Appendix A: Threats to be addressed by the strategy

A.1 Landslides

Processes

A landslide is the movement of soil or rock down a slope. Landslides occur episodically, driven by gravitational forces. Understanding the timeframes for the geomorphic development of a landscape provides a maximum range for the likelihood of a landslide event (Dahlhaus & Miner 2002). However, the individual site conditions and local triggering factors need to be considered to refine the estimate of occurrence. For any given site, the evidence of current or past slope movement, slope angles, slope aspect, geological structures, vegetation, drainage and experience of the assessor will all influence the final estimate of likelihood of a landslide occurring within a particular timeframe.

The steepness of the slope is a causal factor in landslides, since gravitational force acts on all slope materials. In the Corangamite region, previous studies (e.g. Cooney 1980, 1982; Wood 1981; Buenen 1995) have related landslide activity to angle of slope based on field observation. However, when these relationships were tested by GIS analysis, the correlation between landslide occurrence and slope angle could not be seen, even in the areas with significant quantities of data. Similarly, no relationship to slope aspect could be established, indicating that other site-specific factors must equally contribute to failures (Dahlhaus & Miner 2000).

Extreme rainfall is the dominant trigger for landslides in south-west Victoria. The previous work by Cooney (1980) provides the most convincing data, using the 1952 Lake Elizabeth landslide and the 1952 Wild Dog Creek landslide as examples. Landslide studies from elsewhere in Australia and the world (e.g. Cruden & Fell 1997) confirm high-intensity and/or prolonged rainfall as the most common landslide triggering factor (Dahlhaus 2003).

Anthropogenic factors must also be considered when assessing the likelihood of landslides. As more urban and infrastructure development proceeds in the region the chance of a catastrophic failure is substantially increased since more weight is added to a slope (buildings, roads, cars), more intensive infiltration occurs (septic tank effluent, gardens, roof and road run-off) and changes are made to slope morphology (roads, embankments, cuts). The combined effect may act to destabilise the slopes, putting property and lives at risk (Dahlhaus 2003). *Figure A1* shows an example of damage caused to a road by a landslide in the Corangamite region.

Figure A1: A landslide that has destroyed a road in the Corangamite region Photograph: A. Miner 2006

In many cases, agricultural practices or environmental works being undertaken may increase landslide risk. If inappropriately considered, investments in environmental works may become liabilities if they result in landslide damage to property or life.

Condition

The landscapes of the Corangamite region are among the most landslide-prone in Australia. Over 2252 (1924 certain) landslides have been mapped in various studies within the Corangamite region *(Fig. A2)*.

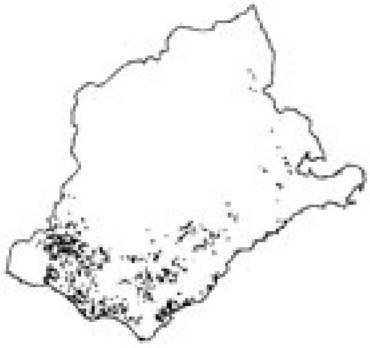


Figure A2: The location of landslides in the Corangamite region

Landslides vary in surface area from a few square metres to more than 120 ha, and in volume from a few cubic metres to over 10 million cubic metres. They are triggered by prolonged and/or high intensity rainfall, man-made changes to the landscape and rare earthquake events. The vast majority of landslides occur in two rock types, the Otway Group rocks and the Gellibrand Marl (Dahlhaus 2003).

Within the Corangamite region over the past 50 years, landslides have caused deaths and destroyed urban and rural infrastructure. The Lake Elizabeth landslide (1952) blocked the east branch of the Barwon River for a year and cost $10 million to repair the damage (URS 2005). Other examples include the Windy Point landslide (1970) which closed the Great Ocean Road for 10 months; the Wongarra landslide (1953) and Princetown landslide (1980) (both of which destroyed dairy farms); and the current Clifton Springs landslide (2001). The cost of these and other landslides has amounted to tens of millions of dollars (Dahlhaus 2003).

Management

Landslide risk management in the Corangamite region has been of growing importance, particularly since the further development of landslide prone areas has coincided with a greater tendency to seek remedy through litigation in our society. These actions have provided the impetus for a review of risk-management practice by local government and professional societies.

Effective management of landslide risk usually requires a site-specific engineering plan designed to reduce or minimise the risk to assets. The management options may include: slope stabilisation works (such as installation of anchors and/or drainage; reducing the load on a slope) reducing the angle of slope, construction of engineered retaining structures, removal of trees or planting trees or other vegetation. Alternatively, the design of the asset may be modified to reduce the consequences of impact by landslides (Dahlhaus 2003).

A.2 Water erosion (sheet/rill and gully/tunnel erosion)

Processes

The processes of soil erosion by water are well understood from research, particularly that by the soil conservation authorities in Australia and the USA. Detailed descriptions and information on erosion are found in many texts including McTainsh & Broughton, 1993 and Young & Young, 2001.

Rainfall erosivity is the potential of rain to erode soil, measured as the power exerted on the soil by the falling rain (Young & Young 2001). Erosivity varies according to rainfall intensity, with intensities of <25 mm/hr considered non-erosive (White 1997).

Sheet erosion may develop where relatively smooth landscapes encourage overland water flow. However, water moving across almost all landscapes separates into individual turbulent flows that produce small meandering channels. As the channels cut down the soil profile they form rills, which are defined as channels less than 300 mm deep (Charman & Murphy 2000). Ultimately, the rills deepen and coalesce to form gullies, which aggregate the flow, increasing its erosive power.

Tunnels may be formed when run-off flows through a crack, root hole or animal burrow into the subsoil. In most soils, the subsoil has a lower permeability than the topsoil, resulting in the water moving across the top of the subsoil as through-flow *(Fig. A3).* Where the subsoil is prone to slaking and/or dispersion, fine particles are carried in suspension, resulting in piping, tunnelling and seepage erosion (Young & Young 2001). Ultimately, the tunnels may collapse to form gully channels.

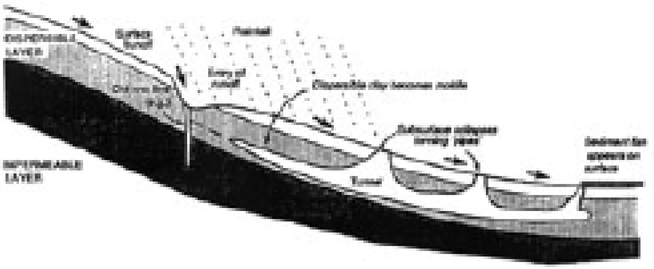


Figure A3: Processes associated with tunnel erosion development

Gullies erode headwards as the concentrated flow of water scours both the channel walls and bed. Eroded sediment is often deposited locally at the mouth of the gully as an alluvial fan. The deepening channel and retreating walls may intercept other sub-surface tunnels and/or the groundwater table, creating additional erosion by sloughing saturated soil into the channel. *Figure A4* illustrates an example of active gully erosion and sedimentation from the erosion site entering a waterway.

Figure A4: The start of an active gully erosion site, which washed sediments into a tributary of the Leigh River

Condition

Sheet/rill and gully/tunnel erosion has recently been mapped for the Corangamite region *(Fig. A5 & A6).* From this study, 1311 (933 certain) sheet/rill sites and 696 (626 certain) gully/tunnel sites have been identified (Feltham 2005). Many of these sites are located near priority waterways and other high-value assets which could be adversely impacted.

Although widespread, sheet/rill erosion is not as visually obvious as other forms of erosion. The most noticeable sheet erosion occurs on slopes where intensive horticulture or cropping is the dominant land use, such as north of Ballarat, where steep slopes are present. Where the slopes are sufficient and the soil properties allow, sheet erosion has developed into rills, which may further develop into gully erosion. Examples include the area near Birregurra, locally known as "the washaways", and in the Murroon district (Dahlhaus 2003).

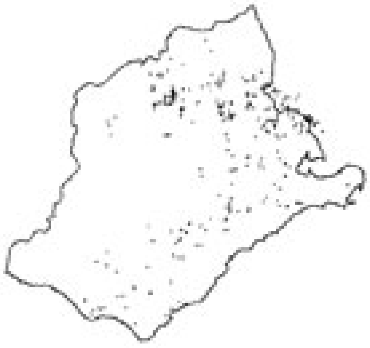


Figure A5: The location of sheet and rill erosion sites in the Corangamite region

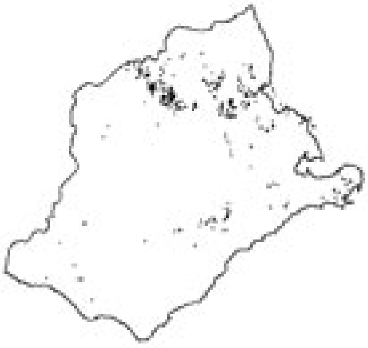


Figure A6: The location of gully and tunnel erosion sites in the Corangamite region

In the Corangamite region, sheet and rill erosion threaten agricultural productivity through the removal of fertile topsoil. Once removed, this topsoil may be deposited in waterways, threatening water quality through sedimentation and nutrient inputs.

Tunnel erosion is particularly prevalent in the weathered Otway Group rocks of lower Cretaceous age (i.e. the Eumeralla Formation). The erosion impacts on agricultural land, water quality and infrastructure associated with residential development. In particular, the residential infrastructure of the townships of Kennett River and Separation Creek has been affected, with tunnel erosion undermining houses and roads. Agricultural land is also affected, with substantial tunnel erosion developing along drainage lines in the steeper, cleared landscapes of Wild Dog Creek valley, Barham River valley, Smythe Creek valley and Wongarra.

Gully erosion is the ultimate result of both tunnel and rill erosion. Gullies are the most visually obvious representation of erosion in the landscape and have been the most common target for rehabilitation in the past. Spectacular examples of gully erosion are found near Elaine and Clifton Springs. Other areas where gully erosion is known to be prevalent include Dereel, Rokewood, Linton, Lismore and Irrewillipe. In many areas, gully erosion is a legacy of past land use, particularly gold mining along creeks and as a result of intense rainfall events after drought. Considerable efforts have been made over the past 60 years to rehabilitate many of these areas, with reasonable success (Dahlhaus 2003).

Management

Maintaining ground cover at 70% throughout the year is the best way to reduce the likelihood of soil erosion. The establishment of perennial pastures and establishing off-stream watering points for livestock also reduces erosion risk. Diverting run-off away from erosion sites, either by using banks or drains, is often used to reduce the impact of water movement in dislodging and transporting soil particles.

Minimal soil disturbance is important in reducing the risk of soil erosion. This includes direct drilling methods to establish crops and pastures. Appropriate cultivation patterns are important on sloping paddocks. Some potato-growing areas encourage winter wheat crops to maintain a ground cover over paddocks to help in reducing rill and sheet erosion during high rainfall months.

Some gully and tunnel erosion sites have been rehabilitated within the Corangamite region. Works conducted have included: the construction of diversion banks and rock chutes, battering of banks and stabilising sites with vegetation. Rabbit control prior to works is essential. Results from erosion remediation in the Corangamite region have been good, if ongoing maintenance has been carried out.

Whole farm planning courses have been conducted for private landholders throughout the Corangamite region over the past 16 years. These courses encouraged landholders to fence paddocks according to land capability. This process decreases the threat of erosion and improves long-term agricultural productivity. Currently, less than 5% of the Corangamite region is fenced according to land classes.

A.3 Acid sulphate soils

Processes

Acid sulphate soils occur naturally in the Corangamite region. These soils have sediments containing iron sulphides below the soil surface. When these naturally occurring sulphides are disturbed and exposed to air, oxidation occurs and sulphuric acid is produced. For every tonne of material that completely oxidises, 1.6 tonnes of pure sulphuric acid can drain into waterways and cause severe short and long-term socio-economic and environmental impacts, such as causing 'fish kills', impacting on aquatic ecosystems, dissolving concrete and therefore impacting on infrastructure (Rampant *et al.* 2003).

The most common activities that disturb acid sulphate soils are:

- agricultural activities that involve land drainage, works to prevent flood and tidal inundation (levees, drains and floodgates) and the use of groundwater. Industry sectors especially implicated are dairying, grazing, cropping and aquaculture
- infrastructure works, especially flood management (levees, floodgates) drainage works, maintenance dredging, laying of utilities (water, sewage, communications) and roads and railways
- urban and tourism development, housing, resorts and marinas
- extractive industries, with sand and gravel extraction from rivers or the floodplain (Rampant *et al.* 2003).

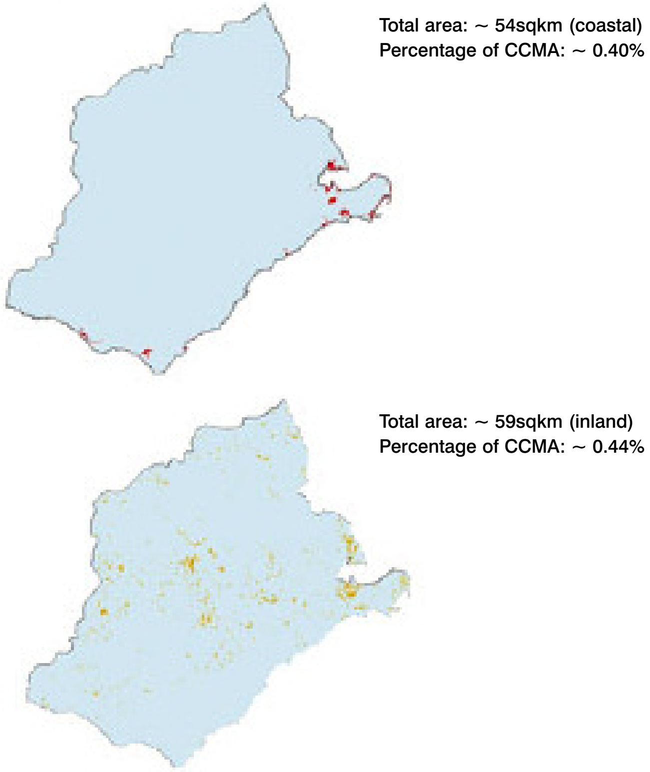
Left undisturbed, potential acid sulphate soils (PASS) cause few or no problems. Urban and regional development is often the main cause of disturbance of potential acid sulphate soils *(Fig. A7).*

Acid sulphate soils are also associated with the mining and processing of brown coal, such as at Anglesea, Lal Lal and Wensleydale. The oxidation of sulphides in the waste dumps associated with these mines results in acid drainage, with the potential for significant impacts on waterways.

Figure A7: Drainage channels contaminated by high levels of acidity leached from disturbed acid sulphate soils

Condition

Potential acid sulphate soils are not found in large areas of the Corangamite region. A study conducted by CSIRO (2005) indicated that there are approximately 54 km^2 of inland and 59 km^2 of coastal potential acid sulphate soils scattered throughout the Corangamite region *(Fig. A8).*



Total area: ~ 54sqkm (coastal)
Percentage of CCMA: ~ 0.40%

Total area: ~ 59sqkm (inland)
Percentage of CCMA: ~ 0.44%

Figure A8: Predicted locations of potential acid sulphate soils in the Corangamite region

Management

The best option for successful management of potential acid sulphate soils is to leave them undisturbed. However, this requires knowledge of their location, followed by protective action to ensure that they are not disturbed. The Corangamite CMA in conjunction with local municipalities, infrastructure and utility managers and EPA Victoria should undertake the management of potential acid sulphate soils.

To improve the base of data, mapping is required to delineate areas of potential acid sulphate soil hazard, particularly in areas more likely to be developed. Once mapped, risk assessment procedures are required to assess the potential for the development of acid drainage and the consequences for regional assets. The risk assessment procedures may ultimately result in changes to municipal planning schemes. Liaison with EPA Victoria is required to manage the potential effects of the off-site impacts of acid mine drainage.

A.4 Secondary salinity

Processes

Secondary salinity in the Corangamite region has been subjected to extensive research over the past 30 years, and has been recently reviewed in the development of the Corangamite Salinity Action Plan (SAP). Primary salinity has been present in the landscape for more than 20,000 years and forms many of the region's environmental assets. However, since the widespread land use changes associated with European settlement, secondary salinity has developed in dryland agricultural areas. The salinity processes are associated with changes to the groundwater and/or soil hydrology (Dahlhaus & MacEwan 1997), which has resulted in an increase in the number and extent of saline water discharge sites in the landscape. The most obvious expression of soil salinity is where salts have accumulated by evaporitic concentration in discharge areas.

Secondary salinity also occurs in areas unrelated to groundwater discharge where salts have accumulated in the soil profile over geological time. In the older landscapes of the region, cyclic salts (present in rainfall) have been accumulating in subsoils through evapotranspiration associated with deeper rooted vegetation *(Fig. A9).* Erosion, soil disturbance and hydrological processes have subsequently brought the salts closer to the surface. This is particularly prevalent where the deeply weathered regolith profiles of the Western Uplands have been exposed relatively recently by erosion or mining disturbance. Changes in the colour of vegetation, pioneering salt tolerant species and bare soil are all indicators of secondary salinity discharge sites.

Figure A9: A secondary salinity discharge site found in the Corangamite region clearly shows bare areas and salt-tolerant species

Condition

Secondary salinity risk, current condition and trends and scenarios in soil and water salinity in the Corangamite region have been described in the background documents to the Corangamite SAP (Heislers & Brewin 2003; Dahlhaus 2003). Although salinity mapping is incomplete and monitoring has been sporadic and inconclusive, there is evidence that secondary salinity has increased alarmingly in some areas *(Fig. A10).* For example, in the Pittong SAP target area, the area of land affected by salinity has grown from 122 ha to 238 ha in the past two decades (Nicholson *et al.* 2003).

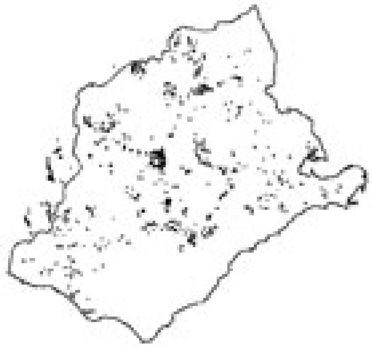


Figure A10: Location of secondary salinity discharge sites in the Corangamite region

Some monitoring was conducted in 2001, when a proportion of mapped salinity sites were revisited. The survey identified an 11% increase in area (Gardiner 2001) and assumed that saline soils sites may have increased by approximately 200 ha in the Corangamite region over the past 10 years.

Assets at risk from secondary salinity have been identified using the Geospatial Salinity Hazard and Asset Risk Prioritisation (GSHARP) model for the Corangamite SAP (Heislers & Brewin 2003). These include the region's Ramsar wetlands, urban water quality for Ballarat and Geelong, the Colac urban area and substantial areas of agricultural land.

Management

The Soil Health Strategy has recognised secondary salinity as a soil-related threatening process in the Corangamite region, and will carry out a risk analysis to determine the locations of the highest risk to assets. It will work with the SAP to address secondary salinity and will focus efforts in areas under high risk that fall outside the SAP target areas.

Detailed management actions have been identified for the SAP target areas, using scenario models, asset manager consultation and benefit-cost analyses. Salinity management using recharge control is recommended for three of the 12 SAP target areas. Discharge management is recommended for all areas, especially those where regional groundwater flow systems are present. Amendments to municipal planning schemes are recommended for all local governments in the Corangamite region. This will ensure that salinity risk posed by new urban and infrastructure developments and the risk of salinity impacting on new developments are considered.

A.5 Waterlogging and soil structure decline

Processes

In waterlogged soils, the lack of oxygen in pore spaces over sustained periods will severely affect plant growth. In wet and compacted soil horizons, where the air porosity is low, poor soil aeration is exacerbated by the production of toxic compounds by soil micro-organisms.

'Soil structure' refers to the arrangement, size and shape and proportion of stable soil aggregates (or peds) in the soil profile. The structure determines soil drainage, porosity, microbial activity, root penetration, aeration, availability of nutrients to plants, water-holding capacity and resistance to erosion and mass movement. Soil structure can be adversely affected by agricultural practises that either breakdown structure or cause soil compaction. The breakdown of soil structure is the cause of:

- restricted root growth, reducing the uptake of water and nutrients by plants
- lower average soil pore size, affecting the water-holding capacity of the soil and the activity levels of soil micro-organisms
- reduced infiltration rates, increasing the likelihood of surface run-off, water erosion and surface ponding.

Soil structure decline can occur through:

- cultivation
- compaction
- aggregate instability.

Cultivation can damage soil aggregates, allowing the organic matter that binds these aggregates together to be consumed by micro-organisms. Inappropriate cultivation may lead to wind or water erosion and soil structure decline, or may have a negative impact on the soil hydrology by altering the drainage of the soil profile (Leeper and Uren 1993).

Compaction of soils generally results from livestock and/or machinery traffic under wet soil conditions. In dairying in particular, the intensity of treading, particularly in moist or wet conditions, leads to compaction, surface roughening and impedance of water and air movement. Organic inputs are high in well-maintained dairy pastures, especially ryegrass pastures, which are strongly mycorrhizal and encourage stable aggregate formation.

Compaction of soils by machinery is a significant issue for cropping and forestry industries. The weight of machinery (particularly in wet conditions) compresses the soil, reducing air and water movement in wheel tracks.

Dispersion is a physico-chemical process observed when a soil aggregate placed in water breaks down to form a milky cloud around it. Dispersive soils are characterised by a high Exchangeable Sodium Percentage (ESP), where excessive sodium forces the clay particles apart in water. The dispersed clay particles can block the pores in the soil, resulting in impeded passage of air and water into the soil profile. Dispersed clays carried across the soil surface can form hard crusts and clods, presenting a barrier to infiltration and root development (McGuiness 1991).

Pugging, a form of compaction, is a significant issue where animals are grazed on landscapes with wet or waterlogged *(Fig. A11)* soils. Severe pugging can occur on the clay soils in dairy country found in the south-west areas of the Corangamite region. A study by MacEwan (1998) confirmed the susceptibility of the region's soils to pugging, especially in landscapes where the soils are saturated or where the watertable is within 20cm of the surface soil.

Figure A11: Pugging in waterlogged soils caused by dairy cattle, leading to soil structure decline

Compaction of surface and sub-surface soils threatens agricultural production as it degrades the productivity of most cropping soils. In addition, compaction caused by machinery can reduce the productivity of the land and increase run-off rates, which may increase the likelihood of water erosion and threaten water quality.

In drier parts of the Corangamite region, compaction of the surface soil as a result of intensive treading of hard-hoofed animals also causes significant soil structure decline, particularly on fine sandy loam soils. Pugging and hoof compaction significantly impact soil health and threaten agricultural productivity.

Soil structure decline is often associated with cultivation in dry conditions, particularly on loam topsoils in the region. These soils are particularly vulnerable to over-tillage, which under dry conditions breaks down the soil aggregates to a 'flour' easily blown by wind or washed by excessive rainfall. This problem is more likely to occur prior to crop or pasture establishment and can threaten water quality by adding suspended sediments to waterways (turbidity).

Dispersive soils occur extensively across the region, particularly in subsoils. The breakdown of soil structure caused by dispersion not only threatens agricultural production, but can also lead to severe erosion that threatens water quality.

Condition

Waterlogging may be a natural condition of the soil, but can worsen with deterioration in soil structure. There is a strong relationship between high likelihood of soil structure deterioration and a high susceptibility to waterlogging. Susceptibility maps indicate that waterlogging is high to very high over more than 50% of the Corangamite region *(Fig. A12).* These susceptible areas are generally located on low-lying heavy duplex soils in higher rainfall areas. High to very high susceptibility to soil structure decline covers similar areas to that of waterlogging, predominant in the south-west section of the region *(Fig. A13).*

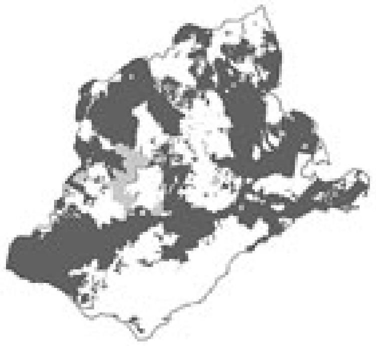


Figure A12: Areas of high to very high waterlogging susceptibility in the Corangamite region

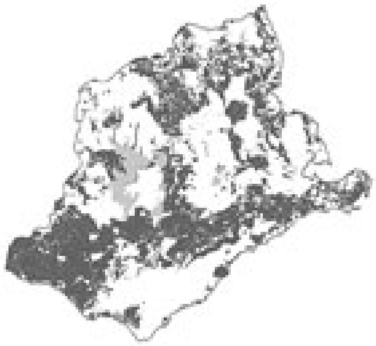


Figure A13: Areas of high to very high soil structure decline susceptibility in the Corangamite region

Management

The dairy industry has long recognised pugging as a significant issue, resulting in the development of the 'Wet Soil Management Initiative' (MacEwan 1998). Grazing practices have been developed that focus on the timely removal of livestock from wet soils and include off-site agistment, restricting livestock access and calving over a longer period.

Surface and sub-surface drainage are commonly used to rehabilitate waterlogged land and improve soil structure. Currently, over 80% of dairy land has some form of surface drainage and up to 20% has sub-surface drainage (MacEwan 1998).

'Graze and spell' rotation has been identified as an effective method of reducing hoof compaction on broadacre grazing land as it maintains good ground cover and higher organic carbon levels. This practice is currently being adopted over 30% of broadacre grazing land in the region (MacEwan 1998).

Compaction of wet forest soils by machinery while establishing or harvesting productive forests is a significant issue in the region. According to the 'Forestry Code of Practices', forestry activities should cease during wet periods to ensure that soil structure is maintained. Currently, most forestry activity on public land stops when soils are too wet. The adoption rates of this Code of Practice on private land are not known.

Over the past decade, extensive research efforts have been directed towards the factors that contribute to waterlogging and soil structure decline under broadacre cropping regimes. The biggest development has probably been with raised bed techniques, which currently cover about 10% of the annual crop area in the Corangamite region. Raised beds aim to reduce machinery compaction by using controlled traffic and to reduce waterlogging by lifting the soil above the saturated zone. Where used, raised beds have significantly improved soil structure and reduced waterlogging on cropping land, while significantly increasing agricultural productivity in high-rainfall areas. The construction of surface drains on crop land is also used to reduce waterlogging and improve agricultural production. It is recognised that the proper installation and maintenance of surface drainage (including raised beds) is critical in minimising off-site impacts, especially where sediments and nutrients may enter waterways and threaten water quality.

The adoption of minimum tillage practices can lessen and even reverse soil structure decline by maintaining organic carbon and limiting soil disturbance. Using tyned implements for crop sowing in preference to disc cultivators can also cut soil disturbance. Currently, about 60% of cropping land is minimal tilled and 30% conducted under 'no till' in the Corangamite region (Ward pers. comm. 2003). Reduction in tillage will help preserve soil structure and further sustain agricultural productivity.

In areas where dispersive soils are present, gypsum may be applied to help maintain aggregate stability, ultimately improving soil structure. In the Corangamite region, 10% of cropped and less than 5% of dairy and broadacre grazing land has gypsum applied. The costs of transporting and spreading gypsum inhibit wider adoption by broadacre grazing and cropping farmers in the region.

A.6 Wind erosion

Processes

The process of saltation (whereby fine sand particles bounce across the ground hitting and detaching other particles) dominates wind erosion. The finer particles are lifted in suspension and carried great distances. Coarser particles are bumped by other particles, resulting in the coarser particles 'creeping' along the surface. The mechanics of wind erosion are fully described in the scientific literature (e.g. McTainsh & Leys 1993).

Studies in Australia have revealed that the wind-blown fraction contained 16 times as much nitrogen, and twice the cation exchange and water-holding capacity of the original soil (Young & Young 2001). Therefore, wind erosion has the potential to threaten agricultural production due to the removal of fertile topsoil, which may end up in waterways and cause water pollution. Wind erosion also threatens air quality.

By nature, coastal dunes are originally and intermittently mobile and are a dynamic and natural feature of the landscape. Dunes become immobilised when some agent binds the surface. This may be a mineral material such as salt or calcareous cement, or sand-binding grasses and shrubs. All coastal dunes should be regarded as potentially unstable and prone to movement as environmental conditions change.

Condition

Wind erosion is mostly seen across the Basalt Plains, the Central Highlands and at points along the coastline. Wind erosion generally occurs on fallowed areas in cropping country and exposed sand dunes along the coast *(Fig. A14).*

Figure A14: Wind erosion in fallowed paddock

Wind erosion of sand dunes is most dynamic along south-west to south-facing shorelines in response to prevailing and strong winds. However, detailed dune position, extent and dynamics are determined by several variables including the beach slope and offshore profile, the geometry of the coastline and the availability of sand (partly a function of shoreline geology). High to very high susceptibility areas for wind erosion are illustrated in *Figure A15.*

The susceptibility of coastal dune movement along the Corangamite coast has not been accurately mapped. Managers in coastal areas suggest that the susceptibility of dunes to movement will vary depending on infrastructure, tides and ground cover protection.

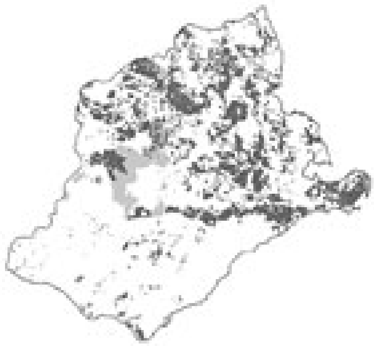


Figure A15: Areas of high to very high wind erosion susceptibility in the Corangamite region

Management

In agricultural areas, wind erosion has been managed by maintaining ground cover throughout the year. Strategically located windbreaks can be effective in reducing wind velocity and therefore risk of soil movement.

Dunes have been revegetated and stabilised by tussocky species such as marram grass. Community groups along much of the Corangamite coastline have been actively involved with DSE in programs to revegetate sand dunes susceptible to wind erosion.

A.7 Soil nutrient decline

Processes

Maintaining a cost-effective balance of available plant nutrients is an important component of farm management. Sustainable land use requires the replacement of extracted nutrients. Nutrients can also be lost from the soil through leaching into the deeper soil profile, in run-off or through soil movement.

In some cases, nutrient extraction or deficiencies may be over-corrected through excessive fertiliser or trace element application leading to off-site impacts including an increased risk of algal blooms and eutrophication processes.

Condition

In their natural, virgin state, soil nutrients are naturally deficient for the levels of agricultural production required of most soils throughout the Corangamite region. As a result dairy, cropping and broadacre grazing managers apply fertilisers to improve productivity. Nutrients are replaced as they are removed from the soil by pastures and crops. The greatest susceptibility to soil nutrient decline is found along the ranges of the Otways *(Fig. A16).*

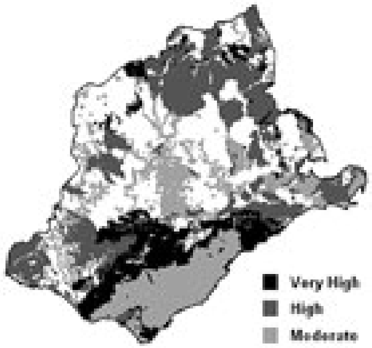


Figure A16: Areas of moderate, high and very high soil nutrient decline susceptibility in the Corangamite region

Management

Approximately 10% of agricultural land managers in the Corangamite region regularly conduct soil tests to determine the nutrient input requirements for the soils. Many land managers could potentially be applying insufficient or excessive amounts and/or the incorrect type of fertilisers to their soils.

'Nutrient budgets', together with soil tests, are recognised as prime indicators for improved nutrient management. Soil tests should be used to identify whether topsoil nutrient levels are at, above or below the target ranges. On areas that are below the target levels, capital applications of nutrients are required. Once target levels are reached, maintenance fertiliser rates should be applied. The aim of nutrient budgeting is to balance inputs and outputs, so that levels are maintained at the optimum for production.

A.8 Soil acidification

Process

Soil pH is used as an indicator of soil acidity or alkalinity. This is based on a numerical scale of 0 to 14 where pH below 7 is acid and pH above 7 is alkaline. The pH scale is logarithmic, meaning that a soil of pH 8 is 10 times more alkaline than a soil of pH 7.

The pH of soil falls as a result of *(Fig. A17):*

- leaching of soil water containing nitrogen, in the form of nitrate from either legumes (e.g. clover) or applied fertiliser nitrogen, which leaches the alkaline-based elements leaving behind the acidic-based elements
- removal of alkaline agricultural products such as hay, wool, meat, and milk
- accumulation of soil organic matter, which breaks down to release acidic elements.

Low soil pH reduces the availability of essential nutrients such as phosphorus and molybdenum, and increases the availability of toxic elements such as aluminium and manganese. Low pH also makes the environment unsuitable for many soil microbes.

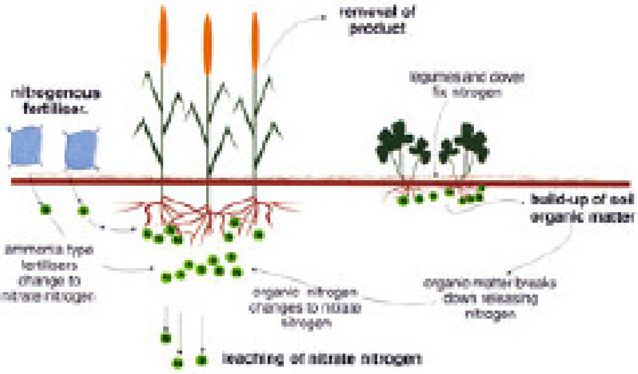


Figure A17: Processes associated with acidification through nitrate leaching

Condition

Soil acidification is a process that is more common in sandier soils, where nitrogen/nitrate leaching occurs more readily. Soil acidification is found throughout the Corangamite region, but appears to be most prevalent in areas of higher agricultural production *(Fig. A18).* These areas have high levels of agriculture-related inputs and outputs, which also increase the likelihood of soil acidification.

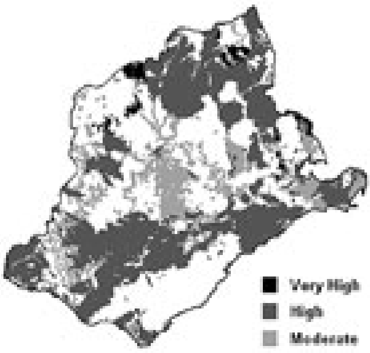


Figure A18: Areas of moderate, high and very high soil acidification susceptibility in the Corangamite region

Management

The only way to reverse soil acidification is to raise the pH through the application of alkaline minerals such as agricultural lime to the soil. The effectiveness of an application of lime will depend on the relationship between pH, soil type, buffering capacity and enterprise. Lime can be incorporated into the soil or simply top-dressed and left to leach into the soil with subsequent rainfall.

In the Corangamite region, more than half the cropping and dairy land is subjected to regular applications of agricultural lime (Bluett and Ward pers. comms. 2003). On broadacre grazing, less than 10% of land has lime applied regularly, because it is generally not cost-effective. As an alternative, land managers may grow more acid-tolerant pasture species. Soil aluminium concentration ultimately determines which pasture species will be productive on more acidic soils. Acid-tolerant species such as cocksfoot, and legumes such as Serradella, help maintain pasture productivity in the face of falling soil pH.

Deep-rooted perennial pastures such as phalaris and cocksfoot can use water from deeper in the soil profile, reducing the potential for nitrate leaching and, therefore, soil acidification. Phalaris retains some deeper roots over the summer and can quickly grow new roots following autumn rains. In the Corangamite region, about 20% of pastures in broadacre areas have a sufficient proportion of perennial species to minimise acidification rates.

Soil testing ensures that excess nitrogen is not being applied through fertilisers; unused nitrogen may leach and cause soil acidification. Within the region, only about 10% of landholders regularly conduct soil tests. Therefore nitrogen leaching could be significant, particularly on sandy soils.

A.9 Soil contamination

Processes

The physical and chemical contamination of soil is largely a legacy of past practices. These commonly include heavy metal contamination from mining, hydrocarbon contamination from leaking fuel tanks and organochlorine and other pesticides from agriculture.

At the time of the development of the SHS, the status of soil contamination in the region could not be readily determined. EPA Victoria has no published study on regional soil contamination sites. However, there are 15 sites in the region where the EPA has issued a notice to the occupier because of pollution or potential for pollution of groundwater, surface water and/or land. These sites are in highly developed industrial areas.

Condition

Heavy metals, particularly arsenic, are associated with past mining activities around Ballarat (Lamb *et al.* 1993; Harvey, 2003), although these sites have not been recognised by the EPA as a significant contamination threat. Dieldrin insecticide was used extensively in the 1950s, 60s and 70s for the control of insect pests in potato crops. This type of pesticide is persistent in the soil and can take up to 200 years to break down by biological processes. Dieldrin contamination sites are mostly found in the Bellarine Peninsula area, east of Lake Connewarre. The use of dieldrin is now prohibited.

The presence of contaminants can restrict the options for land use. At worst, contaminated sites can be declared unsuitable for any use, as the contaminants may cause death or illness of humans and livestock. In other cases, contaminants may limit the productive use of the soil, such as when animals grazed on contaminated soils are declared unfit for human consumption. The mobilisation of contaminants from the soil has the potential to cause severe impacts to the environment.

Management

Contaminated sites usually require individually tailored management solutions, which must comply with EPA regulations. For instance, all sites contaminated by dieldrin have been identified. At these sites, landholders develop property management plans to ensure that dieldrin does not spread off-site and that any livestock grazed in these paddocks spend time on uncontaminated paddocks prior to sale.

A.10 Soil organic carbon (matter) decline

Processes

Organic matter is any material that contains carbon compounds that were formed by living organisms, covering a wide range including: leaves, stems, branches, moss, algae, lichens, decaying animals, manure, droppings, sewage sludge, sawdust, insects, earthworms and microbes.

There are three main components of organic matter in soils:

- dead forms of organic material – mostly dead plant parts
- living parts of plants – mostly roots
- living microbes and soil animals.

The breakdown of organic matter is a complex process that involves chemical alteration of organic matter, physical fragmentation and finally, release of mineral nutrients. Organic matter breakdown is a biological process. Soil organisms (micro-organisms, earthworms, micro-arthropods, ants, beetles, etc), perform the chemical and physical changes. Each type of organism plays a different role in the breakdown.

Breakdown starts almost immediately after the organism, or part of it, dies. The organic material is first colonised by micro-organisms using enzymes to oxidise the organic matter and obtain energy. In the case of leaves and roots, their surfaces are colonised by micro-organisms even before they die. Soil animals such as earthworms assist in the decomposition of organic matter by incorporating it into the soil where conditions are generally more favourable for decomposition than on the surface. Earthworms and other larger soil animals, such as mites, collembola and ants, fragment organic material, increasing the surface area and allowing more micro-organisms to colonise the organic matter and decompose it.

During decomposition, complex organic chemical molecules progressively break down into simpler organic molecules. These undergo further decomposition into mineralised nutrients. The first organic compounds to be broken down include simpler amino acids and sugars. Cellulose is broken down more slowly. Complex molecules such as phenols, waxes and lignins remain in the soil for the longest time (Abbott 2002).

High levels of organic carbon are essential for good soil health, improving soil structure, raising fertility, reducing erosion and encouraging soil biota. Soil organic carbon also helps maintain agricultural production and reduces potential off-site risks, such as sediments entering waterways as a consequence of soil erosion.

Condition

Although there is little or no information available on soil organic carbon levels in the Corangamite region, it can be assumed that higher organic carbon levels are likely in higher rainfall areas featuring long-standing perennial vegetation, with minimal agricultural land use. *Figure A19* illustrates the difference in soil organic carbon levels at a farm scale under different management practises.

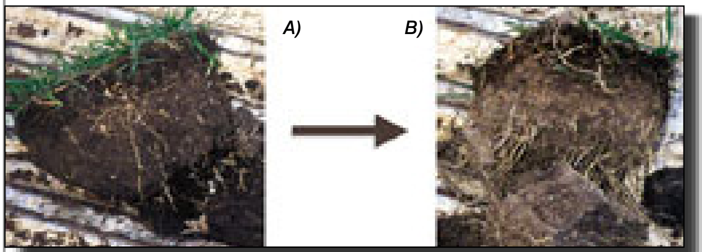


Figure A19: Two soils from neighbouring paddocks, soil 'A' has high organic carbon levels, while soil 'B' has lower carbon levels due to poor land management practises

Management

Within the Corangamite region, only a minority of pastures are predominantly perennial species. Increasing the proportion of perennial species in pastures will increase organic carbon in soils at depth. Perennial species have a much higher biomass and therefore provide greater amounts of organic carbon to the soil. Grazing regimes that encourage pasture regeneration, such as 'graze and spell rotation', are effective contributors to the maintenance of higher organic carbon levels.

Maintaining soil organic carbon levels is as important in cropping paddocks as it is in pasture paddocks. Stubble retention contributes to the maintenance of higher carbon levels in soils. Incorporating pasture phases into the rotations also helps maintain higher organic carbon levels.

A.11 Soil biota decline

Processes

Soil biota, or organisms, are extremely diverse and abundant. It is believed that there are twice as many species of organisms alive in the soil than in tropical rainforest canopies. Soil biota are grouped into three categories according to their size. The first group is the microfauna, which are the smallest of the soil animals and range from 20 – 200μm (e.g. protozoa). The mesofauna is the next largest group and range in size from 200μm – 10mm (e.g. mites, collembola and nematodes). Macrofauna is the largest soil biota, and includes earthworms, beetles and termites.

Associations between bacteria and plants that fix atmospheric nitrogen include species of Frankia bacteria and certain tree species such as those of the genera Casuarina and Allocasuarina. Another example is between that of Azospirillum and certain grass species. The most well-known plant-bacteria association that fixes atmospheric nitrogen is the symbiotic relationship between rhizobia and legume plants (Abbott 2002).

Biological fertility of soils, while hard to quantify, provides great opportunities for land management and monitoring because of its dynamic nature. Understanding the biological state of soils may provide early warning of land degradation, thereby enabling the employment of more sustainable land management practises (Abbott 2002).

Figure A20: A Soil Mite commonly found in soils
Photograph: B. Marcot

Condition

Little is known about soil biota conditions in the Corangamite region. Soil biology is complex and a better understanding of the mediatory effect the biological components have on chemical and physical fertility needs to be identified. In the region, it is most likely that high biota numbers will be found in soils that are well structured, have high organic carbon levels and a neutral pH.

Management

Soil biota play an important role in the breakdown of organic matter, improving soil structure and releasing nutrients for plants. The level of soil biota is an excellent indicator of soil health and is vital in maintaining agricultural productivity.

To make the soil environment more favourable for soil biota, Abbott (2002) believes the following best-management practices should be followed:

- conduct appropriate crop rotations (especially legume-based), that improve nutrient and organic matter levels, break disease cycles and provide more diverse nutrient sources for soil biota
- maintain soil fertility by conducting regular soil tests and applying fertiliser according to crop and paddock needs. Most biota are sensitive to soil acidity, therefore adding agricultural lime will raise the pH to foster biological activity.
- retain crop stubble to encourage higher levels of organic matter as a food source for soil organisms
- reduce soil structure decline to maintain pore spaces and drainage
- reduce waterlogging because many soil microbes do not adapt to anaerobic environments.

In the Corangamite region, stubble is burnt on 60% of crop land (Bluett pers. comm. 2003), potentially impacting on organic matter and biota in the soil. Other stubble management practices used in the region include retention, incorporation and grazing. Burning stubble exposes surface soils to wind and water erosion. Retaining stubbles is one alternative, but may require investment in seeders capable of handling larger volumes of crop trash.