gentle terrain is usually more stable and requires less maintenance than a track with high steep batters that are difficult to stabilise. The design should be based around the limitations of the soil rather than the vehicle as the limits of stable track design are much lower than four wheel drive vehicle capability.

A well-designed track:

- lies above flood level
- follows the contour of the land as much as possible
- uses ridge tops and north and west facing slopes where possible
- involves minimal cutting and filling
- has a slight grade to stop water ponding on the track and creating boggy areas
- has a slight cross-slope to encourage drainage
- is separated from streams by vegetation buffers to trap any eroding soil
- has effective outlets for drains and culverts to minimise erosion.

Areas to avoid when designing a new track include:

- natural waterways
- low-lying wet areas and soaks on hillsides
- actively eroding or historically eroded areas, especially areas where mass movement has occurred
- native vegetation
- cultural heritage sites.

Track grade

The grade is the slope running along the length of the track (not across the track). The greater the slope the faster water will flow along it, increasing the risk of erosion, so the aim is to keep the grade as low as possible. Steep track sections require careful design and usually mean more drainage works and higher maintenance costs. Grades of 10° (18%) slope should be the maximum as steeper grades need special drainage works, and may need hard surfaces.

Use the worksheet for estimating slope (page 175) to work out the grades for sections of the track.

Track construction

Construct and maintain tracks in low rainfall periods (see page 144 for rainfall information) and use an excavator rather than a bulldozer on steep slopes. Book contractors well in advance to ensure construction happens when erosion risk is low. Earthmoving equipment can spread weeds and soil-borne diseases so ask contractors to clean their machinery before it comes onto the property or hose it down at a secure point before starting work. Aim to get vegetation established on any disturbed ground as quickly as possible after construction or maintenance work.

Clearing

Before construction, clear the track area of trees and woody shrubs to avoid having them incorporated into fill batters. Try to limit clearing to 0.5 m on either side of the track. If trees have to be removed outside this area, cut them rather than bulldoze to minimise soil disturbance. Land clearing for routine agricultural management activities (RAMAs) is permitted without approval under the Native Vegetation Act 2003, provided that it is kept to a minimum and within specified distance limitations.

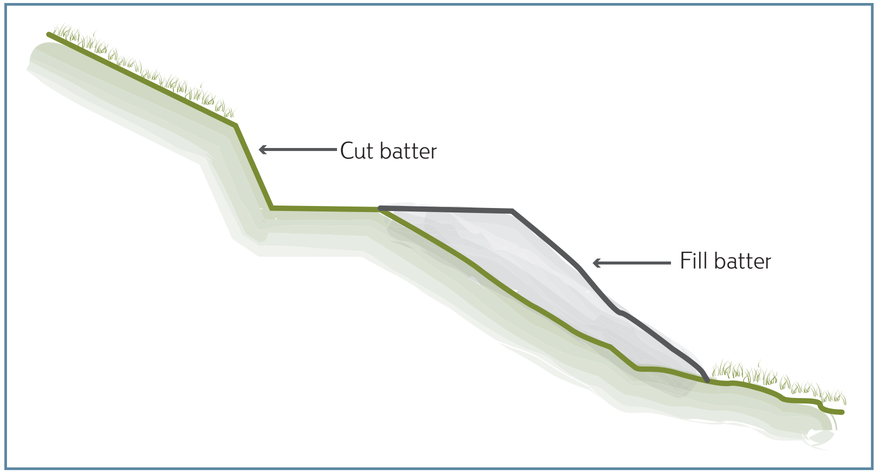
For tracks on rural zoned properties the maximum clearing width allowed is 6 m (4 m on rural residential zoned properties), with stricter conditions on protected riparian zones next to waterways.

For more information on land clearing regulations see http://www.nativevegetation.nsw.gov.au/fs/fs_06.shtml

Road batters

A road batter is a constructed earth slope cut into the hillside or made of fill material. A track running across a slope will often have a cut batter on the upslope and a fill batter on the down slope.

Typical profile of a track constructed across a slope with cut and fill.
Adapted from: Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Cut batters

Cut batters should be close to vertical for heights up to 1.5 m. These batters may suffer from slumping initially, but will usually stabilise with follow-up maintenance. Cut batters higher than 1.5 m, or persistently collapsing batters, require stabilising with laying back, retaining walls or diverting run-on water around the batter.

Fill batters

Fill batters should be no steeper than 1:2 m, and flatter where possible. Disturbed fill is much less stable than a cut batter so rapid establishment of vegetation cover is essential to stabilise them. Where practicable stockpile topsoil and leaf litter to respread over areas to be revegetated.

Track drainage

Rain falling on a compacted track quickly concentrates into erosive streams that scour soil and make the track difficult to negotiate. The track surface needs to be shaped so that water runs across rather than along the track and doesn't pond on the surface.

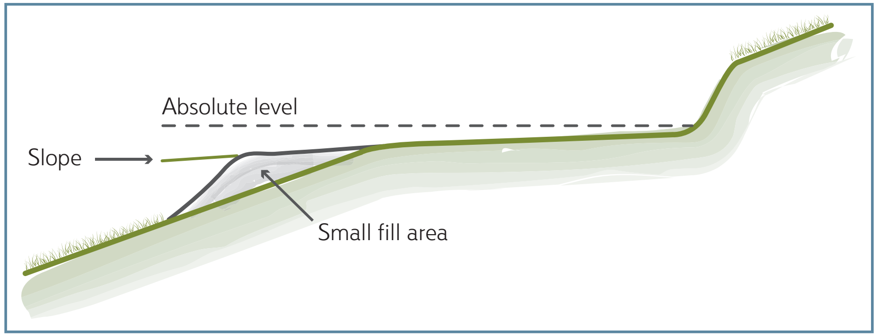
Crossfall drainage

The purpose of crossfall drainage is to take water across the track and off to the side, but where water does not drain quickly enough, regular drainage structures will be needed as well. There are three types of crossfall drainage.

Outfall drainage

Outfall drainage directs water from the track to the outside edge. The track is shaped so that the inside edge of the track is higher than the outside edge. Water flows across and off the track to the downslope side. Outfall drainage is used when the track's fill batters are small and not likely to erode. Earth windrows formed on the outside edge of the track during construction or grading need to be removed because they redirect water along the track.

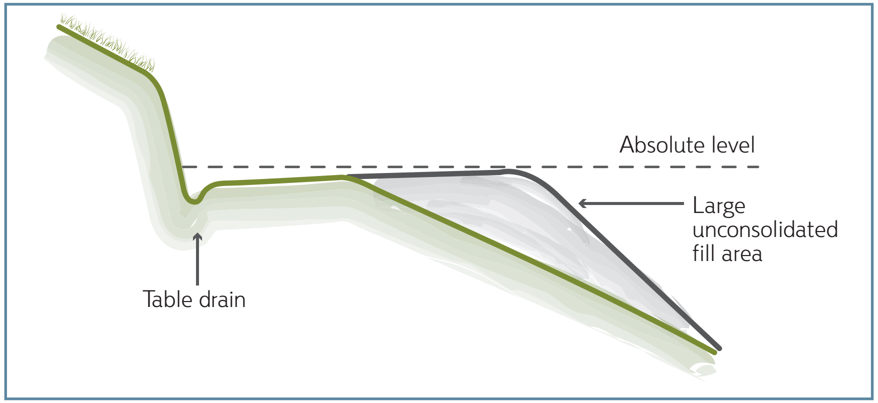
Outfall drainage takes water across the track to the outside slope.
Adapted from: Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Infall drainage

Infall drainage directs water to the inside edge where table drains carry it to drainage structures that cross the track. Infall drainage is used when the track is constructed on large or erodible fill batters, or the outside bank is more than a metre high.

Infall drainage carries water to the inside of the track.
Adapted from: Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Crown drains

These drains are used for tracks on ridges or gentle slopes.

Crown drains shed water to both sides of the track from the high point in the centre of the track.
Adapted from: Earthmovers Training Course, Soil Conservation Service of NSW, 1992

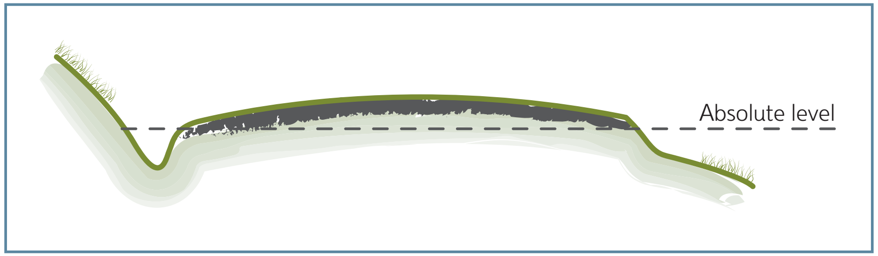


Table drains

Table drains run alongside the track and carry water from the track to disposal areas via culverts, cross banks or mitre drains.

Culverts

Culverts are pipes buried below the track surface to carry water under the track. They need to be large enough to carry major flows from the catchment above the inlet. They are laid as close as possible to the natural drainage line down the slope to avoid turbulence and scouring at the inlet and outlet. The water emerging from the pipe needs to be discharged safely (see page 100).

Rock protects the batter where this culvert emerges.
Source: Tim Duckett IECA

Batter dropdowns

Where a culvert pipe emerges above the foot of a downhill fill batter the water path needs to be stabilised to prevent undercutting of the track. Batter dropdowns are drain channels stabilised with rock or concrete to carry water down past the foot of the batter without eroding the soil.

Cross banks

Cross banks are earth banks across the road (also known as 'whoa-boys'), to intercept water running down the track and divert it off to the side. Cross banks need to be located at points where there are stable areas to receive the drain water (see page 100).

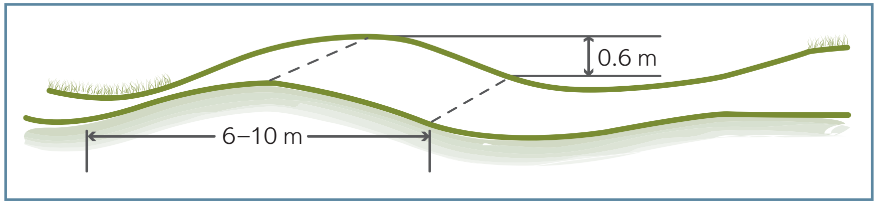
A cross bank stops water running down the track slope.
Source: Michael Frankcombe IECA

Cross banks work best when constructed at a slight angle to the track with a grade of approximately 1:20 to prevent water ponding on the road in the cross bank drainage channel.

Dimensions

Dimensions of cross banks need to be tailored to the types of vehicles that will use the track. Easily trafficable cross banks can only be constructed on slopes of less than 12° (21%) because of the increase in grade on the approach and descent from the bank. The diagram below shows dimensions for a cross bank that can be negotiated by most vehicles.

Typical dimensions for an easily trafficable cross bank.
Adapted from: Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Construction

Earth required to construct cross banks is usually borrowed from the track on the upslope side of the bank. Sufficient earth must be used to give the required dimensions after compaction. A long shallow excavation is better than a short deep one.

Typically, a bulldozer rips the road to a depth of 20–30 cm for 15–20 m back from the chosen drainage line. The loose earth is pushed down the road line to form a bank, starting from the uphill side of the track, then shaped and compacted to form the finished bank.

Cross bank drains must be big enough to carry the maximum flow without overtopping. If the bank overtops it needs to be made higher, or other cross banks need to be built along the track.

Enough cross banks need to be constructed to prevent rills from developing in the track surface. The table below shows recommended spacings for different slopes and soil categories. On an existing track a good rule of thumb is to put in a cross bank at the top of a rilled section.

Recommended maximum spacing for cross banks.
Source: Earthmovers training course – Soil Conservation Service of NSW, 1992

Track grade (%)	Slope degrees	Low soil erodibility	High soil erodibility	Very high soil erodibility
		Brown and red soils derived from fine-grained sediments	Red soils on fine-granites, fine-grained sandstones and basalt	Grey and yellow soils derived from granites, or sedimentary deposition, especially coarse-grained types
Up to 14	0–8	70–90 m	60–70 m	20–30 m
14–21	8–12	60–70 m	50–60 m	*
21–28	12–16	40–60 m	*	*
28–36	16–20	30–40 m	*	*
36–40	20–22	20–30 m	*	*

Note: * indicates tracks should not be constructed on these soil types within the given slope range.

Spoon drains

Spoon drains have a similar function to cross banks, but are constructed by excavating a wide shallow depression across the track and spreading the earth thinly along the track surface. They are used mostly on tracks with very low grade.

A recessed pipe set into a steep gravel track.

Recessed pipes

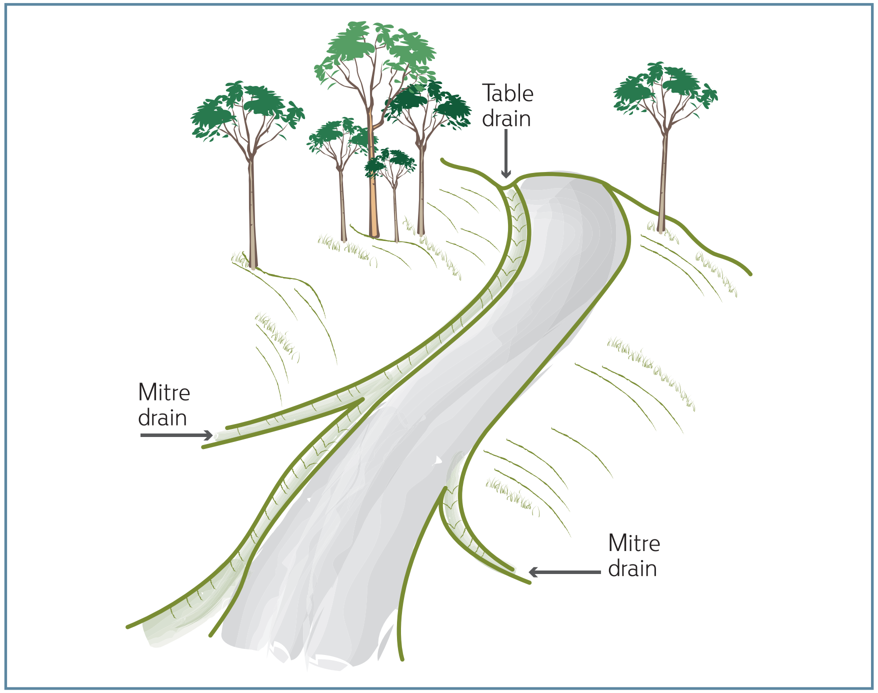
Where slopes are too steep to allow trafficable cross banks, hardened spoon drains can be constructed by recessing a half steel or concrete pipe into the track surface. This allows for a deeper, narrower channel that can drain fast flowing water and allow vehicle traffic. The recessed pipe crosses the track at a more oblique angle and a steeper grade than an earth cross bank. The faster flow of water will help to keep the pipe clean. If the grade is too flat, the pipe will fill with sediment and water will flow onto the track. Recessed pipes are likely to need more frequent maintenance than earth banks. The drain outlet must be stable and robust due to the concentrated flow of water discharged.

Mitre drains

Mitre drains are surface channels that take water from the track shoulder, table drains or cross banks to safe disposal areas. They angle away from the track, and are spaced as close together as practicable.

Ideally, mitre drains are less than 50 m apart, and much closer on steep slopes or in erodible soils. The slope of the mitre drain needs to be less than 5° (9%) to avoid scouring and needs to discharge to a stable area.

A track should have frequent mitre drains to direct water away from the track and its table drains.
Adapted from: Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Drain outlets

Water draining off tracks needs to be discharged onto dense vegetation such as grass to filter sediment and hold underlying soil in place. Where there is enough space, give the drain outlet a broad edge so that water spreads rather than concentrates. If this is not possible place rocks at the drain outlet to dissipate the energy of fast flowing water. Avoid discharging drains directly into waterways.

Sediment traps

Once track construction starts soil will inevitably erode from the site during rain. To stop this soil entering waterways install sediment traps such as silt fences or hay bales at all drain outlets.

Track crossings

Where tracks cross a watercourse or drainage line they are vulnerable to erosion. Water needs to be directed across or under the track so that the track remains passable. The amount of work needed to maintain crossings depends on the topography and the volume of water in the watercourse or drainage line. Where the track has to cross a natural watercourse, approaches need to be as flat as possible. Steep approaches usually form rills and gullies, or wash out in floods, and require frequent maintenance.

Fords

Fords are preferable to culverts or bridges as they occur naturally or can be constructed with minimal disturbance to the streambed and banks. If the crossing site is not naturally rocky, a stable crossing can be built with well-compacted rock or hard fill brought to the site. Rock fill needs to be extended up the banks to the flood flow height of the stream, and hard fill should sit no higher than the bed of the stream. Do not push soil into a ford to make the grade easier for vehicles. Rather than reshaping the approaches to a crossing, consider constructing a bridge or culvert.

A natural rock platform used as a crossing point.

Shallow depressions or swampy areas can be paved with stones or logs placed across the track. Do not use logs to ford a flowing stream as they are often dislodged in flood events.

Culverts

Culverts are suitable for crossings in small upslope catchments or over streams that do not carry much debris as debris can quickly block the culvert and make it ineffective. The culvert must be large enough to accommodate peak flows or be designed as a concrete causeway. It is important that the culvert design allows fish to move freely up and down the stream.

For more information on fish friendly road crossings go to the NSW DPI website http://www.dpi.nsw.gov.au/fisheries/habitat/rehablitating/road-crossings

This older style culvert crossing is designed to function as a causeway in high flows.

This modern box culvert causeway is more 'fish-friendly' than the older style.

Bridges

Bridges are required where the drainage line is a deep gully, or likely to carry large debris. Bridge design is beyond the scope of this handbook, but for safety a bridge must be designed to support at least its own weight and the weight of the heaviest vehicle that will cross it. In fast-flowing streams bridge supports may need to be protected by concrete, rocks or timber to protect against washing out in floods.

A timber bridge spans a deeply incised stream channel.

Track surface

Concrete can be used to stabilise steep, high use tracks.

The choice of surface depends on the type and volume of traffic that will use the track. Bare soil is not usually a stable surface for a track because it is vulnerable to erosion and may become slippery and boggy when wet. Grass cover is best for low use tracks, with gravelling where ruts develop. Frequently-used tracks may require gravelling. Steep sections of high traffic roads where gravel washes away may need a hardened surface such as bitumen or concrete.

Maintenance

Maintenance is usually most necessary and required more frequently in the early years following construction, until soils consolidate and vegetation becomes established. Most damage to roads and tracks occurs when a drain fails through filling in, blockages or banks wearing down.

Regular maintenance can help avoid costly large-scale repairs.

Basic track management principles are outlined below.

- Don’t drive in the same wheel tracks all the time and use lighter vehicles where possible.
- If possible, avoid driving on the track when soil is wet. This will help stop wheel ruts forming and reducing the effectiveness of the cross drains.
- Inspect the track after heavy vehicle use or rainfall and repair any damage as soon as possible.
- Check all drains at least once a year, and repair and clear where necessary.
- If surface drains are in order, but erosion of the track is still occurring, install a new cross bank or spoon drain at the top of rilled sections.
- Leave material that slumps from cut batters untouched unless it restricts the width of the track or blocks a table drain. If necessary, remove spoil carefully without undercutting the toe of the batter.
- When working on a track, minimise soil disturbance. Avoid blading soil except where necessary to form the surface.
- Remove any windrows formed through grading or reshaping that might prevent water draining off the track.
- Revegetate immediately after soil disturbance while the soil is soft, regardless of the season.
- Do not remove more timber than is necessary to maintain access along the tracks and to maintain drains.
- Where necessary cut timber rather than bulldoze it, especially above cut batters or within drainage lines.

Managing gullies, tunnels and mass movement

5

Sometimes the scale of an erosion problem can be daunting. It is important to investigate the cause of the erosion, what can be done to reduce the problem and the options for rehabilitating the eroded landscape.

Gully erosion

Gullies form when concentrated water flows scour soil and carve out deeper watercourses. The fast flowing runoff hits a 'nick' point such as a rabbit burrow, root hole, stock or vehicle track, or a rill in bare soil. The energy of the flowing water scours away the soil at this point and undermines vegetation.

Once the vegetation and topsoil are removed gullies can spread rapidly up and down drainage lines. Technically, a gully can be as small as 30 cm deep, but established gully systems can be over 5 m deep.

Gullies can form in most soils, but sodic or dispersive subsoils are the most vulnerable to gullying. A dispersive soil has chemical properties that make it effectively dissolve in the water running through or over it.

Gully features: an upslope catchment area, one or more headcuts, a floor and walls.

This characteristic makes the soil much more vulnerable to erosion by water. Gully erosion is relatively common in the region. New or active gullies can spread quickly, but once they stabilise they may lose very little soil. Only active gullies will benefit from stabilisation works. Disturbing old gullies that have already stabilised may well start further erosion.

Assessing gully activity

Gully erosion can look dramatic, but if the gully has stabilised it may be better to leave it alone. Disturbing dispersive soils may reactivate the gully and cause more erosion. To check whether the erosion is active, look at the gully head, walls and floor.

Gully head

If the gully head is active it will be cutting into the drainage line above the gully, moving back up the slope. To check whether there is movement, take regular photographs of the site and compare them, or regularly measure the distance from the gully head to a fixed point.

An active gully head

Gully sides

Active gullies tend to have vertical sides. Once they stabilise, gully walls slump to a natural batter and grass over.

Active gully sides

Gully floor

In active gullies the floor lowers over time as more soil is scoured out. Regularly measure the distance from the floor to natural land level and compare the measurements to check floor movement.

Water source

If the gully is active, the erosion will be caused by surface flow, or groundwater seepage, dissolution of the subsoil and slumping. It is possible for both processes to occur together, but the measures to address each are different.

If groundwater seepage is emerging close to the surface (less than 30 cm deep) the water source may be nearby. Water emerging from deeper in the soil profile has probably travelled some distance underground.

Groundcover

As a general rule of thumb 70% groundcover is needed to protect soil, but in areas of high water flow this needs to be thicker, up to 100% cover. If groundcover percentage is low the gully may be at risk of reactivating, even if it is currently stable.

Land management

Gully erosion indicates that the soil is beyond its capacity to cope with the land use or the management practices. Current land management needs to be reviewed and other options considered for the affected land. Vegetation in drainage lines may need to be managed differently to adjacent paddocks.

Troubleshooting

Reduce water flow

Gullies are caused by water flow, so the basic strategy is to reduce the volume and power of water entering the gully.

Increase infiltration

Reduce the amount of runoff from the catchment area above the gully by increasing groundcover and the complexity of vegetation (see page 8). If vegetation above the gully is sparse, look at changing the grazing regime, or removing stock from the area so that plants can regenerate. Plant deep-rooted perennial grasses in and on the sides of ephemeral waterways that have the potential to become gullies.

Divert water away from the gully head

Diverting water away from the gully line, or around an unstable section of a gully may be possible, especially in small catchments. Water diversions need to be considered carefully as there is the risk of creating a new problem if the water cannot be safely conveyed and discharged.

A back-push diversion bank keeps water out of a gully downslope.

Reduce subsurface flows

It can be difficult to be sure where subsurface flows are coming from, but even within the soil, water tends to flow downhill. It may be possible to reduce the amount of water emerging into the gully by encouraging deep-rooted, heavy water-using plants upslope of seepage points. Trees, especially eucalypts, are very effective solar-powered groundwater pumps. Tree roots also provide structural support to soils prone to slumping.

Stabilise active gully heads

Install gully control dams

Gully control dams submerge the gully head which removes the erosive force of water flowing over the gully head and prevents the head moving any further upslope. Water must be returned to the watercourse at a safer location via:

- a pipe that conveys water to the gully floor
- an emergency spillway
- a diversion bank that carries the water to a grassed area (only appropriate for small catchments).

A gully control dam

The success of dams and diversion banks depends on a stable spillway and outlet which can be difficult to obtain in erosion-prone soils with severely eroding gully sides or bed.

These dams should be considered similar to other dams, and designed and constructed with regard to the watercourse and its catchment. Specialist technical advice is recommended to ensure gully control dams are effective.

Install drop structures

Although expensive, drop structures built at the gully head can stop the headcut continuing to move upslope. These structures are designed to capture all of the water (even in peak flows) coming over the gully head, carry the water to the gully floor and dissipate the energy of the falling water so that it does not cause further erosion of the gully floor. Designing and building drop structures needs specialist advice as there are a number of ways in which these structures can fail.

Features of well-designed drop structures are detailed below.

- **Guide walls** or **banks** prevent upslope water cutting around the structure.
- A **cut off trench** at the top, filled with impermeable material, prevents water undercutting the structure.
- A flume or **chute** carries water away from the structure quickly. The lower the grade of the chute the less reinforcing is required. Vegetation may be sufficient in small catchments if the flume slope is broad and has a low grade. Hardened surfaces such as concrete or rock blankets are necessary for more concentrated flows and steeper grades.

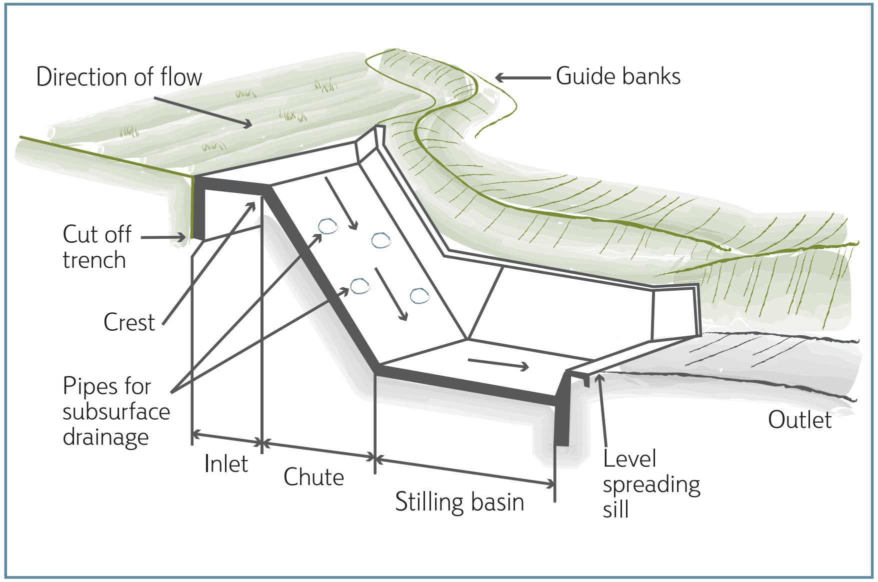
A concrete drop structure

- The structure **copes with flood flows** or has an emergency spillway.
- Subsurface flows can drain through the flume or chute when it is constructed from an impermeable material.
- A large enough **stilling basin** dissipates the energy of the water coming down the chute.

Rock drop structure with earth guide walls

- A broad **level sill** spreads the slowed water as it re-enters the natural flowline.

Important features of drop structures.
Adapted from Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Manage gully lines

There are several simple, relatively low cost management options for managing existing gully lines to reduce further soil losses.

- Fence the sides to keep stock out of gullies; this will encourage faster stabilisation and re-establishment of natural revegetation.
- Establish good vegetation cover on the gully floor to trap sediment and minimise further erosion.
- Plant trees and shrubs on the edges and above the banks of gullies to stabilise the walls.
- Slow water flow and promote sedimentation with a series of small check or grade stabilisation structures.
- Avoid filling eroded gullies with solid objects like old drums, tyres, car bodies, concrete or rubbish. They concentrate water flows and remove more soil from the gully walls and floor.

Reduce further gully erosion by fencing off, planting trees and encouraging good vegetation cover.

Reshape the gully

Earthmoving equipment can reshape a degraded gully for productive use. The practicability of this depends on soil type, gully depth and whether the gully is to continue as a watercourse. The deeper the gully the greater the area that will have to be disturbed to create bank batters of a reasonable grade. In deep gullies it may be more practical to minimise the disturbed area and focus on fencing and revegetation of the existing profile.

Reshaped areas have a high erosion potential and so need to be revegetated quickly. There is usually a limited supply of topsoil available for stockpiling and respreading at gully sites so reshaping is most successful in deep soils where the subsoil does not have structural or chemical limitations to plant growth.

Avoid reshaping where the subsoil is likely to be difficult to stabilise (eg sodic soils) or establish good vegetation cover in, as the gully is likely to reform itself back to steep walls, only with a much wider gully floor. Reshaping alone will not stabilise an active gully head. Specialist advice is needed on the feasibility of reshaping and suitable techniques.

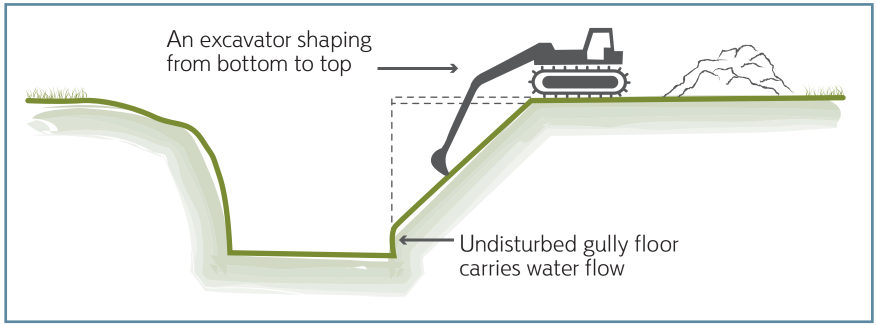
Fill in no flow areas

Material pushed in to fill a gully is not likely to be stable enough to carry water flow, so this should only be considered where run-on water can be safely diverted to an alternative watercourse. Where water can be permanently diverted, the gully and a large area around it can be reshaped to fill in the gully and create practical slopes to revegetate to an appropriate land use.

Reshape walls

Avoid gully reshaping in subsoil that is difficult to stabilise or revegetate (eg sodic soils), as the gully needs to continue to function as a watercourse, and the gully floor is stable, gully walls can be reshaped to assist in revegetation. Avoid disturbance to the gully floor as this will increase erosion, and do not attempt to reshape the walls if the gully floor is not already stable. The material that is moved to batter back the gully walls should be lifted out of the gully.

An excavator working from outside the gully pulls the wall material out of the gully.
Adapted from: Earthmovers Training Course, Soil Conservation Service of NSW, 1992



Prevent new gullies forming

It is easier and cheaper to prevent new gullies forming than to stabilise or rehabilitate existing gullies. In areas with a history of gully formation, or where there is a recognised gully risk, property management planning (overall management and infrastructure) and grazing and cropping strategies can significantly reduce the potential for new gullies to form.

Property management planning

- Manage catchments to reduce runoff.
- Map land capability classes and match farm practices to land capability.
- Site and construct roads, fences and laneways to cause minimal concentration and diversion of surface water.

Grazing management

- Locate watering points, stockyards, shade areas and gates away from gully-prone areas.
- Be prepared to fence off and exclude stock from land vulnerable to gully erosion when early signs of erosion appear in a watercourse.
- Manage stocking rates and grazing intensity to maintain >70% groundcover at all times.

Cropping management

- Use structural erosion controls and reduced tillage practices.
- Construct, stabilise and maintain adequate waterways.
- Ensure contour banks discharge into waterways at stable points.
- Do not cultivate sensitive areas.

Tunnel erosion

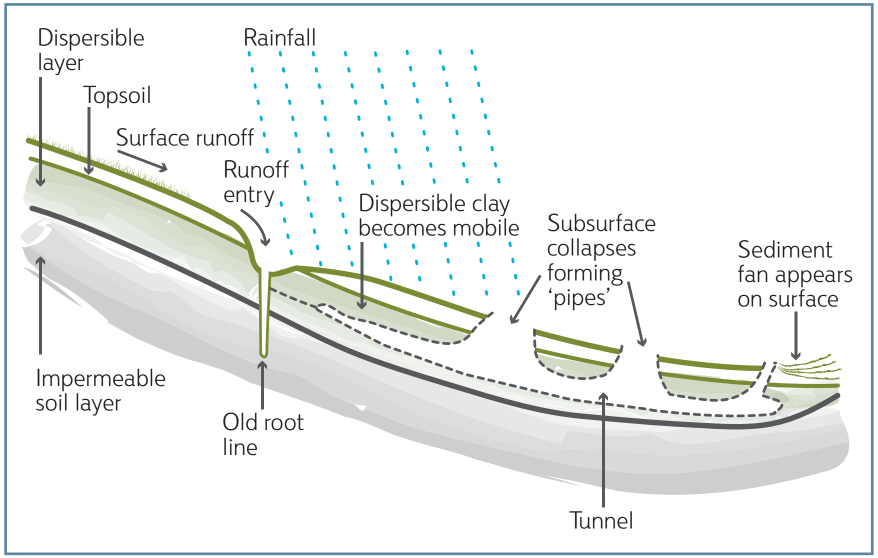
A tunnel exiting into a gully, with a sinkhole behind.
Source: David Morand DECC

Tunnel erosion is a form of water erosion often described as the precursor to gully erosion. It occurs mainly on sodic soils and can also occur in other soil types where there are concentrated subsurface flows.

Tunnels start when surface water moves into the soil through cracks, channels, disturbed topsoil, rabbit burrows or old tree root cavities. As it moves through the soil, the water dislodges easily erodible soil particles and creates small tunnels. Once formed, tunnels enlarge during subsequent wet periods.

Because it occurs below the soil surface tunnel erosion is difficult to see and manage. By the time it becomes visible at the soil surface damage is usually extensive. The tunnel roofs eventually collapse, causing sinkholes and gullies. The tunnels are hazardous because the soil above them can collapse with weight of livestock and farm equipment.

Schematic diagram of tunnel erosion and some of its above ground indicators.
Adapted from: http://www.dse.vic.gov.au/dpi/nreninf.nsf/childdocs/



Visible indicators

Indicators of tunnel erosion include sediment fans, sinkholes and exit holes in gully walls. Regular checking of known and potential tunnel erosion areas will detect new tunnels.

Sediment fans

When water in the tunnel flows onto the soil surface, usually further down the slope, it will leave sediment. Larger heavier particles drop out quickly near the tunnel outlet, while lighter particles will stay in the water longer before they drop out, resulting in a fan-shaped deposit. Sediment fans indicate that tunnel erosion is well-established.

A sediment fan at the outlet of a tunnel.

Sinkholes

As tunnels enlarge, small patches of surface soil collapse, creating sinkholes. Sinkholes tend to form earlier in vegetated areas where soils are softer than in areas where the soil horizons are more compact and rigid. As numbers of sinkholes increase they merge to form gullies.

Exit holes in gully walls

Large openings in vertical faces of gully walls may be the exit points of tunnels, especially if you see water flowing from them after rain.

Tunnel entrances can be difficult to spot.

Repair and management of tunnels

Tunnel erosion is difficult to manage because it is often hard to find where the tunnel starts, and sodic soils are so erodible. Research is still needed into techniques that ensure success and are cost-effective. Efforts to remediate tunnel erosion need to be evaluated against the risks of creating further disturbance to soils that are difficult to stabilise with vegetation. Mechanical, chemical and revegetation techniques are available and it may be appropriate to use a combination of these to suit the particular situation.

Mechanical techniques

Control rabbits

Rabbit burrows create localised access for runoff to enter the subsoil and start tunnel erosion. Existing burrows need to be ripped, and the disturbed soil ameliorated with gypsum and revegetated.

Divert surface water

Reducing the amount of water that flows onto and into the eroded area is the only practical way to prevent tunnel development. Diversion techniques could include graded banks with appropriate soil amelioration of the bank and channel.

Deep rip around the site

The soil surface around tunnel erosion areas is often hard-set which prevents infiltration. As a result, surface water can only enter the soil at points of weakness such as cracks and holes. Deep ripping or chisel ploughing around and above the erosion area will promote more even infiltration into the topsoil.

Excavate tunnels

The tunnel floor is usually hard and impermeable, so deep ripping the floor will break-up existing flowlines. Rip and excavate tunnels in all directions to at least 15 cm below the tunnel base. Finish by ripping along the contour.

Chemical techniques

Apply gypsum or lime

Gypsum chemically changes sodic soils by replacing the sodium attached to the clay particles with calcium. However the cost of applying gypsum to large areas affected by tunnelling may be prohibitive. In acid soils, lime can achieve a similar effect and simultaneously make the soil less acid.

The amount of lime or gypsum required to be effective is determined by soil testing, and will usually be somewhere between 2–5 tonnes per hectare. The stabilising effect of gypsum and lime is not long-lived due to leaching by rainfall, so once initial applications of ameliorants have brought the soil pH to 6.5–7 small amounts need to be applied regularly.

Revegetation techniques

Establish vegetation quickly

Re-establish vegetation as soon as earthworks are completed. The plants will provide a protective groundcover, slow water flow, reduce excessive soil water, and bind the soil. Non-dispersive topsoil may have to be brought onto the site to produce a level finish and establish a rapid vegetation cover.

Plant species for specific functions

Grass will provide a fast growing cover on new earthworks. Vigorous, growing grass will encourage microbial activity which will, in turn, improve both soil structure and aggregate stability. The composition of annual and perennial species to be sown should suit the local climate and soil properties. Annuals provide quick cover and protection and perennial species have extensive and deep root systems that bind the soil and promote water uptake. Trees planted above and around the reclaimed area will prevent soil water building up and creating an erosion risk.

Choose plant species suitable for your site

Contact local Landcare organisations for advice on what to plant.

Mass movement

Mass movement is the rapid movement of a mass of rock/earth/debris down the slope, due to a distinct zone of weakness in the underlying geology that separates the material in the slide from the material underneath. Certain areas may be more prone to mass movement because of their geology and landform, but the risk increases with removal of groundcover and deep-rooted vegetation.

Types of mass movement

There are two main types of mass movement in the region.

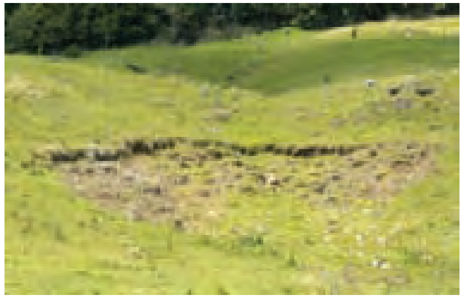
Shallow landslips of soil and debris on steeper, drier slopes

These landslips are easily recognisable by the soil and bedrock exposed in the body of the slip, and the soil and rock debris deposited further down the slope. They occur suddenly and movement is rapid.

Shallow landslips on a dry slope

Deep-seated slumps and flows on wetter footslopes

Indicators of slumps and flows include a hummocky surface, water ponding on top of the soil, fresh cracks in the soil, and leaning trees and fence posts. These landslips move slowly, similar to the flow of a viscous liquid, and the toe of the landslip may resemble porridge. Older slumps and flows are often covered in lantana or crofton weed. They continue to move each wet season and active slips may move up to 7 m a year.



The toe of the landslip may resemble porridge.

This movement will topple and kill individual trees, break fence lines and disrupt pasture, allowing blady grass and foxtail to invade.

A deep-seated slump on a wet slope

Risk factors

In agricultural land, all mass movement results from combinations of intense rainfall, steep slopes, underlying geology and clearing of deep-rooted native vegetation. In the region the main factors are the action of water and removal of native vegetation, especially native forest, exacerbated by intense rainfall.

The hummocky lower slopes tell us the soil is moving.

Vegetation

Most landslips occur because there is a decrease in the forces that hold soil and partially weathered rock material together on the slope. As the pore spaces in the soil/weathered rock fill with water, the ability of the material to stick together or resist movement declines (shear strength). At the same time the weight of the soil increases, making it more prone to move downhill.

Removal of deep-rooted native vegetation has two impacts. Less vegetation means fewer roots in the soil to hold it together as its shear strength declines, and more water in the soil. Thus it takes smaller rainfall events to fully saturate the soil/weathered rock, and as a consequence create a greater risk of mass movement.

Geology and soil type

There are also areas in the region where the underlying geology increases risk of mass movement. Where a different rock or soil type lies over the top of another, there may be differences in the way in which water moves through the layers, with the potential to lead to a build-up of water where the layers meet. This water can then act as a lubricant, allowing the top layer to slip across the one underneath.

Areas where this is likely to occur in the region coast include steep escarpments of volcanic material, and geological contact zones where different rock types lie next to or on top of each other. Mass movement risk is further increased if the toe of the slope has been removed in construction of a road cut or building site.

Cracks across a slope show mass movement is occurring.

Prevention and treatment

Most prevention and control works involve:

- diverting excess water
- replanting native vegetation, especially deep-rooted trees and shrubs
- excluding stock.

Specialised engineering works may be necessary where buildings and other infrastructure are threatened.

Divert surface water

Excess surface water can be diverted past mass movement prone areas using U-shaped drains to drain the water to a safe and stable area such as a natural watercourse. Surface drainage control is often combined with subsurface control works.

Divert sub-surface water

Subsurface water draining between different soil and rock types often emerges as springs at the soil surface. Spring water saturates downslope soils, creating a mass movement hazard. Tapping these springs and piping the water elsewhere reduces the hazard and provides water for stock, irrigation and household use.

A conventional spring tapping unit consists of a container with an entry pipe on the uphill side to tap the groundwater, and an outlet pipe on the downhill side to pipe the water away from the slip area. Simple spring tappers can be made from plastic containers, metal drums or concrete troughs. A more sophisticated model is a lidded box made from treated timber or marine ply, the lid stopping the box filling with soil and litter. Perforated pipe covered with filter cloth can be driven horizontally into the ground to collect the groundwater, but it is more effective to excavate the seepage area and fill it with gravel. This provides a reservoir for the groundwater.

A large subsurface drain upslope of a landslip collects water for disposal elsewhere.

Replace vegetation

A mixture of quick growing trees and shrubs planted 3–5 m apart will intercept rain in the tree canopy, bind soils, lower the watertable, and generally stabilise the slope. The best trees for revegetation of mass movement sites are rapid growing, have extensive root structure and a high transpiration rate, and will tolerate the soil conditions. For example, a single eucalyptus tree can remove up to 500 litres of water a day under favourable conditions. Choose species that are already growing naturally on similar soils, slopes and aspect. Careful stock management is necessary to allow trees to re-establish and to maintain at least 90% soil cover.

Engineered structures

Geotechnical advice is required for any specialised engineering works to stabilise a landslide.

Buttress fill works

In buttress fill works, subsurface drainage and fill is placed at the lower section of the landslip area to counteract the upslope sliding mass. These works should always be carried out in conjunction with native tree replanting to fully stabilise the area.

Riverbank control works

Controlling major river bank erosion involves preventing the removal of the toe of the slope. This could involve revegetation of the river bank as well as placement of appropriate control structures, such as check dams, rock walls and other bank protection devices. Professional geotechnical engineering expertise is required to ensure that works deal with the likely range of flow conditions in the river or stream. Fencing off of the riparian zone to exclude stock and the adopting specific strategies to control plant growth can reduce erosion of the riverbank caused by stock movement and foraging.

Restraining works

There are various options for binding the moving mass of material to the more stable material below, such as pile works, anchoring works and cast in place pile works. However these are not cost-effective unless significant infrastructure is threatened. Professional geotechnical advice is essential for such works.

Treating shallow slides and slumps on steeper, drier slopes

The most effective treatment involves a multi-faceted approach.

- Sow grass seed or legumes on bare soil areas to prevent continuing soil erosion and further slope failure.
- Divert runoff from the top of the slip.
- Smooth out soil debris to help regrassing and prevent weed invasion.
- Plant trees upslope, on and around areas of severe landslip. Close spacing of trees (3–5 m) can reduce the probability of slope failure by up to 70%.
- Exclude grazing animals while grass and tree plantings establish.

Treating deep-seated slumps and flows on wetter footslopes

Remediation of these areas focuses on water management.

- Drain surface water with shallow open drains.
- Divert water flows from the slip area.
- Install spring tappers and subsurface drains to pipe seepage water away from the slip area.
- Seal soil cracks and smooth hummocks.
- Plant trees.
- Control stock in the wet season.

Tree plantings and fencing off of this landslip attempt to reduce the risk of further movement.

6 Erosion basics

The word erosion is derived from the Latin *erodere* meaning to gnaw away. Soil erosion occurs when the soil is being ‘gnawed away’ by the forces of raindrop impact, water flow, wind and gravity. Essentially, these forces

- detach particles of soil
- carry or transport the particles
- deposit the soil particles.

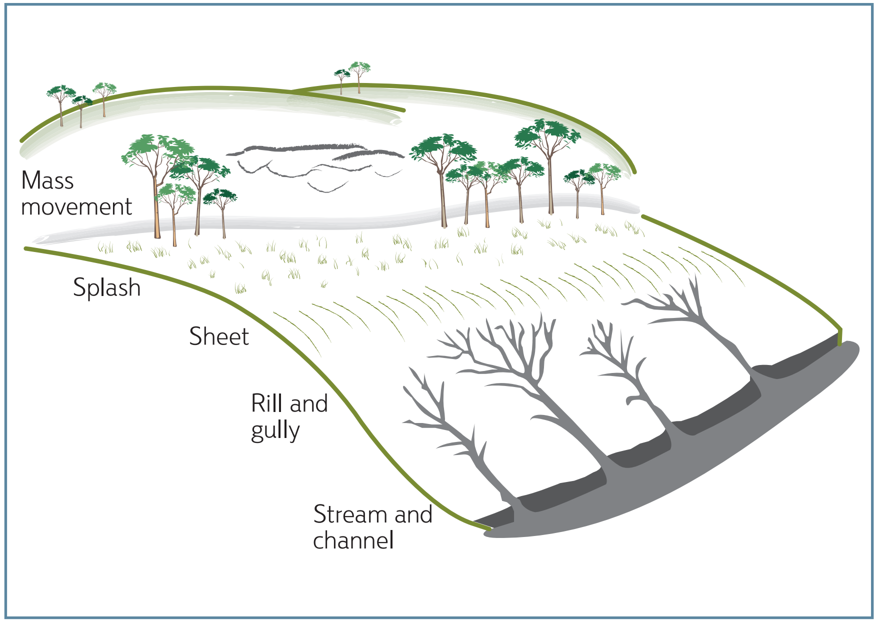
Erosion processes

When the velocity of the water or wind carrying soil particles is reduced, heavier soil particles drop out as sediment. Around 90% of sediment eroded by water is deposited on low lying land and in waterways, lakes and dams where it causes pollution and loss of aquatic habitat. The remaining 10% of sediment reaches the ocean. Sediment is the most common water pollutant in the world.

Types of erosion

Erosion takes many forms due to the effects of climate, topography, land use, groundcover and the erodibility of the soil type.

Types of erosion
Adapted from: http://www.cep.unep.org



Splash erosion

Splash erosion is the first stage of the water erosion process. It occurs when raindrops hit bare soil. The explosive impact breaks up soil aggregates so that individual soil particles are 'splashed' onto the soil surface. The splashed particles can rise as high as 60 cm above the ground and move up to 1.5 m from the point of impact. The particles block the spaces between soil aggregates, so that the soil forms a crust that reduces infiltration and increases runoff. Vegetation or mulch cover can reduce or prevent splash erosion.

Splash erosion

Sheet erosion

Sheet erosion is the removal of soil in thin layers by raindrop impact and shallow surface flow. It results in loss of the finest soil particles that contain most of the available nutrients and organic matter in the soil. Soil loss is so gradual that the erosion usually goes unnoticed, but the cumulative impact accounts for large soil losses. Early signs of sheet erosion include bare areas, water puddling as soon as rain falls, visible grass roots, exposed tree roots, and exposed subsoil or stony soils. Soil deposits on the high side of obstructions such as fences may indicate active sheet erosion.

Sheet erosion
Source: Col Begg NSW DPI

Soils most vulnerable to sheet erosion are cultivated and overgrazed soils where there is little vegetation to protect and hold the soil. Vegetation cover is vital to prevent sheet erosion because it protects the soil, impedes water flow and encourages water to infiltrate into the soil. The surface water flows that cause sheet erosion may concentrate and cause rill erosion depending on the slope, soil surface and soil erodibility.

Rill erosion


Rill erosion Source: Terrence Hudson

Rills are shallow drainage lines less than 30 cm deep. They develop when surface water concentrates in depressions or low points through paddocks and erodes the soil. Rill erosion is common in bare agricultural land, particularly overgrazed land, and in freshly cultivated soil where the soil structure has been disturbed.

The rills can usually be removed with farm machinery. Rill erosion can be reduced by reducing the volume and speed of surface water with grassed waterways and filter strips, ripped mulch lines, contour drains and graded banks. Cropping systems that use minimal cultivation and retain more than 70% groundcover will prevent rills forming. Rill erosion is often described as the intermediate stage between sheet erosion and gully erosion.

Gully erosion

Gullies are channels deeper than 30 cm that cannot be removed by normal cultivation. They can be spectacular to look at, but in the long term they stabilise and cause less soil loss than sheet and rill erosion. Gullies occur when smaller water flows concentrate and cut a channel through the soil. Most gullies extend upslope as a result of the head of the gully being continually undercut and collapsing. However, collapse and slumping of sidewalls usually contribute a greater proportion of soil loss.

Tunnel erosion


Tunnel erosion Source: David Morand DECC

Tunnel erosion occurs when surface water moves into and through dispersive subsoils which erode easily when wet. The tunnel starts when surface water moves into the soil along cracks or channels or through rabbit burrows and old tree root cavities. Dispersive clays are the first to be removed by the water flow. As the space enlarges, more water can pour in and further erode the soil. As the tunnel expands, parts of the tunnel roof collapse leading to sinkholes and gullies. Indications of tunnel erosion include water seepage at the foot of a slope and fine sediment fans downhill of a tunnel outlet.

Wind erosion

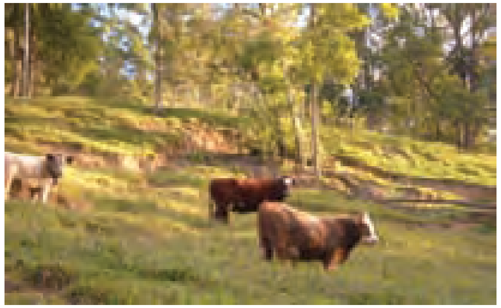

Wind erosion Source: Michel Dignand NSW DPI

Wind erosion is the detachment and movement of soil particles by air moving at more than 20 kph. Wind moves the soil in two ways, suspension and saltation. Suspension occurs when the wind lifts finer particles into the air, leading to dust storms. Saltation occurs when the wind lifts larger particles off the ground for short distances, leading to the formation of sand drifts.

Wind erosion tends to occur predominantly in low rainfall areas when soil moisture content is at wilting point or below, however all drought-stricken soils are at risk. Often the only evidence of wind erosion is an atmospheric haze of dust comprising fine mineral and organic soil particles that contain most of the soil nutrients. Actions to minimise wind erosion include improving soil structure so wind cannot lift the heavier soil aggregates, retaining vegetative cover to reduce wind speed at the ground surface and planting windbreaks. Landholders should be prepared for severe wind erosion in summers after dry autumns and winters.

Mass movement

Mass movement is the downward movement of soil and rock under the influence of gravity. It is most frequent on slopes above 25° with little vegetation and annual rainfall over 900 mm, and often occurs after heavy storms when soil becomes waterlogged and heavy.



Mass movement

Mass movement is common due to the region's geology and intense rainfall events. Factors increasing mass movement include erosion or excavation undermining the foot of a slope, weight loads of buildings or embankments, and loss of stabilising root systems and changes in soil water pressure through removal of vegetation. Remediation actions include diverting water away from slip-prone areas, fencing off suspect areas, and revegetating with trees and perennial pastures.

Streambank erosion

Erosion of streambanks can be caused by the erosive force of stream flow, which scours out the bank, or by bank collapse and slumping due to loss of vegetation and trampling of bank soil by livestock. Remediation actions include removal of livestock, revegetation and strategic bank or channel works.

Streambank erosion

Universal Soil Loss Equation

US scientists developed the Universal Soil Loss Equation in the 1950s to predict soil loss due to water erosion in agricultural fields. Using the equation, soil loss was calculated as the product of weighted factors for:

» rainfall erosivity

» soil erodibility

» slope length and gradient

» groundcover

» prevention practices.

While the first two factors are fixed for any particular situation, landholders can have a significant impact on the calculation by shortening slope length, establishing groundcover and introducing prevention practices.

The USLE has been extensively revised and is now known as the Revised USLE or RUSLE. It uses complex computer modelling to calculate erosion losses, and is the province of erosion specialists.

Erosion factors

Several factors contribute to soil erosion processes:

climate, soil erodibility, landscape, groundcover and land use.

These factors combine to determine a soil's erosion hazard. Each specific land use has its own erosion hazard.

The risk of erosion varies with land use and a site's position in the landscape.

Climate

Climate can be defined as the variability of weather conditions prevailing over a specific period of time for a particular region. In the region the principal climate factors influencing erosion associated with agricultural practices are rainfall, temperature and wind speed.

Rainfall factors

Rainfall erosivity is the capacity of the rainfall to cause erosion. Heavy, fast falling rain is much more erosive than gentle soft rain. Rainfall erosivity is the principal cause of soil erosion in the region where large amounts of rain can fall in a very short time. The region has the highest annual rainfall in the state. The table on page 144 shows mean monthly rainfalls in the region.

Frequency of rainfall

Rainfall frequency is defined as the number of rain days per month. If rain falls every day, and there is no sunlight to evaporate the moisture, soil becomes saturated, leading to runoff and possible surface erosion. In some cases mass movement of soil can occur, where water draining through the soil flows along a harder subsoil or rock, creating a slippery plane on which the heavy wet soil slides. In the region, the mean number of rain days per month varies from 6 in the drier months to 17 in the wet season, depending on location.

Intensity of rainfall

Rainfall intensity is measured by the amount of rain that falls within a given time. Severe storms can dump huge amounts of water in a short time, producing large volumes of fast-flowing runoff that scour the soil and carry tonnes of soil into waterways. Where there is intense rainfall over a longer period, there is much greater likelihood of erosion and mass movement. While exceptional rainfall events can occur at any time, the long term average monthly rainfall figures are the most reliable guide for planning on-ground activities that can disturb the soil or leave it devoid of groundcover for any length of time. This information helps landholders plan their activities for times when there is less potential for erosive rainfall.

Mean monthly rainfall (mm) recorded at selected weather stations since records were collected.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alstonville	177.6	234.3	283.7	196.8	198.6	151.5	91.9	73.0	52.4	108.3	132.2	160.6
Armidale	104.5	98.6	65.0	45.9	44.4	57.1	49.2	48.4	58.7	79.6	109.6	89.2
Bellingen	180.2	199.6	217.3	153.7	119.0	108.6	79.4	57.6	56.2	96.2	111.9	137.6
Casino	134.7	158.9	149.5	95.6	79.6	66.5	58.3	42.0	42.1	69.6	85.7	114.8
Coffs Harbour	180.3	215.3	245.2	179.7	167.1	112.9	74.7	78.1	60.0	88.0	129.8	146.0
Glen Innes	112.6	92.1	71.9	43.0	48.4	55.8	54.3	50.5	55.5	79.3	86.9	107.5
Grafton	129.9	127.5	119.2	85.3	68.0	65.5	56.5	40.4	45.9	62.7	79.2	101.6
Kempsey	133.4	153.4	153.7	115.8	94.9	96.4	67.9	62.0	55.1	77.1	91.8	110.2
Lismore	155.4	183.6	188.4	129.2	115.3	97.0	80.3	54.9	50.4	73.2	94.1	121.3
Murwillumbah	189.7	234.7	223.9	170.0	150.4	88.0	70.7	50.0	39.3	84.9	124.4	158.6

Seasonal distribution of rainfall

Seasonal distribution of rainfall describes the rainfall pattern during the year. Traditionally, the region's rainfall is heaviest in the summer and autumn, and driest in the winter and spring. Landholders know that it is important to have groundcover in the summer and autumn months to protect the soil during expected periods of intense, erosive rainfall. However, the seasonal distribution is not entirely predictable, and unusually heavy falls can occur in the traditionally drier months.

Amount of runoff

Rainfall becomes runoff when the soil cannot absorb the falling rain. Once rainfall is greater than the soil's capacity to absorb it, water collects on the soil surface and runs off into drainage lines. As the water flows across the surface, the force of the flow detaches and transports soil particles. The topsoil often has greater infiltration capacity than the subsoil, so once the topsoil is saturated, runoff will increase because the rainfall cannot infiltrate the subsoil. This occurs particularly where there is a clay subsoil underneath a sandy topsoil. Continued rainfall on such a soil can cause severe erosion due to the high runoff.

Intense rainfall leads to erosive runoff. Source: Lynette Walters

Temperature and wind speed

While rainfall is the main climatic influence on erosion in the region, temperature also influences erosion. Hot dry weather dries out soils, particularly in areas further away from the coast, and makes the soils prone to wind erosion. Winds detach the dry soil particles and carry them either along the soil surface or in the air. Air haze seen in the region in dry periods is actually due to the presence of tiny suspended soil particles. The dry particles are also easily eroded by water when droughts break. Frosts can also influence erosion by killing off groundcover and making the soil more easily eroded.

Soil erodibility

Soil erodibility is the soil's susceptibility to erosion, and is determined by how easily soil particles can be detached and transported from the soil surface. Larger soil particles such as sand are more easily detached. Smaller particles such a clay are more easily transported. Highly erodible soils can be up to 10 times as susceptible to erosion as less erodible soils.

Soil location

Soils tend to erode differently in different parts of the catchment. Soil behaviour at the top of hillslopes is determined by the rocks from which the soil is derived. Soils lower down the slope comprise parent material and soil particles eroded from higher up the slope. Lowest parts of the landscape and hollows naturally tend to be wetter than other parts of the landscape. The higher soil moisture levels promote plant growth, so there is less erosion.

Tops of ridges

On the tops of ridges, soils have often eroded down to weathering rock, forming very stony soils. Soils remaining between the rocks are highly erodible due to their shallowness and to the minimal vegetation cover due to poor nutrient levels.

Upper catchments

In upper catchments where streams begin, slopes are generally steep. In times of heavy rainfall the force of water pouring down the steep slopes erodes soil in its path, often forming gullies. It is good management practice to leave vegetation intact on steep slopes to minimise erosion.

Lower slopes and floodplains

Soil eroded from the steep upper catchments settles out as the water flow slows down, depositing alluvial soils in valleys and floodplains. These soils are high in organic matter, usually fertile, sometimes poorly drained, with potential for erosion.

Soil texture

Soil texture is determined by the proportion of sand, silt and clay particles in the soil. Fine-textured soils high in clay have low soil erodibility levels because the clay particles are firmly attached to each other and not easily separated by force. However, in droughts they can dry out and be picked up by wind, creating haze. Self-mulching clays that break down naturally into small particles are highly erodible because the particles are easily detached by wind and water.

Coarse-textured soils high in sand are not easily eroded by water because rainfall can infiltrate them easily, so there is little runoff to detach and transport them. However, sandy soils are prone to wind erosion because the individual particles are easy to detach.

Medium-textured soils high in silt are the most erodible. These soils tend to produce increased runoff, and the soil particles are easily detached and transported.

Soil structure

Soil structure, the arrangement of soil particles and aggregates, has a great impact on erodibility. In soils with good structure, soil particles are bound together in aggregates by organic gums, and iron and aluminium oxides. The larger aggregates are hard to break apart into individual particles, and harder to move by water or wind. In soils with poor structure, the individual particles are held together by pressure, so are easily detached by the force of wind or water.

Well-structured soils with large aggregates like this one are less prone to erosion.

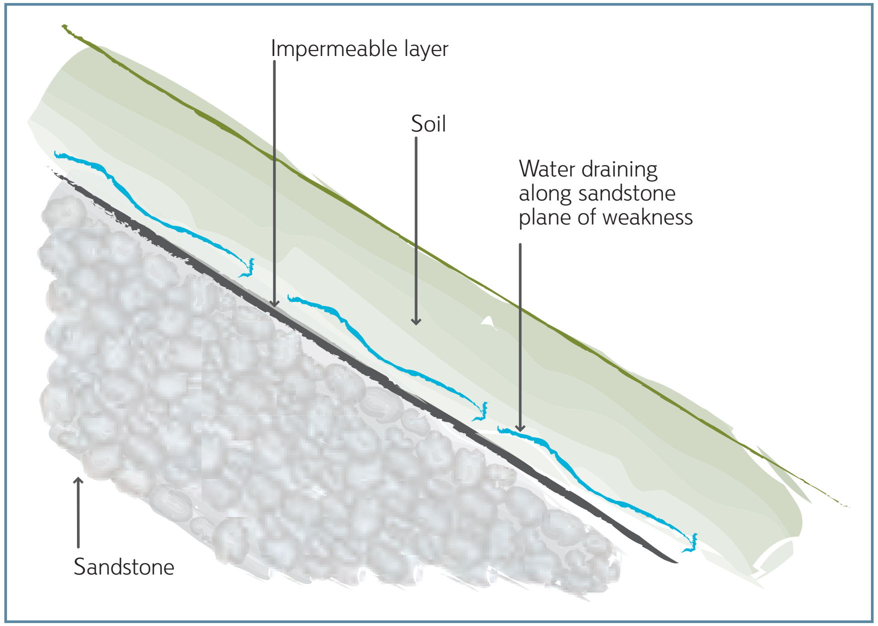
Organic matter (humus)

High humus levels in the soil helps soil particles aggregate into larger lumps that are heavier and more difficult for wind or water to move.

Soil permeability

Soil permeability affects how well water can move through the soil. Soils with low permeability increase runoff. In the region this is a particular problem where heavy clay subsoils underlie sandy topsoils because the movement of the water accumulating at the subsoil surface erodes the sandy layer above. It is also a problem in soils lying over clay or rock where the water flows along the underlying subsoil or rock, creating a slippery plane along which the heavy, saturated soil can 'slide'. Permeability is also reduced in soils with compacted layers caused by animal or machinery, or in soils with surface crusts.

Soil permeability



Seasonality

Soils vary in erodibility during the year. Soils are more erodible by water when soil moisture is high, because runoff is greater. They are more erodible by wind in dry seasons, because soils are drier and lighter, and particles are more easily detached.

Erodibility of Northern Rivers soil types

Dermosol

Source: David Morand DECC

Dermosols

These are well-structured soils commonly formed on basalts, but not restricted to them. They vary in depth up to 1 m, with a topsoil of clay loam to light clay and a subsoil of light medium to heavy clay. They are often dark and include the soils also known as chocolate soils. They are found west of Dorrigo, at Ebor, and east and northwest of Lismore including Kyogle and up to the McPherson Range. They are common soils of the steeper basaltic and sedimentary country, but also occur within alluvial plains.

Erosion hazard: Moderate to high depending on slope and groundcover.

Ferrosol

Source: David Morand DECC

Ferrosols

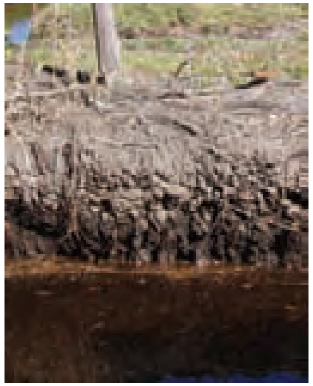
Ferrosols are friable red soils generally derived from basalt. As the name suggests, these soils are high in iron. Their red colour is due to high iron oxide content, which promotes good structure. The soil profile grades from a clay loam topsoil to a medium clay subsoil. These soils are often very friable and crumbly.

Erosion hazard: Prone to water erosion if left bare.

Hydrosols

These are wet soils of coastal and inland swamps. Those on the coastal floodplains often contain potential acid sulfate soils. These wet soils are generally characterised by a bluish grey subsoil, a reflection of the lack of oxygen available.

Erosion hazard: Given their location and high clay content, they are highly unlikely to erode. However, acid scalds may be subject to wind erosion.



Hydrosol

Source: David Morand DECC

Kandosols

These soils generally uniform throughout the profile and lack structure. They are usually loamy with a gradual increase in clay content at depth. Freshly turned, they are dull and dusty rather than shiny like clay soils. Differences in subsoil colour are due to several factors, including drainage and parent material.

Red Kandosols occur in several isolated patches underlain by igneous, sedimentary and metamorphic rocks. The topsoil is sandy clay loam, changing to light clay at depth. They are generally very permeable, well-drained and highly erodible. In the region, they are found north west of Dorrigo, west of Sawtell, Bostobrick, and Round Mountain.

Kandosol

Source: David Morand DECC

Yellow Kandosols are yellow due to poorer drainage, but the colour may only reflect that of the parent material. The topsoil is grey brown to brown and below that yellowish. They are found in the Macleay and Hastings valleys, and on alluvium derived from metamorphic rocks.

Erosion hazard: Highly erodible.

Kurosol

Source: David Morand DECC

Kurosols

These strongly acid soils generally have a marked textural difference between the topsoil (usually a sandy loam) and the subsoil (a heavy clay). They are also known as duplex soils because of this texture difference. They develop from sedimentary and metamorphic rocks. These soils are extremely erodible once vegetation is removed so are best left under natural forest cover.

Erosion hazard: Highly erodible once cleared.

Podosol

Source: David Morand DECC

Podosols

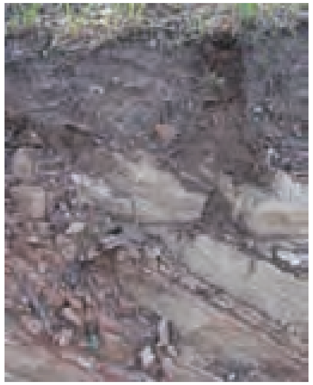
Podosols are sandy soils with a bleached horizon overlying subsoils that have accumulated organic matter or iron oxides. They are typical of older coastal sand dunes and sand plains, but can also be found inland, derived from granites and sandstones.

Erosion hazard: Erodible when dried out.

Rudosols

Rudosols are stony soils with no real soil horizons. They are found on steeper slopes where much of the soil has eroded away, and on dunes, and are also formed on recent sediment within floodplains. The soils saturate rapidly in heavy rain, leading to early runoff. They are highly erodible, particularly on slopes where there is minimal vegetation due to poor nutrient levels. These soils are best left under natural cover to reduce the erosion hazard.

Erosion hazard: Highly erodible.



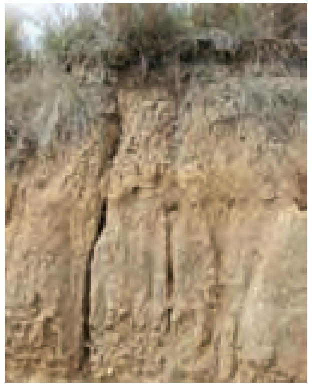
Rudosol

Source: David Morand DECC

Sodosols

Sodosols are mildly acidic to alkaline duplex soils with high levels of exchangeable sodium cations in the subsoil. When sodic soils are wet, each clay particle becomes surrounded by a significant water film which forces the particles away from each other. When this happens, the clay particles are said to have dispersed. The dispersed particles are seen as cloudy water in runoff. Dispersible soils are of concern to farmers because they are easily eroded by water. Erosion in sodic soils is often in the form of gully and tunnel erosion.

Erosion hazard: Extremely high.



Sodosol

Source: David Morand DECC

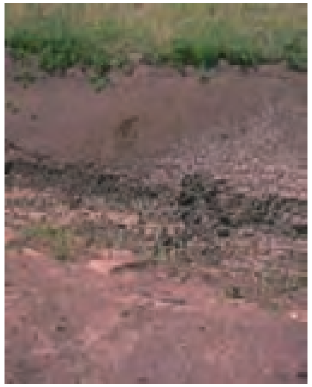
Tenosol

Source: David Morand DECC

Tenosols

Tenosols are shallow, stony soils similar to Rudosols, but with some soil formation evident (eg a colour change with depth).

Erosion hazard: Highly erodible.



Vertosol

Source: David Morand DECC

Vertosols

These soils are also known as cracking clays. The Richmond River floodplain between Casino and Coraki is dominated by Vertosols that are generally derived from basalt. Montmorillonite is the main clay mineral in these soils; leading to significant shrinking and swelling with changing soil moisture contents. Vertosols are often described as self-mulching due to the development of a fine aggregate assemblage on the surface.

Erosion hazard: Very low given its high clay content and low position in the landscape, but sheet erosion is common when groundcover is removed.

Soil tests for high risk soils

Sodicity and the dispersible soils that result increase the risk and extent of soil erosion. It is important to understand if your soils have these problems, especially when planning earthworks and constructing dams.

Field test for dispersion

- Place a small lump of soil in a dish of rainwater (not chlorinated tap-water).
- If a milky cloud appears around the lump as it breaks down, the soil is probably sodic.
- Avoid constructing any structures in these soils if possible.
- If construction is necessary, get the soil laboratory tested.

Laboratory tests will provide information of the extent of the problem, the possibility of and appropriate strategies for successful amelioration to reduce the risk of major erosion. Check with the laboratory to which you will send your soil sample about the information you need to provide and instructions on how to collect the soil sample.

Emmerson Aggregate Test (EAT)

This test is used to determine gypsum requirements to reduce crusting in cultivated soils, or to assess the suitability of subsoils for constructing water holding embankments.

The EAT test is based on observations of a soil crumb placed in distilled water. The soil is classified on a scale of 1 to 8, where class 1 soils are completely dispersible and class 8 the most stable.

The best result for dam construction is in the middle range, classes 3–5. This is because dam walls built from soils that disperse too much may fail due to piping and tunnelling, while those built from soils with too little dispersion will not compact and reform sufficiently to produce a seal.

Class 1 soils have a high susceptibility to tunnelling and should be avoided for the construction of embankments. Class 2 soils may be acceptable if treated with an ameliorant such as gypsum to reduce dispersion. At the other end of the scale, embankments constructed from soils with a score of 6–8 are unlikely to hold water without extra efforts to achieve compaction and an ameliorant such as sodium tripolyphosphate (STPP) to induce some dispersion.

Exchangeable sodium percentage (ESP)

Soils are considered sodic when the ESP is >6%. Soils with an ESP between 6–14% are moderately dispersive, and have been associated with dam walls failing due to tunnelling. Soils with an ESP >14% are highly dispersible and are highly susceptible to tunnelling, and also to surface sealing which makes them difficult to revegetate.

Particle Size Analysis (PSA)

PSA is used to classify the texture of the soil. Knowing the texture of a soil is very useful in predicting its behaviour in different conditions, its susceptibility to erosion and its permability – the speed at which water moves through the soil. The texture grade is a more specific classification than the soil types described on page 150.

In a PSA test soil aggregates are physically broken up and agitated into water, so that the laboratory can separate the particles into different fractions based on the size of the particles.

20–20000µm	sand
2–20 µm	silt
0–2 µm	clay

Particle size analysis is essential to determine the dispersion percentage of the soil.

Dispersion percentage

This test is used to identify whether earthworks in this type of soil are likely to fail due to tunnelling. The test estimates the percentage of the soil material (clay and fine silt) which is easily mobilised in water. Highly dispersible soils have a high dispersion percentage.

A PSA test must be undertaken first. A sample of the soil is shaken in water, the liquid drained off and the PSA analysis performed again on the remaining soil. The dispersion percentage is the ratio of the percentage of soil particles <5 µm remaining after the shaking in water test compared to the original PSA result.

The critical values for dispersion percentage in terms of a soil's suitability for earthworks depend on the proportion of clay (particles <5 µm) in the soil (table below). Earthworks and embankments constructed in soils with higher than critical dispersion percentage values are likely to fail due to erosion.

The critical dispersion percentage for soils depends on the proportion of small particles in the soil.

Total % of soil particles <5µm	Critical dispersion percentage
25	20%
30	33%
35	42%
40	50%
50	60%

Landscape

Land uses appropriate for the landscape with cropping on the river flats, a well-vegetated riparian corridor, grazing on lower slopes and forest on the steeper slopes. Source: Natalie Moore NSW DPI

Land use

Choosing an appropriate land use is the main consideration for landholders in preventing and managing soil erosion. In the first instance, this means choosing a land use appropriate to the slope. The more level the land, the more land use options are available. As the land becomes steeper, fewer land use options are practicable, particularly bare soil cultivation as cultivated soil is extremely vulnerable to erosion.

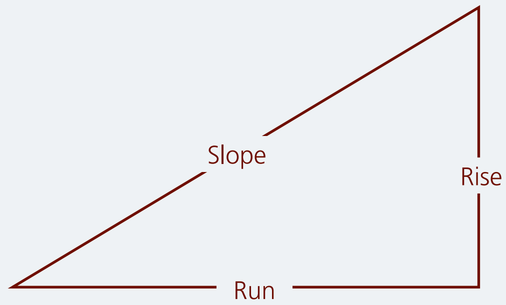
Slope length and gradient

Water erosion increases with steepness and slope length. The steeper the slope, the faster and more forceful the runoff. The longer the slope, the greater the volume of water in the runoff. Doubling the slope percentage approximately doubles the soil loss on slopes that are likely to erode. Slope has a much greater effect on rill and gully erosion than on sheet erosion.

Slope percentage and slope degree

Slope percentage is calculated as the rise of the slope divided by the run times 100.

For instance, the slope percentage of a slope that rises 1 metre for every metre of run is calculated as (1÷1) × 100 = 100%, which is equivalent to a 45° angle.



The table below gives some slope percentages and angle equivalents. In NSW slopes greater than 18° or 33% are defined as protected lands.

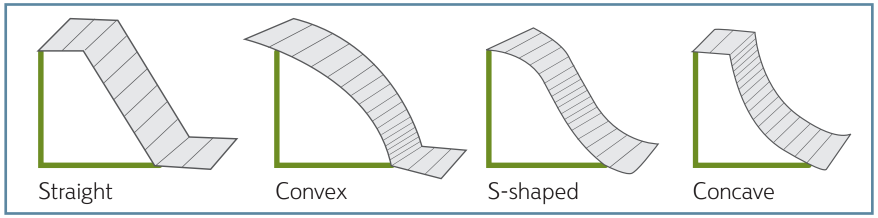
Slope percentage and slope degree

Slope (%)	5	10	15	20	25	30	33	36	58	100
Slope degrees	2.5	5.7	8.5	11.3	14	17	18	20	30	45
1 in	20	10	6.6	5	4	3.3	3	2.8	1.6	1

Slope shape

The shape of a slope indicates how stable it is. Straight slopes and S-shaped slopes tend to be more stable than concave or convex slopes. Erosion at a specific location on a slope depends on its distance from the origin of the surface runoff and the steepness at the location. If the location is far down the slope and runoff has accumulated from above, soil will erode quickly.

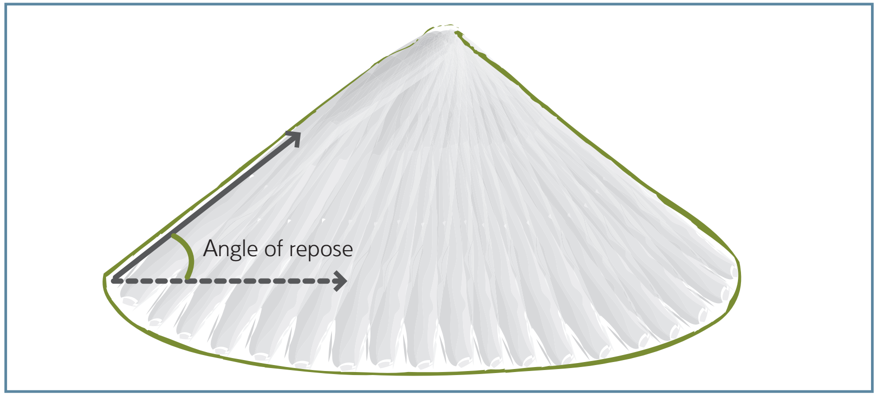
Slope shapes



Angle of repose

The angle of repose is the angle a pile of soil forms naturally with the ground. The maximum angle of a stable slope is determined by the shapes of the particles, their cohesion and friction. Soil that is steeper than its angle of repose is more likely to erode.

Angle of repose



Slope management recommendations

The following table indicates the standard land use for different slopes in the landscape. However, erosion potential also increases with soil erodibility and slope length and these factors must be taken into account. In the more western parts of the region, it is general practice not to cultivate areas with slopes greater than 10% (5.7°).

Erosion hazard and management practices for different slopes.

Slope (%)	Landscape	Erosion hazard	Runoff rate	Management
0	Level	Very low		
1	Nearly level			
2				
3	Very gentle slope	Not severe		Cultivation normally practised and erosion control readily achieved by conventional management and simpler control practices
4		Increasing erosion		
5				Cultivation practised but may need a range of erosion control practices including contour banks
6	Gentle slope			
7				
8			peaks ~ 8%	
9	Moderate slope	Rapid increase in erosion		Cultivation should be periodic with the protection of a full range of control practices including graded banks. Contour banks should be avoided as they tend to pond water. Pasture or forestry preferable.
10				
11				
12				
13				
14				
15				
16	Steep slope			
17				On slopes >16% native vegetation is preferable with carefully controlled grazing, if at all. Bench terraces allow cultivation.
18				
19				
20-25		Erosion rate peaks and levels off		
26-30				
>30	Very steep slope			

Legislation

The control of soil erosion in New South Wales is administered under several Acts. Current versions of all Acts are available through the Internet.

Soil Conservation Act 1938

This Act aims to protect catchment areas, rivers, lakes, lagoons, creeks, swamps and marshes from the effects of soil erosion, land degradation, siltation and sedimentation.

Native Vegetation Act 2003

This Act provides for the identification and mapping of areas that are vulnerable to soil erosion, sedimentation and landslip. The Vulnerable Land Natural Resource Management Plan, made under this Act, identifies three categories of such areas (known as 'vulnerable land'). The three categories are steep or highly erodible land, protected riparian land, and special category land. Clearing of native vegetation on these mapped lands requires approval except in particular situations specified under this Act. This Act includes provisions in Property Vegetation Plans to require work to prevent adverse impact on soils when clearing takes place.

Water Management Act 2000

This Act provides for the integration of the management of water with soils and other aspects of the environment. Water activities, works and use should avoid or minimise land degradation impacts.

The Act now incorporates provisions that were formerly included in the Rivers and Foreshores Improvement Act 1948 relating to permits under Part 3A of that Act.

Protection of the Environment Operations Act 1997

Part 5.3 of this Act prohibits the pollution of waters.

Fisheries Management Act 1994

Part 7 of this Act protects fish habitat, and prevents blocking of fish passage by construction of a dam, floodgate, causeway or weir, or otherwise causing an obstruction.

Environment Planning and Assessment Act 1979

This Act requires conditions of consent for erosion controls as part of development consent. Check with the local council before undertaking any work that disturbs soils.

Common Law

English common law recognises that the landowners have the sole right to possess natural resources on their land, and manage them how they wish, as long as exercising that right does not impact on the rights of adjacent landholders. This means landholders whose soil erosion impacts on adjacent land may be liable for the damage caused to the neighbour (Bates 2002)[1].

1 Bates, G., 2002. Environmental Law in Australia, 5th edition. Reed International Books. Chatswood

Worksheets

To understand erosion risks and how to manage them you need to understand how much water is likely to fall on and flow through your land, know how steep a slope is and what percentage of groundcover you have. The worksheets in this section will help you calculate these values.

Catchment information answers

Results from Worksheets 1A to 1E

Throughout this guide we suggest there are times when it may be useful to understand the amounts of water likely to concentrate at particular site – the peak discharge. We have prepared five activities to guide you through working out a site's peak discharge. You can use the table below to fill in your answers from the activities.

Name of site: ____

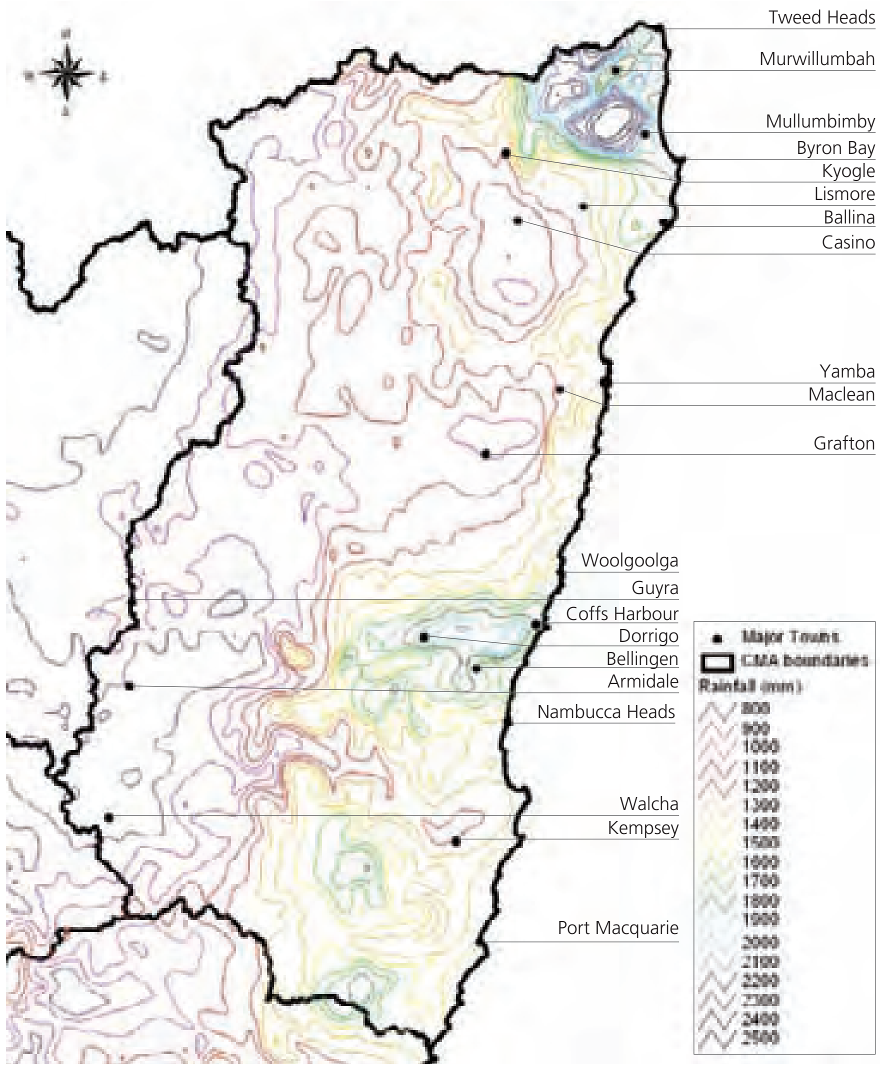
Location: ____

Type of structure
(eg contour bank, dam spillway): ______________________________

Worksheet Number	Catchment Information	Units
1A – Annual rainfall		mm
1B – Catchment area		ha
1C – Annual runoff yield		m^3
1D – Peak discharge in 1 in 10 year event		m^3/sec
1E – Risk period required		years
– Peak discharge for required risk interval		m^3/sec

1A: Finding average annual rainfall

To find the average annual rainfall, locate your property on the map below and match the colour to the rainfall legend.



For more accurate and detailed rainfall information (essential when designing structures) go to the Bureau of Meteorology (BOM) website at www.bom.gov.au, or contact the BOM NSW Regional Office on (02) 9296 1555.

1B: Estimating the size of a catchment

The catchment is all the area of land that water can drain from to a specific point the catchment outlet.

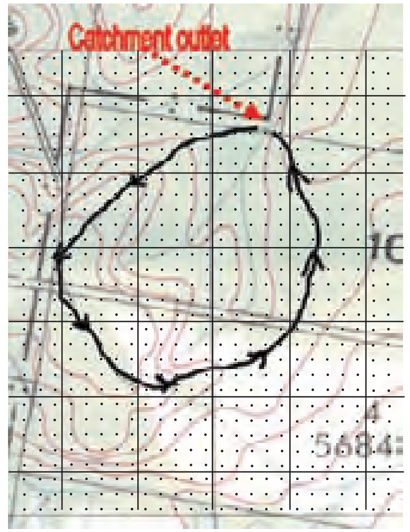
To complete this activity you will need:

» A 1:25000 topographic map for your area, and

» a dot grid overlay (available from newsagents). If you cannot purchase a dot grid overlay for your map you can make one yourself from a piece of clear plastic. Draw a grid with 1 cm squares, with 10 dots in each square.

1. Locate the catchment outlet – the point from which you want to know the size of the catchment above.
2. Draw a line around all the area that is uphill of your point of interest.
   - From one side of the point take a line out to follow where the contour lines make a convex bend away from your feature up to the ridge top or a higher drainage structure that diverts water away.
   - Do the same from the other side of your point.
   - Join the lines by following along the top of the ridge or higher drainage line.

   The line you have drawn is the catchment boundary.
3. Place your dot grid overlay over the map and count all the whole grid squares that lie within it. (Include dots that the catchment boundary is on top of). In the example shown there are 4 whole squares.
4. Count all of the dots in grid squares that are cut by the catchment boundary. In the example there are 114 dots in 10 incomplete squares.
5. To work out the area use the directions that came with your dot grid overlay, or if you are using a home-made one each grid square represents an area of 250 m x 250 m or 6.25 ha, and each extra dot represents an area of 0.25 hectare.



Catchment area (ha) = (number of whole squares x 6.25) + (number of dots from incomplete grid squares x 0.25)

From the example Catchment area = (4 x 6.25) + (114 x 0.25)
= 25.0 + 28.5
= 53.5 ha

If you are working from a map with a scale other than 1:25000 use this table to select the figures to multiply your numbers of squares and dots by.

Conversion factors for the dot grid overlay with different map scales.

Map scale	Hectares / dot	Hectares / cm^2
1:500	0.0001	0.0025
1:1000	0.0004	0.01
1:10000	0.04	1.0
1:12500	0.0625	1.5625
1:25000	0.25	6.25
1:50000	1.0	25.0
1:100000	4.0	100.0
1:250000	25.0	625.0

1C: Estimating annual runoff from a catchment (catchment yield)

There are several methods that can be used for estimating the amount of runoff you could expect in a given year from a catchment. The following process will give a rough estimate, and is simple to determine.

Average annual runoff (m^3) = A x R x P x 0.1

Where:

A is the catchment **area** in ha (from Worksheet 1B)
R is the average annual **rainfall** in mm (from Worksheet 1A)
P is the runoff **percentage** (select from table below).

Use the table below to estimate the percentage of rainfall that will run off your catchment with a reliability of 8 years out of 10. Find the range that your average annual rainfall would sit in and follow across to the column that describes the dominant soil properties in the catchment. The runoff percentage is given as a range, the lower limit would apply to a forested catchment, the upper to a farmed or developed catchment.

Catchment runoff

Source: Jackson, L. Earthmovers Training Course – Erosion control and design principles, 1992

Average annual rainfall (mm)	Runoff as a percentage of average annual runoff (P)			
	Shallow sand or loam soils (%)	Sandy clays (%)	Elastic clays (%)	Clay pans, inelastic clays, shales (%)
>1100	10–15	10–15	15–20	15–25
901–1100	10–12.5	10–15	12.5–20	15–20
501–900	7.5–10	7.5–15	7.5–15	10–15

1D: Estimating peak discharge

Peak discharge is an estimate of the largest amount of water that can be expected to flow out of a catchment during or immediately after a high rainfall event. The peak discharge is expressed as cubic metres of water per second (m^3/s) for a specified risk interval.

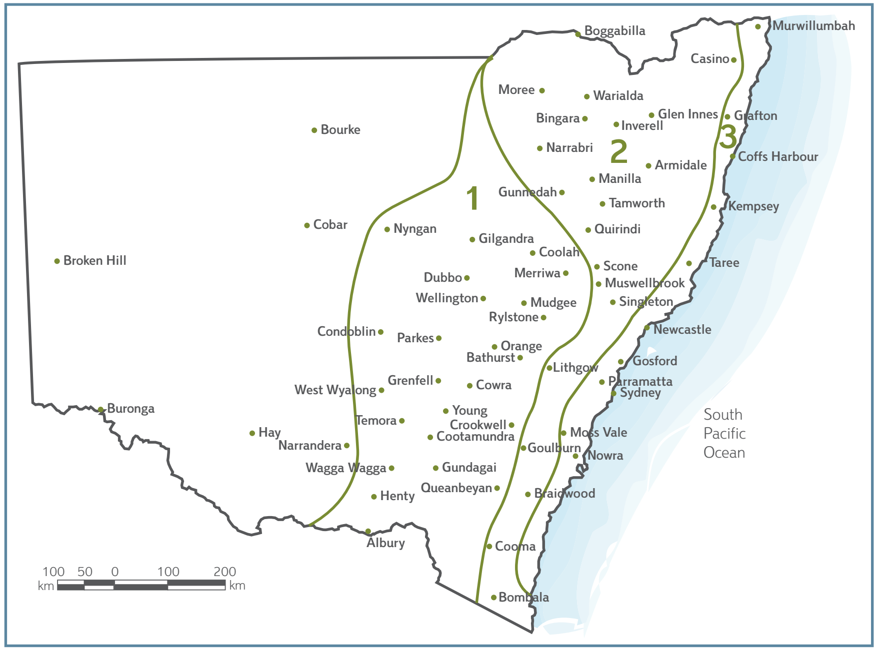
This is the amount of water that any structure at that point will need to be designed to accommodate.

There are a several ways to calculate an estimate of peak discharge. Some are quite complex and require detailed information resources. The method presented here is a simplified model that is applicable only for eastern NSW for catchment areas up to 260 ha in size.

1. Identify your zone (1, 2 or 3) from the map below.

NSW discharge zones

Source: Jackson, L. Earthmovers Training Course – Erosion control and design principles, 1992

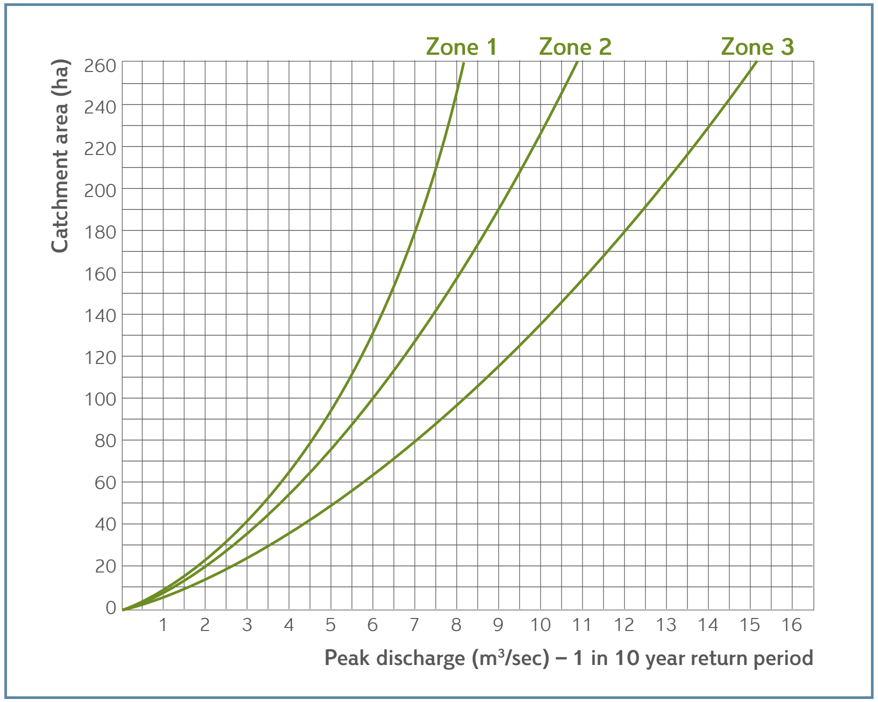


2. Using the grid diagram below:

- find the area of your catchment on the vertical axis to the left
- place a ruler horizontally across the diagram to draw a line across from that point
- mark the point where your line crosses the curve from your zone
- Turn the ruler so that it is lying vertically across the diagram, and draw a line from the point you have marked down to the bottom axis. This will give you the peak discharge for your catchment in m^3/sec for a 1 in 10 year flood. For example, the peak discharge for 1 in 10 years for a 15 ha catchment in Zone 3 is 2.2m^3/sec.

Estimate of peak discharge for eastern NSW

Source: Jackson, L. Earthmovers Training Course – Erosion control and design principles, 1992



Note: Increase discharge by 30% where catchments are continually farmed or for soils that have low infiltration rates. Decrease discharge by 20% for catchments not farmed or for soils with high infiltration rates.

1E: Calculating different risk intervals

The risk interval, or return period, is the average period in years between the occurrence of a storm of specified magnitude and an equal or greater storm. It is an average figure, not an interval. For example, a storm with a return period of 5 years does not occur regularly every 5 years, but would probably occur 5 times in a 50 year period.

A 10 year risk interval is the minimum you would want to use to design for drainage features like diversion banks. Small structures like a graded bank might use a lower risk interval such as 2 or 5 years. Dams and constructed waterways should be designed for 20 year risk intervals. Where there is risk of substantial damage should the structure fail use a higher risk interval.

To calculate a different risk interval multiply your 1 in 10 year peak discharge by the appropriate conversion factor.

Conversion factor for risk periods

Risk period (years)	2	5	10	20	50	100
Conversion factor	0.7	0.9	1.0	1.1	1.3	1.5

For example:

Where the peak discharge for a 1 in 10 year interval
= 2.2 m^3/sec

The peak discharge for a 1 in 50 year interval
= 2.2 m^3/sec x 1.3
= 2.86 m^3/sec

2: Estimating slope

Estimating slope over a paddock

Source: NSW Rural Fire Service, Building in bush fire prone areas – Guidelines for Single Dwelling Development Applications

1. Pick a spot between 40 m and 100 m away and have an assistant of similar height stand as a reference point. If you do not have an assistant pick a nearby tree as a reference point and tie a bright ribbon or tape around the trunk at your eye height.
2. Standing at the edge of the slope or at some point on the slope to be measured, hold one end of a centimetre rule 30 cm in front of your face, level with your eye so that it hangs down.
3. Looking past the rule at the assistants head or marker, note how many centimetres on the rule their head is below your eye level.
4. The table below will convert this to a slope range.
5. It is important to hold the end of the rule at eye level and let it hang straight down 30 cm in front so that a reasonable level of accuracy is gained.

Measurement on rule (cm)	Converted slope range
Less than or equal to 0	Upslope or flat
0–3	0–5°
3–5	5–10°
5–8	10–15°
8–10	15–18°
Greater than 10	Greater than 18°

Estimating slope over 1 metre

You can work out the grade of short slopes using a one metre builder's level and a tape measure. Rest one end of the bar (held level) on the track at a representative spot, and measure the distance down to the track surface at the point directly below the other end of your bar. This distance in centimetres is equal to the percent slope.

3: Assessing groundcover

Simple method – Quadrat measurement

Place a 50 cm x 50 cm square frame (quadrat) on the ground and estimate the percentage groundcover in it. Do this ten times across the paddock and average the results.

Simple method – Walking measurement

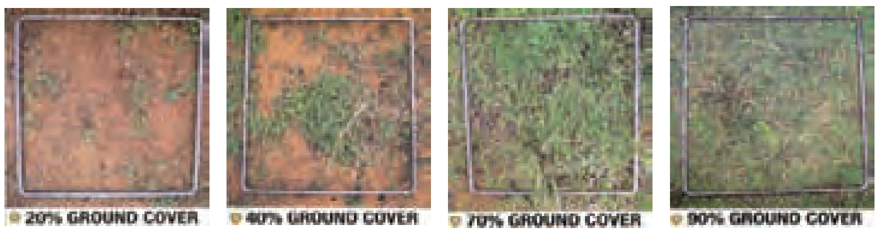
Take 10 paces and check how often your foot strikes bare soil or mud.

- 1–2 times means there is enough ground cover to protect the soil from erosion.
- 2–6 times means there is not enough groundcover to protect the soil.
- 7–10 times means the soil is likely to leave the paddock as dust or suspended in runoff water.

Detailed assessment – Step point method

(A more detailed version of the Walking measurement method). Using the field sheet overleaf:

1. Walk through the area and with each step record with a tally mark the groundcover type at the tip of your boot.
2. Count the tally marks for each category to give number of hits.
3. Add all hits together to give the total number of hits. (You need at least 100 hits to get meaningful results)
4. Calculate the percentage of hits by dividing the number of hits for each category by the total number of hits (check: percentage of hits column should add up to 100)
5. Subtract the bare soil percentage from the total (100%) to give an indication of your percentage groundcover.



Source: Greg Lodge NSW DPI

Field sheet for the Step point method

Paddock/area name: ______________________________

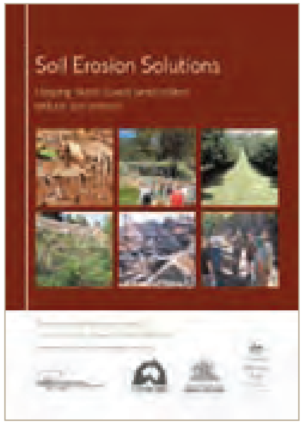
Date assessed: ______________________________

Groundcover type	Tally of hits	Number of hits	Percentage of hits
Grass			
Legume			
Weed			
Other plant			
Leaf litter			
Manure			
Rock			
Woody debris			
Bare soil			
	Total number of hits		
		Total	

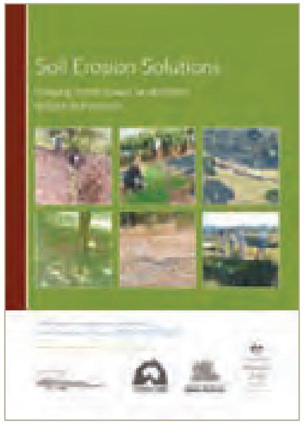
Groundcover = 100% – Bare soil % ☐

Soil Erosion Solutions publications

Case studies 2005-06



Case studies 2007-08



Fact sheet 1

Types of erosion

Fact sheet 2

Indicators of erosion

Fact sheet 3

Monitoring erosion

Fact sheet 4

Groundcover

Fact sheet 5

Gully erosion

Fact sheet 6

Roads and tracks

Fact sheet 7

Planning your erosion project

All available from: http://www.dpi.nsw.gov.au/agriculture/resources/soils/erosion

More information

The following pages list some useful publications that are referred to, or have been used to inform material in this guide.

NSW DPI

Establishing and managing smothergrass on macadamia orchard floors
http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0018/242271/establishing-andmanaging-smothergrass-on-macadamia-orchard-floors.pdf

Leaking farm dams
http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/164038/leaking-dams.pdf

Maintaining groundcover to reduce erosion and sustain production
http://www.dpi.nsw.gov.au/agriculture/field/pastures/management/production-management/groundcover

Managing in drought
http://www.dpi.nsw.gov.au/agriculture/emergency/drought/managing

Northern Rivers soil health card
http://www.dpi.nsw.gov.au/agriculture/resources/soils/testing/health-card

Protect your land - use cover crops
http://www.dpi.nsw.gov.au/agriculture/horticulture/vegetables/soil/protect

Protect your soil from compaction
http://www.dpi.nsw.gov.au/agriculture/resources/soils/structure/compaction

Sodic soils
http://www.dpi.nsw.gov.au/agriculture/resources/soils/sodic

Soil and water management practices for blueberry growers in northern NSW
http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/197190/Blueberry-soil-water-management-northern-NSW.pdf

Soil and water best management practices for NSW banana growers
http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/242359/soil-and-water-best-management-practices-for-nsw-banana-growers.pdf

SOILpak for vegetable growers
http://www.dpi.nsw.gov.au/agriculture/horticulture/vegetables/soil/soilpak

Soilwise pocket guide for looking after soils
http://www.dpi.nsw.gov.au/aboutus/resources/bookshop/soilwise

Other sources of information

Earthmovers training course. Soil Conservation Service 1992
http://www.lands.nsw.gov.au/soil_conservation/education_and_training

Farm dam - planning, construction and maintenance
Lewis, Barry (2002) Landlinks Press Collingwood.
http://www.publish.csiro.au/pid/2641.htm

Farm dams regulations
http://www.naturalresources.nsw.gov.au/water/dams.shtml

Keeping it in place: controlling sediment loss on grazing properties in the Burdekin River catchment
http://www.mla.com.au/NR/rdonlyres/F22B363E-5B5D-4DAD-8EDF-256F53E1F1B5/0/LPI395Keepingitinplace_300605small.pdf

Northern Rivers soil BMP guide - coffee
http://www.soilcare.org

Northern Rivers soil BMP guide - macadamias
http://www.soilcare.org

Northern Rivers soil BMP guide - perennial horticulture
http://www.soilcare.org

Northern Rivers soil BMP guide - vegetables
http://www.soilcare.org

Index

Notes

Saving Soil

A landholder's guide to preventing and repairing soil erosion

Soil is the basis of land fertility and productivity. Soil erosion degrades the land that the soil is lost from, and when it gets into our creeks and rivers it's pollution. This book is a practical guide to keeping soil on north coast farms. It explains how to:

- manage erosion in grazing, cropping and orchard enterprises
- control water flow using drains and banks
- avoid erosion when building dams
- build roads and tracks with minimal erosion
- fix gullies, tunnels and landslips
- calculate erosion potential.

Northern Rivers CMA Catchment Management Authority

NSW DEPARTMENT OF PRIMARY INDUSTRIES