Soil Conservation in a Changing Environment: Responding to an Emergency

Notes from the Dixon's Creek Workshop 22-24 June 2010

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Cover image: Erosion following the Kilmore East-Murrindindi fire in 2009.
Photographer: Tim O'Donnell, Nillumbik Shire Council.

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Background

About this workshop

Fire recovery, like other natural disasters, presents staff with a different range of problems and a new group of clients. Working in this field can be quite challenging, with a landscape that is highly susceptible to soil erosion and clients who have a range of conflicting priorities.

Significant government funding has been allocated to organisations such as DPI for fire, flood and drought recovery programs over the past 10 years. Within DPI, this funding has been used to provide a range of services including: case management, pest plant and animal control, soil conservation, pasture recovery, native vegetation management and whole farm planning.

The involvement of soil health staff in drought, bushfire and flood recovery over recent years has highlighted the need for DPI to undertake ongoing training in the soil erosion field. This workshop was run as part of DPI's 2009 Bushfire Recovery Program and was the result of a significant effort by management to enhance DPI's capability in this area.

The Dixons Creek workshop aimed to provide participants with basic skills in the control of soil erosion and sedimentation following a bushfire. The workshop focused on water erosion in grazing and forested land along the foothills of the Great Dividing Range. The workshop was attended by staff from Department of Primary Industries (DPI), Shire of Yarra Ranges, Nillumbik Shire Council, and City of Whittlesea.

The workshop aimed to provide the following competencies:

- a good understanding of the impact of soil erosion and sedimentation on private and public assets, and capability to undertake an erosion risk assessment
- a good understanding of the process and cause of soil erosion and the ability to identify the various types of soil erosion that occur in Victoria
- the ability to interpret, collect and record basic field data using a range of mapping and spatial techniques
- a basic understanding of techniques that can be used to control soil erosion and sedimentation following a bushfire, as well as the ability to select and implement basic control measures
- a basic understanding of the design, construction and maintenance of roads, stream crossings and dams, as well as an awareness of some of the more common problems that occur following a bushfire
- a good understanding of OH&S and responsibilities relating to soil conservation and sediment control works with a strong focus on bushfire recovery activities.

Photo opposite: The Dixons Creek Workshop.
Photographer: Lina Peralainen, DPI

Impact of bushfires

Impact of Bushfires

High intensity bushfires associated with forested land along the Great Dividing Range can have massive and long lasting impacts on soils, water, catchment health and infrastructure. When fires are combined with a long period of drought, the impacts are far worse.

All of the major bushfire events in this type of landscape over the past ten years have resulted in extensive erosion and sedimentation problems. The loss of vegetation, organic matter and topsoil dramatically increases runoff and makes soils highly vulnerable to erosion. The absence of actively growing plants after fire results in waterlogged soils and extended periods of streamflow and seepage.

Soil disturbance from stock, mining activities, logging and the network of roads and tracks has significantly aggravated the erosion problem in many parts of the state.

Following the recent Kilmore East-Murrindindi bushfires, many areas have experienced unprecedented runoff and flooding. While runoff calculations would suggest peak flood flows should only increase by around 30 per cent after a bushfire, anecdotal evidence suggests flows of far greater magnitude. In one location near Whittlesea a local creek has flooded surrounding farm land four times in four months. According to a local landholder, the creek has not flooded in the 44 years he has lived on this property.

Extensive sheet erosion has occurred across the entire fire-affected area. Most of the sloping country has been swept bare of ash and surface soil, while on steeper slopes, particularly those facing to the north, there has been a greater occurrence of sheet and rill erosion. Following the Grampians fires in 2005, between one and five centimetres of sandy topsoil was washed off the steeper slopes.

In both fire events, this sediment load has had a major impact on the physical and biological condition of local rivers and streams by blocking waterways and in many cases totally destroying the local ecology.

The ash and sediment has also had a significant impact on stock and domestic water supplies. It has reduced reservoir storage capacity, filled farm dams with sediment, and polluted the water – making it unsuitable for stock and domestic consumption.

The fires and subsequent rainfall events have had a massive impact on roads, tracks and crossings. Big flows, high sediment loads and fire debris have resulted in the destruction of many roads, stream crossings, culverts and associated road drainage systems.

The bushfires have also caused extensive gully and rill erosion. While the majority of sites where gully and rill erosion have occurred are associated with existing structures such as dams, roads and access tracks, some sites have developed in more pristine locations.

Photo opposite: Extensive sheet erosion following the Grampians bushfire, 2006. Photographer: Clem Sturmfels, DPI.

Causes of soil erosion

Introduction

In simple terms, soil erosion is the wearing away of the earth's surface. It is the process by which soil particles are detached, transported and subsequently deposited in another location. It is the result of various agents including wind, water, ice, gravity and a range of living organisms (e.g. wombats, rabbits, lichen).

Soil erosion by water has played a major role in the landscape today – the hills, valleys and mountain ranges. Without soil erosion there would be no highly productive deep alluvial soils, massive gravel deposits or spectacular scenery. Some soil erosion is essential to maintain the physical and biological health of the landscape and river systems.

While soil erosion played a major role in the development of the Australian landscape, the extensive erosion of crop and grazing land that has occurred across Australia over recent years is not part of the 'natural cycle'. Prior to European settlement, the Australian landscape had been stable for more than 10,000 years.

The situation is quite different in younger countries such as New Zealand where soil erosion continues to play a major role in shaping the landscape. In that country, the movement of very large quantities of sediment is an integral and important part of the natural cycle.

Above: Natural erosion associated with mountain uplift, New Zealand, 2004. Photographer: Richard Keys (private collection).

Photo opposite: Gully erosion, Moyston, 2006. Photographer: Clem Sturmfels, DPI.

Gully erosion in the Central Highlands of Victoria commonly occurs in deep valley trenches filled with alluvial sediments. The trenches and the sediments that fill them are a product of ancient erosion and deposition cycles. The shape and grade of these valleys is also a reflection of these cycles. A commonly held belief is that today's erosion problems are not 'man made' but simply a continuation of this 'natural' process. Science, however, does not support this theory.

Soil erosion normally occurs when there is a significant change in the landscape or in the forces that drive the natural cycle. These changes can be quite gradual or more sudden. Gradual changes include geological forces such as the uplift of mountain ranges in New Zealand, climate change or the evolution of plants and animals. The more sudden changes include earthquakes, fires, floods, droughts and human settlement. Soil erosion can also be initiated when the landscape crosses a 'geomorphic divide' such as when a river breaks through its banks to form a new channel.

The vast majority of Australian soils are very shallow, weakly structured and are relatively infertile. They are the weathered remains of a very ancient geological landscape. As a result, much of the Australian landscape is highly vulnerable to soil erosion. From a geomorphological point of view many parts of Australia were (and still are) sitting on a knife-edge, just waiting for a trigger to initiate a new erosion cycle.

Most of the soil erosion in Australia is the direct result of human activity (anthropogenic causes). A small change in runoff conditions, disturbance to the soil, or a combination of both, has had catastrophic impacts across Eastern and Northern Australia.

European settlement involved clearing native vegetation, the introduction of cloven-hoofed animals, overgrazing, rabbits and a range of cultivation and drainage practices. This resulted in less rainfall interception, less absorption, reduced retention rates and faster overland and stream flows – causing increased runoff and bigger flood flows. The physical condition of the soil was also changed through the loss of deep rooted native vegetation, leaf litter and organic matter. It was then subjected to surface sealing, compaction, and various forms of disturbance.

Anthropogenic gully erosion, upper Wimmera River catchment, 2004. Photographer: Clem Sturmfels, DPI.

The process of land degradation following European settlement in Victoria was captured in a very detailed letter written by Mr John G. Robertson to Governor Latrobe in 1853. In the letter he describes his experiences of migrating to Australia and settling in the Wannon district in 1840.

Robertson talks about the loss of deep-rooted native grasses, the soil becoming bare and compacted, the appearance of salt springs and hundreds of landslips. A quote from part of his letter is as follows:

"*Many of our herbaceous plants began to disappear from the pasture land; the silk-grass began to show itself in the edge of the bush track, and in patches here and there on the hill. The patches have grown larger every year; herbaceous plants and grasses give way for the silk-grass and the little annuals, beneath which are annual peas, and die in our deep clay soil with a few hot days in spring, and nothing returns to supply their place until later in the winter following. The consequence is that the long deep-rooted grasses that held our strong clay hill together have died out; the ground is now exposed to the sun, and it has cracked in all directions, and the clay hills are slipping in all directions; also the sides of precipitous creeks - long slips, taking trees and all with them. When I first came here, I knew of but two landslips, both of which I went to see; now there are hundreds found within the last three years.*

A rather strange thing is going on now. One day all the creeks and little watercourses were covered with a large tussocky grass, with other grasses and plants, to the middle of every watercourse but the Glenelg and Wannon, and in many places of these rivers; now that the only soil is getting trodden hard with stock, springs of salt water are bursting out in every hollow or watercourse, and as it trickles down the watercourse in summer, the strong tussocky grasses die before it, with all others. The clay is left perfectly bare in summer.

The strong clay cracks; the winter rain washes out the clay; now mostly every little gully has a deep rut; when rain falls it runs off the hard ground, rushes down these ruts, runs into the larger creeks, and is carrying earth, trees, and all before it. Over Wannon country is now as difficult a ride as if it were fenced. Ruts, seven, eight, and ten feet deep, and as wide, are found for miles, where two years ago it was covered with tussocky grass like a land marsh". [1]

While the clearing of forest is often associated with soil erosion, in areas such as the Wannon it was clear that more subtle changes initiated the erosion cycle. John G. Robertson attributes the damage to the change in plant species, overgrazing and compaction associated with the introduction of stock.

It is important to recognise that while some areas of the state are highly vulnerable to erosion, such as in the Wannon, other areas can be much more resilient. Much of the landscape in the Yarra Valley affected by the recent bushfires fits this category. In these areas, bigger changes are required to initiate the erosion cycle. The rate of erosion is relatively low and there are likely to be a bigger range of control options available.

Soil erosion physics

"Get the physics right, the biology will look after itself" says David Cummings, former DPI Soil Conservationist, about using logic and science to manage soil erosion.

While there are many complicated physical, chemical and biological interactions that influence the erosion and deposition cycle, the main process is driven by a few basic principles. A good understanding of these basic principles is essential in planning and implementing effective erosion control works.

Soil erosion involves the detachment, transportation and deposition of soil. The main factors that affect this process include the:

- ability of soil and vegetation to absorb the impact forces of falling water such as raindrops or waterfalls
- ability of soil and vegetation to withstand the frictional forces of flowing water, such as in a river or stream

[1] Robertson, JG 1853, Letter to Lieutenant-Governor Charles La Trobe dated 26 September, 1853, in Bride, TF 1898 (ed) *Letters from Victorian Pioneers,* Government Printer, Melbourne.

- energy level of falling water (potential energy)
- energy level of flowing water (velocity).

Erosion, transport and deposition of sediment in an erosion gully, Ararat, 2004. Photographer: Clem Sturmfels, DPI.

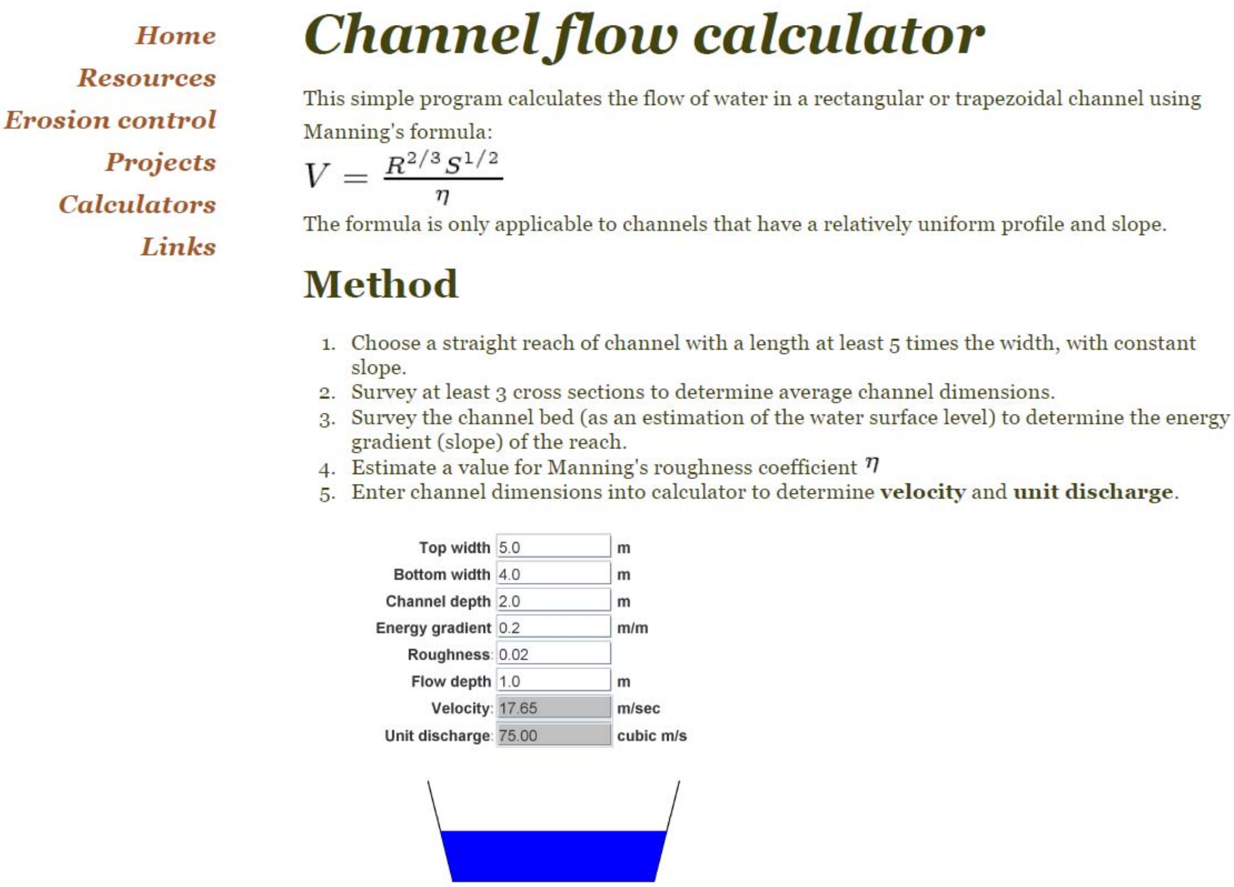
The ability of soil to withstand these forces is dependent upon the size, shape, density and distribution of its individual particles as well as soil structure and vegetation cover.

In simple terms, the rate of soil erosion (or deposition) is determined by the soil's inherent erodibility, its vegetation cover and by the force of the water hitting or flowing over its surface.

This principle forms the basis for most design work, whether it is a simple diversion bank or a more complex energy-dissipating structure. It is also the basis for the Revised Universal Soil Loss Equation which can be used to predict soil loss due to sheet and rill erosion.

Most design work is focused around the interaction between flowing water, vegetation and soil. The impact of forces such as rainfall and waterfalls tend to be ignored except when designing larger gully head structures.

Below: Web-based program for calculating stream-flow in a rectangular or trapezoidal-shaped channel, based on Manning's Equation. Source: http://stumbles.id.au/clem



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Channel flow calculator

This simple program calculates the flow of water in a rectangular or trapezoidal channel using Manning's formula:

$$V = \frac{R^{2/3} S^{1/2}}{\eta}$$

The formula is only applicable to channels that have a relatively uniform profile and slope.

Method

1. Choose a straight reach of channel with a length at least 5 times the width, with constant slope.
2. Survey at least 3 cross sections to determine average channel dimensions.
3. Survey the channel bed (as an estimation of the water surface level) to determine the energy gradient (slope) of the reach.
4. Estimate a value for Manning's roughness coefficient η
5. Enter channel dimensions into calculator to determine **velocity** and **unit discharge**.

Top width	5.0	m
Bottom width	4.0	m
Channel depth	2.0	m
Energy gradient	0.2	m/m
Roughness	0.02	
Flow depth	1.0	m
Velocity	17.65	m/sec
Unit discharge	75.00	cubic m/s

Relatively simple soil and vegetation erodibility tables, such as the one shown opposite, can be used to design most earthworks. Making use of these tables requires a basic understanding of channel hydraulics and maximum permissible velocities. Maximum permissible velocities describe the maximum speed of water that various soil types and grasses can tolerate before they start to erode.

The soil and vegetation erodibility tables are based on limited overseas research. While they appear to produce reliable results, they are conservative. The tables are based on the worst case scenario – extended periods of flow in saturated soils. Where flows are of a relatively short duration (less than 1 hour) on non waterlogged soils, maximum permissible velocities can be significantly higher than those shown in the existing tables. The author has noted well grassed, dry waterways tolerating flows in excess of 3 metres (m) per second.

The science of open channel hydraulics forms the basis for soil conservation design. One of the formulas used in open channel hydraulics, Manning's Equation ($V = R^{2/3} S^{1/2} /n$), is commonly used to calculate the depth, volume and velocity of water flowing in a man-made or natural channel. Manning's Equation and the soil and vegetation erodibility tables mentioned above are used extensively in the design of waterways, grass chutes and diversion banks. Manning's Equation can also be used to predict peak flood discharge and to check the capacity of various erosion control designs.

The speed of water in any open channel is determined by the shape and slope of the channel, the depth of flow and the roughness of the channel bed.

A web based tool for calculating flow in a simple trapezoidal-shaped channel, based on Manning's Equation is shown on the previous page.

In-situ soils are naturally much more resistant to erosion than soils recently deposited in a stream bed. This is due to better soil structure, biological binding agents and the longer period of time it takes for soils to reach saturation. This can be used to advantage in the design of a variety of erosion control techniques based on vegetation. The use of a trickle flow pipe in a dam allows the grassed spillway to tolerate much higher flows than would normally be possible. The local climate and topography can have a significant impact on soil erodibility. Moist, south facing valleys tend to be more resistant to erosion due to deeper and more fertile soils and a better cover of vegetation.

Surface Material	Permissible Velocity (m/s)	Surface Material	Permissible Velocity (m/s)
Sand	0.4	Sandy loam	0.5
Silty loam	0.6	Stiff clay	1.2
Fine gravel	0.8	Coarse gravel	1.2
Grass: Kikuyu	1.8 – 2.5	Grass: Couch, Bent, Fescue	1.5 – 2.2
Grass mixtures	0.8 – 1.5	Stones 150 mm	2.5 – 3.0
Stones 300 mm	4 - 5	Gabions/Reno mattresses	4 - 6
Jute matting	1.5 – 1.8		

Maximum permissible velocities for various materials [2]

[2] Table data compiled by the author from the following references:

Garvin, RJ, Knight, MR & Richmond, TJ 1979, *Guidelines for minimising soil erosion and sedimentation from construction sites in Victoria*, Soil Conservation Authority, Melbourne.

Country Roads Board 1982, *Road Design Manual, Chapter 6: Drainage,* Country Roads Board, Kew, Victoria.

Agostini, R, Bizzarri, A & Masetti, M 1981, *Flexible gabion structures in river and stream training works – Section one: Weirs for river training and water supply,* Officine Maccaferri S. P. A. Bolgna, Italy.

Treemax 2003, Erosion solutions revegetation products, catalogue, Mulgrave, Victoria.

Soil erosion processes

Introduction

A good understanding of erosion processes is essential in determining appropriate control techniques and avoiding failure. These processes can be divided into five main categories: splash, sheet, rill, tunnel and gully erosion. However, most sites will involve a combination of different erosion processes all interacting with each other. Determining which erosion process or processes are occurring can be difficult. To make an accurate assessment at more complex sites, multiple site visits under a variety of flow conditions may be required.

Splash (raindrop)

Splash (or raindrop) erosion is normally the first and often the most important stage in the erosion process. It is the result of raindrops hitting the exposed surface of the soil. The potential energy of raindrops is absorbed in breaking up soil aggregates, lifting soil particles into the air, splashing and compacting the soil surface. In a typical intense thunderstorm (25 millimetres (mm) in 30 minutes), enough energy is absorbed to lift the top 100 mm of soil 0.5 m into the air.[3] The dislodged particles are then moved down-slope by surface runoff and gravity.

Sheet erosion

Sheet erosion describes the detachment and transport of soil in a continuous layer or sheet during the process of splash erosion. Once the soil particles have been detached (and excited) by raindrop impact, they are transported down-slope by sheet-flow and gravity. Particles of clay, silt and sand fill the soil pores and reduce infiltration, resulting in an increase in runoff and further erosion. Typical sheet erosion can be observed in a summer thunderstorm where significant areas of land can be eroded in a 'sheet' by flowing water. The velocity of runoff in sheet-flow is usually very low, with erosion only occurring when soil particles have already been lifted into suspension by splash erosion. The process of sheet erosion involves rolling, lifting and abrading of soil particles. The extent of erosion is usually limited by the energy of the water and the amount of soil already in suspension. Sheet erosion mainly occurs on sloping cultivated land and on land where the surface cover of vegetation has been seriously depleted by overgrazing or salinity. Sheet erosion also occurs on the bed and banks of erosion gullies. In many cases, more sediment is produced in a gully from sheet erosion than from other erosion processes.

Rill erosion

Once sheet-flow has travelled a certain distance, it starts to concentrate into small channels or streams of water. Under certain conditions the velocity of water in these channels is high enough to dislodge particles of soil and wash them downstream, forming a shallow channel known as a rill. Unlike gully erosion, rill erosion is more ephemeral in nature. In many cases it is constantly shifting from side to side in response to a complex mix of interacting conditions. These conditions include: flow velocity, sediment load, channel dimensions and slope. Rills are defined as small gullies up to 30 centimetres (cm) in depth – about the size that can be obliterated by normal cultivation practices.

Above: Splash, sheet and rill erosion. Breaking of the drought, 1983, Ararat. Photographer: Clem Sturmfels, DPI.

Photo opposite: Headward erosion, Strathewan, 2009. Photographer: Tim O'Donnell, Nillumbik Shire Council.

Tunnel and sub-surface erosion

Tunnel erosion is one of the most insidious forms of soil erosion. It can occur under the ground, virtually unseen except for small fans of silt oozing from the ground. Tunnel erosion is a major problem in the upper Wimmera River catchment, as well as around Coleraine and in Gippsland. Traditionally, tunnel erosion is associated with highly dispersive soils; however, it can also occur in a range of other soil types.

Deterioration of the native pasture cover and organic matter by grazing causes poorly structured soils to develop an impermeable compacted surface. Increased runoff from these areas concentrates in natural depressions, stump and rabbit holes, rapidly infiltrating through cracks in the soil. As

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[3] Rosewell, C J 1985, Soil erosion on arable land, in Charman, PEV (ed), *Conservation Farming*, Soil Conservation Service of NSW, Sydney.

the water moves through the cracks, slaking and dispersion occur and the tunnelling process begins. As the hydraulic pressure increases, the liquid soil re-appears down-slope as bright yellow fans of silt.

Tunnel erosion in dispersive soils, upper Wimmera River catchment, 1998. Photographer: Clem Sturmfels, DPI.

Over a number of years, scouring of these channels forms a large underground passage which eventually collapses, forming a gully. While tunnelling is normally associated with highly dispersive soils, in the author's experience this is not always the case. There are numerous examples of tunnelling in poorly structured sedimentary soils where the level of dispersion is relatively low. In these cases, soils have often been subjected to a history of poor management and are usually prone to rapid slaking.

Tunnel or sub-surface erosion also occurs in a range of other soil types such as high shrink/swell clays, soils with sandy or gravel layers, and organic valley marsh soils.

In impermeable soils, seepage is confined to cracks, burrows, yabby tunnels and root holes. Seepage along these channels slowly sluices out material to form a cavity known as a crevice tunnel. Slaking and dispersion sometimes aid this process.

Gully erosion (scour, headward, sides and floor)

Gully erosion can involve a range of different interacting processes. Some of the terms used to describe gully erosion include: scour gully, headward erosion, bank and bed erosion. Often gullies start from a simple scouring action or a collapsed tunnel before some of these other processes begin to occur.

A scour gully occurs when runoff is concentrated onto loose unprotected soil or alluvium. The sluicing process is similar in some ways to rill erosion, with the lifting, rolling and abrasion of material. It can also occur in heavier soils where the soil particles are released by slaking or where very high velocities occur. Scour gullies usually result from high intensity runoff, long steep slopes and concentrated flows. They develop length quickly before cutting downwards and sideways.

Headward eroding gullies (waterfalls) can be initiated by scouring, tunnelling, or natural/artificial nick points such as a rabbit burrow, stump hole or a stock track. Clearly, some form of differential erosion is required for a head to form.

Headward-eroding gully with waterfall, St Andrews, 2009. Photographer: Tim O'Donnell, Nillumbik Shire Council.

As gullies deepen, they also tend to get wider through the forces of gravity, surface and subsurface erosion. This widening process can be described as bank erosion and in many ways is similar to processes occurring in larger streams and rivers. Soil loss from bank erosion can often exceed soil loss from gully head processes. Like in rivers, bank (and bed) erosion can be exacerbated by gravel deposition, meanders and undermining.

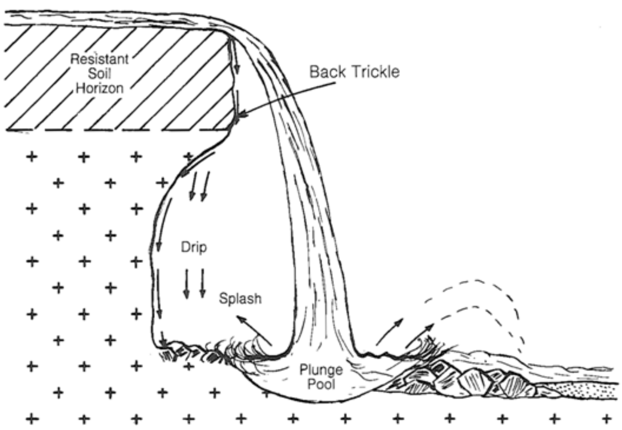
There are numerous, often interacting processes that cause gully head and gully bank erosion. In some cases these processes can work independently of one another; however, in most cases more than one process is needed for erosion to continue.

A waterfall is one of the more common gully-head-forming processes. In a waterfall, the potential energy of the water is absorbed by blasting away the soil and transporting it downstream. This is most effective when a bench or slope exists above the gully floor. Once a vertical face has formed and a plunge pool has been created, most of the energy is absorbed in the pool and little further erosion occurs. The only exception to this is when the water is redirected back onto the headwall by wind or fallen soil.

Spalling and slaking occur when surface water trickles down the back of the gully wall. Spalling is when water soaks slowly into the surface causing flaking or peeling of the moist layers. Slaking is the collapse of weakly structured soil into small particles. Significant hollows often form before the whole wall collapses.

'Gravity collapse' occurs when heavier saturated soil breaks or slumps away from the parent material. It can occur in the form of large blocks where existing cracks are involved, such as in columnar soils or as a mud flow in the case of non-cracking soils. For this process to continue, another form of erosion must occur to transport away the fallen material. In the upper Wimmera River catchment, 'Gravity collapse' commonly occurs as a result of undermining in vertical-sided gullies.

Sub-surface seepage can wash out entire layers of sand, gravel and weakly structured clay. Removal of the whole layer is known as extrusion sapping. Extrusion tunnelling, however, involves removal of a small section only. Again, other erosion processes are required to allow sapping to continue.

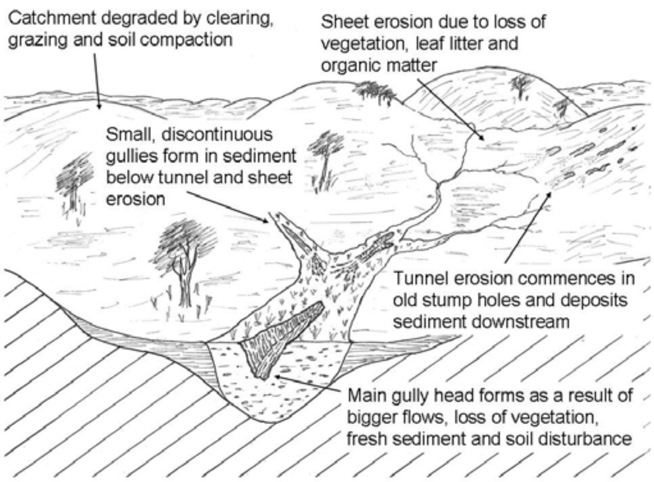


Main erosion processes at a caved gully head [4]

Erosion initiation

As mentioned at the start of this section, several of the five main erosion processes are likely to be involved at any one erosion site. Erosion can commence in many different ways depending on the soil type, climate and land management. Most erosion is the result of a small simple trigger, not a large catastrophic event.

As an example, in a degraded agricultural environment, a small tunnel might be initiated by an old stump hole or rabbit burrow. The sediment fan produced by this tunnel could initiate further tunnelling or small gullies. In turn, these might then produce large sediment deposits in the main drainage line. Increased stream flows from clearing and sheet erosion flowing over this material could then initiate significant gully head erosion.



Typical erosion evolution in the upper Wimmera River catchment.

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[4] Source: Charman, PEV & Murphy, BW 1991, Soils: their properties and management – a soil conservation handbook for New South Wales, Soil Conservation Service New South Wales.

Site assessment

The goal of site assessment is to collect data to ensure your decisions are based on science and logic – not emotion and guesswork.

Introduction

Inadequate site assessment can have a significant and long term impact on the success of erosion control works. Around the Coleraine district in South Western Victoria there has been a very high failure rate of concrete gully head structures due to the high shrink/swell capacity of local soils. Had this issue been identified during the initial site assessment stage, many expensive failures could have been avoided. The structure above, which failed in 2008, will cost approximately $40,000 to replace.

Inadequate site assessment can also lead to over-designing of structures and other control options, resulting in excessive cost. At a site near Crowlands in the upper Wimmera River catchment, two rock chutes were recently constructed to stabilise a short section of gully erosion, at a cost of approximately $60,000. However, the site had a small catchment and a wide, flat, well grassed area adjacent to the gully. This lent itself to a simple diversion bank, grassed waterway and gully battering costing approximately $10,000. This latter option would have been effective, simple and cheap and – unlike the rock chute option – would have had minimal ongoing maintenance.

A detailed, systematic and thorough site assessment allows works to be prioritised, the most appropriate solution selected, and unnecessary expenditure to be avoided. This assessment forms the basis of a risk management strategy that ensures the most valuable assets are protected, that public funding is spent in an effective and efficient manner, and that the risk of failure and the need for ongoing maintenance are minimised. It also helps to ensure activities are aligned with current Government policies and priorities.

Finding a practical solution to erosion problems can be incredibly difficult; sometimes impossible. A detailed site assessment will help on this journey. Some of the smallest jobs can be the most difficult erosion problems to solve.

Above: Failed concrete chute in black cracking clay, Coleraine, 2008. Photographer: Clem Sturmfels, DPI.

Photo opposite: Assessing an erosion site, St Andrews, 2009. Photographer: Tim O'Donnell, Shire of Nillumbik.

For some sites the assessment process can be relatively simple with appropriate control techniques being determined immediately. At more difficult sites, assessment can take a day or more to complete. It is important that the assessment covers both the immediate area, and wider catchment and property perspectives.

The key objectives of the site assessment are to:

- clearly identify the asset/s under threat (location, magnitude and value)
- determine the severity of the erosion problem and urgency of works
- assess where the erosion cycle is up to (geomorphology)
- determine landscape/site resilience to further erosion and possible control works
- identify possible control strategies.

Site assessment process

Before a site visit:

- locate problem site on aerial photo, topographic map or GIS layers
- prepare one or more aerial photo enlargements (or maps) of the site. Include streams, contours and crown allotment boundaries
- locate/draw in the property boundary
- measure the size of the catchment and estimate its likely runoff
- check geology/soils map of area (critical in an unfamiliar area)
- check annual rainfall
- check relevant property files and other records for background information and likely fire impacts
- make an initial assessment of the site (and surrounding landscape) using stereo photos, topographical maps or GIS layers
- organise equipment required for the visit (camera, PDA, aerial photo, notebook and pencil, GPS unit, scale rule, clinometer, level, staff, survey book, tape measure, pegs).

Meet with landholder to:

- determine landholder concerns and objectives
- collect anecdotal/historical information about the site (how far has gully moved?)
- inspect whole farm plan (if available)
- assess current level of management
- assess landholder's ability to implement and manage rehabilitation works.

Site inspection tasks include:

- taking photos – general catchment view, panoramic view around site and close up of erosion problem (include an object to give the photo some scale)
- setting up photo-point (if relevant)
- identifying the assets at risk (upstream/downstream), their value and whether they are privately or publicly owned
- mapping the erosion site, noting erosion length, width and depth
- locating and mapping erosion 'hot spots'
- identifying likely cause of soil erosion
- identifying erosion type/s and likely processes
- determining the rate of spread/severity (age of vegetation in the floor, evidence of fresh sediment etc.)
- noting the location of saline springs, rock bars and vegetation in the gully floor
- recording (if possible) depth of flood flows using flood debris and silt deposits as a guide
- noting the age and maturity of the erosion channel (how much further can it go? what will happen if nothing is done?)
- assessing soil erodibility and basic engineering properties, collecting soil samples if needed
- assessing catchment topography, slope, condition and vegetation cover
- noting possible solutions, indicating type and location of works
- deciding the next action.

Soil assessment

A basic assessment of the soil properties will:

- help identify the erosion processes occurring at the site
- allow assessment of soil erodibility and likely rate of spread
- assist with selecting a control option
- identify engineering constraints

For some sites this may only involve a quick look, while for other sites it may involve a more detailed examination. A few soil samples and profile photos should be taken at all significant erosion sites.

The soil assessment should involve sampling the entire profile accessible at the site, and may also involve sampling from test holes away from the main drainage line if these soils are likely to be needed for construction purposes.

A basic soil assessment normally involves:

- soil texture
- aggregate stability
- soil structure
- stoniness

A more detailed soil assessment also involves an assessment of:

- organic matter
- colour
- soil mottling
- depth to impeding layer
- shrink/swell capacity

In large or more complex sites, a thorough engineering investigation is strongly recommended.

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Bank erosion caused by slaking and blockfall, 2004. Photographer: Clem Sturmfels, DPI.

For more details refer to:

Charman, PEV & Murphy, BW 1991, Soils: their properties and management, a soil conservation handbook For New South Wales, Sydney University Press.

Murphy, S, Lane, P et al. 1999, Field guide and assessment kit soil erosion hazard and soil permeability assessment and classification, unpublished, Centre for Forest Tree Technology, Heidelberg, Victoria

Erosion and sediment control principles

The principles of erosion and sediment control involve slowing the impact of humans to give nature and all of its ecosystems a chance to catch up, protect water supplies, ensure sustainable food production and protect the built environment.

Introduction

Control options need to focus on reducing water energy or lowering soil erodibility. Broadacre works can be undertaken to reduce runoff, such as land class fencing, rotational grazing and pasture improvement. Water can be slowed and spread out with the use of vegetation, diversion banks or grassed waterways. Soil can be protected by removing stock, sowing oats or by applying straw/woodchip mulch. In a bushfire situation, the options can be more limited and often will focus on more short-term or emergency protection works.

There are a wide range of materials and techniques that can be used to control soil erosion and reduce sediment following a bushfire. They commonly involve simple earthworks, temporary diversions and sediment traps. The 2009 DPI Bushfire Recovery Program has also involved some more significant works such as the construction of large rock chutes. Works can vary in cost from $1,000 to over $50,000. A resource produced by the author – Erosion Control Techniques – lists the more common erosion control techniques used in Victoria. This resource, which was handed out during the workshop, includes a simple description of each technique, its application, limitations and approximate cost.

There is no simple way of choosing the best solution for any given site. At a small number of sites the answer will be fairly obvious; at many sites it can be quite difficult. As many CMAs have demonstrated over the last ten years, rock will solve most problems; however, it may not be the cheapest or most sustainable solution.

It is important to understand the needs of the landowner and the requirements of local government and other agencies before making a final choice of control option. A farmer's priorities might include access and ease of maintenance, while the manager of a National Park may also be looking to minimise risk and damage to the environment. Erosion and sediment control works may require a planning permit, Works on Waterways Permit, dam construction license or some other form of approval prior to construction. These permits and approvals should be sought in a timely manner in order to avoid delays in implementation.

Set out below are some common principles used by the author in identifying the most appropriate control techniques.

Selecting the best technique

Focus on asset protection

It is important to focus on the purpose of works and select a technique which best meets this need. What are the assets to protect? What is the simplest way to achieve the desired outcome? Following a bushfire it will often be cheaper and simpler to build a well designed sediment trap than to immediately tackle the source of the problem. There may be more environmental benefits in erecting some land class fencing and eradicating blackberries than there would be in stabilising a very old, slow moving gully head. It is important to be very clear on what the aim is, even for simple works such as building a sediment trap. Is the aim to trap leaves and branches to prevent them from blocking a pipe? Or is the aim to stop coarse sediment from entering a farm dam or to prevent fine clay particles from entering an urban water supply?

Finding a new equilibrium

The best control technique is the one that protects high value environmental and man-made assets, while at the same time allowing the landscape and associated ecosystem to move towards a new equilibrium. This new equilibrium will depend on what stage the erosion cycle is at, the value of the asset and the local site conditions. Using more sustainable, conservative options such as revegetation may not immediately stop an erosion process; however, could well result in a more stable landscape in the longer term.

At a site where an erosion gully has nearly hit bedrock, the best solution may be to let it finish its erosion cycle, and perhaps to focus on revegetation options and building some sediment traps downstream. Where a major highway is under threat from a very active gully head, a large concrete drop structure may be the only practical solution. Where a new gully head has appeared following the fires and is threatening an otherwise well grassed valley floor, total rehabilitation (fill and revegetate) might be the most sensible solution.

Photo opposite: Workshop participants inspect erosion control works, Steels Creek, 2010. Photographer: Lina Peralainen, DPI.

Planned obsolescence

All works will eventually fail – earthen banks will wear away, pipes will corrode and rock chutes will be overwhelmed by a large flood event. While regular repair and maintenance should be part of any ongoing management, planning for failure is also an important part of the design process. In the case of a rock chute this might involve battering of surrounding gully heads to provide an alternative passage for the flow of water. In other cases this might involve fencing and revegetation of the entire area.

Conservative and simple

Whenever possible, keep your solutions as small and simple as possible. This is particularly relevant following a bushfire, where it can be difficult to make a proper site assessment and the risks of failure are very high due to the increased risk of flooding. Look for temporary techniques such as diversion banks, straw bale weirs, homemade chutes constructed from corrugated iron or old carpet. During planning, it often pays to break down a more complex erosion site into small sections. Look for the best control technique for each section before attempting to combine your ideas into one overall solution.

Trigger principle

Following a bushfire, it is not unusual to lose significant quantities of ash or loose surface soil as a result of sheet erosion. The loss of surface vegetation and increase in runoff makes this process inevitable in heavy rainfall events. More severe erosion of the intact soil profile through tunnelling, rill and gully erosion usually requires a more significant land use change to initiate or trigger the erosion process. In the Kilmore East-Murrindindi bushfire area there are a number of land use changes that appeared to have triggered the erosion process. These include soil disturbance from old mining activity, changes in vegetation composition due to logging and grazing and the concentration and diversion of water due to the extensive network of roads and tracks.

This trigger principle can also be used to control soil erosion. Often the process of deposition can be initiated with quite small changes in surface or stream flow conditions. This could be a few branches or some mulch spread on the ground surface, diversion of flow with a small bank or a series of small temporary straw bale weirs in the bed of a stream. Total exclusion of stock will aid this process.

Using vegetation

Experience has shown that the best and most sustainable erosion control techniques are those which mimic nature and use vegetation to provide long term protection. These can include the use of traditional techniques such as grassed chutes, diversion banks and waterways. In addition, a series of small timber or rock weirs can be constructed to trap sediment and promote the growth of aquatic plants such as cumbungi and cane grass. In higher rainfall areas of Victoria, a range of deciduous woody plants have been used to effectively stabilise active gully erosion. The planting of vegetation in a specific pattern to control soil erosion, is described as a form of bioengineering. Bioengineering was pioneered in Western Europe during the eighteenth and nineteenth century.

Sod-seeding of a variety of native and introduced grass species can also be an effective technique. Early trials of Vetiva grass at a number of sites around Coleraine are looking quite promising.

The design process

During the design process:

- clearly define the purpose of your work based on your site assessment
- clearly identify and prioritise erosion hot spots
- identify the processes occurring at each site and determine what type of works are needed (e.g. trap sediment, reduce runoff, protect the soil or slow and spread water)
- note the soil and site constraints that might undermine your control works
- make a list of the possible treatment options
- look at the entire project, combine individual ideas and eliminate non-viable options
- use the following checklist to confirm your choice.

Active gully erosion stabilised with gabion weirs, gully edging and revegetation, Navarre, 2009. Photographer: Clem Sturmfels, DPI.

The proposed erosion control technique should:

- protect onsite environmental and heritage values
- cause minimal site disturbance
- require minimal maintenance
- fit in with existing farm plan, management and landholder skills
- fit in with wider plans and strategies for the landscape
- have all necessary licences and permits. These might include a planning permit, Works on Waterways permit and dam construction license
- have a relatively long service life
- be able to be easily repaired or upgraded
- be as inexpensive as possible
- minimise greenhouse gas emissions.

Sediment control techniques

Introduction

There is a very high failure rate in the use of sediment traps in post-fire recovery activities. Work done in the USA and observations from recent fire events in Victoria suggest a failure rate exceeding 30 per cent. This high failure rate can be attributed to poor design, poor selection of materials and inappropriate construction techniques.

The poor design of many of these structures reflects the lack of suitable technical information on this subject. Much of the available information is based on controlling sediment on construction sites and is not appropriate for broadacre fire recovery works. One exception is the 2006 Treatment Guide in the United States Department of Agriculture Forest Service Burned Area Emergency Response (BAER) report – for details see the useful references list at the end of this document. The lack of technical information has resulted in poor choices of materials, such as the excessive use of synthetic silt fencing seen in fire recovery projects of recent years. Inappropriate use of this material has contributed to the very high failure rate of sediment traps.

Above: A successful straw bale and log sediment trap in a steep site, St Andrews, 2009. Photographer: Tim O'Donnell, Nillumbik Shire Council.

Photo opposite: Sediment-filled dam, Buxton, 2010. Photographer: Clem Sturmfels, DPI.

Purpose

Apart from their primary role in trapping sediment, sediment traps also reduce soil erosion by slowing and spreading flows, increasing water infiltration and promoting more rapid revegetation. Tree heads and logs placed on contours across steep upper slopes do an excellent job in trapping small pockets of sediment, and in providing a suitable environment for plant growth. Their direct impact on sediment control might be minimal; however, their impact on regeneration and long-term sediment control can be quite significant. Log or gabion weirs not only trap sediment themselves, but also promote deposition upstream by reducing stream velocity. A straw bale sediment trap works in a similar way; however, is cheaper and easier to install.

Synthetic silt fencing is the only material readily available that can be used to filter out very fine soil particles. This makes it ideal where there is a need to protect high value assets such as an urban water supply. However, the low permeability of the fabric tends to make it impractical for treating large areas. Silt fencing is ideal for the construction industry where it is primarily used to control sheet erosion in small catchments. Silt fencing is not recommended for trapping sediment in large catchments where water and sediment has concentrated in a drainage line, gully or stream. In the most recent fires, old rabbit netting proved to be a highly effective and inexpensive way of trapping debris, ash and sediment.

Design principles

A good site is essential for effective sediment control. A wide, flat valley floor will store a lot more sediment than a steep and narrow one. A wide, flat valley also spreads the flow, reducing the risk of overtopping and downstream erosion. It is preferable to build a series of low sediment traps rather than a single large one. Spacing sediment traps approximately 50 m apart maximises storage potential, minimises risk and reduces the chance of downstream scouring.

It is important that the purpose of the sediment trap is clearly defined prior to commencing work. What is the asset to be protected? What is the objective both in the short and longer term? Which design offers the best solution?

Other points to consider

When designing sediment control works, also consider:

- the estimated volume of sediment
- the type of sediment (leaves, branches, ash, charcoal, soil)
- the catchment area and likely flood flow
- what size sediment trap is needed to handle predicted flood flows (1 straw bale per hectare (ha), 10 m silt fence/ha)
- how many sediment traps are required
- if there is there a suitable site for sediment trap construction
- whether biodegradable materials will be used or whether the structure will be removed at a later date
- how to avoid outflanking
- whether the proposed structure can be easily accessed for cleaning and maintenance
- whether there is an experienced construction crew available.

Roads, culverts, stream crossings and dams

Introduction

Significant damage to roads, dams and stream crossings can occur following bushfires. The damage is associated with the increase in flooding and movement of fire debris and sediment. As well as posing an immediate threat to the structure itself, soil erosion associated with this damage poses a threat to adjoining landholders and water quality downstream. The repair of roads, dams and stream crossings is an integral part of the current fire recovery program.

In the upper Yarra River catchment, the failure of these structures has been compounded by inappropriate development, poor planning and substandard construction techniques. As a result, there are many examples of sediment-filled dams, eroding spillways, failed stream crossings and deep scours in driveways and access tracks.

The aim of this session is to provide the basic principles associated with design, construction and maintenance of these structures, with a particular focus on private land.

The construction or repair of roads, dams and stream crossings often involves a range of permits and licences. It is important to ensure that these are in place prior to commencing works.

Above: Severe erosion of roadside table drain due to inadequate cross-drainage, Grampians, 2009. Photographer: Stewart Davidson, Parks Victoria.

Photo opposite: Failed road crossing, St Andrews, 2009. Photographer: Clem Sturmfels, DPI.

Roads and tracks

What does a good road look like?

A well designed road should provide safe, all weather 2WD access. It should have a smooth, even surface with no sudden changes in grade or direction. The road pavement should be stable, provide good traction, and require minimal maintenance. The road shoulders, batters and table drains should be well designed, stable and free from sheet, rill and tunnel erosion. A well designed road should have little impact on existing drainage patterns and should not create significant soil erosion and sedimentation issues.

Where is the best location to build a road?

The best location to build a road is along a ridgeline or spur. This will reduce soil disturbance, improve drainage and reduce the need for culverts and stream crossings. The route should avoid steep slopes, minimise the number of stream crossings, avoid swampy areas and significant stands of native vegetation.

How steep should a road be built?

As a general rule, the grade of a gravel road should not exceed 10 per cent. Cars start to lose traction at grades above 15 per cent. Low-use 4WD tracks can be built up to grades of 30 per cent as long as the material is suitable and adequate cross-drainage is provided.

What are the key features of a low maintenance road?

The most important part of road construction is drainage. A well built road will be higher than the surrounding landscape and will shed water rapidly. As a result, the road pavement will remain dry, durable, free of erosion and will require little ongoing maintenance. The water will also be moved away from the road quickly and efficiently by table drains, run-offs and culverts. Road foundations need to be built from strong, stable materials free of organic matter.

Such materials should consist of well graded silt, sand and gravel with a low plasticity and shrink/swell capacity. The materials should be watered during road construction to ensure optimum compaction. The road surface should be topped with a 100 mm deep layer of well graded gravel to form a final wearing surface.

What is the best shape for a road?

A crowned surface with a 4–6 per cent cross-grade provides the most effective and robust road profile. This shape is based on techniques developed by the Romans around 2,000 years ago. Their process involved excavating a wide flat channel before refilling it with appropriate road-making materials. A crowned road surface minimises the risk of erosion by 'sheeting' the water rapidly to the road shoulder and table drain. As the grade of the road increases, a higher crown is required to maximise this effect. The other common way to build a road is by cross-sloping; either in-sloping or out-sloping. Out-sloping is generally preferred as it avoids concentrating large quantities of water into the table drain on the upstream side of the road. For safety reasons, out-sloping should only be used on relatively straight sections of road with a non-slippery surface. A flat road profile is often used for low-use 4WD tracks and firebreaks. To ensure adequate drainage, strict adherence to cross-drainage is essential. This can be in the form of speed humps, or small open drains across the road surface.

At what intervals do culverts, cross-drains and run-offs need to be installed?

Culverts, cross-drains and run-offs should be installed wherever the road crosses an obvious drainage line. Extra drainage should be added to ensure the water flowing in the table drain does not exceed critical velocities. Obviously a wide, well grassed table drain or one built on rock will withstand much bigger flows than a narrow 'V' shaped drain. When designing these structures, reference should be made to tables such as the one shown on this page.

Soil Erosion Hazard	Road Grade							
	1:50 1° 2%	1:25 2° 4%	1:15 3.5° 6.5%	1:12 4.5° 8%	1:10 6° 10%	1:8 7° 12%	1:7 8° 14%	1:5 11° 20%
Low	250	170	130	115	100	100	100	100
Mod	200	150	120	105	100	100	100	NP
High	160	130	110	80	60	60	NP	NP

NP : Road grade not permitted

Recommended distances (in metres) between run-offs, cross-drains and culverts on roads [5]

On flat ground, culverts, cross-drains and run-offs can be spaced at 250 m intervals; however, on steep ground they may need to be as close as 50 m apart. On a very steep 4WD track or firebreak they may need to be as close as 20 m apart to prevent erosion. It is essential that run-offs direct flows away from the road and are 'self cleaning'.

How steep should road batters be?

The slope of a road batter will vary depending on material, compaction and surface treatment. A well compacted and revegetated fill batter can be safely constructed with a slope of 2 horizontal to 1 vertical; however, a flatter slope is needed for unconsolidated materials. The slope of a cut batter can vary from 2 horizontal to 1 vertical for clay, to 1 horizontal to 1 vertical for well graded gravels or rock (see the table below).

Soil Type *	Slope (Vertical to Horizontal)
Rocks – slip plan horizontal or dipping away from cutting	1:0.5
Rocks – shale or mudstone	1:1
Rocks – slip plane dipping toward cutting	1:1.5
Gravel	1:1.5
Clay/loam fill consolidated	1:2
Clays	1:2
Sands/silt	1:2.5
Clay/loam fill unconsolidated	1:4

Guide to maximum slopes (horizontal: vertical) for batters, according to soil type or stability of rock formation [6]

*Note: The above table should be used as a guide only. Steeper batters may be appropriate when the judgement is based on experience of working with existing roads of a similar grade, soil type and method of construction.

[5] Source: Department of Natural Resource and Environment (c. 1996), *Gippsland Forest Management Prescription*, unpublished report, Department of Natural Resource and Environment, Victoria.

[6] Ibid

Culverts and stream crossings

Where is the best location to cross a waterway or stream?

An ideal location for a stream or waterway crossing will have a relatively flat approach angle, a low stream bank and a floor of rock or well consolidated gravel. A wider stream bed is preferred for a ford or floodway while a deeper, narrower crossing is more suited to culverts or bridges.

What sized pipes should be used?

Accurately determining culvert pipe size is a time consuming and complex process and cannot be easily covered in these notes. The pipe size is determined by calculating the peak flood discharge then using a suitable pipe capacity table to select the appropriate pipe diameter based on the local site conditions. Usually culverts are designed to carry a 1-in-10-year storm event. To minimise blockage, minimum pipe diameter should be 300 mm for cleared land and 375 mm in forested areas.

What types of crossings can be used?

This will depend on the intended use of the crossing and specifications determined by the local water authority. Crossings can range from a simple ford using a rock or concrete base, a pipe or box culvert or a properly designed low-level floodway or bridge. Access ramps should be stable, well formed and protected from erosion. Road drainage must be redirected away from the crossing and disposed of in a well vegetated area adjacent to the crossing.

A well designed crossing should:

- minimise disturbance to the stream bed and banks
- minimise changes to flow conditions or water energy
- allow the easy passage of flood flows
- allow for fish passage
- minimise sedimentation to the stream.

Culvert installation

1. Clear away and stockpile all vegetation, woody debris, topsoil and organic matter. Excavate into the bed of the stream until a firm base of compacted clay, gravel or rock is reached.
2. Backfill the excavation with suitable bedding material, such as well graded gravel or crusher dust, to a minimum depth of 100 mm. This material should be compacted and trimmed to form a flat, even grade – parallel to, and just below the existing stream bed.
3. Install the pipes, ensuring careful and accurate alignment in both the vertical and horizontal plane. Whenever possible, the new culvert should be installed to match the natural slope and alignment of the existing stream bed.
4. Backfill under and around the pipe haunch with the bedding material. This material should be compacted carefully using hand tools.
5. Moist clay/loam, free of organic matter and contaminants, should then be used to complete backfilling around and above the pipe from the haunch to the design road level. This material should be compacted using a sheepsfoot roller or similar device. Batter slopes should not exceed 2 horizontal : 1 vertical.
6. All disturbed areas, including fill batters should be covered with at least a 100 mm layer of topsoil and sown using an approved seed and fertiliser mix.

Well designed stream crossing for farm driveway or access track, Koornalla, 2010. Photographer: Penny Richards, DPI.

Other issues to consider during culvert installation:

- Class 4 pipes should be used for heavy loads. Class 3 pipes are only suitable for very light traffic
- Box culverts should be used where adequate pipe cover (300 mm) cannot be achieved.
- Pipe installation should always commence at the downstream end of the site with the pipe bell facing upstream.

- Minimum allowable fall in a culvert is 1 in 200; maximum allowable fall is 1 in 5.
- In tunnel-prone soils, bedding material should be stabilised with cement, and pipe-joins sealed with a 200 mm wide mastic strip.
- Where a number of pipes are being installed adjacent to each other, a space should be left between pipes to ensure design loading capacities are maintained. The space between the pipes should be between 300 mm and 900 mm.
- Concrete headwalls can be installed to reduce stream bed erosion.

Farm dams

Soil erosion associated with farm dams has been a significant issue in the Kilmore East-Murrindindi bushfire area. A history of poor design, substandard construction and limited maintenance, has made dams in this area highly vulnerable to damage. Small problems that existed before the fires have worsened significantly as a result of an increase in runoff and flooding. Typical problems include: sediment, leakage and tunnelling, spillway erosion, inlet erosion and overtopping of dam banks.

Effect of sediment on dams

The impact of bushfires on farm dams can vary significantly. In the Grampians fires, a prolonged drought followed by extremely strong winds ahead of the fire front resulted in many dams being filled with sheep manure, organic matter and soil. In comparison, the fire in the Kilmore East-Murrindindi area resulted in large quantities of ash, woody debris, gravel, sand and soil being deposited into farm dams.

Apart from sheep manure, none of these materials pose a direct threat to water quality for stock and domestic use. Wood ash consists of relatively inert materials including calcium carbonate, a variety of organic compounds and trace elements. Ash commonly sits on the surface of the dam for a short time reducing oxygen levels and discolouring the water. Sheep manure, soil and other organic matter will increase the nutrient status of the water and in the right conditions can result in algal blooms and bacterial growth. While most stock will tolerate quite badly polluted water, they should be excluded once the dam shows significant discolouration, strong odours or signs of algal growth.

Removing fire sediment from farm dam, Grampians, 2006. Photographer: Clem Sturmfels, DPI.

Fire sediment can have a significant impact on dam capacity. In many cases it will only form a shallow layer in the base of the dam; however, in more extreme cases dams can become totally filled with sediment. Cleaning out dams can be a difficult and expensive process, particularly in larger storages. It usually involves emptying out the water and then using a large excavator to scoop out the sediment. In a larger dam this might involve handling the sediment a number of times.

The following points need to be considered when undertaking dam cleaning operations:

- Batter slopes below the dam full supply level should be 3 horizontal to 1 vertical or flatter.
- Material removed from the dam should be left in a neat, stable heap, above full supply level, out of any waterway and away from the dam inlet, excavation and spillway.
- The heap should be left with a domed top and be free-draining. Batter slopes on the heap should not exceed 3 horizontal to 1 vertical.

Dam leakage and tunnelling

Dam leakage and tunnelling is a major issue in farm dams across Victoria. Dam leakage and tunnelling is usually the result of poor planning, poor design and the use of inappropriate construction techniques. In a small number of cases, dam leakage and tunnelling can be directly attributed to problem soils.

Typical causes of dam leakage and tunnelling include:

- building dams through gravel seams, over fractured bedrock or old mine shafts
- using highly aggregated or highly dispersive soils
- using poorly graded soils, lacking adequate clay- and silt-sized particles
- topsoil, timber and organic matter incorporated into the dam bank
- inadequate soil moisture during construction
- inadequate compaction during construction
- no core trench to prevent leakage under the bank.

Severe tunnelling in large dam bank, St Andrews, 2009. Photographer: Tim O'Donnell, Nillumbik Shire Council.

Repairing failed dams can be a risky and expensive operation. It should only be considered where there is clear evidence that the dam was well built in the first place and the problem is isolated to one small area.

Spillway erosion

Erosion of dam spillways is a common problem, especially following a bushfire. The spillway of a dam plays a critical role in returning high energy water to the floor of the drainage line and avoiding damage to the dam wall and surrounding landscape. A well designed spillway must ensure flow velocities are maintained below critical levels, both within the spillway channel and immediately downstream. This normally requires a wide, flat, well grassed channel ending with a long 'spill section' or spreader. It is vital that the area below the spillway is maintained with a thick and vigorous cover of vegetation. Simple techniques for the repair of an eroding spillway include: extending the spillway to a new disposal area, installing a trickle flow pipe, installing a grass chute or constructing a new spillway at the other end of the dam bank.

Inlet erosion

This is a common problem with dams located in steeper terrain. It normally occurs when the dam excavation has been extended too far upstream, above and outside the dam's normal full supply level. As a result, water entering the dam is flowing over raw ground rather than a well grassed valley floor. This problem is not easy to solve and usually requires some sort of engineering solution such as a small rock chute or drop structure.

Overtopping of the dam bank

Overtopping of the dam bank is usually the result of insufficient freeboard on the dam bank, a poorly designed or blocked spillway, or a combination of both factors. Overtopping of a well built and revegetated dam bank causes few problems and is usually easy to rectify, either by lifting the dam bank or by widening the existing spillway.

Dam checklist:

A well planned and designed farm dam should have the following characteristics:

- All the required permits and licenses issued prior to commencing construction.
- All of the dam excavation area is under water when the dam is full.
- The dam foundations are sound and waterproof.
- The catchment area is adequate to fill the dam on a regular basis.
- The dam has a well constructed spillway designed to handle a 1-in-40-year storm event.
- The soil used to construct the bank consists of a well graded gravel, sand and silt mixture with the following characteristics:
  - more than 10 per cent clay
  - at least 20 per cent clay and silt
  - low to medium levels of dispersion

- not prone to tunnelling
- has a low shrink/swell capacity.

- The soil used to construct the bank was at optimum moisture content, was placed in thin layers and compacted carefully during construction.
- Selected clay was used to build a clay core extending from the base of the bank to its crest.
- The dam size matches the likely demand with extra allowance for periods of drought.
- The dam is as deep as possible, preferably exceeding 5 m.
- The batters of the dam excavation and upstream bank do not exceed a slope of 3 horizontal to 1 vertical.
- The downstream batters of the dam bank do not exceed a slope of 2 horizontal to 1 vertical.
- The crest of the dam bank is at least 1 m above full supply level.
- The crest of the dam bank is at least 3 m wide with a domed top.
- All disturbed soil above full supply level has been covered with topsoil and sown to an appropriate mixture of seed and fertiliser.

Runoff calculations

Introduction

Runoff can be measured in two ways – total catchment yield and peak flood discharge.

Total catchment yield is the total volume of water yielded by a catchment over a period of time. It is used to design reservoirs and dams and calculate minimum environmental flows. Total catchment yield is calculated by multiplying catchment area x rainfall x runoff percentage. Runoff in Victoria ranges from 1 per cent on light soils in low rainfall areas to more than 30 per cent on heavy soils in high rainfall areas. Total catchment yield is usually measured in cubic metres (m^3) or megalitres (ML).

Peak flood discharge on the other hand is a measure of the maximum flow for a given period of time and is regularly used in the design of erosion control structures as well as bridges, urban drains and dam spillways. Peak flood discharge is usually measured in cubic metres per second (m^3/sec). The results of some recent peak flood discharge calculations for the Kilmore East-Murrindindi bushfire area are shown in the Appendix.

Above: Flood flows test out a newly constructed rock chute, Elmhurst, 2007. Photographer: Pauline Boatman (private collection).

Photo opposite: Summer thunderstorm, Ararat, 2004. Photographer: Clem Sturmfels (private collection).

Factors influencing runoff

The factors affecting runoff can be divided into two groups – those associated with rainfall and those associated with the catchment.

Rainfall

Rainfall duration, intensity, timing and aerial distribution influences both the rate and volume of runoff. Infiltration capacity reduces with time so that a storm of short duration tends to produce significantly less runoff than a storm of longer duration. Higher rainfall intensities usually produce higher rates of runoff. High intensity summer storms can produce major flows for small catchments but rarely have much of an impact on larger catchments. This is because thunderstorms tend to be quite localised.

Catchment

Catchment factors affecting runoff include: size, shape, orientation, topography, soil type and vegetative cover. While runoff rates and volumes are directly proportional to catchment area, the peak flood discharge is not. As catchments increase in size, it takes longer for peak flows to occur (time of concentration). As a result, the impact of individual storm events is reduced, leading to a relatively smaller peak flood discharge.

Long, narrow catchments tend to produce lower peak flood discharge than more compact catchments – also due to the longer 'time of concentration'. Topographical features such as surface depressions and swampy areas increase infiltration and reduce runoff. Steeper slopes result in shorter concentration times and higher flows. A good cover of vegetation can significantly reduce peak flows by intercepting and retaining surface water. Soil type has a significant impact on peak flows as it directly influences the rate of water infiltration.

Calculating peak flood discharge

There are two commonly used empirical methods for calculating the peak flood discharge of smaller rural catchments. These are the 'Rational Method' and the 'SCS-USDA Method'. Australian drainage and soil conservation authorities have used the Rational Method for many years. The SCS_USDA method was introduced in the late 1970s as an easier way to calculate peak flood discharge.

Reliability

The Rational Method appears to be the most reliable technique for calculation of peak flood discharge in small rural catchments. Studies indicate that the Rational Method has an accuracy of around 30 per cent. Actual field measurement, such as a stream gauging station or channel flow calculations, will always provide results that are more reliable, and should be used to check the more theoretical techniques such as the Rational Method.

The Rational Method

The Rational Method is based on a very simple formula:

The peak flood discharge at a given point is equal to the catchment area x rainfall x amount of runoff.

The formula is:

Q = CIA/360

Where
Q = Peak Flood Discharge (m3/sec)
C = Coefficient of Runoff
I = Rainfall Intensity (mm/hour)
A = Area of Catchment (ha)
60 = Adjust Units Only

Coefficient of runoff (C)

The coefficient of runoff is a factor used to predict the proportion of rainfall that runs off an area during a storm event. The coefficient of runoff is affected by rainfall intensity, vegetation, topography and soil type. The easiest way of calculating the coefficient of runoff is with the use of Turner's Table.[7] This simple table uses a range of landscape attributes to determine likely rates of runoff.

[7] Country Roads Board 1982, *Road Design Manual: Chapter 6, Drainage,* Country Roads Board, Kew, Victoria, p 9.

Rainfall intensity (I)

Rainfall intensity is the average rate of rainfall measured in mm/hr expected for a given period of time (time of concentration) and specific recurrence interval. Rainfall intensity can be very high for small catchments with a short time of concentration, but fall away rapidly as the catchment size and time of concentration increase. Rainfall intensities also vary according to local climatic conditions. Rainfall intensity charts for Victoria are available in a number of publications or can be accessed directly from the Bureau of Meteorology.

The time of concentration is based on the time it takes for water to concentrate from all parts of the catchment. This is assumed to occur when the furthest drop of water from a given storm event reaches the nominated outlet point. This calculation usually involves adding together the time for sheet flow and the time for stream flow for a given set of topographic, vegetation and soil conditions.

Recurrence interval is an expression of the probability of a certain rainfall event occurring. For example, a recurrence interval of 1-in-100 years means that there is a 1-in-100 chance of the event occurring in any one year. As with other 'natural' events, there is no absolute measure of rainfall. Records to date are all that can be relied on. The design of structures cannot justify catering for all known rainfall events.

Bridges, drainage systems, dam spillways and stormwater channels are all designed to cater for a predetermined storm event described as 'recurrence interval' or 'return period'.

Typical recurrence intervals used in Victoria are:

bridges and major structures:	1 in 100 years
cross-drainage for freeways and roads:	1 in 50 years
farm dam spillway:	1 in 40 years
erosion control structure (no bypass):	1 in 40 years
erosion control structure with bypass:	1 in 20 years
diversion banks:	1 in 20 years
urban drainage:	1 in 10 years.

Catchment area (A)

The catchment area is the total area of land that contributes runoff to the outlet point. It is relatively easy to calculate from aerial photos or topographical maps. Catchment area is usually measured in hectares.

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Photo opposite: Eroding table drain, St Andrews, 2009. Photographer: Clem Sturmfels, DPI.

Appendix

Typical peak flood discharge, Kilmore East-Murrindindi bushfire area, 1-in-20 year return period

357 ha = 9 m^3/sec (gently sloping, unburnt catchment)

270 ha = 20 m^3/sec (steeply sloping, burnt catchment)

52 ha = 3.9 m^3/sec (moderately sloping, burnt catchment)

15 ha = 2.5 m^3/sec (steeply sloping, burnt catchment)

10 ha = 1.5 m^3/sec (moderately sloping, burnt catchment)

Units

Volume

1 cubic metre (m^3) = 1,000 litres (L)

1 megalitre (ML) = 1 million litres (L)

1 megalitre (ML) = 1,000 cubic metres (m^3)

Flow Rate

Cubic metres/second (m^3/sec)

Velocity

Metres/second (m/sec)

Area

1 hectare (ha) = 2.5 acres

1 hectare (ha) = 10,000 square metres (m^2)

1 square kilometre (km^2) = 100 hectares (ha)

Photo opposite: Sheet-eroded hillside, Steels Creek, 2009.
Photographer: Clem Sturmfels, DPI.