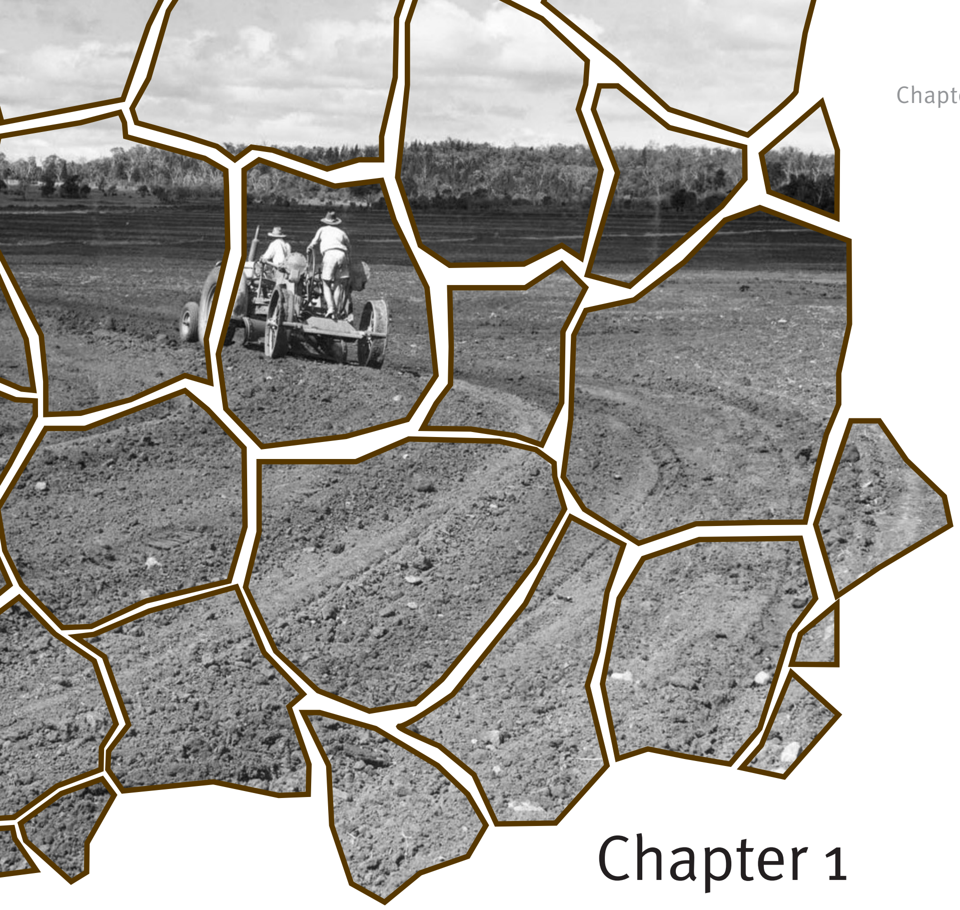


Chapter 1

An introduction to soil conservation in Queensland

Key points

- Land may become degraded through a range of processes including: erosion, salinisation, soil structure decline and fertility decline. These processes occur naturally in different locations to varying levels but poor land management greatly increases their extent and adverse impact.
- Land degradation is widespread across Queensland, costing the state in excess of $2 billion per year in lost agricultural income, infrastructure damage and reduced environmental services.
- The story of land development in Queensland over the past 150 years has been one of expansion and intensification of agriculture. Mistakes were made along the way and the story is also one of perseverance and ingenuity as Queensland farmers and graziers encountered and solved land degradation problems.
- The greatest land degradation threat to rural Queensland is water erosion. Water erosion can be controlled by applying the three principles:
  — using land according to its capability
  — provide soil surface cover
  — controlling runoff.
- These guidelines provide practical advice for landholders, consultants, extension officers, policy makers and others with an interest in soil conservation. They are drafted with Queensland particularly in mind but contain information that will be useful for conservation land management in other areas.

Contents

Glossary

acidification: when the acid reaction throughout most or all of the soil profile falls to a pH of 6.5 or less. Acid soils generally become a problem when the pH drops below 5.5.

aluminium toxicity: the negative effect that dissolved aluminum in soil can have on many plants. Aluminium toxicity can be a consequence of soil acidification as lower pH can lead to the release of increased quantities of aluminium into solution within the soil.

chromosols: soils with strong texture contrast between A horizons and B horizons. The latter are not strongly acid and are not sodic.

clay: mineral particles less than 0.002 mm equivalent diameter that are the chemically active mineral part of the soil and are responsible for many of the important physical and chemical properties of a soil.

conservation cropping: a farming system that aims to conserve soil, water and energy resources, while providing for farm productivity and economic viability; generally involves stubble retention and rotation of grain crops with cover, forage or green manure crops.

contour bank: a constructed earth embankment, incorporating a channel on the upslope side, typically traversing a slope on or close to the contour to control and/or prevent the erosion of that slope.

controlled traffic farming (CTF): a cropping system in which the crop zone and the machinery traffic lanes are distinctly and permanently separated. In practice it means that all implements have a particular span, or multiple of it, and all wheel tracks are confined to specific traffic lanes.

creep: more or less imperceptible transportation of soil particles under the influence of various erosive agents.

dispersive soil: a structurally unstable soil that readily disperses into its constituent particles (clay, silt and sand) in water.

Emerson aggregate immersion test: classification of soil aggregates based on their coherence in water by placing small dry aggregates in dishes of distilled water and observing the conditions under which they slake, swell or disperse.

environmental services: qualitative functions of natural non-produced assets of land, water and air (including related ecosystems) and their biota; includes provision of raw materials and energy used to produce goods and services, absorption of waste from human activities, and basic roles in life support and provision of other amenities such as landscape aesthetics.

erodibility: susceptibility (of a soil type, or part of the landscape) to erosion.

erosion: wearing away of the land surface by rain or irrigation water, wind, ice or other natural or anthropogenic agents that abrade, detach and remove geologic parent material or soil from one point on the earth's surface and deposit it elsewhere.

erosivity: potential ability (of an eroding agent such as rain, runoff or wind of a particular strength/intensity and duration) to cause erosion.

ferrosols: soils with B2 horizons that are high in free iron oxide (>5%), and which lack strong texture contrast between A and B horizons.

fertility decline: depletion of the nutrient store in soils leading to reduced plant growth and yield.

gully erosion: a complex of processes whereby the removal of soil is characterised by large incised channels in the landscape. Such channels are generally deep enough (usually >0.3 m) to interfere with, and not to be obliterated by, normal tillage operations.

kandosols: soils which lack strong texture contrast, have massive or only weakly structured B horizons, and are not calcareous throughout.

land capability/suitability: systematic arrangement of land into various categories according to its ability to support particular land uses/land management systems and the treatment required to sustain those uses/management systems without degrading the land. Land capability classification evaluates the potential of land for major land uses (e.g. cropping, pastoral or non-agricultural), whereas land suitability classification assesses the potential of land for a specific land use or a specific crop.

land degradation: decline in quality of natural land resources, commonly caused through improper use of the land.

mass movement: an erosion process in which gravity is the primary force acting to dislodge and transport land surface materials (includes the processes of creep, earthflow, slumping, landslips, landslides and rock avalanches).

peds: individual, natural soil aggregates.

peneplain: a land surface of considerable area and slight relief, reduced almost to a plain by long periods of erosion.

rill erosion: removal of soil by runoff from the land surface whereby numerous small channels are formed, generally no more than 30 cm deep.

salinisation: accumulation of free salts in part of a landscape typically caused by hydrological changes as a result of human use of land, particularly in areas of marine geology.

saltation: particle movement in water or wind where particles skip or bounce along a stream bed or land surface.

sand: soil particles between 0.02 mm and 2.0 mm in equivalent diameter.

scalds (or clay pans): a poorly vegetated (or bare) impermeable clay surface where surface soil has been removed by wind and/or water erosion.

sheet erosion: removal of a fairly uniform layer of soil from the land surface by raindrop splash and/or runoff without forming perceptible channels.

silt: soil particles between 0.002 mm and 0.02 mm in equivalent diameter.

slaking: partial breakdown of soil aggregates in water due to the swelling of clay and the expulsion of air from pore spaces.

sodicity: a soil condition where the amount of exchangeable sodium (ESP) in a soil is greater than 5%. Excess exchangeable sodium adversely affects soil stability, plant growth and/or land use. A soil with more than 15% ESP is considered strongly sodic.

sodosol: a soil defined in the Australian Soil Classification system as having a clear or abrupt textural B horizon and in which the major part of the upper 0.2 m of the B2 horizon (or the major part of the entire B2 horizon if it is less than 0.2 m thick) is sodic and not strongly acid. Soils of this type are characteristically highly dispersive and are prone to gully erosion.

soil structure: combination or spatial arrangement of primary soil particles (clay, silt, sand and gravel) into aggregates such as peds or clods and their stability to deformation.

Southern Oscillation Index (SOI): calculated using the pressure differences between Tahiti and Darwin, the SOI gives an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean.

suspension: movement in water or air where particles are kept dispersed by fluid motion in currents, by turbulence and/or by molecular motion of the surrounding medium.

texture contrast soils (also known as duplex): soils where the B horizon is dominated by a texture class one-and-a-half (or more) finer than the A horizon. Texture in duplex soils is highly variable, with the topsoils ranging from coarse sand to clay loam and the subsoils from light to heavy clay.

total grazing pressure: the ratio of the demand for forage to the availability of forage at a point in time including the demand from all herbivores—cattle, horses, sheep, native and feral animals, and insects such as grasshoppers or locusts.

tunnel erosion: a process involving the hydraulic removal of subsurface soil, causing the formation of underground passageways (i.e. tunnels) in landscapes.

Universal Soil Loss Equation: a mathematical relationship developed in the USA to predict long-term average soil losses in runoff under specified environmental and management systems.

vertosols: clay soils with shrink–swell properties that exhibit strong cracking when dry, and at depth have slickensides and/or lenticular structural aggregates.

water ponding: a technique used for reclaiming scalded and unproductive country whereby u-shaped earth banks are constructed to pond water, improving soil conditions and enabling vegetation to establish.

waterway: a stable, longitudinally sloping water disposal area used to discharge surplus runoff allowing it to flow to a lower level without causing erosion; maybe natural or constructed.

1.1 Introduction

This chapter introduces land degradation in Queensland and provides a general background to the guidelines. It describes the different forms land degradation with a focus on water erosion, the process that represents the greatest threat to Queensland soils. It also provides a brief summary of the past, present and expected future of soil conservation in Queensland.

1.2 Principles of soil conservation

Land degradation is defined as: the temporary or permanent lowering of the productive capacity of land (‹http://www.fao.org›). It includes a range of types of erosion plus other processes such as salinisation, fertility decline, acidification and soil structure decline. Some forms of land degradation such as severe gully erosion are very obvious while other forms such as sheet erosion and acidification are more insidious. In Queensland land degradation occurs on all types of land: Crown land and privately owned land; urban and rural land.

1.2.1 Impacts of land degradation

It has been estimated that more than 80% of cultivated land in Queensland is affected by land degradation such as water erosion (Department of Primary Industries 1994). Some of the districts most severely affected include the:

- horticultural and sugarcane lands on the coast
- Atherton Tableland
- cereal cropping lands of the Central Highlands
- Dawson–Callide valley
- inland Burnett region
- Darling Downs and Western Downs.

Soil losses from erosion may be considerable if preventative measures are not taken. On the Darling Downs, unprotected cultivated land in upland areas may lose up to 60 tonnes of soil per hectare in one year depending on the slope, whilst steep unprotected cropping lands in tropical areas may lose up to 2100 tonnes of soil per hectare in one year (Department of Primary Industries 1994). These losses greatly exceed the estimated average tolerable hillslope soil erosion rate for Australia of ‹1 tonne per hectare per year (Bui et al. 2011), and they are clearly unsustainable.

The impacts of land degradation occur both on-site and off-site. On-site impacts include:

- loss of topsoil reducing the water and nutrient storage capacity of the soil leading to lower productivity
- exposure of subsoil that often has poor physical and chemical properties that can render the land incapable of supporting viable agricultural enterprises and increase the risk of further erosion
- productivity losses due to salinisation, acidification, wind erosion or mass movement
- reduced soil porosity and increased soil temperatures, reducing microbial activity and impairing overall soil health
- increased cultivation costs (and increased machinery damage)—for example where paddocks are severely gullied—as well as loss of arable land, and grazing land; and reduced property value
- reduced water and fertiliser use efficiency, resulting in increased fertiliser requirements and reduced economic viability
- poorer crop establishment and increased death of crop plants, leading to increased requirements for supplementary sowing and reduced yield.

Off-site impacts include:

- crop and pasture losses due to smothering from silt deposited in low-lying or sheltered areas by an erosion event

- pollution of downstream waterbodies by nutrients and chemicals (e.g. fertilisers or pesticides washed from paddocks) transported with sediment, and damage to aquatic habitats through sediment deposition
- damage to infrastructure such as roads and railway lines by sedimentation or undermining due to increased flood flows
- poorer human health (e.g. respiratory illness due to pollution of air by fine particles in suspension resulting from wind erosion) or other health issues due to pollution of drinking water or recreation areas.

The costs of land degradation to the Queensland community are difficult to quantify but are undoubtedly very high. Agriculture is an important part of Queensland's economic and social fabric; Queensland agriculture, including primary processing, directly contributes more than $14 billion worth of production to the state's economy and employs more than 90 000 people within the state (State of Queensland 2013). Land degradation has been estimated to cost 5% of agricultural production Australia wide (Gretton and Salma 1996), which for Queensland equates to a direct loss of $0.7 billion annually and around 5000 jobs. Agriculture in Queensland also supports an array of secondary industries such as transport logistics, processing, refrigerated storage and sales, which are collectively estimated to contribute a further $22 billion annually (State of Queensland 2013). If secondary industries are included, the potential direct impact of agricultural land degradation on Queensland's economy is around $2 billion per year.

The off-site effects of soil erosion are even more difficult to value. Including costs of associated road and railway maintenance, water treatment and dredging, off-site effects of soil erosion were estimated to cost Queensland more than $30 million annually in 1990 (Russell et al. 1990) or around $110 million per year in today's terms. Water quality impacts alone are very significant. In 2013, continuation of water supply to hundreds of thousands of people was threatened when Mt Crosby, one of Brisbane's main domestic water treatment facilities, had to be shut down due to sediment pollution as the result of erosion during a severe flood (*Brisbane suburbs risk running out of drinking water*, Brisbane Times, January 29, 2013).

The United States Environment Protection Agency estimates that every dollar spent in catchment management reduces water treatment costs by an average $27 (SEQ Catchments 2013).It is also estimated that the replacement value of each megalitre (ML) of storage capacity lost to sedimentation in Queensland is $4000 (SEQ Catchments 2013). A single erosion event may result in many thousands of ML being lost (Figure 1.1). For instance, cropping lands in the Lockyer catchment are estimated to have contributed around 30 million tonnes of soil (sufficient to displace approximately 30 million ML) to the Brisbane River during a single flood event in 1996 (SEQ Catchments 2011).

Land degradation also impacts on a range of non-market goods, or environmental services. Whilst these impacts remain largely unquantified it is likely that they far outweigh the direct economic impacts. These indirect impacts can be equally important (or even of greater importance) in motivating land managers to adopt soil conservation measures. Soil erosion can become a very visible problem and an obvious threat to the future viability of a property. Soil conservation measures, such as tree planting and groundcover maintenance, can greatly improve the aesthetic appeal of a property as well as reduce wear and tear on machinery, and enhance biodiversity.

Figure 1.1: The plume of sediment resulting from a flood on the Fitzroy River in 1989 extended more than 15 km from shore and more than 60 km north of the river mouth (photo Bob Packett)

Landholders are becoming more aware of the impact of their practices on the external environment and of the marketing advantages when consumers are aware that their food is produced in an environmentally friendly manner. In 2006–07 Queensland farmers reported spending a total of $121 million on land and soil conservation works including almost half a million person days, with an average investment per business of $7000 and 29 days (Australian Bureau of Statistics 2007). On top of this, the Queensland Government has allocated $80 million over five years from 2013 to 2018 to the Regional Natural Resource Management Investment Program which supports natural resource management—including soil conservation—in Queensland (‹https://www.dnrm.qld.gov.au/land/accessing-using-land/natural-resource-management/nrm-investment-program›).

In addition, a stocktake undertaken in 2010–11 found that Australia's total current investment in soil research, development and extension across all government sectors was $124 million and around 850 full-time equivalent staff (including postgraduates) annually (Soils Research, Development and Extension Working Group 2011). Exactly how much of that investment occurred in Queensland is not available, but the proportion is likely to be in the order of 15–20% of the total (or around $20 million and 170 staff).

1.2.2 Erosion processes

Erosion is a natural process: it is responsible for the shape of our landscapes. As well as occurring naturally, erosion can be accelerated by human activities. It is when that occurs that landscapes become degraded.

Equation 1.1

A = R*K*L*S*C*P

Where:

A = average soil loss in tonnes/hectare/year

R = rainfall erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cropping factor

P = supporting practices factor.

Models have been developed to help us understand and predict soil erosion. The Universal Soil Loss Equation (USLE) is the most widely used erosion model. The USLE was developed from erosion plot and rainfall simulation experiments by scientists from the USA Department of Agriculture in the 1970s (Wischmeier and Smith 1978) and has gained wide acceptance throughout the world over the past 30 years. The USLE was designed to estimate long-term average annual soil loss caused by sheet and rill erosion from segments of arable land under various cropping conditions (Rosewell 2001). Using the USLE the potential soil loss from different management options can be calculated and compared—see Equation 1.1.

The factors R, K, L and S are characteristics of the environment that determine how much soil would be lost if the soil was maintained in a bare condition with no soil conservation practices applied. This figure is then reduced by the C (crop and pasture management) and P factors (such as contour cultivation) to reflect the effect of different farming regimes.

The USLE has a number of well-documented limitations, including:

1. The model applies only to sheet erosion since the source of energy is rain; it never applies to gully or steam erosion or mass movement.
2. The model has been tested and verified in peneplain and hilly country with 1–20% slopes, but not in young mountains, especially slopes steeper than 40%, where runoff is a greater source of energy than rain and where mass movement is significant.
3. The relations between kinetic energy and rainfall intensity generally used in this model apply only to the American Great Plains and not to mountainous regions although different sub-models can be developed for the index of rainfall erosivity, R.
4. The model applies only for average data over 20 years and is not valid for individual storms. A modified USLE model (MUSLE) has been developed for estimating the sediment load produced by each storm, which takes into account not rainfall erosivity but the volume of runoff.
5. It neglects certain interactions between factors in order to distinguish more easily the individual effect of each. For example it doesn't take into account the effect on erosion of slope combined with plant cover.
6. The P factor accounts only for contour cultivation and not the use of contour banks. As contour banks reduce slope length, their effects can be accounted for by the L factor. However, the USLE does not take into account the fact that besides reducing the effective land slope, contour banks manage runoff to prevent it from concentrating and becoming an erosive force as it proceeds down the slope. Such concentration can contribute to rill and gully erosion.

The USLE is a useful research and education tool, and has been used in Queensland to provide recommendations on what are appropriate landuse measures across Queensland—that is, landuse practices that are sustainable, and those that are not. The USLE parameters have been derived by Queensland researchers to establish plot-size and field-size trials to measure rainfall erosivity and erodibility of typical soils under cultivated conditions.

The USLE is a very useful tool to help us understand the erosion process overall and the key factors involved, but as it is not a design tool it has rarely been used for the specific design of on-ground measures. As outlined in later chapters, soil conservationists, with the support of USLE research work, have used a mixture of experience and empirical models to define suitable soil conservation measures.

The two primary methods of controlling soil erosion are to:

- maximise surface cover, and
- on cultivated lands, manage runoff with structures such as contour banks or mounds on upland areas; and employ strip cropping on floodplains.

Although field trials based on the USLE have confirmed or modified adopted recommendations, the practices described above can readily be implemented without reference to the model. Land managers can maintain high levels of surface protection with current technology, although this can be limited by droughts, fertility decline, grazing, hay making, harvesting practices or crop type.

Rainfall erosivity

Raindrop impact and moving water are a potent combination. Erosion begins when raindrops impact on bare soil surfaces. Raindrops have considerable kinetic energy that breaks down soil aggregates (or peds) into the smaller individual sand, silt and clay particles that make up soils. Fine soil particles are splashed into the air by raindrop action, returning to the soil surface to form a seal which retards further water entry and increases runoff. The fine particles released by raindrop impact are more readily removed by runoff than when they were aggregated into peds.

The high energy of heavy rainfall is a major driver of erosion in Queensland. Intense summer storms and events such as cyclones are capable of producing very high rates of erosion. The most intense rainfall occurs on the wet tropical coast where annual average rainfall totals vary from 200–4000 mm. In contrast, rainfall in the south-west arid zone averages just 150–250 mm per year. In the northern areas of the state, a high proportion of the rain falls in the summer months. South of the Tropic of Capricorn, winter rainfall becomes an important part of the annual total, rising to about 40% along the southern border of the state.

Soil erodibility

Erodibility is a characteristic of the soil that describes the susceptibility of the particles that form soil aggregates (or peds) to becoming detached and transported by erosive agents. Erodibility is a function of the mechanical, chemical and physical characteristics of the soil. It is independent of the other factors influencing soil erosion such as topography, land use, rainfall intensity and plant cover, but may be affected by land management and may change through time. For instance, as soil moisture levels increase during a long rainfall event or when rain falls on an already wet soil, the amount of lubrication and water pressure between soil particles increases, weakening the structure and making the soil more erodible.

Highly erodible soils are those where the individual particles are most easily detached and transported by erosive forces. In the USLE, soil erodibility is represented by the 'K' factor that is defined as the rate of soil loss per erosion index unit as measured under standard unit plot conditions.

Soil erodibility can be assessed by long-term field measurement or by rainfall simulators which apply artificial rainfall to a range of soils and surface cover conditions.

The most erodible soils are those that are sodic and dispersive. Dispersive soils are usually predominantly composed of particular types of clays that readily break down into individual particles. Soils with a high proportion of silt may also be dispersive. Sodic clays are a special case where sodium ions are attached to the clay particles. When exposed to water, the size of the sodium ions increases, forcing the individual clay platelets to separate and causing the soil to disperse. Around 46% of Queensland has soils with these properties, including much of the arid inland where serious erosion can occur despite very low average annual rainfall. Known as 'sodosols' these soils have contrasting textures between the topsoil (A horizon) and subsoil (B horizon): the topsoil is generally light-textured and non-dispersive (such as a sand or loam) with an abrupt change to an impermeable and dispersive clay subsoil. Dispersion can also occur with other soil types, such as the clay soils of the Brigalow lands, which can be dispersive in both the topsoil and subsoil. Dispersive soils are susceptible to gully and tunnel erosion. The dispersion ability of a soil can be tested using the Emerson aggregate immersion test that involves observing what happens when a small aggregate of the soil is placed in water.

Soils that are not dispersive can still be very susceptible to erosion—for example the sandy soils of coastal areas or the vertosols (black cracking clays) of the Darling Downs and the Central Highlands. Unlike soils that disperse, the aggregates of vertosols retain some of their natural structure after they have been removed by runoff. These relatively large particles are readily deposited when runoff velocity is reduced such as in a contour bank or waterway, and they generally travel only a limited distance. Sandy soils have very little soil structure but because of their large particle size they are very porous and can usually accept high rates of rainfall. However, sand particles are loosely bound and have very little resistance to flowing water. Fine sands (0.2–0.02 mm in diameter) can be removed by very low velocity flows. The high erodibility of unconsolidated sand is illustrated by the rapid loss of sand from beaches when exposed to stormy seas or of sandy river banks which can disappear quickly when exposed to floodwaters. The sand from which the banks are composed has no shear strength when heavy and wet, such as when flood waters recede, and is prone to collapse in such circumstances.

Soil dispersion is different from, but is often associated with, the process of soil slaking. Slaking occurs when soil aggregates that are rapidly wet break down into small sub-aggregates. Rapid wetting impedes the movement of air through the soil pores, compressing it and causing the pores to explode outwards, thus destroying the soil aggregates. Slaking can contribute to tunnel and gully erosion in cracking clay soils such as those on the Darling Downs and the Central Highlands. In very dry weather, large cracks may develop in these soils. These cracks are interconnected laterally and when storm rainfall occurs, water can fill the cracks and flow downslope through the soil. This causes the soil to swell and the cracks to eventually close, however not quickly enough to prevent significant volumes of water from flowing through them.

Some soils have hard-setting surfaces that reduce the rate of infiltration during rainfall but which also resist erosion. These soils can have low rates of erosion themselves; however, they can contribute to high rates of runoff with erosive power further down the slope where the soils may be less protected. Soils that are regularly cultivated tend to be very susceptible to erosion. Cultivation reduces cover and creates a layer of loose soil, overlying the soil compacted by the wheels of tractors, implements and harvesting equipment. The cultivated layer can be removed in a sheet, exposing compacted soil underneath (Figure 1.2).

Figure 1.2: Compacted subsoil exposed by removal of cultivated top layer of soil

1.2.3 Types of erosion

Erosion is defined by the Soil Science Society of America as: the wearing away of the land surface by rain or irrigation water, wind, ice or other natural or anthropogenic agents that abrade, detach and remove geologic parent material or soil from one point on the earth's surface and deposit it elsewhere (‹https://www.soils.org/publications/soils-glossary›). Erosion can take a number of forms, as described in the paragraphs below.

Sheet erosion

Sheet erosion is defined as the removal of a relatively uniform thin layer of soil from the land surface by rainfall and largely from runoff in a sheet flow that has not formed into channels. Sheet erosion is often not very obvious but can still result in loss of significant amounts of soil that would otherwise be productive. Sheet erosion is common under pastures and on cropping land where surface cover during fallows (the period between crops) is insufficient. The raindrop effect is the major driver of sheet erosion. Sheet erosion also occurs when the tilled surface soil of a cultivated paddock becomes saturated. If the soil below this layer is compacted, the saturated topsoil can move down-slope as a loose mass, in a process similar to landslip. Sheet erosion is also common in arid inland areas where the removal of topsoil creates scalds (see below). Scalding is most prevalent on solodic soils, in frequently flooded alluvial areas, and on seasonally flooded clay soils. The USLE predicts average annual soil loss (in tonnes per hectare per year) from sheet erosion.

Rill erosion

Runoff has a natural tendency to concentrate as it moves towards a stream and the end point of a catchment. As runoff concentrates, its velocity and power increases, and its ability to detach particles becomes greater. When this occurs, the capacity of the runoff to erode soil greatly increases and a rill is formed. Rills are defined as small, intermittent watercourses with steep sides that are usually only several centimetres deep. Once a rill becomes more than 30 cm deep it is referred to as a gully. Rills are common in cultivated paddocks. They are very obvious soon after an erosion event but are less obvious once the paddock has been cultivated.

Gully erosion

Gullies are the most visible form of soil erosion. They are defined as channels resulting from erosion and caused by the concentrated but intermittent flow of water usually during and immediately following heavy rains that are deep enough (usually ›0.3 m) to interfere with, and not be obliterated by, normal tillage operations. Gullies are normally steep-sided and deeply incised watercourses. They can occur in drainage lines or other areas where runoff has concentrated and may occur in isolation or over large areas as a dominant feature in the landscape. Gully erosion is both a natural and a human-induced process. Natural gully erosion plays a major role in landscape evolution. The Grand Canyon in Nevada, USA, is just an extreme example of gully formation. Gullies, and the streams they feed into, help carve out valleys and supply alluvial sediment to fill floodplains and create deltas.

Gullying can occur on any soil types but those with dispersive subsoils are the most vulnerable. Around 45% of Queensland has soils with at least some dispersive properties. Gullies can occur anywhere in a natural drainage line as runoff flows from the most remote part of a catchment to its outlet. However, a drainage line is not a prerequisite for a gully to occur. Any management practice or infrastructure that concentrates runoff has the potential to cause a gully in any place in the landscape. This includes furrows in cultivation, roads, tracks, dam spillways, cattle pads and fence lines. Information on how to prevent and repair gully erosion is provided in Chapter 13.

Tunnel erosion

Tunnel erosion is an insidious process where water movement through the soil creates tunnels below the ground surface. In some circumstances most of the runoff from a high-intensity storm falling on bare ground may end up in the tunnel system with very little of the rainfall being stored in the topsoil. The tunnels can remain unnoticed, progressively expanding with each runoff event until they collapse to form potholes or sinkholes that can then join up to form a gully. By providing a ready outlet for additional tunnels to feed into, the formation of this initial gully may cause the overall gully system to expand rapidly.

In Queensland, tunnel erosion occurs predominantly in the 500–1200 mm rainfall zone and has been observed mostly in the south-east corner of the state. Areas highly prone to tunnel erosion are those with texture contrast soils—where the topsoil is permeable and overlies an impermeable and dispersive (or dispersible) subsoil—and which have been partially or totally cleared of native vegetation. Further detail regarding the conditions under which tunnel erosion can develop is provided in Chapter 13.

Streambed and streambank erosion

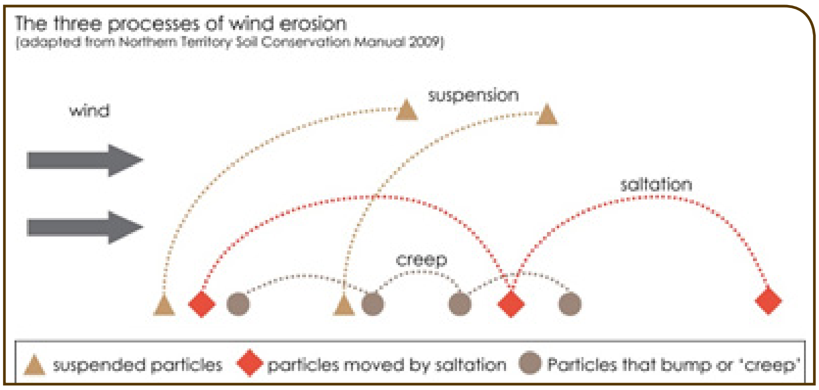
It is natural for the bed and banks of streams to erode, for sediment to be transported by streams, and for stream channels to move. These processes acting together help to form the floodplains and alluvial terraces that are common in the middle and lower reaches of many of Australia’s river systems, and which contribute so much of Queensland's agricultural productivity. For long periods the rate of change in a stream may be slow and imperceptible. However, flood events that generally occur infrequently can cause sudden dramatic changes that may affect the stability of a stream for decades afterward.

Streambed erosion, often a precursor to streambank erosion, can be a natural process associated with down-cutting in a floodplain to establish a new stable base following a geological event. For example, falling ocean levels or stream capture during past geological eras are believed to have been a significant factor contributing to the erosion of streambeds in some parts of Queensland. Streambed and streambank erosion can destroy valuable agricultural and recreational land and threaten infrastructure such as roads, bridges and buildings. It can also greatly increase sediment and nutrient loads, leading to decreased water quality. The processes involved in streambed and streambank erosion and their management are detailed in Chapter 10.

Wind erosion

The inorganic components of soils are particles of sand, silt and clay. Individual soil particles generally need to be less than 0.1 mm in size in order to be moved by wind. Non-aggregated particles of sand and silt are most susceptible to removal by wind erosion. Individual clay particles have an average diameter of only 0.001 mm but they usually clump together in aggregates that are too heavy to be moved by wind. There are three processes by which particles are moved by wind or water (Figure 1.3). The smallest particles enter suspension and are transported quickly over long distances; intermediate-sized particles travel over lesser distances more slowly by bouncing (saltation); and the largest particles travel slowly over short distances by rolling (creep).

Figure 1.3: The three processes of soil erosion (adapted from Jolley 2009)



Wind erosion is a common cause of land degradation in the arid and semi-arid grazing lands of inland Queensland, and is one of the processes leading to desertification. Wind erosion is also a natural process. The large parallel sand dunes in south-west Queensland, including the Simpson Desert National Park, are the result of wind erosion and deposition over thousands of years. These dunes are constantly moving, even under moderate wind speeds, and roads and tracks can be covered by drifting sands in only a few hours.

Every few years Queensland experiences a significant dust storm. These are generally the result of powerful winds associated with frontal weather travelling from the inland. Much of the dust originates from sediments in the west and south-west of the state that have been carried by previous floods in rivers in the Lake Eyre catchment. In normal years, sediments deposited in alluvial areas are protected by the abundant pasture growth that occurs after the flood. However, where sediments reach saline areas, vegetation growth will be minimal. After the floodwaters soak in or evaporate, the fine sediments left on the smooth, bare surfaces are susceptible to removal by wind, especially if the area has been heavily grazed during periods of drought

Wind erosion is generally not a serious issue in the 2% of Queensland that is used for cropping, although there are localised events in some drier years. These areas generally receive high rainfall and most of the soils are well-structured clays. The relatively large aggregates formed by these clays are too coarse to become airborne. However, cultivated sandy and red loamy soils that are present in some cropping areas are susceptible to wind erosion when they have no cover and are in a dry, finely worked condition.

Scalds

Scalds, or clay pans, are bare areas resulting after topsoil has been removed by wind and/or water erosion. Raindrops hitting a bare soil surface can 'sort' the soil so that the aggregates break down into individual sand, silt and clay particles and these are rearranged and packed tightly together. When this occurs, the pore spaces at the soil surface are filled, creating a sealed surface that can set like concrete. Under normal conditions, evaporation draws water—and any salt that may be present—to the soil surface, whilst rainfall then effectively washes the salt back down through the profile (by dissolving it and percolating downwards through the soil). When a surface seal forms, very little rainfall is able to penetrate into the soil. However, the salts keep rising and over time can concentrate in the surface layers of the soil in amounts that inhibit plant growth.

Early explorers noted some evidence of apparently 'natural' scalds; however, overgrazing is undoubtedly the cause of the great majority of scalds present in Queensland today. Scalds are usually found on soils with a light-textured surface adjacent to watercourses, in depressions or at the base of foothills. Because scalded land has lost its topsoil, it is very difficult to return it to its former productivity. Nevertheless, there are techniques that help achieve a degree of recovery as well as enhancing biodiversity and sequestering carbon.

Successful scald reclamation depends on one key factor: improving the permeability of the soil surface so that water infiltration is improved and plants can establish. 'Water ponding', a method of creating small ridges across scalded areas to create localised microclimates by collecting runoff, sediment and vegetation seed, has been used with some success in south-west Queensland and western New South Wales (Ringrose-Voase et al. 1989). Treated scalds should be fenced to remove grazing pressure caused by domestic, feral and/or native animals. In periods of exceptional rainfall advantage can be taken of the often rapid colonisation of scalded areas by pioneering plant species. However, under normal conditions it is very difficult to revegetate scalds without other management actions.

Mass movement

Mass movement includes the processes of creep, earthflow, slumping, landslips, landslides and rock avalanches. Mass movement occurs on sloping land, generally during periods of prolonged heavy rainfall when water entering permeable soils is impeded by a barrier such as bedrock or a clay-rich soil horizon. When this occurs the soil above the barrier may start to move downhill under the influence of gravity. Slope failure often results from a complex interplay of factors including:

- the amount and intensity of rainfall, particularly high-intensity falls
- rainfall over short periods that fills soil pores and increases pore water pressure
- clearing of deep-rooted native vegetation and its replacement by shallow-rooted species more susceptible to erosion
- rock, soil and sediment types (geologies) susceptible to failure.

Mass movement is triggered by natural causes such as geological predisposition to failure and meteorological phenomena, as well as by human activities. It can occur in undisturbed environments although the majority of the reported incidences result from soil disturbance and interference with soil water movement in constructing infrastructure such as buildings, roads, railways and pipelines or clearing vegetation and cultivating soils. Tree roots provide structural strength and also remove soil water from deep in the profile. For this reason, trees should not be cleared from locations known to be susceptible to landslip, and where such areas have already been cleared, locally adapted, deep-rooted, fast-growing trees should be planted. Also, as excessive water intake into a slope is the most common trigger of landslip, obstructions such as dams or cross-slope drains should be avoided in susceptible areas.

In Queensland, mass movement is most common on cleared slopes of basaltic plateaus and ranges as well as other in permeable soils overlying sandstone in coastal areas (Figure 1.4). The most susceptible regions are south-east Queensland, the Atherton Tableland and the ranges around Mackay. Mass movement causes direct physical damage to infrastructure such as houses, roads and fences, and soil disturbed by mass movement can also become more susceptible to other forms of erosion. Prevention of mass movement is far preferable to subsequent rehabilitation which is expensive, time-consuming, and may only be partially effective.

Figure 1.4: A landslip at Currumbin Hill Gold Coast, July 2005 (State of Queensland 2008)

1.2.4 Other forms of land degradation

Salinisation

Salinity occurs when salts from deep in the soil profile are concentrated in the soil/root zone and at the soil surface by evaporation from a shallow watertable and transpiration by vegetation. Salinity is measured by passing an electric current between the two electrodes of a salinity meter in a sample of soil or water. The electrical conductivity (EC) of a soil or water sample is influenced by the concentration and composition of dissolved salts. Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level. Salts occur naturally in the soil—originating from ancient marine sediments, weathering of rock, or rain and wind. When the watertable is raised, for example following land development or irrigation, salt stores from deep in the soil profile can move towards the soil surface. Rising watertables that result in salinity may be the result of excessive irrigation (known as irrigation salinity) or of additional water movement through the soil profile due to replacement of native vegetation such as trees with lower water-using crops or pastures (known as dryland salinity). Salinity may also be caused by the use of poor-quality irrigation water and the inappropriate siting or poor construction of above-groundwater storages.

The climate in Queensland generally militates against the development of salinity. Most rain in Queensland falls in summer and evaporation almost always exceeds rainfall. Under these conditions, the soil profile is rarely fully saturated and recharge occurs only when a succession of wet periods prevents the soil from drying out. The risk of salinity in Queensland is also reduced by the fact that irrigation in this state is generally not on relic marine basins that are naturally high in salts. Only about 10 000 ha of Queensland—at Emerald, Bundaberg, Maryborough, and in the Cairns and Townsville areas—are considered to be seriously affected by dryland salting compared with more than two million hectares affected in the rest of Australia. Most affected areas in Queensland are located in coastal and subcoastal regions receiving more than 500 mm and less than 1500 mm annual rainfall.

Soil that is badly affected by salting becomes unproductive and is at risk of other land degradation processes such as erosion, due to a lack of protective vegetation and the tendency of salty soil to readily disperse. The increased salinity of groundwater can affect yields of salt-sensitive crops, and can make the water unusable for livestock or domestic purposes. In badly affected areas, soil salt content can become so high that only salt-tolerant plant species will grow or—even worse—salt crystals may be evident on the soil surface and the area is devoid of all vegetation. To treat salinity it is critical to regulate the entry into or passage of water through the soil. The main strategy to prevent salinity is to maintain vegetative cover to reduce the evaporative concentration of salts. In particular, clearing trees in groundwater recharge areas should be avoided to prevent the development of further salinity problems. Where salinity is already evident, water inputs need to be reduced, for example by revegetating recharge areas with high water-using plants, by reducing irrigation inputs or by intercepting water with selective revegetation and/or diversion structures. In addition, water outputs need to be increased, for example through selective ground water pumping and drainage and establishing salt-tolerant vegetation. Queensland's Salinity management handbook (Department of Natural Resources 1997) contains extensive information about how to identify and manage salinity.

Acidification of cropping lands

Acidity is measured in pH units, a measure of the concentration of hydrogen ions in the soil solution: the lower the pH of soil the greater the acidity. Nutrients are chemically bound to organic and inorganic components of the soil. The strength of these bonds and hence the ease with which plants can access nutrients, or that nutrients can be lost through leaching, is affected by the soil pH. Plant growth and most soil processes, including nutrient availability and microbial activity, are optimised across a soil pH range of 5.5–8.0, and suppressed at levels outside that range. Soils that have a pH of less than 5.5, particularly in the subsurface, will restrict root access to water and nutrients and may also exhibit aluminium toxicity. When the pH drops, aluminium that is often present in large amounts within soil becomes soluble. A small drop in pH can result in a large increase in soluble aluminium. Soluble aluminium retards root growth, restricting access to water and nutrients that can result in poor crop and pasture growth, reduced yield and smaller grain size. The effects of aluminium toxicity on crops are usually most noticeable in seasons with a dry finish as under these conditions access by plants to stored subsoil water for grain filling is restricted.

Acid soils occur naturally in humid areas. About 79% (74 million hectares) of the area of Queensland that receives more than 500 mm of annual rainfall has a surface soil that is acidic, and over 8% (8 million hectares) is strongly acidic (pH in water is 5.5 or less). Agricultural practices can, however, accelerate acidification, for example by adding large amounts of nitrogen-based fertilisers to neutral or naturally acid soils.

Also, removing a high proportion of plant material, which is naturally alkaline when returned to the soil, will progressively reduce the pH. Acidification has been found to occur in Queensland under nitrogen-fertilised sugar cane (320 000 hectares affected) and grass pastures (23 000 hectares affected). The sodosols and chromosols of the Oakey area in southern Queensland have also been found to have become acidic after several decades of grain cropping that involved application of nitrogen fertiliser. Ferrosols—for example those in the Atherton Tableland, South Burnett and Childers areas—are also at risk, whilst vertosols are least at risk.

Acidification can be treated by spreading agricultural lime (a natural neutralising agent), by adopting less-acidifying farming practices (such as using less inorganic fertiliser or retaining more organic matter), and by growing acid-tolerant species and cultivars.

Fertility decline

Fertility decline refers to depletion of the nutrient store in soils, leading to reduced plant growth and yield. Nutrients may be lost from the soil by removal in harvested crops, by soil erosion or by leaching. As a result of nutrient decline, significant areas of cultivated land in Queensland are now unable to produce economic crop yields and high protein grains without the use of fertilisers. This includes, for example, about 350 000 hectares of cultivated land in southern inland Queensland, which has been under cultivation for at least 50 years. Research has shown that, of the soils used for grain growing in Queensland, the rate of fertility decline is highest in soils formed under brigalow. These soils occur in the Western Downs and the Dawson–Callide districts. Fertility decline is also a problem in the much prized vertosols of the Darling Downs and the Central Highlands. It also occurs in the ferrosols of the Burnett region and the Atherton Tableland, and in a variety of soils along the Queensland coast used mainly for field crops, sugar cane and horticulture crops.

Organic matter plays a key role in preventing fertility decline as it binds nutrients (especially nitrogen) in the soil, preventing them from being lost by leaching. The organic matter content of soils has been shown to decline rapidly following clearing and with continuous cropping. This is a particular problem in friable red clays and other soils of coastal areas previously under rainforest. Some nutrients, such as phosphorus, are naturally in limited supply in many Australian soils and deficiencies will occur unless losses are replaced. Fertility management aims to maintain soil organic matter, structure, nutrient status and pH. This can be achieved by: including pasture and legume phases in crop rotations; adding natural or inorganic fertilisers; and reducing tillage. It is important to regularly test soil and plant nutrient status to ensure that sufficient of the correct type of fertiliser is applied to meet the needs of the crop but not so much that adverse impacts are caused to the environment.

Structural decline

Soil structure refers to the arrangement of soil particles into units (peds, aggregates and blocks) interspersed with cavities or pores, and the stability of these units when exposed to various stresses such as wetting, raindrop impact and load from vehicles or animals (compaction). A well-structured soil permits relatively unrestricted movement of water, gases and plant roots. A poorly structured soil restricts movement, retarding root growth and increasing runoff, leading to reduced production and increased risk of erosion. The reduction in production potential associated with structural decline has not been quantified but it is considered to be widespread on agricultural soils.

Decline in soil structure following cultivation and compaction has been observed on all cropping soils in Queensland. Farmers noticed early on that cultivation and seedbed preparation become more difficult in some soils after they have been farmed for several years. Continuous cultivation can lead to the formation of a compacted plough pan that retards infiltration of rainfall and root growth.

The tendency to form a plough pan is increased by tilling soil when wet. When rainfall is erratic and difficult to predict as it is in much of Queensland, the flexibility available to farmers to control moisture conditions or timing of tillage and harvesting is limited. Reducing the frequency of tillage (e.g. by adopting conservation cropping practices (Figure 1.5)) and restricting tillage during wet conditions allows swelling clay soils to dry and crack, thereby alleviating structural decline in these soil types. Farming machinery (e.g. tractors, harvesters and grain bins) has progressively become larger and heavier over the decades, subjecting soils to greater loads with increased risk of compaction. Controlled traffic farming minimises the compacted area by confining machinery wheels to the same tracks with each pass.

Figure 1.5: Conservation cropping approaches such as sowing into the stubble of the previous crop retained in-situ increases soil organic matter and reduces structural decline (photo Ken Dixon)

Soil organic matter plays an important role in maintaining the stability of soil units. Increasing soil organic matter content, for example by introducing a pasture phase in the crop rotation, is also recommended as a way of reducing structural decline.

1.2.5 Principles for controlling land degradation

Some erosion problems are relatively straightforward to address provided funding and suitable expertise is available. However, others can be complex and may require weighing up many options before a decision can be made about which is the best course of action to take. Whatever action is taken, there are three important principles to consider in protecting the land. These principles are outlined below and are reflected throughout the Guidelines.

Principle 1: Use land in accordance with its capability. Physical factors such as soil type and land slope relevant to a set of climatic conditions determine how vulnerable a piece of land is to erosion and what type of control measures will be required. Land at serious risk of erosion may require a highly modified form of land use that is less likely to cause erosion, or may need to be retired from agricultural use altogether.

The various methods developed to assess land capability and suitability in Queensland are described in Appendix 2.

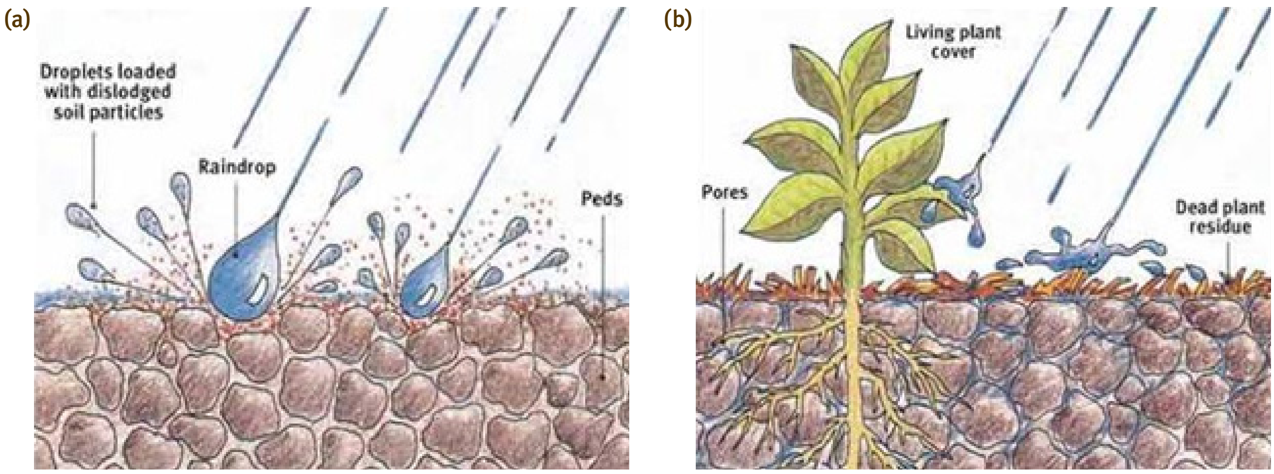
Principle 2: Provide some form of cover on the soil surface. Cover helps maintain the integrity of the soil structure by protecting the surface from raindrop impact and from runoff. Cover also moderates the microclimate at the soil surface, protecting soil biota and maintaining soil health. If the cover is organic—e.g. live vegetation—it also adds organic matter to the soil, improving the structure and nutrition.

Soil surface cover controls erosion by reducing rainfall erosivity and by slowing down runoff. Surface cover cushions the impact of raindrops, protecting the porous surface structure and maintaining the capacity of the soil to absorb rainfall and runoff (Figure 1.6). Any runoff that does result where soil is well vegetated will be impeded by the cover and is less likely to concentrate into an erosive force.

Where surface cover has been reduced (e.g. by disturbance or clearing), overland flows will be less impeded, runoff will start to concentrate and its erosive power may then cause rill and gully erosion. This can trigger a downward spiral of degradation as runoff travelling at high speed is less likely to enter the soil and consequently less soil moisture will be available to plants, reducing growth and in turn exposing the soil to further erosion.

Cover also cools the soil surface, reducing evaporation losses. It causes runoff to deposit seeds and manure, creating a favourable medium in which plants can establish, and protects soils and vegetation from wind erosion. Wind moves much faster over a soil surface without cover, which gives it more power to remove soil and abrade plants.

Figure 1.6: Effect on stability of soil surface when raindrops fall on a) bare soils or b) soils protected by plants or mulch



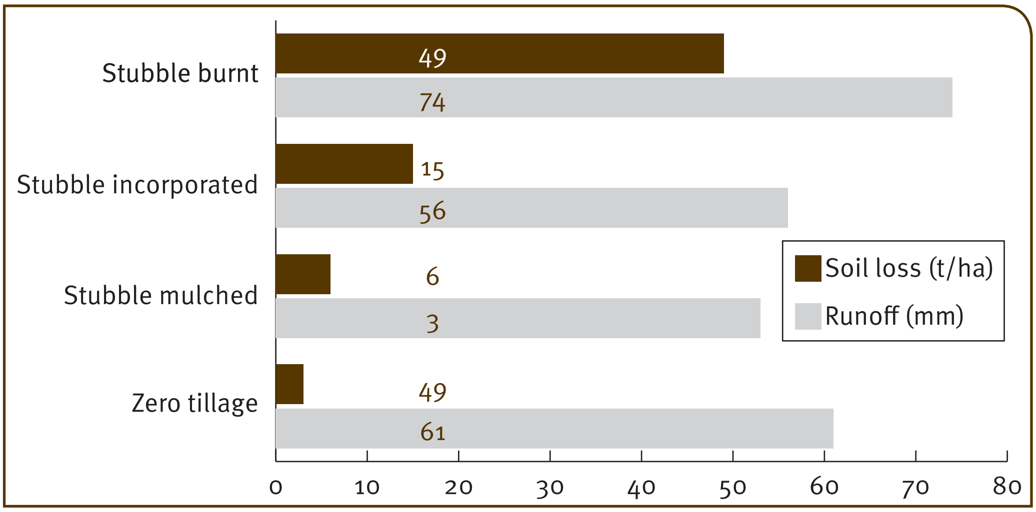
The results of an experiment at Mt Mort, near Ipswich (Table 1.1) illustrate the importance of cover in reducing runoff and soil loss. The experiment compared runoff and soil loss during a single 54 mm storm from three differently treated experimental catchments. Treatment C, in almost bare condition, lost more than 700 times as much soil and more than 20 times as much rain in runoff as did Treatment A with almost complete cover. Treatment B with an intermediate level of cover still experienced much reduced levels of soil loss and runoff.

Table 1.1: Results from a 54 mm storm at Mt Mort, SE Queensland (Finlayson and Silburn 1996)

Treatment	A	B	C
Percent cover	87	69	6
Total runoff from storm (mm)	1.5	14	38
Percent of rainfall that ran off	3	26	70
Soil loss (t/ha)	0.03	0.3	22
Depth of soil lost (mm)	0.002	0.02	1.7
Sediment concentration (g/L)	1.5	1.9	63
Nitrogen removed (kg/ha)	0.14	1.9	15.3
Phosphorous removed (kg/ha)	0.02	0.26	4.3

The long-term effects of varying the type of cover are illustrated by an experiment conducted at Greenmount on the Darling Downs (Figure 1.7). This experiment compared runoff and soil loss between four different crop fallow treatments over an 11-year period. Each treatment was conducted within a separate contour bay, with up to 80% of the soil lost from each bay deposited in the contour bank below it. Burning stubble resulted in an average annual soil loss 16 times more than zero till, 8 times more than where stubble was mulched, and 3 times more than when stubble was ploughed in. Runoff did not vary between treatments by as much as soil loss but was still substantially greater where stubble was burnt than with any of the other three treatments.

Figure 1.7: Average annual runoff and soil loss at Greenmount, Darling Downs, 1978–1989 (Wockner and Freebairn 1991)



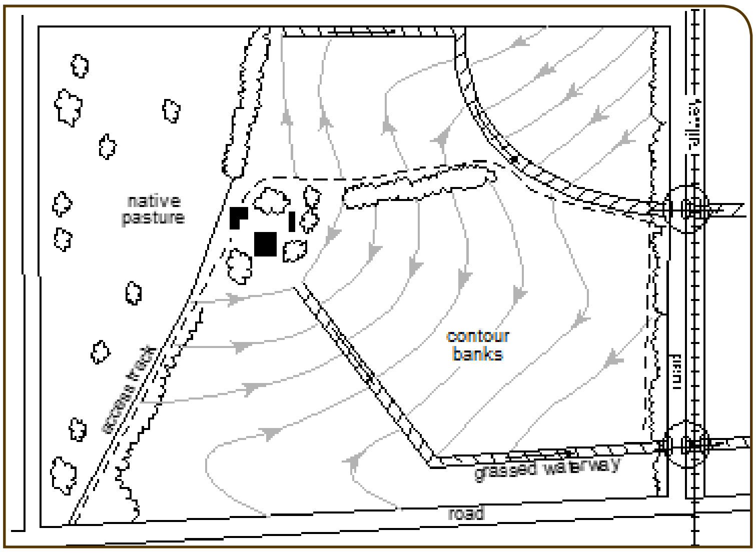
The critical level of cover to protect soils under pastures in tussock grasslands is considered to be about 40% cover and 1000 kg/ha of dry grass (Department of Primary industries 1994). To be most effective this level of cover should be in place at the beginning of the summer storm season. Whilst artificial cover (such as plastic sheeting or jute matting) may be cost-effective for small-scale intensive activities such as horticulture and infrastructure works, there are few options for artificially improving cover in extensive grazing lands. It may be feasible to apply some form of low-quality hay to small areas and by applying hay in strips on the contour this protection could be extended to a larger area than if it were applied as continuous cover. For instance, graziers in the Burdekin district have used round bales of cane trash laid out in strips on the contour to help rehabilitate small areas of degraded land. However, if this method is used, care is required to ensure that weed seeds are not imported in the hay.

It is also worth noting that while high runoff events drive most soil erosion, small trickle flows can also erode soil. During periods of prolonged low-intensity rainfall, saturated soils can lose their structural integrity and even liquefy. Such soils become susceptible to erosion even though runoff rates may be quite low.

Principle 3: Control runoff before it develops into an erosive force. In most instances, it is best to aim to use rain at, or as close as possible to, where it falls. However, this is not always possible. Some periods of runoff are inevitable, especially where rainfall is episodic and intense, as across much of Queensland. As water runs off, it naturally tends to concentrate into progressively larger and more powerful flows. Almost half of the erosion-susceptible cropland in Queensland has been treated with measures such as contour banks and strip cropping to control runoff. Runoff control measures require careful planning to manage flows within and between properties and across roads and railway lines. Poorly designed and/or executed runoff control measures can easily exacerbate erosion problems.

Prevention is always better than cure. Good planning is essential to prevent erosion issues from developing in the first place and/or exacerbating those already present. Each property has a unique combination of soils, topography, climate and management inputs. Because of this, soil conservation plans need to be developed for the individual circumstances of each property (Figure 1.8). However, those plans also need to take into account the context of the catchment and region in which the property is located. Chapter 2 provides more information about soil conservation planning.

Figure 1.8: Property plan showing examples of runoff control measures



1.3 Soil conservation in Queensland

Agriculture has been an important part of Queensland's social and economic fabric for more than 150 years. Since the first European settlement, agricultural industries have provided a livelihood for many thousands of Queenslanders and been a major earner of export income for the state. Agriculture is by far the most extensive land use and as such has played a key role in shaping the landscape of the state. The experience of soil conservation in Queensland closely parallels the history of rural land use, which in turn is the history of agricultural development in the state.

1.3.1 The past

Past agricultural land development in Queensland can be described as occurring in three broad phases.

Pre 1940: Pioneering

For the first century following European settlement, agriculture developed with little concern for other environmental values. The population of Queensland increased slowly over this period, from less than 30 000 in 1840 to only about 1.1 million 100 years later, about half of whom lived in rural areas. Early European settlers had limited knowledge of the constraints of the soils they were developing for agriculture. Land was believed to be in unlimited supply and subdivision was usually based on a geometric, rectangular system with little consideration of natural drainage systems, topography and soil types. Even mountains were subdivided—and cleared!!

Agricultural development of the state was led by grazing. Grazing expanded rapidly, with both sheep and cattle introduced and extensive grazing properties established throughout the state during this period. Conditions for early pastoralists were not easy. Unfamiliar with Queensland's tropical and semi-tropical climate, early settlers had to battle against droughts and floods. Land not suited to agriculture was often cleared and stocking rates were excessively high, particularly in the early years of droughts. Total grazing pressure was further inflated in inland areas when groundwater was tapped from the Great Artesian Basin for the first time in 1884, and distributed through properties by systems of interconnected (usually open) bore drains providing permanent water.

Governments did everything they could to encourage intensification of agriculture through various closer settlement and soldier settlement programs. Many of these subsequently failed but still left long-term imprints on the landscape. Early attempts to establish cropping began in near-coastal areas in the late 1800s, with tropical crops such as sugar cane and maize. Wheat and lucerne became important crops in the early 1900s (Figure 1.9) and production of hay became a common activity. Towards the end of the 19th century a dairying industry was established in higher-rainfall inland and coastal areas-.

Figure 1.9: Planting wheat in Queensland around the turn of the 20th century

1940–1990: Expansion and industrialisation

Over the 50 years between 1940 and 1990, agriculture in Queensland rapidly expanded and industrialised. This was accompanied in turn by a growing appreciation of the limitations of the land and of the need to change land use and land management practices to address past mistakes and so prevent further land degradation. The story of land development in Queensland for this period consequently became also a story of solving land degradation problems.

The population of the state increased rapidly over this period, from around 1.1 million in 1940 to more than 3 million in 1990; and the mechanisation that followed World War II allowed agriculture to expand rapidly and intensify. Cropping became well established in inland areas such as the Darling Downs, Western Downs, Atherton Tableland, Dawson–Callide valley, the Central Highlands and the inland Burnett region. This was further encouraged by government-sponsored agricultural land development schemes, the largest of which—the Fitzroy Basin (Brigalow) Development Scheme—cleared 1.8 million hectares in central Queensland between 1962 and 1976. Government-initiated irrigation schemes also drove agricultural intensification with, for example, expansion of: sugar production around Bundaberg (1975) and Ayr (1988); cotton around St George (1967) and Emerald (1972); and tobacco at Mareeba (1958).

By the 1940s serious erosion problems were apparent. Rapid expansion of cropping and clearing of grazing lands had encouraged many unsustainable practices: unsuitable land had been cleared and cropped; paddocks were being ploughed up and down the slope; crop stubble was either burnt or buried, leaving finely worked soils exposed to high-intensity rainfalls; and grazing pressure was often excessive. For example, at this time it was common practice on the Darling Downs to cultivate steep slopes to grow winter crops such as wheat, barley and oats as well as summer crops such as corn and sorghum. The stubble was generally burnt soon after harvest of the winter crop in November, leaving the soil without any cover and vulnerable to erosion at the beginning of the summer storm season. With the soil surface bare, heavy rainfall would produce high volumes of runoff that concentrated to erode topsoil, form rills and gullies and deposit silt in lower parts of the paddock and on adjacent road and rail corridors.

By the 1950s it was widely recognised that soil erosion had become a major problem in Queensland's cropping areas and there was general acceptance across the community that something had to be done about it. By this time, an estimated 16 000 ha of cultivated land in Queensland had become so badly eroded it had to be withdrawn from cultivation (Ladewig and Skinner 1950). While erosion was also a widespread problem in grazing lands, most attention was initially focused on cropping lands where the effects of erosion were most dramatic. Efforts to promote land conservation had in fact already started back in the 1930s. The first contour banks were built near Toowoomba in 1935 and interest in the use of this technique to control erosion had quickly spread through nearby cropping regions. Whilst adoption of these practices was slowed by World War II, the effectiveness of contour banks was so impressive that demonstration sites were quickly established on the Darling Downs after the war.

Increasing interest in soil conservation led to the creation in the 1950s of a separate soil conservation section within the agriculture branch of the Department of Agriculture and Stock, and the establishment of government soil conservation offices, staffed with trained experts, on the Darling Downs, Atherton Tablelands and in South Burnett and central Queensland. Contour bank and waterway systems were constructed on demonstration farms on the Darling Downs and in the Kingaroy districts on sites chosen to be easily seen by the travelling public.

From the 1950s onward governments invested heavily in research and extension: there was much to learn about land management, including how to use contour banks and waterways to conserve soils. Field days (Figure 1.10) were conducted on demonstration farms as a means of communicating knowledge gained through research and from the direct experiences of farmers. That these field days attracted crowds of up to 700 people is indicative of the level of concern about soil conservation within the community at this time. Queensland's first soil conservation legislation was gazetted in 1951 (and subsequently revised in 1965 and 1986) to provide a mechanism to plan and coordinate soil conservation works so that runoff could be safely coordinated between properties and within local catchments.

Figure 1.10: Strip-cropping field day on the Darling Downs in 1966

Through the ensuing decades, demand for soil conservation advice and assistance continued to increase. Land development in central Queensland and the Darling Downs continued apace (at a rate of about 80 000 ha per year), in response to lower beef prices, higher grain prices and good rainfall. Meanwhile, serious erosion events caused by periods of very high rainfall maintained the interest of landholders in soil conservation. Between 1973 and 1986, soil conservation plans were prepared for 3500 different properties involving 550 000 ha of land. By the early 1980s, soil conservation officers were surveying contour bank layouts on 50 000 ha each year. Soil conservation works costing more than $6.5 million were constructed during that period and by 1993 more than 1.3 million hectares of cropland had been treated with soil conservation practices such as contour banks, grass strips and strip cropping (Carey 2008).

From the 1970s the importing of specialised machinery from the USA, which could sow into crop stubble, greatly expanded options for erosion control in cropping lands. This development, together with improvements in access and the use of herbicide from the 1980s onward, removed (or at least greatly reduced) the requirement for heavy tillage to control weeds and prepare a seedbed. With the added advantages of reduced runoff and soil loss and greatly increased efficiency of water use, conservation tillage rapidly found favour among farmers. By the early 1980s, these practices were already established as the standard throughout the grain growing areas of the state.

Better land suitability assessment is integral to improving land conservation practices. Land resource information is a must for sound planning from regional to farm level and is an essential basis for research and extension. Early Queensland settlers and surveyors assessed the suitability of land for cropping and/or pastures based on their perceptions of relationships between fertility, soil colour and vegetation types. Mistakes were often made in early land development, contributing to severe land degradation at times even to financial ruin. In the late 1940s and through the 1950s, the Queensland Bureau of Investigation conducted broadscale soil surveys starting in central and southern Queensland cropping areas. The CSIRO undertook similar land system and soil surveys from the1950s to the 1980s throughout Queensland. Since that time, the Department of Primary Industries has continued land system surveys including of grazing lands, as well as more detailed soil surveys of irrigation areas and other cropping areas.

1990s to the present day: Consolidation

The last 25 years has seen a period of consolidation in agriculture and soil conservation practices, building on the gains made since the 1950s. The following progress has been made:

- Steep land (>10–12%) has continued to be taken out of cultivation and returned to pasture or native vegetation, a move also driven by economics since cultivating the shallower soils on steep slopes is not profitable for most crops.
- Fallow management has improved greatly with the further adoption of conservation cropping practices following technological advances such as the introduction of herbicide-resistant crop strains. These practices are now also being increasingly adopted in the production of sugar cane, where they are known as trash retention.
- Contour banks and waterways have been constructed and maintained to manage runoff in many upland areas, and strip cropping to manage floodwaters has been widely adopted on floodplains that are subject to erosive flooding.

- Graziers have become more aware of the need to match the demand for pasture with the amount of pasture production, and user-friendly decision support systems have become readily available on-line to assist them with this. Stocking rates have become much more conservative and graziers are modifying fences and watering points to better manage grazing pressure.
- Long-term weather forecasting tools such as the Southern Oscillation Index (SOI) have become widely accessible through the internet and are being used for instance by graziers to better match stock numbers with pasture potential.

This period has seen a major overhaul of the administration and governance of public investment in soil conservation. Prior to 1990, national governments had left soil conservation to the states, making limited investment and showing limited interest in the issues. This all changed with the emergence of the Landcare movement in the late 1980s and the declaration by (then) Prime Minister Hawke of the 1990s as the 'decade of landcare', accompanied by major federal government investment through the National Landcare and One Billion Trees programs. These programs very substantially increased the pool of public funding available for soil conservation activities. They also helped to change the mode of delivery by promoting investment through community-based local (Landcare) and eventually catchment-wide ('Regional Bodies') organisations. At the same time, state government agencies, faced with increasingly constrained budgets and shifting priorities, have progressively become more centralised, reducing their regional presence that had previously been very significant, and withdrawing from direct extension that had previously been a major part of their role.

1.3.2 The present day

The current pattern of land use across Queensland reflects the soils, topography and climate in the different regions. These influences include:

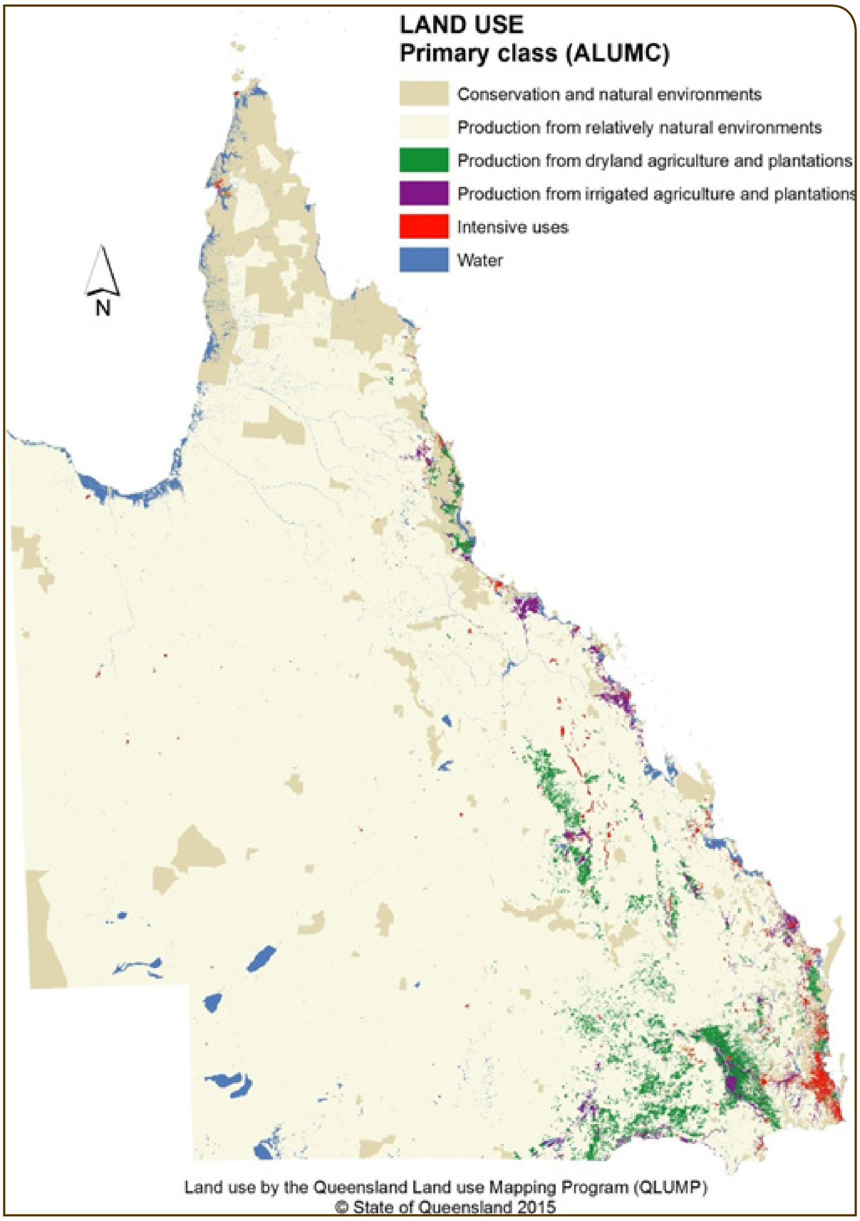
a. Topographically, the Great Dividing Range—in Queensland a low mountain range with peaks generally between 600 m and 900 m, except for the Wet Tropics where it is more precipitous—separates the narrow coastal plain from the wide and generally flat to undulating inland plain, and which has a few low ranges of up to 600 m high. The coastal plain is dissected by short, relatively fast-flowing streams, while much of the inland plain features highly interwoven and ephemeral watercourses with wide floodplains.
b. The most widespread soils in Queensland are:
   - red and yellow soils (kandosols) throughout much of the inland and far northern areas
   - texture-contrast soils (sodosols) that are erosion-prone and relatively infertile, on the inland foothills of the coastal range and in northern inland and far south-western areas
   - clay soils of high fertility (mainly vertosols), which tend to be open grassy plains, in central, western and southern areas.

   Other soils that are fertile and suitable for agriculture, but are less widespread, include:
   - well-drained, friable clay-loam soils high in iron (ferrosols) occurring in patches in generally elevated country along the coastal range
   - a diverse group of soils with loam to clay textures (dermosols) that are extensive on the coastal plain and adjoining foothills, particularly in the north.
c. Queensland's climate is characterised by warm to hot temperatures and extremely high rainfall variability, including frequent droughts interspersed with flooding rain. The north of the state is influenced by the monsoon, with

distinct wet and dry seasons. The average annual rainfall along the coast is 1000 mm in the south to 3200 mm in the north, and west of the range it drops quickly to 700 mm, declining to less than 200 mm further west. The dry inland plains experience cold nights in winter and very hot days in summer. Cyclones can cause damage to infrastructure and agriculture on the coast, but are a major source of rainfall for the inland areas that are prone to long periods of very dry conditions.

Land use across the state is mapped by the Queensland Land Use Mapping Project (QLUMP) using a combination of remote sensing and other datasets (Figure 1.11). QLUMP uses the consistent Australian Land Use and Management (ALUM) classification (Australian Bureau of Agriculture Resource Economics and Sciences 2010). ALUM uses a three-level hierarchical structure that reflects the range in intensity of intervention in each land use. There are six classes at the primary level—five of which represent progressively increasing levels of intervention or potential impact on the natural landscape and the sixth is areas under water. Classes at the secondary levels also relate to land use whilst at the tertiary level classes relate to commodities or vegetation types.

Figure 1.11: Current land use in Queensland mapped to the primary ALUM class



At the primary level of classification, land is currently used as follows:

- 16 million hectares or 9% of Queensland is used for conservation and natural environments. This is land that has a relatively low level of human intervention including land that has been formally reserved by government for conservation purposes (such as national parks), or conserved through other legal or administrative arrangements. Land used for conservation and natural environments is scattered throughout the state with concentrations in the north.
- 150 million hectares or 86% of Queensland is used for production from relatively natural environments. This includes land that is subject to relatively low levels of intervention and is mainly native or partially improved pastures grazed by livestock and native forest used for timber production. Grazing is the dominant agricultural land use in all regions of the state.
- 4 million hectares or 2% of Queensland is used for production from dryland agriculture and plantations. This includes land that is used principally for primary production, based on dryland farming systems such as broadacre production of cereals, pulses and other agricultural crops and forestry plantations. Agricultural cropping is concentrated in the eastern regions of the state, from the New South Wales border (between Hebel and Stanthorpe) north through Toowoomba and Biloela to Dysart and Clermont, whilst forest plantations are predominantly located in south-east Queensland and the higher-rainfall and coastal areas.
- 1 million hectares or 0.6% of Queensland is used for production from irrigated agriculture and plantations. This includes crops such as annual and perennial horticulture and sugar cane, where water is applied to promote additional growth over normally dry periods, although crops may receive only one or two irrigations per year, depending on season, water availability and commodity prices. Horticultural crops are grown along the east coast from the Atherton Tableland to the New South Wales border and include the Lockyer and Fassifern Valleys, the Granite Belt, South Burnett, Chinchilla, Mundubbera, Gayndah, Emerald, Nambour, Gympie, Lower Burnett, Capricornia Coast, Mackay and the Burdekin. Sugar cane is grown in a narrow belt along the east coast from Mossman to the New South Wales border.
- 1 million hectares or 0.6% of Queensland is used for intensive uses. Intensive uses involve high levels of interference with natural processes—such as industry, residential and transport, mining or intensive animal industries (feedlots, piggeries, poultry and eggs). Urban areas are concentrated along the coast, mining in the central and southern inland, whilst intensive animal industries are scattered throughout eastern districts.
- 3 million hectares or 1.7% of Queensland is water. This includes both natural and artificial water features.

Current best practice soil conservation on cropping lands

The current recommendation for controlling erosion on cropping lands is conservation cropping (reduced or zero tillage); contour banks and grassed waterways on sloping lands (>1%); and strip cropping on broadacre floodplains. Conservation cropping practices have been designed specifically to protect the soil surface by maintaining plant cover throughout the year. Conservation cropping practices include:

- growing crops that provide good ground cover and retaining stubble on the soil surface during fallow periods
- using crop rotations that provide high levels of protection throughout the year
- using pasture leys

- opportunity cropping to minimise fallow duration
- using herbicides to minimise the frequency of tillage
- using grazing animals for weed control during fallows.

These practices are now used on at least 70% of Queensland's sloping croplands whilst interest in conservation cropping practices in other systems (e.g. sugarcane production) has increased rapidly in the last 10 years. Detailed information on how to implement these strategies is contained in Chapters 3 to 10. Also, Chapter 12 outlines a range of strategies for soil conservation for horticulture enterprises.

Conservation cropping has been criticised by some people concerned about its reliance on herbicides. However, the available evidence does not support these concerns. Lands in Queensland that have been continuously managed under conservation cropping since the early 1980s show no obvious evidence of deterioration in the health of the soil. Nevertheless, it is important that farmers use a range of methods of control to avoid weed species developing herbicide resistance. Crop rotations, for instance, assist with the control of weeds and diseases, while incorporating legumes and a pasture phase in the rotation can increase soil fertility. Also, there is a growing demand in some sections of the community for organically grown crops produced without the use of chemicals. Farmers are finding this demand difficult to meet. One of the challenges for organic growers is that the use of tillage (instead of herbicide to control weeds) reduces surface cover levels, which increases the risk of erosion.

Current best practice soil conservation on grazing lands

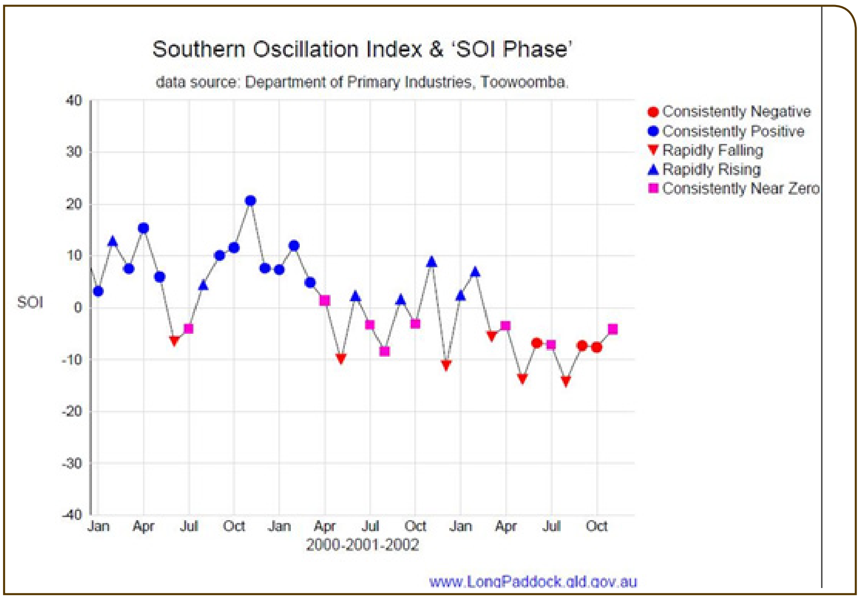
Much grazing land is on hillslopes, areas which are often subject to erosion by raindrop splash. Furthermore, gully erosion can occur wherever runoff concentrates under the influence of overland flows flowing into: drainage lines; roads and tracks; fence lines; or dam by-washes. Chapter 14 contains further information on managing erosion risks associated with property infrastructure.

The most effective method of controlling erosion in grazing lands is to maintain adequate levels of cover on the soil surface. To achieve this, stock numbers need to be managed to match the current and expected seasonal conditions. Graziers have to make regular decisions about how many animals they should run on a piece of land, taking into account the added impact of native herbivores and feral animals. The ideal stocking rate varies, matching stock numbers and the nature of the stock to available feed and expected growth. Regular monitoring of pastures is necessary to achieve this, as conditions can change quickly. Long-term weather forecasting, using predictive tools such as the SOI (Figure 1.12), has greatly improved the capacity of graziers to make good decisions with respect to seasonal conditions.

Opportunistic spelling should be part of a grazing strategy. A total spell in a good year is commonly recommended to allow preferred species (i.e. palatable perennials) to recover from past grazing. Grazing pressure can also be better managed by manipulating watering points. Watering points should be located to discourage stock from concentrating in areas vulnerable to erosion.

Fire is another useful tool in grazing land management. Fire can be used to encourage preferred pasture species and to control woody weeds (large areas of grazing lands in Queensland are tree-covered or subject to woodland thickening). However, fire needs to be managed carefully. While trees and shrubs can negatively impact on pasture growth, excessive burning (e.g. annually) of pastures will further reduce ground cover and promote runoff and erosion.

Figure 1.12: Monthly SOI values for 2000 to 2002, the period leading into the 'millenium drought', declined steadily, a strong prediction of below average rainfall (longpaddock.qld.gov.au)



Trees play a vital role in grazing landscapes by providing shade and shelter, recycling nutrients and using moisture that may otherwise 'leak' into ground water and contribute to salinity problems. They also stabilise streambanks and prevent landslip on susceptible steep slopes. However, trees compete with herbaceous vegetation and grasses, and whilst forests provide leaf litter covering the soil surface, in more arid areas they may provide limited protection at ground level from erosion caused by raindrop impact and overland flow. This can be exacerbated by heavy grazing removing any understorey groundcover vegetation underneath the trees.

In the control of erosion, surface cover is essential and bare areas beneath trees are vulnerable. Shelter belts or tree corridors contribute to biodiversity, provide shelter for livestock and reduce the drying effects of winds. Trees also help to reduce wind velocities, protecting soil from wind erosion. However, It is not practical to plant extensive belts of trees in the vast, arid inland areas where wind erosion is most prevalent. Hence well-managed pastures are the key to providing erosion protection in these areas.

Contour banks are recommended to control erosion on hillslope cropping land, but they are not considered necessary for erosion control on grazing lands. It is not uncommon, however, to have contour banks on grazing lands that were previously used for cropping. Much of this land proved unsuitable for long-term cropping and was returned to pasture, but the contour banks remain. Under these circumstances the contour banks will normally have subsided so that they are now below specification and may present an erosion risk. Such areas should be monitored and if the banks are contributing to erosion problems they should either be levelled or fully restored.

Current best practice soil conservation under intensive land uses

These Guidelines focus on erosion control in rural areas. The same principles apply when addressing erosion in areas under intensive land uses, although the range of potential interventions is much greater under intensive uses. This is because these lands are usually already heavily modified, because the threats are much more localised, and because the available resources, including funding, are generally greater.

Technical advice for addressing soil conservation under intensive uses (such as erosion and sediment control in urban areas) is widely available. For these reasons, limited information about management of intensive uses is included in these guidelines.

1.3.3 Future challenges

As the world's population increases, we will need to ask more of our soils to meet the challenge of increasing agricultural production to ensure everyone has enough to eat. Climate change is expected to make the task of managing agricultural lands even more complex. Changes in temperature (both maximums and minimums), more intense rainfall events but reduced rainfall overall, and increased evaporation are all likely to reduce the productivity of both crops and pastures (State of Queensland 2012), with a subsequent increase the risk of erosion.

Queensland typically experiences long periods of low rainfall and limited runoff with consequential minimal erosion, interspersed with occasional periods of intense rainfall and brief, severe erosion events. Such a pattern can lead to complacency about the risk of soil erosion and result in neglect of important soil conservation measures. Considerable progress has been made in the control of land degradation in Queensland rural lands, but the task is far from complete. For example:

- Soil surface cover in many cropping area of Queensland is still inadequate in many seasons.
- Some upland cultivated areas are unprotected by contour banks or existing banks are poorly maintained.
- Some waterways that receive runoff from contour banks have become unstable and are in need of maintenance.
- Floodplains continue to experience erosive flooding.
- Surface cover is frequently inadequate in some Queensland grazing lands, leading to wind and water erosion, particularly during the extended periods of dry weather that regularly occur in these areas. Serious gully erosion continues to add sediment to streams and coastal waters.
- Many issues related to salinity, acidification and declining soil fertility and structure are still to be addressed.

The long-term decline in terms-of-trade experienced by farmers generally, as well as continuing restructuring of the industry, are an ongoing concern for the capacity of farmers to address soil conservation issues. In the past the main concern was that many farms were too small and unviable and that as a consequence—particularly during poor seasons and difficult economic times—the land became stressed and degraded as landholders were forced to try and manage through without knowing how long the difficulties would persist.

Increasingly, as farms have become consolidated and corporatised in response to these pressures, a new concern has arisen. This is that rural areas are becoming depopulated and the capacity to address soil conservation is declining as land managers find themselves spread more and more thinly as they are forced to operate with reduced inputs and in an increasingly complex regulatory and market environment. This problem threatens to become even worse as the average age of farmers and graziers across Australia continues to rise.

1.4 These guidelines

In 1966 soil conservation officers working in different parts of Queensland combined their knowledge to produce the first Queensland Soil conservation handbook, published by the Department of Primary Industries. The handbook set out the design methods and criteria together with recommendations for most of the erosion control situations encountered in Queensland cropping lands. It did not contain information on erosion in streams that was the responsibility of the Queensland Water Resources Commission at that time.

Selected chapters of the earlier version were updated in the early 1970s to translate imperial measures into metric when Australia adopted the metric system. In 2004 the original handbook was replaced by the publication: Soil conservation measures: a design manual for Queensland (Carey and Stone 2004). This publication was produced by the Queensland Department of Natural Resources and Mines and focused mostly on the implementation of soil conservation measures in cropping lands.

This publication is an update of the 2004 version, and contains considerable additional information as well as an expanded content range.

1.4.1 Intended audience

These guidelines are intended for use by people engaged in soil conservation practice, education and extension. With the dissolving of the Soil Conservation Service in the 1990s, these roles are now filled by a mixture of agri-business consultants, employees of community-based organisations, staff of state government agencies and local government and, of course, landholders themselves.

1.4.2 Scope

These guidelines cover a wider range of topics than the 2004 Manual, including gully erosion, property infrastructure, land management on floodplains and in horticultural lands, and stream stability. They are primarily focused on management of water erosion because this is by far the greatest land degradation threat to rural Queensland. They are also biased toward cropping lands because these are the most limited and highly prized lands for rural production.

There is limited detail about managing land uses where cover is high—for example the implementation of minimum and zero tillage in cropping lands and the management of pastures to match production and demand—because these are now standard practices. It is considered that there is already a large amount of information on these topics from other accessible sources, such as the many agronomists and pasture specialists working in these agricultural industries.

The guidelines do not include information on how to survey soil conservation measures or how to construct them, as this requires considerable specialist knowledge and skills that are best accessed by hiring reputable contractors or consultants or by consulting experienced landcare practitioners.

1.4.3 Format

The chapters in these guidelines are arranged in six groupings:

1. Preliminaries (Preface, Foreword and Chapter 1): contains background information that introduces the guidelines.
2. Planning (Chapter 2): includes principles covering overall property development and management, as well as information on legal aspects of planning. Some chapters in other sections also contain information about soil conservation planning (e.g. Chapter 12: Soil conservation in horticulture).
3. Runoff estimation (Chapters 3, 4 and 5): addresses the first step in designing soil conservation structures—hydrologic estimation of the rate of flow that a structure will be required to accommodate. The processes related to runoff are described in these chapters, with a special emphasis on the impacts of stubble retention practices. Two methods of estimating runoff for small rural catchments are detailed.
4. Channel design (Chapters 6, 7, 8 and 9): addresses the second step in designing soil conservation structures—the hydraulic design of a structure that can accommodate the design runoff. Some general principles are provided, along with detail about designing contour and diversion banks and waterways.
5. Special applications (Chapters 10, 11, 12, 13 and 14): include information about land management on floodplains, stream stability, soil conservation in horticulture, gully control and property infrastructure.
6. Appendices: contain frequently used tables and charts consolidated in one place for ease of use.

Each chapter includes a glossary and list of references and other information sources. Most of the references dated prior to 1995 were prepared by staff of the Department of Primary Industries—the state agency responsible for soil conservation programs up until that time. Many of these publications have been difficult to obtain as often only limited quantities of hard copy were produced; however, many are now readily accessible electronically through the Queensland Government Department of Environment and Heritage Protection library catalogue ‹qld.gov.au/environment/library›.

Land management field manuals have been prepared for most of the cropping lands of the state. These manuals provide useful information on land resources and land management with specific references to soil conservation. In many cases, because of their state-wide scope, they provide more specific information relating to the design of soil conservation measures than can be provided in these guidelines.

1.5 Further information

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