8. SOIL CONSERVATION

Conservation of natural resources is essentially a study of the land and its use, and how man can be fitted into his environment to give both fulfilment of his needs and a quality of surroundings with an assurance that these conditions will continue from generation to another.

Soil conservation is achieved when land is managed in such a way that productivity is maintained or improved without detriment to other lands, water supplies or other resources. This is a complex undertaking because systems of management need to be devised for individual land components, depending on susceptibility to a range of processes and off-site effects. For example, management on a hillslope susceptible to erosion may need to cope not only with *in situ* erosion and leaching of nutrients, but also with inadequate use of water, which promotes off-site erosion and salting.

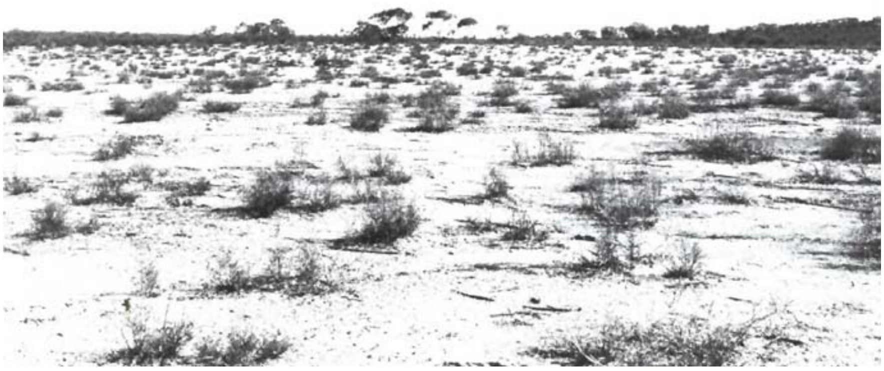
Although the Soil Conservation Authority (partly incorporated into the Land Protection Division of the Department of Conservation, Forests and Lands) played a major role in stabilising land within and to the north of the Eppalock catchment, thee are still many thousands of hectares requiring reclamation and stabilisation.

Processes of soil deterioration

In the Campaspe River catchment are found many forms of soil deterioration – some a legacy of earlier days and some the result of recent mismanagement. Symptoms such as active gullies, sheet-eroded paddocks, silted dams, bare salted areas and other problems indicate that the type and intensity of land use has exceeded the capability of the land to sustain it.

The following list indicates the wide range of soil deterioration processes considered here,

Water erosion	sheeting (sheetwash) rilling (shallow impermanent channels) gullying (deep permanent channels) tunnelling stream-bank erosion deposition of eroded material
Wind erosion	windsheeting Deposition of eroded material
Mass movement	landsliding (a general term embracing many variations) Soil creep
Salinisation	(also known as ‘salting’)
Hydrological deterioration	increasing soil wetness (flooding, waterlogging) increasing soil dryness
Chemical deterioration	loss of nutrients (for example, by leaching, volatilisation, harvesting, erosion) acidification
Physical deterioration	loss of structure (compaction by cultivation, root pressure, trafficking, chemical change, erosion, etc) crusting (by raindrop impact, salting, chemical change, etc)
Biological deterioration	loss of humus (for example, by decreased biomass, erosion)



Mechanical harvesting of eucalypt leaf for oil has left this area devoid of litter and unprotected from the effects of rain.

History

It appears that local ecosystems were relatively stable immediately before European settlement. The early white settlers came mainly from Great Britain and Europe, where quite different environmental conditions prevailed, bringing with them farming methods quite unsuitable to the frequently shallow, stony and infertile local soils. Times were hard on both man and the land, although some of the early squatters were perhaps kinder to the country than most, having large runs enabling them to move stock to the more favourable areas in times of stress.

In the 1850s, when the gold rush was paramount in Victoria, demands on the land to supply timber, food and water, and to withstand the frantic digging and heavy density of people and traffic, became excessive. Land deterioration was so severe and extensive that many areas still show the scars of this mismanagement. Land deterioration continued largely unabated over the ensuing decades and it was not until the 1950s, a hundred years later, that the Victoria government set up a soil conservation authority to hasten the development and use of appropriate management practices.

Incidence of soil deterioration

In the drier northern zone of the catchment, sheet, rill and gully erosion and compaction are widespread, mainly on the Ordovician settlements, Devonian granite and Permian tillite.

Most of the soils in the drier northern and central areas are highly erodible, having weakly structured surfaces that are low in organic matter and prone to detachment by raindrop impact. The incidence of sheet erosion varies with land management standards, but in general varies with land management standards, but in general varies from severe on the cleared steeper hills and ridges to slight on the near-level plains. Gullying here is most severe on and beside cleared sheet-eroded hills and ridges. The subsoils also tend to disperse and slake, encouraging soil detachment. Increased salinity in many low sites also promotes gullying through weakened plant cover. In valley alluvium, layers of differing permeabilities frequently provide pathways for seepage, enhancing mechanisms such as sapping and undercutting.

The combined processes of salting, sheet erosion, compaction and gully erosion have produced this example of severe land deterioration.

Wind erosion only occurs readily on the open plains with weakly structured or loose surfaces or on exposed sandy soils on granitic rocks. Most loamy and clayey topsoils will drift under poor management during prolonged droughts.

In the higher-rainfall areas to the south, the landscape is relatively stable, with the longer and more reliable growing season providing adequate vegetative cover. Erosion is confined to localised disturbances. Acidification is now recognised as a major cause of reduced productivity in the south.

Susceptibility of land to soil deterioration

The terms ‘hazard’ and ‘susceptibility’ are often used interchangeably, causing much confusion. Susceptibility of land to a specific deterioration process is defined here as a constant inherent feature, but the hazard changes, depending on the level of management and on the type of land use. For example, if red sodic duplex soils occur on a 10% slope in a Mediterranean climate, the susceptibility to tunnel and gully erosion may be high. This is a warning that the land must be managed very carefully and not pushed beyond its limited productivity.

Land types have been rated for susceptibility in the land system descriptions (Chapter 7) for the common forms of soil deterioration.

Processes

Table 10-17 indicate the mechanisms and processes involved, together with the influence of land characteristics and management factors for each form of land deterioration.

In each table, Column 1 defines the form of deterioration and then identifies the processes involved.

Column 2 summarises the specific characteristics of the vegetation, climate, geology, topography and soils that influence one or all of the processes listed in Column 1.

Column 3 lists the factors directly involved in the land deterioration processes. Having identified these factors, it is then possible to look critically at the effects of existing and new land management practices.

Column 4 provides guidelines on those management practices most likely to control each form of land deterioration.

The more common soil deterioration processes recognised within the catchment, the susceptibility of the land and relevant management practices are discussed below.

Sheet and rill erosion by water

The degree of deterioration by this process is extremely difficult to assess because of the considerable variability in soil loss within a paddock and the problem of measuring something that is not there. Significant soil loss can occur without direct observation and perhaps its only when the silted dam needs cleaning out, wen the bottom wires of the fence have been buried or when the cultivator set at its customary depth begins digging up clay that deterioration by sheet erosion is recognised.

Soil loss from sheet-rill erosion greatly reduces productivity. In the case of the widespread duplex soils the retention of the topsoil layer is critical for crops and pastures. The top of the B horizon is a most unfavourable seedbed and rooting medium, and partial or total removal of the A horizon will reduce potential productivity accordingly. If land is not carefully managed, the rate of erosion will far exceed the rate of soil formation and the soil resource will be depleted. One millimetre depth of soil is equivalent to approximately 12 tonnes of soil per hectare, but the topsoil also contains nutrients, organic matter, seed and the macroporosity so desirable for a seedbed. Continued sheet erosion, especially on duplex soils, reduces the depth and water-holding capacity of the topsoil and therefore reduces its effectiveness as a seedbed. Most local soils have very slow rates of formation and should therefore be regarded as a non-renewable resource, thus requiring special management.

The susceptibility of land is governed largely by the topsoil texture, slope of the land and length of slope (Table 10). Other factors include hydrophobicity, percentage stone cover, tendency for aggregated to slake and disperse, size and weight of surface particles or aggregates and the probability of intense rainfall, particularly during the summer.

Land systems on Ordovician sediments with steep slopes and shallow stony loams – namely, Fryers, Koala, James, Ida, Myola and Wolfscrag – have a high susceptibility to sheet erosion. With the exception of Ida and Fryers land systems, the native vegetation on the steep slopes has been replaced by shallow-rooted, low-producing native pastures, which provide inadequate cover.

Table 10 – Land characteristics and management factors involved in sheet and rill erosion.

Processes	Land characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Sheet and rill erosion occur when the forces due to rainfall, flowing water and gravity overcome the cohesion and weight of the soil particle/aggregates.	**Vegetation** - structure, percent surface cover (including litter) - leaf area, rooting depth and perenniality	• exposure of surface soil • intensity of raindrop impact • infiltration/run-off ratio • velocity of surface flow • transportation and hence infiltration rate and volume of surface flow	All aspects of the vegetation are affected by selection of species and control of biomass by practices such as: cultivating clearing trafficking fertilising grazing trampling harvesting burning
Processes involved are: detachment of exposed soil by - raindrop impact - surface flow	**Climate** - rainfall intensity/duration - seasonal rainfall/evapotranspiration regime	• intensity of raindrop impact • volume of water exceeding infiltration rate and hence volume of surface flow • soil water content and hence infiltration rate and volume of surface flow	
transport by - rain splash - surface flow	**Geology** - permeability of rock or unconsolidated sediments	• soil water content and hence infiltration rate and volume of surface flow.	
Deposition Surface flow occurs on any sloping surface when the rainfall rate exceeds the infiltration rate.	**Topography** - microrelief - slope degree and length - slope and landform shape - position in landscape	• infiltration/run-off ratio • velocity of surface flow • volume and velocity of surface flow • tendency to concentrate surface flow • volume of run-on	Contour cultivating, contour banking and strip cropping reduce slope length and affect microrelief.
Off-site effects include increased sedimentation and run-on in streams and on lower lands	**Soil** - profile permeability - depth and water-holding capacity - size/weight of surface particles/aggregates - cohesion of surface particles/aggregates, including tendency to slake and disperse - tendency to surface seal and hydrophobicity - percent stone cover	• infiltration rate and hence volume of surface flow • infiltration/run-off ratio • detachment and transport • detachment • infiltration rate and hence volume of surface flow • volume of run-on	The above management practices controlling biomass affect soil organic matter content, which in turn affects all listed soil characteristics except surface rock. Direction soil compaction and disruption by trampling, trafficking and cultivating affect soil permeability, water-holding capacity and size/weight and cohesion of aggregates.

Land systems with a moderate susceptibility to sheet and rill erosion occur on a wider range of parent material. They include: Theaden Hill, Sutton Grange, Sargent, Cobaw and Alexander on granodiorite; Macedon on rhyodacite; Mount Camel Range on basalt; and Glen Cooee, Glenholt, Kimbolton, Ida, Muskerry and part of Heathcote on Palaeozoic sediments. Recommended management involves fencing out the steeper areas and preventing grazing by sheep and rabbits, thus allowing natural revegetation to occur. The loss in fodder from such areas is slight considering that only limited grazing can occur before causing permanent damage.

Gentler slopes with a moderate susceptibility offer a wider range of land use options with less severe management requirements. Regular fertiliser applications and the establishment of improved pastures can maintain a protective ground cover while improving organic matter content and aggregation of topsoil. Cultivation for cropping or pasture renovation needs to be done on the contour, with fallow periods kept to a minimum. An alternative to fallowing to graze heavily then burn or spray before direct-drilling the seed. Strip-cropping along the contour is a common practice in New South Wales and Queensland, but not in Victoria where paddocks are too small. Contour and graded banks can effectively reduce the length of slope without hindering the movement of agricultural machinery.

Steep slopes, shallow soils and lack of vegetative cover are the basic ingredients for run-off, sheet erosion and off-site salting problems.

Gully and tunnel erosion

The susceptibility of land to tunnelling and gullying depends on a number of interrelated factors (shown in Table 11). As the volume of overland flow increases and becomes channelised, the erosive power increases and resistance of the soil aggregates and their cohesion, or the tendency to slake and disperse, will determine the resistance. Both the annual and seasonal rainfall directly influence the soil moisture content and, depending on the infiltration rate, the volume of overland water flow within each subcatchment.

Gully erosion occurs particularly in areas on Ordovician sediments, but is also common on granitic and glacial parent materials. When gradational soils and stony loams on the crests and upper slopes are cleared of the native eucalypt forest, some rain percolates through the soil profile to the water table, but some becomes overland flow with the potential to sheet-erode the sloping land and scour out the drainage depressions. Duplex soils have a relatively impermeable subsoil, so when the topsoil becomes saturated any excess rainfall become overland flow. Hard-setting topsoils accentuate the problem of excessive run-off, with their reduced infiltration and low water-holding capacity.

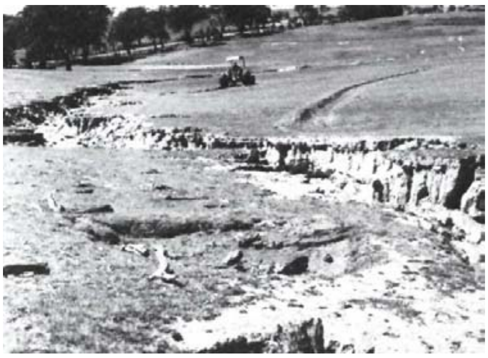
Summer storms, which are unpredictable, localised and usually intense, cause severe soil loss, especially on the cultivated and overgrazed areas. The slow-wetting topsoils, common throughout the north of the catchment, readily shed water, leading to sheet and gully erosion. Further south the longer growing season and cooler summers promote moister soil profiles and continued ground cover, particularly as the grazing of perennial pastures is the dominant land use.

The presence of gullies and tunnels adversely affects productivity in a number of ways. As well as the land directly lost from production, the soil adjacent to the gully or tunnel is excessively drained, thus reducing the vigour and number of plant species able to survive. The movement of stock and vehicles becomes increasingly difficult and time-consuming, while the storage capacity of dams below the gully/tunnel is reduced and the water discoloured by the transported sediment.

Ripping with a single tyne, along the contour, is an effective method of reducing run-off

Areas with a high susceptibility to gully erosion occur in the drainage depressions of the Glen Cooee and Knowsley land systems, where the sodic subsoils are dispersible and therefore extremely prone to gullying. Salting reduces the protective vegetative cover and this furthers the development of rills, channels and eventually gullies.

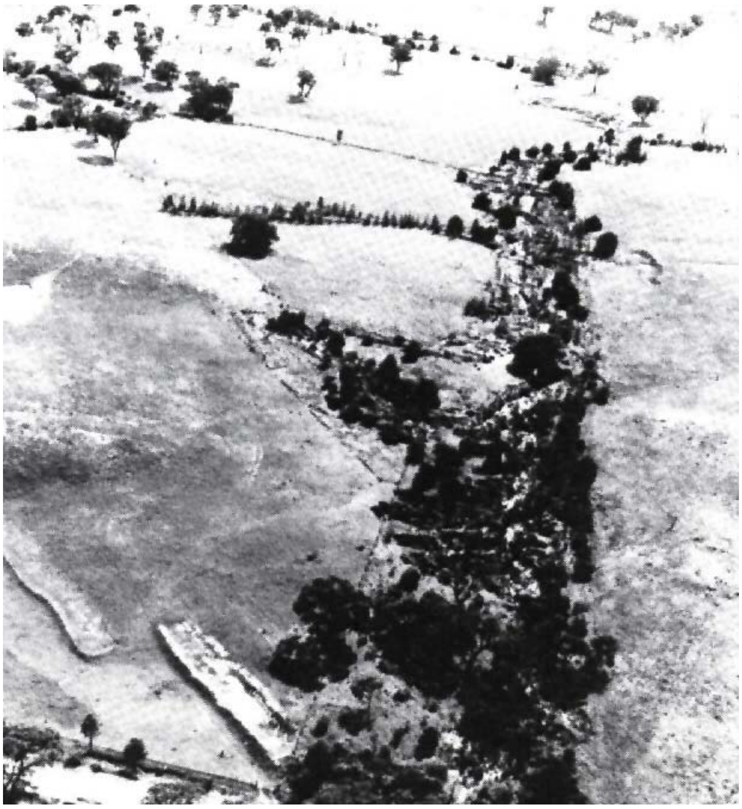
Active gullies indicate that the expectations of the landholder exceed the capability of the land.



Areas with a moderate susceptibility occur mainly on Palaeozoic sediments – in the Fryers, Heathcote, Ida, James, Koala, Muskerry, Myola East, Wellsford and Wolfscrag land systems. Other areas, such as Sutton Grange, Sidonia, Lonsdale and Axe Creek land systems, generate sufficient overland flow or receive sufficient run-off from adjacent land to put erosional pressure on unconsolidated sediments in the drainage depressions.

Reducing the overland flow of water is an essential first step in preventing gully erosion. A knowledge of the local soils and their tendency to disperse is important because contour banking or deep ripping could increase tunnelling. In general, land management should be directed towards increasing water use by planting deep-rooting species such as trees or perennial pastures.

When gully erosion is advanced, common control measures include the construction of fences to keep out stock, of gully head structures and of diversion banks. Other measures include gully infilling, planting trees, shrubs and densely rooted grasses, eradicating rabbits and excluding cultivation from the management program.



Gullies can be stabilised with a combination of diversion banks, tree-planting, fencing and gully head structures.

Table 11 – Land characteristics and management factors involved in gully and tunnel erosion.

Processes	Land characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Gully and tunnel erosion occur when the forces due to rainfall, flowing water and gravity overcome the cohesion and weight of the soil particles/aggregates	**Vegetation** - structure, percent surface cover (including litter) - leaf area, rooting depth and perenniality	• Exposure of surface soil • Intensity of raindrop impact • Velocity of channelised flow and hence particle detachment and transport • Transpiration and hence infiltration rate and volume of surface and subsurface flow.	All aspects of the vegetation are affected by selection of species and control of biomass by practices such as: cultivating clearing trafficking fertilising grazing trampling harvesting burning
Processes involved are: detachment of exposed surface soil by - raindrop impact - channelised overland flow - cracking	**Climate** - rainfall intensity/duration - seasonal rainfall/evapotranspiration regime	• Intensity of raindrop impact • Volume of surface and subsurface flow • Volume of surface and subsurface flows via regulation of soil water content	
detachment of subsoil by - subsurface flow in permeable strata and along cracks and tunnels - cracking	**Geology** - previousness of rock or unconsolidated sediments	• Soil water content and hence infiltration rate and volume of surface and subsurface flow • Lateral or vertical movement of water	
transport of particles/aggregates by - channelised overland flow - subsurface flow - gravity collapse deposition	**Topography** - microrelief (both of channel and catchment to a site) - channel slope degree and length - position in landscape and catchment area - catchment slope degree and length - slope and land-form shape	• Infiltration/run-off ratio • Velocity of surface flow • Infiltration/run-off ratio • Velocity of surface flow • Volume of surface and subsurface flows reaching site • Infiltration/run-off ratio • Velocity of surface flow • Tendency to concentrate surface flow	Contour and diversion banking, strip cropping and contour cultivating reduce catchment slope length and catchment area; they also affect microrelief. Contour and diversion banking, strip cropping and contour cultivating reduce catchment slope length and catchment area; they also affect microrelief.
Gully erosion is regarded as having occurred when the channel is too deep to be crossed or cannot be obliterated by tillage. Off-site effects include increased sedimentation and run-on in streams and on lower lands.	**Soil** - profile permeability - depth and water-holding capacity - size/weight of soil particles/aggregates - cohesion of particles/aggregates, including tendency to rack, slake and disperse - differential permeability within a horizon due to the presence of cracks and channels - percent stone cover	• Infiltration rate and hence volume of surface and subsurface flow • Lateral or vertical movement of soil water • Volume of surface and subsurface flow • Lateral or vertical movement of soil water • Volume of surface and subsurface flow • Detachment and transport • Detachment • Movement of water along preferred channels • Volume surface flow	Type and amount of biomass production will affect soil organic matter content, which will in turn affect most listed soil characteristics. Soil disruption and compaction by trampling, burrowing, cultivating and trafficking will affect profile permeability, water-holding capacity and size/weight and cohesion of soil particles/aggregates.

Streambank erosion

Both the valley gradient and the volume of water transport affect the meandering pattern of a stream. Should the volume of water entering the system increase, the number of meanders will tend to be reduced and stream-bank erosion will become more active. Thus, changes in land use that increase the amount of run-off will increase erosion of stream banks.

Fences, land, building and roads and other facilities can be threatened as the stream course adjusts within an alluvial plain to reach equilibrium with the increased discharge. Sediment load increases also, with the increased stream velocity causing sedimentation and water turbidity in storages.

Moderate susceptibilities exist only on the alluvial land systems Axe Creek and Runnymede and the basaltic land systems Marydale and Redesdale, all of which have incised meandering stream beds.

Stream-bank erosion is not a major local problem within the Campaspe catchment area, due in part to the flood control effect of the Upper Coliban, Lauriston and Malmsbury weirs on the Coliban River and Lake Eppalock on the Campaspe River. However, in the smaller subcatchments, unsuitable land use and poor land management can reduce infiltration and transpiration of water, thereby increasing the hazard of flooding and stream-bank erosion of the small ephemeral streams. To reverse this trend, contour management practices such as banking, cultivating and strip-cropping reduce effective slope length and increase infiltration (see Table 12). The establishment of perennial pastures and maintenance of dense ground cover reduce overland water flow and increase infiltration.

Along the stream itself, bank erosion can be reduced by removing debris such as logs and fallen trees, which cause turbulence and undercutting of adjacent banks. The banks can also be stabilised by establishing a dense cover of vegetation and by excluding stock, or at least by providing stock with stabilised access areas to the water.

Excessive run-off increases the hazards of sheet, rill, gully and stream-bank erosion.

Table 12 – Land characteristics and management factors involved in stream-bank erosion

Processes	Land characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Stream-bank erosion occurs when forces due to water movement along a stream channel are sufficient to detach and remove soil material from the stream-bank	**Vegetation** - structure, percent surface cover (incl. litter) - leaf area, rooting depth and perenniality	• Streambank stability • Transpiration and hence infiltration rate and volume of surface flow • Volume and velocity of stream flow	All aspects of the vegetation are affected by the selection of species and control of biomass by practices such as: cultivating clearing trafficking fertilising grazing trampling harvesting burning
Processes involved are: detachment of soil by stream-bank by - slaking - undercutting - collapse of bank transport by channel flow deposition	**Climate** - rainfall intensity/duration - seasonal rainfall/evapotranspiration regime	• Volume of water exceeding infiltration rate and hence volume of surface flow • Soil water content and hence infiltration rate and volume of surface flow • Volume of surface flow	
	Geology - permeability of rock or unconsolidated sediments in the catchment	• Soil water content and hence infiltration rate and volume of surface flow	
	Topography - slope, degree and length	• Volume and velocity of surface flow	Removing fallen trees and other debris may reduce turbulence and under-cutting of stream-bank.
	Soil - permeability of soils within the catchment - soil depth and waterholding capacity - cohesion of soil particles/aggregates including tendency to slake and disperse - size/weight of surface particles/aggregates	• Infiltration rate and hence volume of surface flow • Infiltration/run-off ratio • Detachment • Detachment and transport	Contour cultivating, contour banking and strip cropping to reduce slope length. Restrict stream access by stock to less sensitive areas Stabilise stream-banks with trees, shrubs and grasses

Wind erosion

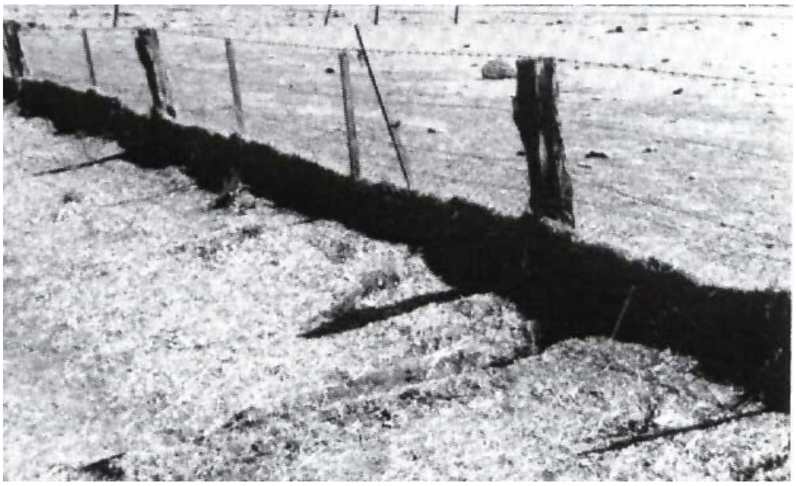
Susceptibility of land to wind erosion is determined by taking into account the inherent characteristics of the soil, the climate and the position in the landscape, as set out in Table 13. The erodibility of the topsoil is a major factor, but structure, texture, stoniness and organic matter content are all significant. Land use and management may have a major and sometimes overriding influence on the degree of deterioration, particularly if dry soils are exposed when erosive winds are likely to occur.

The topsoil contains accumulated nutrients, seed and organic matter, and in a cropping sequence can be cultivated to produce the fine tilth desirable for good seed-soil contact. Wind erosion not only reduces these qualities but adds the costs of clearing deposited material away from fences, roads, railways and water channel. Many soils have a shallow topsoil overlying a dense, relatively impermeable clay. Removal of such a topsoil will expose the subsoil, reduce water infiltration and cause increased run-off and a large fall in productivity.

The loose sandy topsoils on granitic parent materials, particularly exposed components of Lonsdale and Sargent land systems, are highly susceptible. The open plains of the Runnymede land system with fine sandy loam topsoils and the lower slopes of granitic areas in the drier north have moderate susceptibilities.

Because the combination of severe wind storms with large areas of exposed soils is not common locally, wind erosion is usually minor and restricted to small areas. However, during the 1982/83 drought, many bare fallows were not sown down or weeds failed to germinate and the bare areas suffered a moderate degree of erosion.

To minimise the hazard, the topsoil must be protected, particularly when dry and when there is a high probability of erosive winds – that is, when winds exceed 30-32 km per hour. Fallows should be as short as possible, with trash retained and the ground surface left in a ridged cloddy condition.



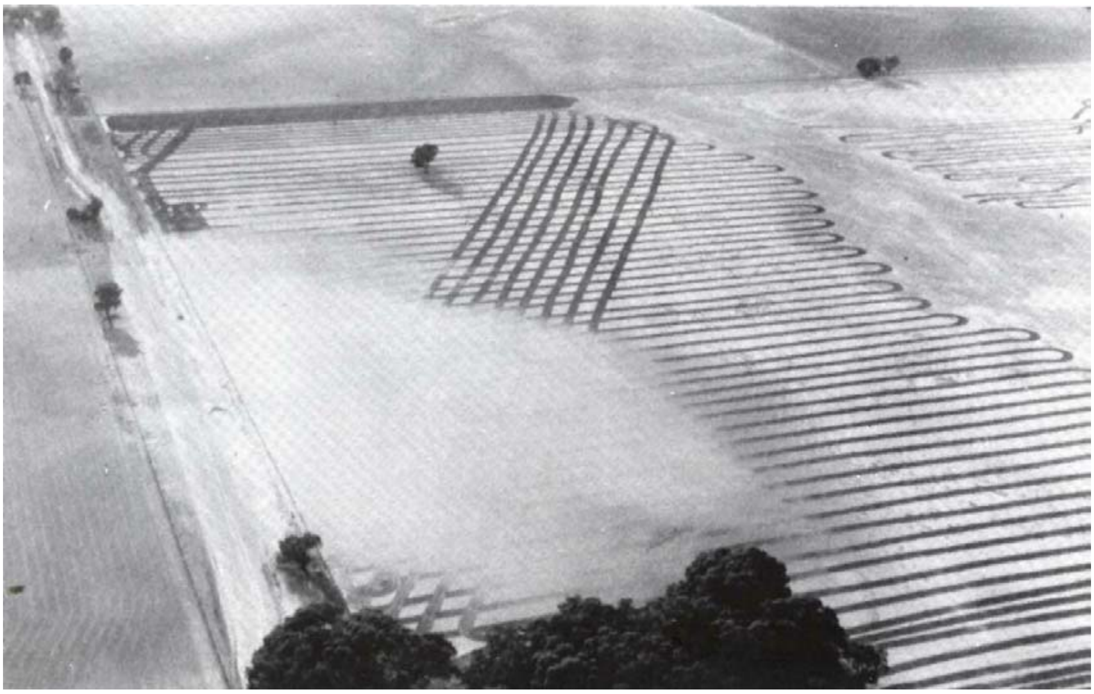
Instances of moderate wind erosion occurred during the 1982/83 drought. This fenceline has trapped large quantities of plant material, seed and soil.

For grazing land, regular fertiliser application will promote a healthy pasture and adequate cover.

Table 13 – Land characteristics and management factors involved in wind erosion

Processes	Land features affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Wind erosion occurs when the force due to wind is sufficient to overcome the cohesion and weight of the soil particles and to allow their movement.	**Vegetation** - structure, percent surface cover (including litter) - leaf area, rooting depth and perenniality	• Exposure of surface soil • Depth of zero velocity layer • Transpiration and hence soil moisture content and particle cohesion	All aspects of the vegetation are affected by selection of species and control of biomass by practices such as: grazing trampling harvesting burning cultivating clearing trafficking fertilising
Processes involved are:	**Climate** - rainfall/evapotranspiration regime - wind strength - wind direction	• Soil moisture content and hence particle cohesion • Detachment and transport • Site exposure	
detachment by abrasion and suction	**Geology** - perviousness of rock or unconsolidated sediments	• Soil moisture content and hence particle cohesion	
transport by creep, saltation and suspension	**Topography** - microrelief, slope degree and position in landscape	• Surface wind strength • Run-on, site drainage and hence soil moisture content and particle cohesion	Retention or construction of windbreaks, cloddy cultivation and ridging affect microrelief.
deposition by entrapment and reduced wind velocity	**Soil** - percent stone cover - size/weight of surface particles/aggregates - aggregate stability (influenced by factors such as presence of carbonates, iron oxides and organic matter, clay mineralogy and biological activity) - profile permeability, depth and water-holding capacity - size/weight of surface.	• Surface wind strength • Detachment and transport • Detachment • Soil moisture content and hence particle cohesion and weight or particles/aggregates	Soil disturbances such as trampling, cultivating affect aggregate stability. Any practices affecting biomass alter the organic matter content of the topsoil.

Eradication of rabbits is essential, together with conservative stocking rates of sheep and cattle. Scalded areas can be cultivated to form a ridged cloddy surface, fenced out and allowed to revegetate.



Drift material from the road reserve on the left has almost obliterated the unusual cultivation pattern on this paddock.

Landsliding (mass movement)

Table 14 – Land characteristics and management factors involved in landslides

Processes	Land characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Landsliding occurs when the shear forces exceed soil/regolith strength; this generally occurs when soil/regolith strength is reduced by an increase in water.	**Vegetation** - leaf area, rooting depth perenniality - total left area and canopy type - root depth and mass	• Transpiration and hence soil water content • Volume of water held by canopy and hence volume available for infiltration • Anchorage of soil by roots harvesting	All aspects of the vegetation are affected by selection of species and control of biomass by practices such as: cultivation, clearing trafficking, fertilizing grazing, trampling burning
Processes involved are:	**Climate** - seasonal rainfall/evapotranspiration regime	• Soil water content	
infiltration of water wetting of basal plane saturation of soil (mudflow)	**Geology** - perviousness of rock or unconsolidated sediments - wet strength of rock/regolith - angle of dip	• Soil water content • Shearing tendency • Shearing tendency	
shearing and movement of soil mass by gravity	**Topography** - slope degree - microrelief and position in landscape	• Lateral gravitational component • Run-on, site drainage and hence soil water content	
Other processes that may be involved include: - loading of soil mass resulting in an increase in shear strength - removal of material from slope toe resulting in reduced slope support Type of landslides covered by this table are: - rock and earth slides	**Soil** - topsoil permeability - presence of slowly permeable layer - cohesion of particles/aggregates including tendency to slake and disperse - depth - clay mineralogy	• Infiltration/run-off ratio • Water content of soil immediately above layer • Soil strength • Soil water content • Soil strength	Compaction and soil disruption by stock and vehicles, and by cultivating, will affect profile permeability

Processes	Land characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
- earth flow (downslope movement of unsaturated soil and weathered rock on a lubricated basal shear plane) - mudflow (movement of saturated soil and rock) - combination slide/flows			

Landsliding (mass movement)

One of the more spectacular forms of land deterioration is that of soil and weathered rock moving en masse down-slope. The movement depends on the quantity of water entering the soil, steepness and permeability of the regolith (see Table 14).

Major mass movement can have special significance among the various forms of erosion. Both the striped and buried areas are usually unsuitable for cropping and for constructions such as houses and roads. The catchment does not contain any high risk areas, but the Alexander and Drummond land systems do have a moderate susceptibility on the steeper slopes.

Stabilisation of hazardous areas may sometimes be achieved by establishing deep-rooting species, preferably trees, to anchor the soil and to transpire rapidly. Diversion and drainage of water may sometimes be practicable.

Compaction

The susceptibility of soils to compaction depends largely on organic matter content, structure, texture, moisture content, profile permeability and water-holding capacity. Moist soils are more vulnerable, since reduced friction promotes the denser packing of particles. Dry soils resist deformation or compaction. Medium – to coarse-grained horizons such as the surfaces on granitic rocks tend to be resistant. However, the risk is severe at the A-B horizon interface, where a very dense layer is formed by the mixture of coarse sand, fine sand, silty and clay particles. Most local soils have a moderate-high susceptibility to compaction, but the risk is lower in the gradational soils on basalt and in the coarse sandy soils on granite and Tertiary sediments. The risk is particularly high in the widespread duplex soils in drier ares with little humus.

Organic matter promotes the formation of aggregates that counteract deformation and compaction. Topsoils with minimal organic matter have a low resilience to compaction and have usually degraded to their maximum bulk density. Soils with moderate to high levels of organic matter may have a high resilience, but the susceptibility may also be high over time through loss of organic matter.

Topsoil compaction is a major form of land deterioration, since it occurs on most land types. Compaction reduces infiltration and aeration and increases run-off, erosion, off-site flooding and deposition.

The dramatic increase in the size of agricultural machines has contributed to the problem of compaction. Cultivation itself exerts downward pressure and frequent working to the same depth develops a plough-sole – that is, a dense layer that restricts the free movement of air, water and plant roots.

Table 15 – Land characteristic and management factors involved in soil compaction

Processes	Land characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Compaction is the increase in soil bulk density and the related decrease in macroporosity that occurs when the physical pressure on the soil exceeds the ability of the soil to restrict deformation and/or when organic matter is oxidised.	**Vegetation** - leaf area, rooting depth and perenniality - structure and species	• Transpiration and hence soil moisture content and soil strength • Type and quantity of organic matter accumulation • Weight of plants • Root pressure on soil by growth and wind heave	All aspects of the vegetation are affected by selection of species and control of biomass by practices such as: grazing, trampling harvesting, burning cultivating, clearing trafficking, fertilising
	Climate - rainfall/evapotranspiration regime	• Soil moisture content and hence soil strength	
	Geology - permeability of rock or unconsolidated sediments.	• Soil moisture content and hence soil strength	
	Topography - position in landscape, slope degree and microrelief	• Run-on, site drainage and hence soil moisture content and soil strength	Artificial drainage, contour banking, contour cultivating and strip cropping will affect soil moisture content
	Soil - texture and stone content	• Soil strength • Minimum bulk volume attainable	
	- structure (dependent on factors such as clay % and mineralogy, carbonate, iron oxide and organic matter content and biological activity)	• Soil strength • Macroporosity	
	- organic matter content	• Resilience to deformation	Any practices that affects the vegetation will affect organic matter content Cultivating will increase oxidation of organic matter
	- profile permeability, depth and water-holding capacity	• Soil moisture content and hence soil strength	

Management practices such as minimum tillage, spray seeding or long pasture phases in a cropping rotation tend to reduce compaction by maintaining organic matter and by reducing mechanical disturbance.

Leaching of nutrients

In general, soils within the catchment have a low inherent nutrient status (as shown in Figure 11) and require additions of fertiliser and nitrogen from legumes to maintain and improve agricultural productivity. Unfortunately the more soluble nutrients can be leached out of the profile, leaving a more acidic medium.

Soil acidification is associated with improved pastures in higher-rainfall and irrigation areas. The addition of nitrogen from either fertilisers or legumes results in acidification of the soil as the nitrogen is converted to nitrate, which then combines with basic cations available from the soil storage or clay mineral exchange sites. When nitrates are taken up by plans or leached from the system the increased soil acidity can initiate further problems, such as aluminium or manganese toxicity, decreased availability of phosphorus, molybdenum, magnesium and calcium or decreased activity of the soil microbes, including nodule bacteria. The build-up of organic matter and its oxidation results in a depletion of base cations and increased soil acidity, as the diagram indicates.

Organic matter oxidation $\dashrightarrow$ CO_2
$CO_2 + H_2O$ $\dashrightarrow$ H_2CO_2
H_2CO_3 $\dashrightarrow$ $HCO_{3-} + H+$
$2HCO_{3-} + Ca{+}{+}$ $\dashrightarrow$ $Ca(HCO_3)_2$

Further acidification occurs when land is used primarily for the production of legume hay and the product, rich in base cations, is exported.

The susceptibility of soils to leaching of nutrients is influenced by climatic factors, such as annual rainfall, its seasonal intensity and distribution, and soil parameters such as organic matter content, clay content and mineralogy, texture, permeability and water-holding capacity (as shown in Table 16).

Percentage base saturation is a useful indicator of the nutrient status. High values generally indicate a high inherent nutrient status, a high resilience to soil acidification and a low degree of deterioration caused by leaching. Duplex soils often have a marked difference in base saturation values between the topsoil and the subsoil.

Those soils considered most susceptible to the leaching of added nutrients are the coarse sandy topsoils found in all the granitic land systems. The organic matter in the A_1 horizon is capable of holding only monovalent cations and the lack of clay implies that all base cations are readily leached from the system. As the topsoil pH decreases, the problem of acidification and aluminium toxicity arises. The friable gradational soils on basalt in the Trentham East, Drummond, Diogenes land systems and on rhyodacite in the Macedon land system, the shallow stony loams of the Ida, James, Koala and Myola East land systems and the shallow gradational soils in the remaining land systems on Ordovician sediments all have a moderate susceptibility rating.

Land management practices designed to minimise land deterioration through the leaching of nutrients have two main aspects: reduction in the volume of water percolating through the profile; and replacement of lost nutrients with fertilisers. Reduction in water volume can be achieved through pasture improvement, which includes the introduction of deep-rooted perennial pasture species in conjunction with a tight control on grazing. Revegetation of steep hills by native trees and shrubs not only reduces water percolation through the shallow profile but reduces run-off and the associated erosion and flash flooding.

Traditional fertiliser use here mainly involves superphosphate, with limited additions of nitrogen, potassium, molybdenum and other trace elements. The net effect has been to lower the pH to levels at which aluminium toxicity occurs. Regular topdressings of lime may be required.

Table 16 – Land characteristics and management factors involved in leaching of nutrients.

Processes	Land features affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Nutrient loss involves the solution of cations and anions in water and their removal as the water percolates down through the soil	**Vegetation** - leaf area, rooting depth and perenniality	• Transpiration and hence soil water content and volume of percolating water.	All aspects of the vegetation are affected by selection of species and control of biomass by practices such as: cultivating clearing trafficking fertilising grazing trampling harvesting burning
Leaching of nutrients is considered here in terms of base cations; the main anion involved is nitrate, the concentration of which fluctuates according to season and surface management, including the use of legumes	**Climate** - rainfall/evapotranspiration regime	• Volume of percolating water	
	Geology - permeability of rock or unconsolidated sediments	• Volume of percolating water	
	Topography - slope degree, microrelief position in landscape and catchment area	• Run-on, site drainage and hence volume of percolating water.	
	Soil - organic matter content - texture - clay mineralogy - water-holding capacity - profile permeability	• Cation exchange capacity (CEC) • CEC • CEC • Infiltration/run-off ratio • Volume of percolating water • Rate of water percolation	Control of biomass affects organic matter content, water-holding capacity and profile permeability. Cultivation and compaction by trampling and trafficking affect water-holding capacity and profile permeability.

Dryland salting

Dryland salting involves the intake of water and salts by percolation through soils and rocks and lateral movement of groundwater. When a rising water table enters the rooting zone, only salt-tolerant species survive and the productivity of recognised crop and pasture species falls. Salts may originate from rock weathering or cyclic salt brought in with rain and dust.

The more permeable soils have been leached, but in deeply weathered soils the salts have accumulated to give extremely sodic subsoils or C horizons. In most of the duplex soils the interaction between climate and vegetation has lead to the development of sodic subsoils. However, formerly absorbed or transpired by the trees, thus increasing percolation and mobilisation of stored salts. The Axe Creek land system, for example, is flanked by Ordovician sediments that have areas totally cleared of trees and a saline water table now lies at the surface of the drainage depressions (Jenkins and Irwin 1980).

The occurrence of salt seeps is affected by the permeability of the soils and sediments. The prime areas of intake are those with permeable soils, notably the shallow uniform or deeper gradational profiles of the steeper hills and ridges. These profiles lack the clay subsoils of low permeability that promote surface run-off rather than deep percolation. Seepage waters tend to follow preferred pathways such as fractures in rocks or permeable beds in rocks or unconsolidated sediments.

Within the Campaspe catchment, dryland salting is confined to the Fryers, Glen Cooee, Glenholt, Heathcote, Muskerry, Myola East, Wellsford and Wolfscrag land systems on Ordovician sediments, the Knowsley land system on Permian tillite and the

Camel Range land system on Cambrian basalt. Minor salt seeps occur on the granitic Sutton Grange and Elphinstone land systems.

Soil salting causes considerable losses in agricultural production, particularly on Ordovician sediments and Permian tillites. It is easily recognised in the field, but affected areas are not easily reclaimed. Pumping and installation of drains may lower water tables, but disposal of effluent is a problem. Research indicates that improved management on a catchment basis is required to remedy local salted areas.

Salting associated with a regional water table may be the result of many decades of mismanagement, and a similar time may be needed to identify the recharge areas and to limit the percolation of water. During the last 2-3 decades much emphasis in land management has been placed on cultivating, furrowing, banking and strip-cropping on the contour, thereby increasing infiltration and reducing overland flow and soil loss. This is acceptable only if the increased intake of water is transpired and not allowed to percolate below the root zone.

To reverse the dramatic increase in salted areas, land use must incorporate species with a higher water use, especially in areas of maximum groundwater recharge, such as the shallow permeable soils on hills composed of Palaeozoic sediments. Replanting with trees and the use of deep-rooted species such as lucerne will encourage a balanced land use.

Unlike other forms of land deterioration, the cause and effects of salting may operate on area that are widely separated. Problems in extension and reclamation occur when the cause is inappropriate management further up the catchment. Effective treatment requires district, regional and State-wide efforts to revise land use and management practices.

Table 17 – Land characteristics and management factors involved in salting

Processes	Land characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Salting occurs when stored salts derived from the atmosphere and from rock weathering become concentrated in the root zone.	**Vegetation** - leaf area, rooting depth and perenniality	• Transpiration and hence volume of water percolating to groundwater.	All aspects of the vegetation are affected by selection of species and control of biomass by practices such as: grazing, trampling harvesting, burning cultivating, cleaning trafficking, fertilizing
Current accessions are insignificant compared with salt storage, except along coastlines or beside saline lakes and salinas.	**Climate** - rainfall/evapotranspiration regime	• Volume of water percolating to groundwater • Accumulation of salts within root zone	
Processes involved are: long-term accession of salts in regolith infiltration and percolation of rainwater leaching of salts to groundwater	**Geology** - permeability f rocks and unconsolidated sediments - clay content of rocks and sediments, often influenced by deep weathering - geological structure and differential permeability of strata	• Leaching of salts • Salt storage • Lateral movement of groundwater • Groundwater discharge • Depth to groundwater • Groundwater pressure	
rise in water levels/pressure lateral transmission of water/pressure accumulation of salts within root zone by evapotranspiration in discharge areas	**Topography** - slope degree - change of slope - local elevation - position in landscape, slope degree and microrelief	• Lateral movement of groundwater • Site of discharge • Depth to water table • Run-on, site drainage and hence volume of infiltrating water.	Contour banking and cultivating affect microrelief, increasing infiltration. Diversion banks reduce run-on and hence infiltration around discharge sites.
Off-site effects include increasing salinity of streams, groundwaters and built storages. Pumping and drainage (mostly in irrigated areas) increase leaching of salts, reduce salt storage and lower groundwater levels/pressures, but disposal of extracted water and salts is a problem.	**Soil** - permeability - water-holding capacity - depth and clay content - microporosity	• Volume of water percolating to groundwater. • Volume of water percolating to groundwater • Salt storage • Evaporation	Practices controlling biomass affect permeability, microporosity and water-holding capacity directly or indirectly through effects on organic matter content.

Bare ground and spiny rush (*Juncus acutus*) are indicative of soil salting

This salt-affected depression has been fenced out and sown to tall wheatgrass (*Agropyron *spp). Reclamation is almost complete.

Following eradication of rabbits and closure of this paddock for 3 years, grass and tree regeneration has dramatically reduced water run-off and erosion.