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Department of Agriculture
Government of Western Australia



**NATURAL RESOURCE
MANAGEMENT ISSUES:
SOUTH WEST REGION**

Compiled by Angela Stuart-Street



July 2003



**RESOURCE MANAGEMENT
TECHNICAL REPORT 244**

Resource Management Technical Report 244

**Natural Resource Management Issues
in the Agricultural Zone of
Western Australia**

SOUTH WEST REGION

Compiled by Angela Stuart-Street

July 2003

Disclaimer:

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

Contents

INTRODUCTION.....	3
ISSUE 1: ACID SULFATE SOILS	5
ISSUE 2: DRYLAND SALINITY	7
ISSUE 3: FLOODING	12
ISSUE 4: IRRIGATION SALINITY.....	15
ISSUE 5: MASS MOVEMENT	20
ISSUE 6: NUTRIENT LOSS AND EUTROPHICATION.....	22
ISSUE 7: REMNANT VEGETATION DECLINE.....	28
ISSUE 8: SOIL FERTILITY DECLINE	32
ISSUE 9: SOIL STRUCTURE DECLINE	34
ISSUE 10: SOIL ACIDITY	37
ISSUE 11: SUBSURFACE COMPACTION.....	40
ISSUE 12: SURFACE WATER SUPPLY SHORTAGES.....	42
ISSUE 13: WATER EROSION.....	44
ISSUE 14: WATER REPELLENCE (NON-WETTING SOILS).....	48
ISSUE 15: WATERLOGGING	48
ISSUE 16: WIND EROSION.....	54

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Introduction

This document has been compiled to provide an analysis of current pressures on agricultural resources of the South West Region. No data are currently available on the actual areas of land affected by the various forms of degradation. Regional land resource surveys have been interpreted to estimate these areas. These estimations are based on characteristics of the soils and landscapes within the region.

Differing ranges of risk are shown for different issues because of varying impacts. For example, estimates for water repellence are presented only for land that displays high susceptibility. In contrast, for mass movement land with estimated moderate to high risk has been highlighted. In other cases, two estimates have been presented for the same issue to highlight the areas most vulnerable as well as the broader risk. An example is the high to extreme and very high to extreme phosphorus export hazard. Climate variability and regional land use practices influence the extent to which an issue impacts on agricultural land.

The methods for the interpretations are documented in Van Gool, Moore and Tille (in prep.) and are held within the Department of Agriculture's Map Unit Database. The calculations are based on the area of agricultural land within the region. Public land under forest, reserves and National Parks is not included. Estimates of areas are presented for each soil-landscape zone within the region. Location of soil-landscape zones and sub-regions is shown in Figure 1.

Each natural resource management issue is covered in four sections:

- 1) **Extent:** Briefly describes the nature and extent of susceptibility to the issue based on the characteristics of the soils and landscape. It also presents data for sub-regions in the South West, a format that the South West Catchments Council and catchment groups may find useful in assessing NRM issues against assets and for formulating targets.
- 2) **Impacts:** A brief explanation of why the issue is important and how it affects agriculture and the environment. For more detail, readers are pointed to the relevant references.
- 3) **Management options:** On-ground actions known to be effective to address the issue.
- 4) **Effectiveness:** The likely effectiveness of each management option is summarised with appropriate references. References are important because they identify where science supports the use of the management actions/options. It is important also to identify where no information is available on effectiveness of remedial actions.

Finally, it is important to consider that the management options are only likely to be effective if adopted by land managers. Many options discussed in the following pages are economically, temporally and spatially challenging and success may not be forthcoming if the land manager cannot, or chooses not to meet, one or all of these requirements to implement change.

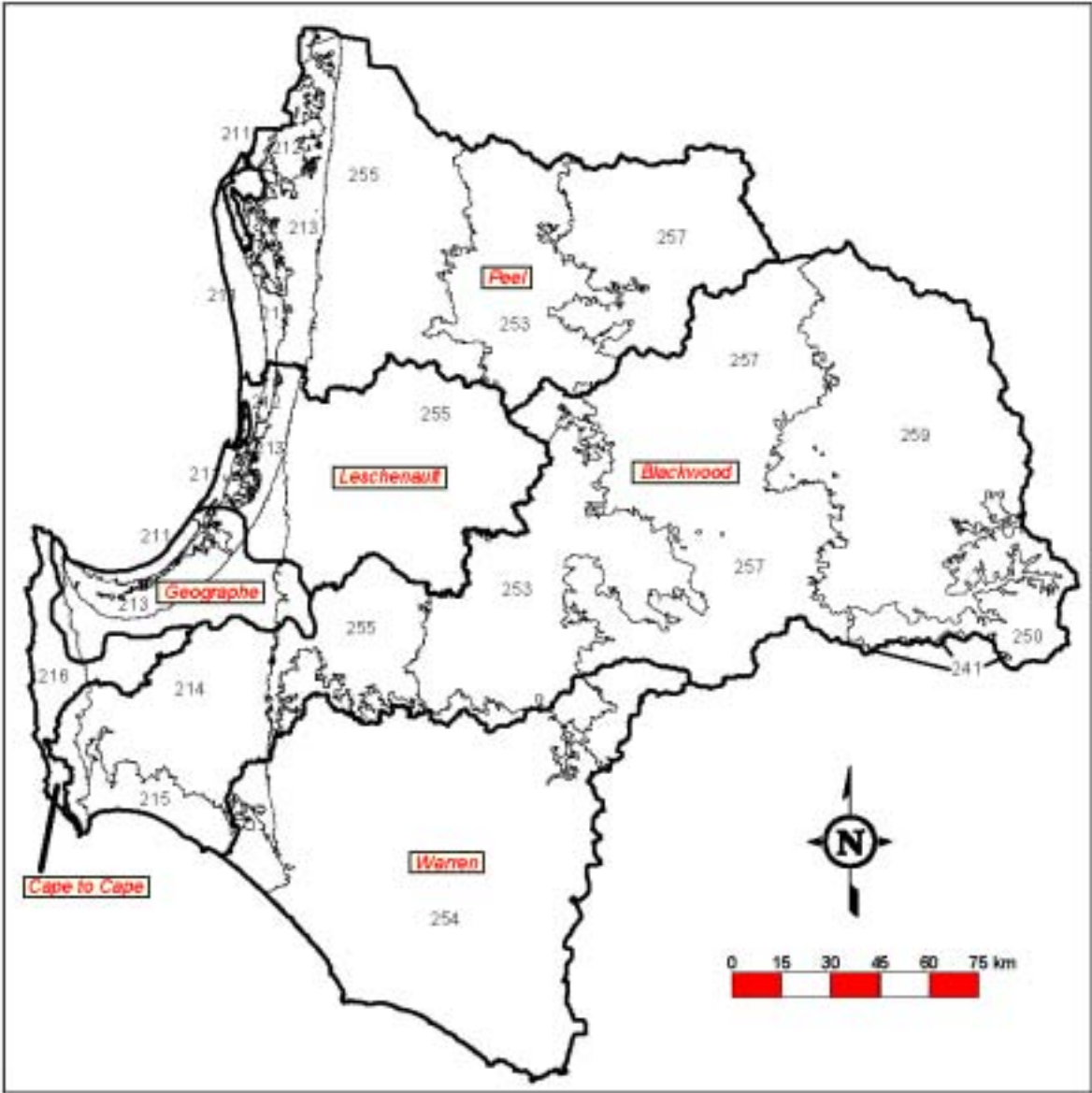


Figure 1: South West NRM Region showing sub-regions and soil-landscape zones

ISSUE 1: ACID SULFATE SOILS

Angela Stuart-Street

Extent

Potential acid sulfate soil is the common name given to soil and sediment containing iron sulfide. These can become actual acid sulfate soils if exposed to air. The extent of existing and potential acid sulfate soils in Western Australia is very poorly understood and urgently requires investigation. While they are usually associated with estuarine deposits, acid sulfate materials have also been identified in swamps on the Swan Coastal Plain near Perth and beneath the Scott Coastal Plain. In addition, it has been recognised in South Australia that extensive inland areas featuring saline soils may also be at risk where deep upwellings of saline, sulfate-rich regional groundwater reach the surface (Fitzpatrick *et al.* 2000). Research into the likelihood of this problem in Western Australia is being undertaken.

Impacts

Acid sulfate soil only becomes a problem if exposed to the air. Disturbance or drainage of these susceptible soils can lead to (Ahern *et al.* 1998):

- Toxic quantities of acid, aluminium, iron and heavy metals contaminating land and adjacent waterways
- Contamination of groundwater with arsenic and heavy metals
- Soil structure decline and increased water erosion risk
- Reduced plant productivity
- Detrimental effects on the health of animals and humans associated with the consumption of aluminium rich water
- Severe impacts on aquatic flora and fauna and riparian vegetation
- Serious effects on infrastructure, including pipes, foundations and road surfaces susceptible to corrosion, which lead to accelerated structural failure.

Acid sulfate incidents in Western Australia include groundwater contamination with increased acid and arsenic levels in the northern Perth suburbs and contribution to the closure of the Beenup mineral sand mine at Scott River.

Management options

The key action is to recognise the existence of potential acid sulfate soil and avoid disturbing the land. Field identification is possible using soil, water and vegetation indicators (Dairy Industry Development Company 2001). Management depends on the quantities of sulfide mineral, acid loads produced and the area under threat. Options include:

1. Efficient water and drainage management systems
2. Careful selection of pasture species and effective pasture management
3. Fencing off affected areas and rehabilitation
4. Revegetating groundwater recharge areas and utilising perennial pastures
5. Establishing tolerant species in scalds to stabilise soil and prevent erosion and acid runoff when it rains
6. The treatment of land or drainage water (within channels and ponds) using liming and aeration techniques (where economical).

Effectiveness

Site specific management options for acid sulfate soils described above have been effective in other States but are largely untested under Western Australian conditions. The underlying management principles should be transferable.

1. Effective watertable management (preventing oxidation) has been the key to efficient management. Wherever possible, these soils should not be drained, and avoiding disturbance is always preferred. If drainage is necessary, then broad shallow drains should be used to prevent disturbing soils. Deep drains should not be used.
2. Highly productive pastures have been established on land influenced by acid sulfate due to careful species selection and management to match the soil conditions.
3. Fencing off and rehabilitating affected land can be successful in small areas. Larger scalds are difficult to manage
4. Revegetation with perennials in recharge areas has lowered watertables.
5. Careful species selection has helped stabilise affected areas, reducing erosion and acid run-off
6. Liming and aeration may be uneconomic on a broad scale, but on a small area may be effective to neutralise sulfuric acid in soil or water

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ISSUE 2: DRYLAND SALINITY

Angela Stuart-Street and Tim Mathwin

Extent

Western Australia has the largest area of dryland salinity in Australia (Land and Water Australia 2000). The estimated extent in the agricultural region in 2000 was 1.9 million hectares. It is predicted to rise to 2.3 million hectares by 2020 (Kingwell *et al.* 2003). The immediate risk is predominantly in the eastern wheatbelt valley floors and adjacent areas. Future risk is expected to impact most severely in the Central and Sandplain Regions.

The Department of Agriculture has prepared a draft Salinity Investment Framework (George and Kingwell 2003) which outlines the estimated extent of salinity under different management scenarios. This was part of a process of reviewing land, infrastructure and other assets at risk. The framework includes the probability of adoption and technical feasibility of management scenarios for each soil-landscape zone.

Table 2.1: Salinity by soil-landscape zone in agricultural land of the South-West NRM Region (Land Monitor 2002)

Zone	Code	Saline land (ha)	%	Low-lying land (ha)	%
Coastal Dune Zone	211	na*		na	
Bassendean Zone	212	na		na	
Pinjarra Zone	213	na		na	
Donnybrook Sunkland Zone	214	na		na	
Scott Coastal Zone	215	na		na	
Leeuwin Zone	216	na		na	
Pallinup Zone	241	<500	2	<1,000	14
South-eastern Zone of Ancient Drainage	250	3,000	2	13,000	10
Eastern Darling Range Zone	253	11,000	2	108,000	20
Warren-Denmark Southland Zone	254	<1,000	<1	21,000	17
Western Darling Range Zone	255	2,000	1	17,000	9
Southern Zone of Rejuvenated Drainage	257	49,000	5	227,000	25
South-western Zone of Ancient Drainage	259	44,000	8	121,000	22
TOTAL		111,000	4	508,000	18

* na: Land Monitor data not available for these areas

Impacts

Secondary salinity following land clearing impacts greatly on the agricultural area. Large areas of once productive land, especially on valley floors, have become saline. Species richness has declined and many South West rivers are now too saline for irrigation or consumption (Moore 1998). Extent and impacts of secondary salinity are detailed in Short and McConnell (2001), Tille *et al.* (2001), George and Kingwell (2003) and Kingwell *et al.* (2003), who discussed economic impacts. Components are summarised below:

- **Loss of productive agricultural land:** Salinity leads to poor growth or death of plants, and is most detrimental combined with waterlogging. It is estimated that about 1.9 million

hectares are salt-affected. Predictions based on current and perceived land uses are that almost 2.5 million hectares of land in agricultural regions may become salt affected by 2020 (Kingwell *et al.* 2003).

- **Loss of biodiversity** caused by detrimental effects of secondary salinity on bushland remnants and wetlands. Twenty-one of 54 wetlands within the agricultural region are at risk from shallow watertables. In addition, an estimated 1500 plant species will be affected, with 450 subject to extinction. It is likely that fauna species will be reduced by 30 per cent in affected areas, and terrestrial animals will decline significantly (e.g. 50 per cent reduction in numbers of water birds using wheatbelt wetlands) due to the salinity-induced death of shrubs and trees (Land and Water Australia 2000).
- **Reduction of potable water supplies:** More than a third of the South-West's previously divertible water has become brackish or saline and cannot be used (Tille *et al.* 2001).
- **Detrimental effects on townsites and infrastructure:** About 4,000 km of road (sealed and unsealed) and more than 200 km of railway line are affected by salinity. Approximately 24,000 km of road, 1000 km of rail and up to 38 rural towns may be affected by damage to buildings, recreation facilities and public utilities including water supplies and waste management systems (George and Kingwell 2003).
- **Increased risk of water erosion** as denuded and waterlogged topsoil is more susceptible to detachment and transport (Tille *et al.* 2001).

Table 2.2: Salinity in agricultural land by sub-region

	Area	Peel-Harvey	Leschenault	Geopraphe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Saline land (Land Monitor 2002)	(ha)	10,000	2,000	na*	na	95,000	3,000
	(%)	2	1	na	na	5	2
Soils currently saline (DAWA 2003) (ECE >400 mS/m at 0-30 cm)	(ha)	10,000	4,000	2,000	0	107,000	5,000
	(%)	2	3	1	0	6	3
Low-lying areas (Land Monitor 2002)	(ha)	80,000	12,000	<500	na	384,000	32,000
	(%)	13	8	<1	na	22	19
Salinity hazard, including current saline areas (DAWA 2003)	(ha)	54,000	6,000	9,000	0	223,000	9,000
	(%)	9	4	7	0	13	5

* na: Land Monitor data not available for these areas

Management options

Effective management of salinity includes both the catchment and the saltland (Moore 1998). Options are outlined below (from Moore 1998, Tille *et al.* 2001, Kingwell 2003):

1. **Adopting low recharge farming systems** is the principal option for containment, replacing annual crops and pastures with alternative, economically viable systems that increase evapotranspiration and reduce water percolating below the root zone (i.e. recharge).
 - *Improve annual crop and pasture agronomy.* Look at species and variety selection, fertiliser applications, weed control and timing of treatments.
 - *Perennial plants:* Pastures capable of growing throughout the year, and trees or fodder shrubs which combine the advantages of deep root systems and year-round growth with higher water use due to their large leaf area.

- *Managing soils with major chemical and/or physical limitations* as they may limit productivity and are often major recharge and/or erosion sites, particularly Acid yellow sandy earths, Pale deep sands, Shallow gravels, rock outcrops and bedrock highs.
 - *Protect, manage and enhance the remnant vegetation* to maintain existing water use and contribute to reducing groundwater recharge.
- 2. Engineering solutions:** Principally used for recovery of saline land and water, and required in addition to increasing plant water use. These options help to prevent water from recharging and remove saline water from the catchment.
- *Managing surface water* includes incorporating water harvesting, pumps, banks and drains into farm and catchment water management strategies.
 - *Managing groundwater* to lower watertables, preventing continued accumulation of salts while allowing rainfall to leach salt from the upper soil profile. These techniques function by increasing the rate of discharge, and consequently reduce the area of groundwater discharge necessary to establish equilibrium. This may involve the use of deep open or closed drains, pumps or siphons.
- 3. Living with salinity** to improve productivity in the use of land and water that is already salt-affected.
- *Saltland pastures and crops* can provide some production from salt-affected land.
 - *Aquaculture* has some potential using groundwater from salt-affected areas or aquifers that supply water to them.
 - *Evaporation basins and salt harvesting* can be used to dispose of saline groundwater until it evaporates (JDA and Hauck 1999). Commercial harvesting of salt and related minerals from an evaporation basin may be possible.
 - *Desalination* converts saline or treated waste water into fresh water suitable for drinking and industrial use. Generally, distillation and reverse osmosis (RO) are used for seawater, while RO and electrodialysis for brackish water (Department of Agriculture 2002).

Effectiveness

“Salinity is a complex problem and the environmental and hydrological processes are highly varied. Each situation involving dryland salinity has its own peculiarities and there is no single, overall solution. Solutions will require a blend of approaches tailored to meet local conditions.” Tille *et al.* (2001).

Most benefits from salinity treatments come from containment and the recovery of salt-affected areas, rather than improved management of saline land (Kingwell and George 2003). Kingwell *et al.* (2003) have provided an economic overview of the salinity threat and assessed plant-based options for salinity management.

1. Adopting low recharge farming systems

- *Improve annual crop and pasture agronomy:* Increasing the water use of conventional annual crops and pastures has only limited potential. Hall (2002) suggested that improving cereal agronomy to reach close to theoretical yield potentials would only increase the water use of an average crop by about 4 per cent. This is mainly because increased biomass production and increased transpiration are largely offset by decreased evaporation from the soil surface. Selecting species or varieties matched to the environmental conditions, and good management of fertilisers and grazing will help extend the period of water use by annuals (Tille *et al.* 2001).

- *Use of perennial plants:* The main role of perennial species is to reduce recharge. They are most effective when used to manage salinity derived from local flow systems. Their effectiveness is related to the area planted – small areas will only have a minor contribution (Kingwell *et al.* 2003). Perennials use more water than annual species in late spring, summer and autumn, and deeper-rooted perennials (trees) are most effective at recharge control (Tille *et al.* 2001). Case studies in major grain growing regions affected by salinity reveal that deep-rooted perennials are a profitable inclusion in farming systems, improving water management and remove or lessen the rate of spread of salinity in some cases (Kingwell *et al.* 2003).
- *Managing soils with major chemical and/or physical limitations:* Any management which reduces waterlogging will help combat salinity. Soil management that improves any chemical or physical restrictions to plant growth and improve crop water use by allowing greater root exploration and more thorough drying the soil profile prior to the next season may have substantial benefits (Tille *et al.* 2001).
- *Protect, manage and enhance the remnant vegetation:* Protecting and enhancing areas of native vegetation will contribute to overall water use as well as protecting wildlife habitat and biodiversity. Remnant vegetation kept in good condition will have a similar water use to native vegetation before clearing (Moore 1998). If remnant areas are small, they have little impact on the catchment water balance.

2. Engineering solutions

- *Managing surface water:* The severity and impact of salinity are diminished if waterlogging is reduced by well designed and sited surface water management structures. It may also contribute to increasing total plant water use by improving conditions for plant growth and removing excess surface water before it becomes groundwater recharge (Tille *et al.* 2001).
- *Managing groundwater:* The permeability of soil material beneath salt-affected areas can influence the effectiveness of groundwater drainage. Effectiveness may vary and careful site assessment and design of the appropriate method of disposal are essential to increase chances of success and to minimise off-site impacts (Tille *et al.* 2001).

3. Living with salinity

- *Saltland pastures and crops:* Successful revegetation with salt and waterlogging-tolerant species will increase water usage, and may help lower watertables (Tille *et al.* 2001). They are likely to be profitable across a range of scenarios, with the optimal area varying considerably according to site characteristics and market conditions (O'Connell and Young 2002, Kingwell *et al.* 2003).
- *Aquaculture:* Use of saline water for aquaculture is well documented (e.g. Tille *et al.* 2001), however operating costs may be prohibitive, plentiful groundwater is needed (A. Seymour, pers. comm.), and good wastewater disposal strategies.
- *Evaporation basins and salt harvesting:* Storage of salt on-site is considered the best short to medium-term option. Commercial harvesting from evaporation basins has been successful in a few cases, but is not usually financially viable for salt disposal unless a local niche market is identified (JDA and Hauck 1999).
- *Desalination:* Developing water resources from saline water is possible using desalination technologies. However, desalination can be costly because it is energy intensive (Department of Agriculture 2002). Mainly the feed water salinity level, energy costs and economies of size determine cost (Kingwell *et al.* 2003). Successful applicability of desalination varies in each situation and may not be cost effective on a small scale.

George and Kingwell (2003) forecast the degree of management expected to be possible for each soil-landscape zone in the South-West, as well as the spatial pattern and sensitivity analysis for each area. Their view of effectiveness is technical feasibility of treatment combined with the likelihood of adoption in each area.

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ISSUE 3: FLOODING

Angela Stuart-Street and Tim Mathwin

Extent

Flooding usually occurs along drainage lines, valleys and low-lying land with poorly defined drainage networks. The frequency is generally highest in high rainfall zones, although the impact may not be the most significant. It can be divided into local flooding restricted to small catchments, and regional flooding affecting large areas such as when major rivers break their banks. Since the mid-1960s, WA has experienced below-average rainfall and relatively little major flooding, especially in the South-West (Water and Rivers Commission 2000).

Rivers and drainage lines in catchments that have been cleared for agriculture are more prone to flooding than where natural vegetation has been retained. Catchments where land is cultivated regularly have an even higher risk due to compaction and hardpan formation allowing less infiltration. Those with increasing areas of salinity and waterlogging experience greater flood peaks because of the proportion that remains saturated between rainfall events (Bowman and Ruprecht 2000).

There is no consistent mapping of the extent of flooding or flood-prone areas. The Water and Rivers Commission produces flood risk maps for heavily populated areas. Some modelling has also been carried out. The following data are based on flood hazards assigned to land units in the Department of Agriculture's soil-landscape mapping.

Table 3.1: Flood hazard in the South-West NRM Region by soil-landscape zone (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Land with moderate to high risk of flood hazard ¹	
			(ha)	%
Coastal Dune Zone	211	34,000	5,000	14
Bassendean Zone	212	64,000	3,000	4
Pinjarra Zone	213	182,000	8,000	5
Donnybrook Sunkland Zone	214	69,000	4,000	6
Scott Coastal Zone	215	27,000	1,000	4
Leeuwin Zone	216	51,000	3,000	5
Pallinup Zone	241	6,000	0	0
South-eastern Zone of Ancient Drainage	250	125,000	7,000	5
Eastern Darling Range Zone	253	529,000	26,000	5
Warren-Denmark Southland Zone	254	125,000	5,000	4
Western Darling Range Zone	255	194,000	11,000	6
Southern Zone of Rejuvenated Drainage	257	910,000	45,000	5
South-western Zone of Ancient Drainage	259	541,000	39,000	7
TOTAL		2,856,000	157,000	6

¹ Land likely to be affected by moving floodwaters at least once in every 10 years

Table 3.2: Flood hazard by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschenault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Land with moderate to high risk of flood hazard¹	(ha)	24,000	10,000	5,000	2,000	102,000	13,000
	(%)	4	7	4	5	6	7

¹Land likely to be affected by moving floodwaters at least once in every 10 years

The hazard estimates indicate not only the landscapes that contribute to flood generation, but also those affected by them. An understanding of flood potential can only be determined from tracking actual events and modelling. This is mainly due to the many variables that contribute to flood generation, such as landscape formation, storm probabilities, land use and run-off generation. Even when flood events are recorded and tracked, there is often spatial absence of accurately observed climatic and run-off data that generated them. For example flooding on the broad valley floors of the Coblinine River and its tributaries is probably less extensive than suggested and would occur about every 10 years. Elsewhere, the proportion of landscape prone to flooding is mostly 2-7 per cent.

Impacts

These can include damage to infrastructure, interruption to communication and transport, crop and stock losses, erosion and consequent sedimentation. The impacts are summarised in Tille *et al.* (2001 page 172).

Management options

The agricultural areas are still undergoing immense hydrological change in response to clearing and development. Our understanding and ability to determine their potential impacts, as well as the ability to develop remedial measures is greatly hindered by a lack of suitable climatic and landscape run-off information. To date, the State has invested poorly in the gauging of streams and catchments other than those used for urban and irrigation water supplies. This limits our knowledge base and ability to model and predict run-off and flood events generated within all but only about 10 per cent of the South-West agricultural area.

Before we are able to make anything more than general statements on flood risk and the methods and economics of reducing this, we need to undertake stream gauging and related modelling on a far greater scale. Our knowledge is based on common sense, supported by tenuous observation, which indicates that on a small scale the following tools (described in detail in Tille *et al.* 2001, page 174) may be effective:

- 1. Lower recharge farming systems** which are designed to combat salinity and waterlogging and may reduce the risk of flooding.
- 2. Temporary detention** wherever possible by incorporating practices that are generally used to reduce soil erosion.
- 3. Installation of earthworks and water harvesting schemes** to regulate and reduce run-off from contributing landforms and catchment areas.
- 4. Groundwater drainage schemes** that de-water areas between storm events to provide greater soil infiltration capacity.

On a regional scale options may include:

- 5. Use of natural lakes and wetlands** as detention basins to attenuate flood events.
- 6. Regional scale drainage schemes** to drain land and divert flood flows away from infrastructure to detention and disposal areas.

Effectiveness

1. **Lower recharge farming systems** have the potential to reduce run-off caused by saturation excess.
2. **Temporary detention** is likely to be beneficial in small and moderate storm events. The benefits are reduced during severe or prolonged storm events.
3. **Installation of earthworks** and water harvesting schemes are often successful on a local scale. These generally provide significant local benefits and cause few off-site problems providing schemes are properly designed.
4. **Groundwater drainage schemes** can be effective at moving surface flows that may enter the groundwater system away from the area and into natural drainage lines. These are likely to be locally beneficial in small and moderate storm events. Sedimentation may become a problem.
5. **The use of natural wetlands:** If properly managed, the flow of water through these can provide benefits in terms of flood control and conservation. However, these projects may require some expert input.
6. **Regional scale drainage schemes** can provide significant benefit on the greater catchment scale, and alleviate community concerns regarding water and flood management. However, these need to be properly designed and may require management by a controlling body.

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ISSUE 4: IRRIGATION SALINITY

Don Bennett and Eric Wright

Extent

The risk of irrigation salinity occurs over a limited area, mainly the Harvey Water Irrigation Area, formerly known as the South West Irrigation Area (30,000 ha), Ord River Irrigation Area (14,000 ha) and the Lower Gascoyne near Carnarvon (2,000 ha).

Irrigation-induced salinity is worse where high levels of salt are applied in the water (e.g. Wellington Dam-Collie Irrigation District), and with clay soils which may contain naturally high levels of salts due to poor transmissivity, reduced leaching and high watertables. Salt accumulation in topsoil is a much greater risk where the watertable is close to the surface. There is still considerable risk even with the application of much fresher water. Salinity has appeared in nearly every irrigation area throughout history, and can be a significant problem in Harvey Water Irrigation Areas fed from very fresh sources other than the Wellington.

The Swan Coastal Plain has significant irrigation-related salinity problems as well as potential for high risk in many currently dryland areas if they were irrigated. George and Bennett (1999) conducted electromagnetic (EM38, EM31) surveys on 20 irrigated and dryland farms between Perth and Busselton (over 2,200 ha) which revealed that:

- 35 per cent had soil in the root zone that was mildly salt-affected (EM38 50-100 mS/m)
- 20 per cent had highly salt-affected soils (EM38 >100 mS/m)
- 40 per cent had highly salt-affected subsoils (EM31 100-200 mS/m)
- 10 per cent had extremely salt-affected subsoils (EM31 >200 mS/m).

In general, the heavier textured soils (Pinjarra Plain) were most at risk, particularly (but not exclusively) those on the western margins, where watertables are generally shallower. Deeney (1988) found that groundwater in the upper 5-10 m of the Harvey Water Irrigation Area was brackish (1000-4000 mg/L) to saline (4000-14,000 mg/L).

A more recent and intensive EM31/38 survey of whole farms over the entire Collie Irrigation District (including both irrigated and dryland in equal proportions) found that 25 per cent had highly salt-affected root zone soils (EM38 >100 mS/m).

Irrigation salinity in other areas is not as widely recognised, perhaps because the systems are at a local or farm scale and dripper or micro-sprinkler systems are used to irrigate horticultural crops. However they still do occur and examples include:

- Irrigation-induced groundwater seepage below horticultural areas in the Forested Hills and Western Woolbelt hydrological zones caused by irrigation recharge into fractured rock or minor sedimentary aquifers.
- Farm scale supply dams becoming brackish due to discharge from seepage resulting in soil salts building up beneath salt-sensitive horticultural crops.
- In the Myalup district on Bassendean and Spearwood sands, surficial groundwater has become too saline in certain areas for some traditional salt-sensitive crops because of recycling and concentration of salts via evaporation.

Impacts

Irrigation soil surface salinity levels generally peak towards the end of the summer (dry season) irrigation period, due to high evaporation rates concentrating salts from irrigation water in the topsoil. These salts are leached to varying extents, depending on soil type, from the topsoil or washed into tail drains during the winter (wet season). The leaching occurs to a greater extent in the sandy and loamy textured soils of the Harvey Water Irrigation Area. This can reduce salinity impacts, particularly when salinity of applied water is low. Unfortunately these soils are not abundant in the current Wellington-fed irrigated area. Salt wash off with run-off is the major mechanism on heavier soils. Details are outlined below:

- **Salinity and plants:** Salinity leads to poor growth or death of plants, and combined with waterlogging is most detrimental for growth. Affected plants appear stunted, with the salt creating a 'drought' effect by hindering water uptake by the roots (Moore 1998).
- **Increased risk of water erosion:** Denuded, waterlogged and poorly structured topsoils are more susceptible to detachment and transport (Tille *et al.* 2001).
- **Increased risk of soil structure decline:** High levels of salt (NaCl) particularly in clayey or loamy soils invariably lead to sodium saturation and soils then become sodic. Sodic soil particles readily dissociate or disperse in fresh water (e.g. winter rain) to become structurally unstable.
- **Increased risk of nutrient run-off:** Saline, poorly structured and waterlogged soils have increased risk of water run-off carrying both dissolved nutrients and nutrients attached to fine soil particles. This is compounded where crop and pasture growth is reduced due to salinity and the plants do not take up the applied nutrients efficiently.

Management options

These are often specific to soil types, crop or irrigation systems. As stated in Tille *et al.* (2001): "Salinity is a complex problem and the environmental and hydrological processes are highly varied. Each situation involving dryland salinity has its own peculiarities and there is no single, overall solution." This is equally true of irrigation salinity and solutions often require a blend of approaches tailored to local conditions.

1. Farming systems and enterprise approaches

- **Selection of soils:** Using free-draining permeable soils and avoiding areas with clay subsoil will maximise productivity potential and minimise risk of salinity. This strategy has limitations for surface irrigation areas because of water loss and high rates of recharge to the water table which can then result in waterlogging and salinity, but is useful for sprinkler and micro-irrigation techniques where application volume is better controlled.
- **Watering schedules and evaporation deficit watering:** Watering to evaporation, crop type and development stage rather than a set interval is important and helps prevent over-watering which can increase salt loads, increase recharge, cause waterlogging and reduce yields (Bennett 2002).
- **Irrigation systems:** Changing from surface to sprinkler irrigation (centre pivot or linear travel) allows improved flexibility in application of water and nutrients to crops and pasture. It removes the limitations of variable soil types (permeability) in applying water using flood techniques.
- **Automation of flood delivery systems:** Installing automatic systems to bay outlets reduces the risk of over-application of water which causes wastage, waterlogging, recharge and increased salt application.
- **Improve annual crop and pasture agronomy:** Matching species and variety selection to salinity levels, better timing of fertiliser applications, weed control, tillage (e.g. deep

ripping to maximise leaching and soil organic matter), and better timing of treatments (e.g. application of lime and gypsum).

- *Use of perennial plants:* Pastures capable of growing throughout the year with some salinity tolerance, and trees or fodder shrubs which combine the advantages of deep root systems and year-round growth with higher water use due to large leaf area.
- *Protect, manage and enhance the remnant vegetation:* To maintain existing water use and contribute to reducing groundwater recharge and increasing water usage from shallow watertables at the district scale.

2. Engineering solutions

- *Irrigation water flushing:* Irrigation water to 'flush' or wash salts from topsoil can be used where salt accumulates. In WA irrigation areas, most flushing of salts occurs naturally during the winter (wet season).
- *Laser levelling:* Used to reduce ponding, waterlogging and groundwater recharge by ensuring a consistent coverage of irrigation water and known application rate.
- *Subsurface drainage:* Can be used to remove excess water from the soil, including areas of high watertable and to manage overwatering from irrigation. Also useful in leaching salts from the soil profile, and to prevent accumulation in lower profile soils.
- *Managing groundwater:* Preventing continued accumulation of salts while allowing rainfall to leach salt from the upper soil profile. These techniques increase the rate of discharge, and consequently reduce the area of discharge necessary to establish equilibrium. This may involve use of deep open or closed drains, pumps or siphons.

3. Infrastructure considerations

- *Irrigation channels:* Ensure channels are sealed, or piping irrigation water, will help reduce groundwater recharge from leakage (Qureshi 1998).
- *Improving water quality:* Options for the Collie River Catchment have been developed to improve the water quality provided to the Harvey Water Irrigation Area (supplied from Wellington Dam). 68 GL are available to irrigate about 6,000 ha in the Collie Irrigation District around Burekup and Dardanup. The Collie Recovery project has developed a strategic plan to reduce salinity in the Wellington Dam over five years from around 1000 to 550 mg/L.
- *District drainage system:* Ensure the system is adequate to effectively carry the run-off during winter storms to prevent long periods of flooding and inundation and has adequate depth and volume to be able to receive water from subsurface drainage and other groundwater management schemes.

Effectiveness

1. Farming systems and enterprise approaches

- *Selection of soils:* Highly effective, however there may be increased capital costs for land in the transition and more suitable land within the bounds of the irrigation system infrastructure may be lacking. Better soil mapping at below paddock scale is required in many areas.
- *Watering schedules and evaporation deficit watering:* Very effective in reducing waterlogging, increasing water use efficiency, reducing salt loads and reducing wastage and recharge, and likely to increase crop and pasture yields (Bennett 2002).

- *Irrigation systems*: Change from surface to sprinkler irrigation (centre pivot or linear travel). Reduces limitations of variable soil types (permeability) in applying water using flood techniques, however many existing surface irrigation areas have grades, channels, banks and fences that would compromise centre pivot operations and cost of changing to sprinklers may be prohibitive. This results in about 30 per cent less water for the same level of production, however it should be noted that increasing application to 90 per cent of flood application levels has been shown to increase growth rates (Richard Morris *pers comm.*). An economic case study needs to be developed.
- *Automation of flood delivery systems*: These have been shown to reduce over-watering by 30 per cent (Bennett *et al.* 2001). They also facilitate better (more frequent with less volume) watering scheduling by reducing the time spent manually controlling water flows.
- *Improve annual crop and pasture agronomy*: By matching production systems to soil (salinity) capability there is scope to increase production by targeting soils with low er salinity and waterlogging risk, and reduce cost of production and off-site impacts by moving to less intensive production systems on less suitable (more saline) land. Soil salinity mapping using EM systems in the Wellington Irrigation Area has shown the potential to help better target production systems and also target areas requiring remedial engineering systems (Bennett *et al.* 2000, Bennett 2001). Annual deep ripping at the end of summer has shown considerable promise as a way of encouraging salt leaching and increasing soil structure by promoting deeper organic matter penetration. High rates of gypsum and lime are effective only on soils that exhibit structural instability by dispersion, but do not slake.
- *Perennial plants* that are capable of growing throughout the year, and have more salinity and waterlogging tolerance than current species will lead to better production and water use via deeper root systems and larger leaf area. Currently few productive options are available and this requires more research but has the capacity for large improvements.

2. **Engineering solutions**

- *Irrigation water flushing*: Considered expensive and may waste the water resource depending on circumstances (Qureshi 1998). Locally, has been shown to have only limited applicability for heavy soils in the Harvey Water Irrigation Area because only the initial wetting front dissolves and carries away surface salts (Bennett *et al.* 2001). It has been shown that the optimum flushing benefit comes from only allowing about 10 per cent of applied water to run off. In most SW irrigation areas, most flushing of salts occurs naturally during the winter (wet season)
- *Laser levelling*: Effective for surface irrigation areas and widely used. Ensures consistent coverage of water and enables a known application rate to be achieved. Is considered a prerequisite and standard practice for all surface irrigation areas.
- *Subsurface drainage*: Can be quite effective. Trials in Harvey Water Irrigation Area showed total salt export from drained areas to be nearly double (60 t/ha) the amount applied in irrigation (35 t/ha) during a three-year period, compared with an undrained area that exported less (29 t/ha) via surface run-off only (Bennett 2002). Nutrient run-off was reduced due to better drainage allowing nutrient and water infiltration and increased plant growth. However it is expensive costing about \$2,000/ha and poor salinity-induced soil structure and root invasion can create ongoing problems.
- *Managing groundwater*: To lower watertables using deep open or closed drains, pumps or siphons prevent continued accumulation of salts while allowing rainfall to leach salt from the upper soil profile. Techniques vary in effectiveness depending on site conditions, requiring permeable soils and underlying aquifers for maximum effect. They can be expensive and technically challenging and have not been undertaken with any success in SW irrigation areas.

3. **Infrastructure considerations**

- *Irrigation channels*: Depends on the age and integrity of the channel system. Older systems are more expensive to maintain and convert to fully sealed systems. Sealed supply channels will prevent groundwater recharge within the irrigation area from supply channel leakage (Qureshi 1998). Priority for sealing channels should be given to areas of most permeable soils. Leaky areas can be readily identified using electromagnetics (Heslop and Murphy 2001).
- *Improving water quality*: The Collie Recovery Catchment project has developed a strategic plan involving catchment and engineering options to improve salinity in Wellington Dam over five years from around 1000 to 550 mg/L (WRC 2003). This will reduce the salinity effects on plants, increase production and halve the salt load being deposited on irrigation areas, however salt loads will still be significant and high enough to maintain some salinity impact on heavier soil types in the area.
- *District drainage system*: Enhanced drainage will facilitate the installation of on-farm subsurface drainage systems allowing greater areas of land to be drained to reduce salt and waterlogging. This would be a long-term process at community or government scale, however is required before adoption of large scale on farm deep drainage schemes could occur in some areas on the Swan Coastal Plain.

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ISSUE 5: MASS MOVEMENT

Peter Tille

Extent

Mass movement (soil creep, slumps, landslides and earth flows) is most common on steep slopes with gradients in excess of 27 per cent, but can also occur on gentler slopes. Land that has been cleared of native vegetation is much more likely to be affected, especially in high rainfall districts. Mass movement is often associated with seepage controlled by geological lineaments such as dolerite dykes, quartz seams, faults and shear zones. Many of the landslides occur on slopes with a relatively shallow depth to bedrock (2-5 m) because these soils tend to reach saturation quickly and then become unstable. The subsoil is often unstable clay or saprock with prominent biotite or mica.

Mass movement is most common along the Darling Scarp (Chittering to Nannup) and in valley systems dissecting the Darling Plateau (e.g. Blackwood, Collie, Preston and Williams valleys). Other locations include the hills around Denmark and slopes of the Avon Valley. Soil creep is probably the most widespread form but often difficult to identify. Landslips are more obvious and can cover up to 20 ha, but are typically less than 0.1 ha in size. The following data are based on land units allocated to the Department of Agriculture's soil-landscape mapping. The area of landslips may be an over-estimate.

Table 5.1: Mass movement by soil-landscape zone in the South-West NRM Region (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Current landslips (slumps, slides and earthflows)		Slopes with moderate to high risk of land instability	
			(ha)	(%)	(ha)	(%)
Coastal Dune Zone	211	34,000	-	-	<500	1
Bassendean Zone	212	64,000	-	-	0	0
Pinjarra Zone	213	182,000	-	-	2,000	1
Donnybrook Sunkland	214	69,000	10	0.01	<1	0
Scott Coastal Zone	215	27,000	-	-	<500	1
Leeuwin Zone	216	51,000	-	-	<100	<1
Pallinup Zone	241	6,000	-	-	0	0
South-eastern Zone of Ancient Drainage	250	125,000	-	-	500	<1
Eastern Darling Range	253	529,000	834	0.13	1,000	<1
Warren-Denmark Southland Zone	254	125,000	1,063	0.48	100	<1
Western Darling Range	255	194,000	2,919	0.65	<500	1
Southern Zone of Rejuvenated Drainage	257	910,000	-	-	3,000	<1
South-western Zone of Ancient Drainage	259	541,000	-	-	3,000	<1
TOTAL		2,856,000	4,826	0.14	11,500	<1

Table 5.2: Mass movement in the South West NRM Region by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschenault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Moderate to high risk of instability ¹	(ha)	2,300	800	350	50	9,000	500
	(%)	<1	1	<1	<1	1	<1

Impacts

The impact of mass movement is summarised on page 201 of the 'South-West Hydrological Information Package' (Tille *et al.* 2001):

- Loss of human life (extreme cases e.g. Gracetown)
- Damage to infrastructure (houses, roads, dams, fences)
- Loss of productive capacity (very minor due to small areas affected)
- Increased risk of soil erosion

Management options

1. **Revegetation:** Planting trees, shrubs and perennial grasses to stabilise soil and dry the profile – page 203 of 'South-West Hydrological Information Package' (Tille *et al.* 2001).
2. **Fencing:** Fencing affected areas to minimise disturbance and protect vegetation – see page 203 of the 'South-West Hydrological Information Package' (Tille *et al.* 2001).
3. **Earthworks:** Construction of banks or drains to divert water from affected areas.
4. **Groundwater removal:** Subsoil drainage, pumps or siphons to remove excess water.

Effectiveness

There has been very limited investigation of the effectiveness of management options in WA.

1. **Revegetation:** Effective in Eastern States when combined with fencing.
2. **Fencing:** Effective in Eastern States when combined with revegetation.
3. **Earthworks:** Unknown.
4. **Groundwater removal:** Unknown.

References

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ISSUE 6: NUTRIENT LOSS AND EUTROPHICATION

Heather Percy, Peter Tille, Rob Summers and Mark Rivers

Extent

Phosphorus and nitrogen are the main nutrients contributing to eutrophication of surface water and groundwater. These may leach through sandy soils and enter groundwater and surface water via groundwater discharge. Phosphorus, attached to clay particles, may also enter surface water directly via soil erosion. Nutrient export in the Coastal Plain is largely influenced by non-point source discharges from broadscale agricultural operations or urban developments, but point sources may be significant locally. These include intensive agricultural developments, effluent from septic tanks, piggeries, dairies, sheep holding yards, meat and vegetable processing plants, fertiliser factories and other industries.

Coastal estuaries and inlets are particularly susceptible to eutrophication. Deeley *et al.* (1999) provided comprehensive information and Tille *et al.* (2001) outlined the factors contributing to eutrophication in these areas as:

- the presence of permanent waterways and large coastal wetlands and estuaries
- intensive agricultural and urban development
- large areas of sandy soils with poor nutrient retention ability
- widespread waterlogging
- artificial drainage systems that rapidly move water and nutrients into susceptible waterways.

Nutrient export pathways and the subsequent risk of eutrophication may also be related to areas of heavier textured soils that are left prone to erosion. There may also be other pathways where nutrients arrive in streams from macropores, and largely avoid the soil mass and buffering it provides against nutrient loss.

The extent of nutrient loss throughout the agricultural areas is very difficult to measure directly and may be best determined by a spatial analysis of soil nutrient levels and nutrient retention capabilities, land use and topographical and hydrological attributes. These may be calibrated through assessment of nutrient levels in the major regional waterways. Soil test results at the required resolution are difficult to obtain, not generally current and provided only in terms of broad regional data. Nutrient loads of some waterways are monitored, and may provide some indication of actual nutrient export rates. In the absence of comprehensive soil, land use, topographical and hydrological data, estimates of the susceptibility of soils and landscapes to export phosphorus based on the land units allocated to the Department of Agriculture's soil-landscape mapping indicate inherent nutrient loss potential.

Table 6.1 needs to be corrected for catchment size. The smaller the catchment the higher the load of nutrient per unit area and the higher the concentration of nutrients. Catchments for the Meredith Drain and Nambeelup Brook are predominantly sandy and could give the false impression that they are the only nutrient hotspots when catchments of similar size and heavier soils discharge significantly more nutrients. Also the phosphorus concentration in the Meredith catchment has fallen due to application of Alkaloam and is now about half the level indicated. While scale is important, so are episodic events, particularly for inland catchments which under average conditions appear insignificant (Murray River). Large inland events could deliver significant quantities of nutrients. Averages or measures of central

tendency are useful and need statistics for regional analysis, but may mask some important characteristics related to nutrient delivery pathways, and potential management options.

Table 6.1: Phosphorus and nitrogen loads of waterways

Catchment and waterway	Area drained ('000 ha)	Average load (t/year)		Average concentration (mg/L)		Average catchment export (kg/ha/year)	
		Total P	Total N	Total P	Total N	Total P	Total N
Peel-Harvey							
Meredith Drain	5	6	16	0.80	2.10	1.20	3.20
Nambeelup Brook	11	8	33	0.60	2.30	0.70	3.00
Harvey River	73	35	199	0.20	1.20	0.50	2.70
Serpentine River	113	23	197	0.10	1.10	0.20	1.80
Murray River	684	7	258	0.02	0.80	0.01	0.40
Leschenault							
Ferguson River	17	2	37	0.05	1.00	0.10	2.20
Brunswick River	26	13	116	0.10	0.80	0.50	4.40
Preston River	83	3	86	0.03	0.80	0.05	1.00
Collie River	290	4	101	0.02	0.50	0.01	0.40
Warren							
Shannon River	41	1	34	0.02	0.70	0.02	0.80
Deep River	47	0	29	0.01	0.80	0.01	0.60
Blackwood							
Blackwood River	2,114	5	557	0.01	1.10	0.00	0.30
<i>Adapted from Deeley et al. (1999) using data collected between 1985 and 1995</i>							

In the absence of comprehensive soil, land use, topographical and hydrological data, estimates of the susceptibility of soils and landscapes to export phosphorus based on the Department of Agriculture's soil-landscape mapping provide an indication of inherent nutrient loss potential.

Water bodies affected by eutrophication include the Peel Inlet and Harvey Estuary, Leschenault Inlet and Geographe Bay. Point sources of nutrients are concentrated on the Coastal Plain in the Peel-Harvey, Leschenault and Geographe Sub-regions. The highest concentrations of phosphorus and nitrogen are found in rivers, streams and artificial drains in the extensively cleared, poorly drained catchments on the Coastal Plains (e.g. Meredith Drain, Vasse Drain, Wellesley and Scott Rivers). Sandy soils are predominant in these catchments. Whilst the concentrations in these sandy catchments are high, the sandy soils result in less run-off and lower loads of phosphorus being exported compared to heavier soils. The heavier soils that are fertilised more have lower concentrations but substantially greater run-off with the net result of similar phosphorus loads between sandy and clay soils. While in some cases the clay soils discharge much more phosphorus than sandy soils, 65 per cent of the coastal catchment has a sandy surface.

There is a trend for the average export of nutrient from a catchment to decrease with increasing area. This is related to in-stream assimilation effects (travel time, sedimentation, biological uptake, nutrient spiralling) and the increasing influence of uncleared or unfarmed land as catchment size increases.

The relatively high proportion of the Darling Range (zone 255) shown as having a high phosphorus export hazard is due to the greater erosion risk attribution for steeper valley slopes and illustrates that nutrient export is not exclusive to sandy catchments.

Table 6.2: Phosphorus loss hazard by soil-landscape zone in the South West NRM Region (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Soils with very high to extreme phosphorus export hazard		Soils with high to extreme phosphorus export hazard	
			(ha)	(%)	(ha)	(%)
Coastal Dune Zone	211	34,000	8,000	24	13,000	37
Bassendean Zone	212	64,000	30,000	48	43,000	67
Pinjarra Zone*	213	182,000	22,000	12	34,000	19
Donnybrook Sunkland Zone	214	69,000	7,000	10	14,000	20
Scott Coastal Zone	215	27,000	10,000	37	18,000	66
Leeuwin Zone	216	51,000	6,000	12	10,000	19
Pallinup Zone	241	6,000	100	2	150	2
South-eastern Zone of Ancient Drainage	250	125,000	7,000	6	7,000	6
Eastern Darling Range Zone	253	529,000	40,000	7	97,000	18
Warren-Denmark Southland Zone	254	125,000	14,000	12	29,000	24
Western Darling Range Zone*	255	194,000	48,000	25	83,000	43
Southern Zone of Rejuvenated Drainage	257	910,000	53,000	6	103,000	11
South-western Zone of Ancient Drainage	259	541,000	40,000	7	60,000	11
TOTAL		2,856,000	285,100	10	511,150	18

* Evidence is mounting that these heavier soils may have been under-rated in the past and heavy fertilisation and intensification of animal industries have resulted in increased risk.

Table 6.3: Phosphorus loss hazard by sub-regions (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschenault	Geopraphe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000*	143,000	126,000	43,000	1,758,000	173,000
Very high to extreme phosphorous export hazard	(ha)	58,000	29,000	22,000	5,000	147,000	24,000
	(%)	10	20	18	12	8	14
High to extreme phosphorous export hazard	(ha)	107,000	49,000	39,000	9,000	265,000	43,000
	(%)	17	35	31	20	15	25

* 210,000 ha is the coastal section of the Peel-Harvey where 90% of the phosphorus originates.

Impacts

The impacts of eutrophication are summarised by Tille *et al.* (2001) pp 217-18 and Weaver and Summers (1998) pp 243-50. Most impacts occur off-site, and include:

- algal blooms and the formation of algal mats on the water surface
- oxygen depletion of the water which may lead to the death of fish and crustaceans

- damage to seagrass meadows in the marine environment due to shading by algal blooms
- toxins from blue-green algae (*Nodularia*, *Microcystis*, *Oscillatoria*) pollute waterways, may kill fish, birds and livestock and are a human health hazard
- waterways may be closed to fishing and recreational uses, affecting income from fishing, tourism and real estate values
- unpleasant odours
- nitrate toxicity of groundwater supplies where nitrogen reaches critical levels
- loss of groundwater, or more expensive treatment to ensure continued use.

On-site impacts include:

- loss of soil fertility due to water erosion and/or through the inefficient use of fertilisers
- toxic effects on crops when groundwater with high nutrient levels is used for irrigation
- toxins from algae contaminate farm water supplies, endangering livestock
- nitrates in groundwater can endanger livestock
- inappropriate and inefficient fertiliser use leading to losses to farm profitability.

Management options

1. **Fertiliser management**

- Match applications to plant requirements by soil testing, tissue testing or rapid sap tests as appropriate (see Farmnotes in references).
- Manage the timing and method of application of fertiliser to avoid run-off and leaching.
- Guidelines for sandy soils on the Swan Coastal Plain (Angell 1999).
- Guidelines for horticulture nutrient management and soil testing in Prout and McFarlane (1996), Anon. (1996), Lantzke and Galati (1997), McPharlin and Hegney (1997).

2. **Using alternative fertilisers:** Coastal super, coarse rock gypsum to supply sulphur rather than superphosphate; non-soluble rock phosphate on acidic sands on poorly drained areas of the Coastal Plain.

3. **Soil amendments** e.g. Alkaloam can improve nutrient retention (Tille *et al.* 2001 p 226)

4. **Streamlining and filter strips:** Fence off and establish buffer strips to filter nutrients and protect waterways. The recommended width of buffer strips varies with land use and soil type and should also consider topographical attributes such as convergent or divergent landscapes, and hydrological attributes such as stream order. Refer to Heady and Guise (1994) and Tille *et al.* (2001, page 227).

5. **Perennial pastures** minimise losses from leaching as they are able to access nutrients longer and deeper than annual species.

6. **Drainage:** By reducing waterlogging, plant uptake of nutrients is increased, but may increase nutrient export, depending on design and climatic and soil characteristics. Regulations apply for saline water and drainage in the Peel-Harvey Catchment (Tille *et al.* 2001, page 228).

7. **Constructed wetlands** can slow water flows, trap sediment and assimilate nutrients. Criteria for their design using examples relevant to the Ellen Brook catchment are presented in Deeley (2000).

8. **On-farm re-use systems:** Management of surface water to harvest and store water and nutrients for use on farm. Can be integrated with engineered options for drainage and water erosion control.
9. **Control of water erosion:** Options are outlined in the Water Erosion section.
10. **Treating point sources:** Storage and disposal of effluent from dairies and piggeries. Guidelines set out in Dairy Industry Strategy working Group (1998) and Latto *et al.* (2000).
11. **Controlling algal blooms in on-farm water supplies:** Silt and manure traps at the farm inlet, use of block alum and barley straw to inhibit algae; chemicals such as Simazine and calcium hypochlorite, to kill algae or for low algae levels, skimming algae and scum off the water. Relevant Farmnotes include:
 - 84/85 Emergency chlorination of farm dams
 - 11/87 Skimming polluted dams – a successful two stage system
 - 103/89 Grass filter strips to prevent dam pollution
 - 43/94 Toxic algal blooms.

Effectiveness

1. **Fertiliser management:** Highly effective, particularly for phosphorus with many soils already having moderate to high status and not requiring additional applications.
2. **Using alternative fertilisers:** Generally effective, when combined with management option 1. Rock phosphate does not release enough phosphorus on most soils but is a good option for a small area of acidic sands on poorly drained areas on the Coastal Plain. For example, 1 and 2 decreased phosphorus application in the Peel-Harvey by 33 per cent between 1982 and 1986 and reduced phosphorus export by 30-40% (Tille *et al.* 2001).
3. **Soil amendments:** Highly effective at reducing phosphorus loads with added benefit of increasing pasture production. For example, Summers and Rivers (1999) report that applying 20 t/ha of Alkaloam over 1,600 ha of sandy soils resulted in a 50 per cent reduction in phosphorus loads and a 25 per cent improvement in pasture production.
4. **Streamlining and filter strips:** Effective, but alternative watering points may be required for livestock.
5. **Perennials:** Effective for grazing systems and between perennial horticultural crops. Perennial buffer strips of only 3 metres wide which have controlled grazing can reduce nutrient and particulate movement by as much as 90 per cent. Substantial increases in animal production have been reported because the pasture production is greatly improved when there is a feed gap.
6. **Drainage:** Depends on soil properties and hydrological processes and may increase nutrient export in some cases. Subsurface drainage can reduce nutrient and particulate run-off under suitable environmental conditions where soils continue to provide nutrient adsorption sites and where leaching is the dominant hydrological pathway.
7. **Constructed wetlands:** Most effective if used to filter run-off from small agricultural catchments rather than large areas or point sources or where the ratio of wetlands to catchment area is high.
8. **On-farm re-use systems:** Management of surface water to harvest and store water and nutrients. Can be integrated with engineering for drainage and water erosion control.
9. **Control of water erosion:** Refer to Water erosion.
10. **Treating point sources:** Highly effective.
11. **Controlling algal blooms in on-farm water supplies:** Effective, but some methods restrict use of water and others require action before blooms occur.

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ISSUE 7: REMNANT VEGETATION DECLINE

Angela Stuart-Street

Extent

The agricultural (or intensive land-use) zone of Western Australia has just 30 per cent or 7.7 million hectares of its original vegetation remaining (Beeston *et al.* 2002). Two-thirds of that vegetation is within the State-managed forest reserves. Shepherd *et al.* (2002) assessed 40 per cent of remaining vegetation patches in the agricultural zone. They found that almost half were significantly disturbed, and 8 per cent at risk from rising saline water tables. The greatest risk is in the wheatbelt.

Across the State, more than 236 million hectares of native vegetation has been mapped, with the biggest remaining area (228.4 million ha) within the rangelands (Shepherd *et al.* 2002). While largely intact, rangeland vegetation has had its floristics changed by grazing and altered fire regimes.

Tables 7.1 and 7.2 show remnant vegetation estimates based on the National Land and Water Resources Audit (NLWRA 1997) data, and the risk to native vegetation from rising water tables against soil-landscape zones from Department of Agriculture mapping, NLWRA and Land Monitor (2002).

Table 7.1: Remnant vegetation on agricultural land in the South West by sub-region (NLWRA 1997)

Sub-region	Remnant vegetation not on State land (ha)	Per cent of sub-region	Per cent of South West Region
Peel-Harvey	262,000	31	7
Leschenault	160,000	51	4
Geographe	32,000	22	1
Cape to Cape	26,000	46	1
Blackwood	299,000	15	8
Warren	116,000	41	3
TOTAL	895,000		31

Approximately 2.7 million hectares (75 per cent) has been cleared across the South West NRM region with 25 per cent (approximately 900,000 ha) remaining as native vegetation on private/agricultural land. The Leschenault, Cape to Cape and Warren Sub-regions retain the highest levels of remnant vegetation. In contrast, while the Blackwood has the largest area of remnant vegetation, this amounts to only 15 per cent of its area. The current impact on vegetation from rising water tables is most prominent in the South-west Zone of Ancient Drainage, with 9 per cent affected. Future risk is also high in this zone with 38 per cent of vegetation expected to be impacted. The Pallinup Zone (241) is expected to have a quarter of its remaining vegetation affected, and in the Southern Zone of Rejuvenated Drainage (257) over one-fifth is at risk.

Table 7.2: Areas of native vegetation by soil-landscape zones, and influences of current and potential water table rise (NLWRA 1997 and Land Monitor 2002)

Zone	Code	Area of vegetation (ha)	% of total	Salinity (ha)*	%	Low-lying areas* (ha)	%
Coastal Dune Zone	211	36,000	40	0	0	0	0
Bassendean Zone	212	19,000	25	0	0	0	0
Pinjarra Zone	213	16,000	7	0	0	0	0
Donny brook Sunkland Zone	214	309,000	83	0	0	0	0
Scott Coastal Zone	215	58,000	65	0	0	0	0
Leeuwin Zone	216	55,000	54	0	0	0	0
Pallinup Zone	241	500	4	10	4	80	26
South-eastern Zone of Ancient Drainage	250	9,000	7	200	2	1,370	15
Eastern Darling Range Zone	253	176,000	27	1,620	1	20,170	11
Warren-Denmark Southland Zone	254	725,000	81	330	<1	41,550	6
Western Darling Range Zone	255	725,000	76	2,690	<1	19,370	3
Southern Zone of Rejuvenated Drainage	257	134,000	13	4,630	4	31,120	23
South-western Zone of Ancient Drainage	259	53,000	9	4,730	9	20,010	38

* Land Monitor (2002)

Impacts

The South-West of Western Australia is recognised as one of 25 global biodiversity hotspots based on plant and vertebrate species diversity and endemism, and on the extent of habitat loss (Myers *et al.* 2000). Many native vegetation types have been extensively cleared, and consequently many species of plants and animals have disappeared or have become rare or endangered. Shepherd *et al.* (2002) assessed the vegetation types or associations across the State. They found that of the 820 types, 119 have only 30 per cent or less of their original extent remaining. Forty-eight of these have 10 per cent or less remaining, and at least two vegetation associations are presumed extinct. The most highly impacted areas are in the wheatbelt, Swan Coastal Plain, and the Blackwood Plateau/Leeuwin Naturaliste/Scott Plain.

Altered hydrology is a particularly serious and difficult problem that has arisen from land clearing. Increasing levels of stress to, and complete loss of, native vegetation due to secondary salinity, waterlogging and inundation is becoming widespread, particularly in lower landscape areas (Beecham 2002). In addition to this, the prospect of using waterways as receival points for groundwater drainage and pumping schemes, which has the potential of delivering excess salty water and incompatible levels of pH, to affect aquatic environments and riparian zones, also needs to be considered.

One of the most significant impacts of remnant vegetation decline that is often overlooked, is the lost potential for the development of new industries based on native biota. This includes oil mallees, melaleucas, sandalwood and other species (Beecham 2002).

Management options

Management of remnant vegetation aims to reduce further loss of biota and includes protection and enhancement to incorporate their role as a natural habitat into the farming system.

1. **Altered hydrology:** Protection of remnants from hydrological processes can only be tackled in the context of the overall landscape. Acquire a detailed knowledge of recharge and discharge characteristics of the catchment. Strategically target revegetation, earthworks and other engineering options, as well as low recharge farming systems and other remedial treatments as part of an integrated landscape approach where they are likely to have the greatest impact (Beecham 2002). (See Dryland Salinity Issue for management options.)
2. **Corridors** protect and connect existing remnant vegetation patches using paddock boundaries, drainage lines and shelter belts as corridors (Lefroy *et al.* 1991)
3. **Fencing remnants** will control grazing by domestic stock (Hussey and Wallace 1993). Establish alternative shelter belts for stock protection.
4. **Weed control:** Maintain native vegetation canopies. A low nutrient system encourages weed resistance in the remnant; spraying of weed species can be effective in the short term; physical removal; scalping. Farmnotes include:
 37/98 Site preparation for successful revegetation
 47/98 Weed control for successful revegetation.
5. **Nutrient imbalance control:** Altering the original soil nutrient balances from organic and inorganic sources may affect the growth of remnant vegetation and alter species composition. Management suggestions are outlined in Hussey and Wallace (1993 p 63).
6. **Feral animal control** e.g. rabbits, foxes, pigs and cats.
7. **Rehabilitation:** Reseeding or replanting of native species, depending on the availability of seed either on adult plants or in the soil (See previously mentioned Farmnotes).
8. **Intervention:** Some form of management (e.g. fire), either one-off or periodic, may be essential to maintain the diversity and function of native communities (if, when and where appropriate), or if the soil structure has been significantly modified, ripping or scarification may be required. The use of smoke-infused water may be an alternative to burning (Lambeck 1999).
9. **Spray drift control:** Chemicals from normal farm operations can damage remnant vegetation, generally from spray drift effects. Management suggestions are outlined in Hussey and Wallace (1993 page 74).

Effectiveness

1. **Altered hydrology:** The current level of response to rising groundwater is unlikely to be large enough to protect ecosystems in low lying landscapes. It may delay or slow the effects. Islands of higher land may be protected by this approach (Beecham 2002).
2. **Corridors:** Variable effectiveness, as the wider the corridor, the less influence of edge effects and external processes. Corridors should be as wide as feasible to reduce deleterious edge effects (Lambeck 1999).
3. **Fencing remnants** is effective if stock exclusion is maintained. Poor recruitment of woodland and understorey species even when remnant areas are only lightly grazed suggests this is required for success (Lambeck 1999).
4. **Weed control:** Effective, if closely monitored with appropriate methods.

5. **Nutrient imbalance control:** Effective, if buffers are in place and management guidelines are followed (Hussey and Wallace 1993).
6. **Feral animal control:** Effective, if monitored regularly.
7. **Rehabilitation:** Variable effectiveness, depending on level of disturbance, and rehabilitation goal, as it is rarely possible to reproduce a functioning system identical to that prior to disturbance (Hobbs *et al.* 1993).
8. **Intervention:** Variable. Should be undertaken with caution as limited information is available about the importance or role of intervention, particularly fire, in the maintenance of plant or animal populations. Critical assessment must be undertaken (Lambeck 1999).
9. **Spray drift control:** Effective if buffers are in place and management guidelines are followed (Hussey and Wallace 1993).

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ISSUE 8: SOIL FERTILITY DECLINE

Angela Stuart-Street

Extent

The native soils of Western Australia are some of the most inherently infertile in the world, and consequently the fertility of many agricultural soils has increased substantially by adding chemical fertilisers and organic matter from crop and pasture residues. Lack of maintenance of soil fertility at recommended concentrations has been identified, however, as a looming threat to production.

The rate of soil fertility decline is variable relative to each type and intensity of land use and associated nutrient losses. This is because the nutrient requirements and product removal vary significantly between agricultural land uses. The successful continuation of agricultural activities requires that the nutrient balance be maintained or improved, and that nutrients removed via agricultural products be replaced both naturally and through fertiliser addition as required. While no comprehensive data on the extent of soil fertility decline is available, generalised assessments of farm gate nutrient balances and organic carbon ranges have been made for the South West in the Australian Natural Resources Atlas (2001).

Table 8.1: Generalised assessments of farm gate nutrient balance for broad land uses within WA's agricultural zone [where negative (inputs < exports); neutral (inputs = exports); positive (inputs > exports)] *

Nutrient	Grazing	Cropping
Nitrogen	Positive	Positive-neutral
Phosphorus	Positive	Neutral-positive
Potassium	Negative	Negative
Sulphur	Positive	Positive-neutral
Calcium	Positive	Positive
Magnesium	Neutral	Negative-neutral

* From Australian Natural Resources Atlas 2001

Table 8.2: Soil organic carbon (%) for agricultural land in the South West

	Percentage							Total
	<0.5	0.5-0.75	0.75-1.0	1.0-1.5	1.5-2	2.0-4	>4	
Soil carbon								
Area (km ²)	922	36,351	54,738	61,079	15,764	27,858	4	196,716

* From: Australian Natural Resources Atlas 2001

Acute nutrient loss is also related to wind and water erosion. Leaching or surface water run-off can also cause substantial losses. Loss of some nutrient 'availability' can also occur by fixation into organic matter and reactions with soil minerals.

Impacts

Allowing continued depletion of nutrients from even fertile paddocks will eventually reduce yields and decrease the productivity and quality of future crops and pastures (Falconer and Bowden 2001). Off-site effects of nutrient loss can include soil acidification and nitrification of water supplies caused by nutrient leaching. Declining fertility is linked to decline in soil structure, increased levels of erosion and secondary salinity. In addition, run-off containing nitrogen and phosphates has been linked to stream and groundwater pollution.

Management options

Nutrient management has moved soil fertility beyond the 'build up' phase into a 'maintenance' phase over much of Australia's intensive agricultural region. Site-specific nutrient management now replaces broad district fertiliser guidelines (Australian Natural Resources Atlas 2001). Short-term options to meet immediate demands goes wrong when early treatment could stop a long term, expensive-to-cure, problem from arising (Bowden 2003).

1. **Monitoring:** Know the nutrient, organic carbon and pH status of the soil.
2. Base **fertiliser decisions** on the standard methods (e.g. soil and/or tissue testing, symptoms etc) appropriate to the nutrient/s in question. Nutrient management decisions are especially important for higher input, intensive systems of land use.
3. **Additions** include fertilisers (supplying adequate amounts of essential plant nutrients), soil ameliorants (e.g. lime, dolomite and gypsum, manure and biosolids that chemically and physically improve the soil) and the use of legumes to increase soil nitrogen status.
4. **Organic matter content:** Follow pasture and cropping management recommendations to maintain and build on levels of organic matter.
5. **Soil erosion:** Reduce or prevent soil erosion to lower acute losses of nutrients.
6. **Water management:** Decrease leaching and run-off by improved soil and water management.

Effectiveness

1. **Monitoring:** Regular monitoring helps to identify nutrient deficiencies and toxicities, pH and organic carbon status. This information can help determine the appropriate management. Alone, monitoring does not solve nutrient decline issues.
2. **Fertiliser decisions:** Anticipate problems so that appropriate and timely steps can be made to address them. Losses become critical when paddock soils are already marginal or deficient in nutrients.
3. **Additions:** Adding chemical and/or organic fertilisers provides the best solution for maintaining soil nutrient status. Leguminous crop and pasture species provide important additions of nitrogen in organic matter.
4. **Organic matter content:** By maximising the levels of pasture and crop residues (within the stubble management capabilities), soil organic matter can be maintained or improved.
5. **Soil erosion:** Improved pastures and stubble residues provide effective ground cover protection for soil, reducing erosion risk.
6. **Water management:** Crops and pastures will use more water if fertilised correctly than when nutrient deficient.

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ISSUE 9: SOIL STRUCTURE DECLINE

Paul Galloway

Extent

Soil structural instability affects about 3.5 million hectares of the South West agricultural region (Hunt and Gilkes 1992). Crusting and hardsetting are most common in medium and fine-textured surface soils, with clay content higher than 10 per cent and low values of exchangeable calcium, magnesium and to a less extent potassium or high value of exchangeable sodium. Low organic matter also exacerbates the problem. High proportions of these soils exist in Western Australia. Management practices strongly influence structural decline. These variables preclude the collation of comprehensive data on the actual extent of soil structure decline. The following estimates are based on the qualified soil groups allocated to the Department of Agriculture's soil-landscape mapping and are based mostly on surface soil texture.

Table 9.1: Soil structure decline susceptibility in the South West NRM Region by soil-landscape zone (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Soils with high structural decline susceptibility	
			(ha)	(%)
Coastal Dune Zone	211	34,000	1,000	3
Bassendean Zone	212	64,000	0	0
Pinjarra Zone	213	182,000	41,000	22
Donnybrook Sunkland Zone	214	69,000	8,000	12
Scott Coastal Zone	215	27,000	1,000	4
Leeuwin Zone	216	51,000	3,000	6
Pallinup Zone	241	6,000	3,000	52
South-eastern Zone of Ancient Drainage	250	125,000	53,000	42
Eastern Darling Range Zone	253	529,000	65,000	12
Warren-Denmark Southland Zone	254	125,000	19,000	15
Western Darling Range Zone	255	194,000	71,000	37
Southern Zone of Rejuvenated Drainage	257	910,000	126,000	14
South-western Zone of Ancient Drainage	259	541,000	137,000	25
TOTAL		2,856,000	528,000	18

Table 9.2: Soil structure decline susceptibility by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschenault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
High structure decline susceptibility	(ha)	96,000	40,000	23,000	3,000	345,000	24,000
	(%)	16	28	18	7	7	14

The most extensive susceptible areas are in the east, particularly the Pallinup Zone, and the South-eastern and South-western Zones of Ancient Drainage. Sodic soils which are usually

associated with structural instability are locally significant in the Harvey Water Irrigation area on the Swan Coastal Plain, particularly the Pinjarra Zone (213) where they impact on irrigation management, waterlogging, salinity and drain stability. The proportion of the Darling Range Zone (255) with high hazard may over-estimated.

Impacts

Some impacts of soil structure decline may cause limited off-site degradation. Reduced infiltration increases run-off and evaporation from the soil surface. Where run-off water and erosion products enter streams, increased sedimentation, phosphorus export and eutrophication may result. Higher rates of evaporation may, over time, cause secondary salinity. The off-site degradation issues caused by soil structure decline are most likely in the higher rainfall and higher relief areas of the Southern Zone of Rejuvenated Drainage (Zone 257). Remedying soil structure decline in these areas is most likely to deliver public benefits.

The following impacts mainly affect the productive capacity of agricultural land:

- *Reduced infiltration* results in less plant available water, which adversely influences yield potential
- *Poor workability* increases costs of operations and machinery wear and causes difficulties in preparing an even seed bed
- *Delayed seeding* can occur when seeding is restricted to narrow windows of opportunity with acceptable soil moistures
- *Reduced seedling emergence* results from surface crusts, particularly for more sensitive crops
- *Reduced aeration* caused by structure decline affecting crop growth by restricting the oxygen supply in the rooting zone
- *Reduced trafficability* can affect the timing of operations, such as spraying and seeding.

Management options

The principal strategy to maintain good structure in surface soils is to reduce the impact of management. This strategy may be preceded by remedial management to restore soils with degraded structure to good condition (Needham *et al.* 1998). The ideal remedial management depends on the factor(s) and process(es) causing poor structure. These are addressed in Hunt and Gilkes (1992), Needham *et al.* (1998) and Hamza and Penny (2002).

1. **Monitor** and assess current condition using the methods listed in the references above.
2. **Minimise tillage** operations and speed, and till only when the soil moisture status is at or below the *lower plastic limit*. (See references for details on determining soil moisture status.)
3. **Minimise damage and trampling** by reducing stock numbers on susceptible soils when they are wet.
4. **Increase organic matter** and retain stubble to protect against raindrop impact and provide a long-term binding agent.
5. **Apply gypsum.**
6. **Deep ripping** plus gypsum application is a necessity if soil is compacted.

A combined package that makes use of some or all of these components has recently been developed for soils of the eastern wheatbelt (Hamza and Penny 2002, Hamza and Anderson 2002, 2003).

Effectiveness

Minimising tillage by direct drilling has significant economic advantages for cultivation/seeding operations on susceptible soils in the northern wheatbelt (Blackwell *et al.* 1995). The benefits of no-till in this study were variable, with no-till out-performing direct drill in some situations and under-performing in others. The gypsum/ripping/stubble retention package developed by Hamza and Anderson (2002, 2003) has economic benefits over untreated soils of \$23-90/ha.

Increasing organic matter by green manuring, brown manuring and green mulching has economic and soil structure benefits (Hoyle 2001). In particular, yield increases and early results suggest rainfall infiltration also increases. The benefits extended several seasons after treatment in heavier soils.

No-till sowing increases infiltration significantly compared with multiple tillage. This reduces potential for water erosion significantly on some soil types (see Bligh 1998).

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ISSUE 10: SOIL ACIDITY

Paul Galloway

Extent

Soil acidity is a widespread problem in the South West agricultural area. Identifying and ameliorating acidity at the surface has rapidly increased due in large part to Department of Agriculture extension programs. According to the National Land and Water Resources Audit, 11 per cent or 2.12 million hectares of topsoils were strongly acid ($\text{pH}_{\text{Ca}} < 4.8$) and another 78 per cent or 15 million hectares were between 4.8 and 5.5 in 2000.

Acidity is most prevalent in sandy soils with a low capacity to buffer pH change. While acid soil is natural in some areas, it is accelerated by some farming practices, including adding acid fertilisers, product removal and leaching of nitrate (Dolling *et al.* 2001). The identification and remediation of subsoil (10-30 cm) acidity is still not common among farmers. Cost effective techniques for remediation are being developed and trialled (Gazey, pers comm.). The following surface and subsurface pH estimates are based on the qualified Soil Groups allocated to the Department of Agriculture's soil-landscape mapping.

Table 10.1: Acid soils by soil-landscape zone in the South West NRM Region (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Topsoil currently strongly acid ($\text{pH}_{\text{Ca}} < 4.5$ at 0-10 cm)		Subsoil currently strongly acid ($\text{pH}_{\text{Ca}} < 4.5$ at 50-80 cm)		Soil with high risk of subsurface acidification	
			(ha)	(%)	(ha)	(%)	(ha)	(%)
Coastal Dune Zone	211	34,000	1,000	2	1,000	3	9,000	27
Bassendean Zone	212	64,000	4,000	6	2,000	2	38,000	60
Pinjarra Zone	213	182,000	11,000	6	500	0	50,000	27
Donny brook Sunkland Zone	214	69,000	6,000	9	1,000	1	15,000	22
Scott Coastal Zone	215	27,000	2,000	8	2,000	7	9,000	34
Leeuwin Zone	216	51,000	5,000	9	100	0	13,000	26
Pallinup Zone	241	6,000	0	0	0	0	1,000	11
South-eastern Zone of Ancient Drainage	250	125,000	2,000	1	2,000	1	21,000	17
Eastern Darling Range	253	529,000	19,000	4	6,000	1	115,000	22
Warren-Denmark Southland Zone	254	125,000	11,000	8	2,000	2	36,000	29
Western Darling Range	255	194,000	9,000	4	1,000	1	44,000	23
Southern Zone of Rejuvenated Drainage	257	910,000	22,000	2	7,000	1	288,000	32
South-western Zone of Ancient Drainage	259	541,000	2,000	0	2,000	0	116,000	21
TOTAL		2,856,000	94,000	3	20,000	1	755,000	26

Table 11.2: Acid soils by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschen-ault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Strongly acid topsoils (pH_{Ca} <4.5 at 0-10 cm)	(ha)	24,000	7,000	12,000	5,000	31,000	13,000
	(%)	4	5	10	11	2	7
Strongly acid subsoils (pH_{Ca} <4.5 at 50-80 cm)	(ha)	6,000	1,000	700	400	14,000	2,000
	(%)	1	1	1	1	1	1
Susceptible to subsurface acidification (includes current acid soils)	(ha)	143,000	35,000	40,000	11,000	479,000	47,000
	(%)	23	25	32	25	27	27

Almost a third of soils with a high risk of subsurface acidification are in the Southern Zone of Rejuvenated Drainage where Deep sandy duplex profiles are dominant. On the Coastal Plains where Deep sands and Wet sands predominate (zones 215, 212) more than 80 per cent of soils have a high risk of acidification.

Impacts

Soil acidity impacts on agricultural production by (Moore *et al.* 1998; Dolling *et al.* 2001):

- Increasing the availability of the toxic element aluminium (Al). (Manganese toxicity due to low pH has not been observed in WA but is often seen in the Eastern States.)
- Decreasing the availability of nutrients such as phosphorus (P), potassium, calcium, magnesium, molybdenum (Mo) and copper.
- Reducing microbial process e.g. involved in the decomposition of organic matter that supplies nitrogen, phosphorus and sulphur.
- Increasing fungal diseases of plants, although some fungal diseases can decrease, for example, 'take all'.

Information is lacking about off-site impacts of soil acidity and further study is required. However, acidity has some impact on at least the following (from Dolling *et al.* 2001):

- increased dryland salinity, waterlogging and flooding
- increased nitrate pollution of groundwater and reduced water quality
- reduced plant yields, farm income, land values and domestic/export earnings
- reduced plant species options for agriculture
- reduced vegetation cover and accelerated run-off and erosion
- irreversible degradation of the clay minerals of soil, hence reduced fertility
- declining pH of waterways and aquatic environments
- increased infrastructure cost as a result of increased salinity, waterlogging, flooding and sediment on road and in drains.

Management options

Options are summarised on pages 128-40 of 'Soilguide' (Moore *et al.* 1998).

1. **Adding alkaline reagents.** Lime as topdressing (to increase surface pH) and banding or incorporating at depth (to increase subsoil pH) is the major recommendation. Other alkaline reagents (e.g. fly ash from cement kilns, dolomite) are alternatives.

2. **Reduce rate of acidification:** Reducing the rate of product removal from paddocks will reduce acidification by reducing export of cations (that are replaced by acid hydrogen ions in the soil). An example is to limit the highly acidifying operation of hay cutting to alkaline soils and to distribute the hay as feed on acid paddocks. Reducing or removing the input of acidifying fertilisers (ammonium-based nitrogen and elemental sulphur) will decrease acidification. Reducing or stopping nitrate leaching will also help. This can be achieved by reducing or splitting nitrogen applications to what the crops can use and by planting perennials that draw on nitrate, water and alkaline nutrient reserves deeper in the soil profile than annual plants are able to do.
3. **Plant acid-tolerant species** that can tolerate lower pH levels can maintain profitability over the short-term. This can be used in conjunction with an amelioration strategy.
4. **Do nothing and accept declining yields.**
5. **Increase rates of fertiliser input.**

Effectiveness

1. **Adding alkaline reagents:** Proven effective and economically viable for surface acidity, and also effective at ameliorating the subsurface with time (Tang and Rengel 2001). Surface liming is effective at maintaining pH in the subsurface if a program is started before significant acidity has developed. Treatment for subsurface acidity is generally more expensive, technically challenging and variable, depending on method of incorporation and pre-existing conditions (such as topsoil pH). The effectiveness of alkaline reagents to ameliorate subsoil acidity is being investigated. Other alkaline reagents are effective (e.g. fly ash from cement kilns, dolomite) but often not as economic or available in large quantities.
2. **Reduce rate of acidification:** Part of an integrated solution in conjunction with adding alkaline reagents. Valuable, but will not solve soil acidity. It may not be economic in some circumstances for farmers to attempt, e.g. reducing acidifying nitrogen fertilisers, as it may be more expensive to use other sources without lime, compared to acid nitrogen fertilisers and lime.
3. **Plant acid-tolerant species** is a short-term measure only; ineffective at reversing acidification as it allows processes to continue.
4. **Do nothing and accept declining yields.** Ineffective.
5. **Increase rates of fertiliser input.** May be effective in maintaining production over the short-term, but ineffective at reversing acidification.

References

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ISSUE 11: SUBSURFACE COMPACTION

Brendan Nicholas

Extent

Subsoil compaction can occur in different soil types and climatic conditions (Rengasamy 2000). However, susceptibility is reduced in strongly structured soils, well drained soils with high organic matter content and drier regions where the soils rarely reach the water content at which severe compaction is possible (Needham *et al.* 1998).

No comprehensive data on the extent of subsurface compaction are available in Western Australia. The following estimates are based on the qualified Soil Groups allocated to the Department of Agriculture's soil-landscape mapping.

Table 11.1: Soils susceptible to subsurface compaction by soil-landscape zone in the South West NRM Region (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Soils with high subsurface compaction susceptibility	
			(ha)	(%)
Coastal Dune Zone	211	34,000	8,000	23
Bassendean Zone	212	64,000	2,000	3
Pinjarra Zone	213	182,000	89,000	49
Donnybrook Sunkland Zone	214	69,000	22,000	32
Scott Coastal Zone	215	27,000	6,000	22
Leeuwin Zone	216	51,000	2,000	4
Pallinup Zone	241	6,000	3,000	52
South-eastern Zone of Ancient Drainage	250	125,000	59,000	47
Eastern Darling Range Zone	253	529,000	208,000	39
Warren-Denmark Southland Zone	254	125,000	60,000	48
Western Darling Range Zone	255	194,000	129,000	66
Southern Zone of Rejuvenated Drainage	257	910,000	335,000	37
South-western Zone of Ancient Drainage	259	541,000	234,000	43
TOTAL		2,856,000	2,856,488	41

Table 11.2: Soils susceptible to subsurface compaction by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschenault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Soils with high subsurface compaction susceptibility	(ha)	295,000	78,000	53,000	17,000	659,000	72,000
	(%)	48	55	42	39	38	41

The largest areas susceptible to subsurface compaction are found in the Western Darling Range Zone and Leschenault Catchment where uniform coarse-textured soils dominate.

Impacts

The main cause of compaction on tilled soils is wheeled vehicular traffic especially heavy tractors. Amelioration can result in large yield increases (Jarvis and Porritt 1985). Compaction can also occur due to development of plough pans and trampling, particularly on wet soils. The principles are summarised by Needham *et al.* (1998) on page 116.

The effect of compaction on crop growth is complicated by different responses from species and cultivars. Subsoil compaction influences plant growth by:

- Decreasing soil pore size and continuity
- Decreasing root penetration and density
- Reducing access to moisture and nutrients
- Predisposing the crop to waterlogging and soil pathogens (Rengasamy 2000).

Management options

1. **Deep ripping:** Using deep cultivation to loosen subsurface layers. See page 124 of 'Soilguide' (Needham, Moore and Scholz 1998) for decision tree.
2. **Controlled traffic:** Still in development. This has become practical due to availability of Differential GPS and self-steering technology for paddock machinery. Also possible using manually steered equipment with marker arms (Blackwell 1998).
3. **Stock control:** Defer grazing, reduce stocking rates or remove stock from soils at risk, particularly when susceptible soils are wet (Needham, Moore and Scholz 1998).

Effectiveness

1. **Deep ripping** is good for all compacted soils. It should not be recommended alone (Needham *et al.* 1998) but combined with gypsum to re-aggregate the soil. On duplex soils where topsoil is >30 cm deep soil responds similarly to uniform coarse textured soils. Where the A horizon is <30 cm deep subsoil properties may override any deep ripping effects (Hamza and Anderson 2002, 2003).
2. **Controlled traffic:** Benefit relates to confining traffic to tramlines and avoiding compaction between them. Confinement to tramlines has the benefit of increasing the effectiveness of deep ripping and reduced overlap saves on inputs (Blackwell 1998).
3. **Stock control** is effective when the soil is close to a lower plastic limit as it helps to reduce structural decline, and can improve workability in following cropping years. Reduced stocking rates and deferred grazing have also been shown to help reduce the degree of structural damage to fragile surface soils (Needham, Moore and Scholz 1998).

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ISSUE 12: SURFACE WATER SUPPLY SHORTAGES

Nick Cox

Extent

Surface water shortages are most widespread in low rainfall areas because rainfall is the primary source of on-farm water. The most affected areas display a combination of rainfall variability in the <600 mm range, up to 1500 mm of evaporation and have large areas within catchments affected by salinity.

Surface water supply shortages are influenced by factors outlined in Tille *et al.* 2001:

- **Low rainfall**, with compounding effects if occurring over consecutive years;
- **Water quality** when catchment areas are affected by salinity or there is an inflow of saline groundwater;
- **Lack of run-off** resulting in catchment areas being small and/or containing highly permeable soils or dense vegetation;
- **Insufficient harvesting structures** such as roaded catchments and banks;
- **Low storage capacities** of water storage structures;
- **Sedimentation** of water storage structures after erosion events in the catchment; and
- **Losses during storage** due to evaporation and leaking storage structures.

Within the South West, the areas most affected are the Eastern Darling Range Zone (253), the Zone of Rejuvenated Drainage (257) and the Zones of Ancient Drainage (259 and 250).

Impacts

Water shortages relate almost entirely to agricultural industry and infrastructure because the natural flora and fauna have evolved to cope with large seasonal variations. However, other degradation processes have made low rainfall years more difficult for native flora and fauna by degrading natural surface water storage. For example, erosion has led to sedimentation of large perennial pools in waterways, causing them to dry up in low rainfall years.

Agricultural impacts include:

- **Reduction or total dispersal of livestock** to match water availability;
- **Death of livestock** through bogging in water storage sediment at low levels;
- **Increased use of central reticulation systems** to meet stock requirements;
- **Increased road repairs** related to use by trucks carting water for stock and household supplies;
- **Reduction in area or total loss of crops** irrigated from surface water storages;
- **Reduction of farm income** through forced sales, water carting and reduced production; and
- **Reduction or death of perennial grasses and plants** in community recreation grounds and residential gardens

Management options

1. **Appropriate water supply planning, risk analysis and regular review** enabling the proper design, construction and ongoing management of water supplies to meet the needs of the farming enterprise.
2. **Correct siting of water supply structures or positioning of water storage structures** to ensure that these are unlikely to be affected by rising saline water tables and have adequate catchment.
3. **Maintenance of existing water supply structures** including regular de-silting programs regular maintenance of catchment banks and roaded catchment works.
4. **Enhancing artificial catchments** which usually include earthen roaded catchments to improve performance of supply schemes by generating run-off from low rainfall events.
5. **Implementation of integrated landcare techniques** that improve water harvesting while addressing recharge, water erosion, wind erosion and waterlogging issues.

Effectiveness

The options have been developed through a combination of research (Burdass *et al.* 1985), demonstration and landowner experience, to greatly increase the efficiency of farm water supply schemes. All of these methods have been successfully promoted through Farm Water Grant (FWG) and Farm Water Supply Loan schemes. Much information on water supply development and implementation has also been published.

Experience serves to demonstrate that the level of input from professional water supply planners often determines the implementation of effective and reliable water supplies.

A review by Hillier (1998) summarised and evaluated the effect the FWG Scheme had on developing more reliable farm water supplies. While the related survey concentrated on the effectiveness of the scheme structure, one of the questions was related to future water shortages. One hundred and twenty-four farmers, 118 of which (91.8 per cent of those surveyed) had completed or were planning to complete their works program, were asked about the need to cart water over the next 10 years. The results are shown in Table 12.1.

Table 12.1: Water carting need

Will you cart water from off-farm?	Responses No.	Responses %
Yes - In the next:		
2 years	12	9.7
5 years	0	0.0
10 years	7	5.6
No	85	68.5
Don't know	20	16.1
Total	124	100

References

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ISSUE 13: WATER EROSION

Peter Tille

Extent

The distribution of erosion is determined by the nature of the soils and landforms in conjunction with land management practices and seasonal climatic events. Sheet and rill erosion are more common on steeper land, but will occur on slopes of <1 per cent if that soil has been heavily grazed or cultivated over the spring and summer, leaving soils bare and exposed, making them vulnerable in the event of heavy summer or opening rains.

The hilly landscape of the lower South West is most seriously affected where it is intensively cultivated for horticultural or pasture production. The most significant events have occurred on land where summer crops have been grown and harvested. This leaves the soil bare and prone to erosion at the break of season.

Similar problems are experienced on land that has been cultivated for field crops, pastures or vegetables (especially if heavy rain falls soon after cultivation and before germination).

Erosion is also associated salinity and waterlogging. Once an area becomes salt-affected it no longer sustains the plant growth that can protect the surface from raindrop impact and surface scouring. As these areas are often close to or associated with natural drainage systems, the many tonnes of soil that are detached and transported into the waterways go largely un-noticed.

Most erosion occurs in episodic events. While severe gully or rill erosion may leave long-term scars on the surface, many forms of erosion are more gradual and less obvious. Sheet erosion may be observed during, and immediately after, a particular erosion event. However the evidence has usually been masked by agricultural activities by the following season. Evidence can be provided by the gradual disappearance of shrubs and fencelines at the foot of hills beneath successive layers of soil. Estimates of erosion hazard shown in Tables 13.1 and 13.2 are based on the land units from the Department of Agriculture's soil-landscape mapping.

Across the South West, soil loss in the range of 0.5-4.1 t/ha/y has been estimated from pasture with no visible signs of erosion (van Moort *et al.* 1994). Sheet and rill erosion is evident in some areas of the Donnybrook Sunland Zone, the Leeuw in Zone as well as the Warren Denmark Zone and Western Darling Range Zone especially between Darkan and Quindanning. In the east, erosion is most common below large rock outcrops or breakaways, especially on hardsetting loams or clays or areas that are prone to the development of non-wetting characteristics. Erosion in the Manjimup district is often associated with vegetable cropping on steeper slopes. The most significant areas with a high hazard are the steeper valleys of the Darling Range (Zone 255).

Impacts

The impacts of water erosion are summarised on pages 183-184 of the 'South-West Hydrological Information Package' (Tille *et al.* 2001) and pages 230-231 of 'Soilguide' (Coles and Moore 1998). Water erosion:

- Reduces soil fertility and productivity by removing fine clay and organic material
- Exposes problematic subsoils (e.g. sodic clays)
- Results in sedimentation of dams and waterways

- Contributes to eutrophication of water bodies
- Reduces trafficability of paddocks
- Can threaten infrastructure such as roads and fences.

Table 13.1: Water erosion hazard in the South West NRM Region by soil-landscape zone (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Soils with very high to extreme water erosion hazard ¹		Soils with high to extreme water erosion hazard ¹	
			(ha)	(%)	(ha)	(%)
Coastal Dune Zone	211	34,000	5,000	15	6,000	18
Bassendean Zone	212	64,000	3,000	5	3,000	5
Pinjarra Zone	213	182,000	6,000	3	8,000	4
Donnybrook Sunkland Zone	214	69,000	2,000	3	8,000	12
Scott Coastal Zone	215	27,000	2,000	7	2,000	7
Leeuwin Zone	216	51,000	2,000	4	5,000	10
Pallinup Zone	241	6,000	100	2	150	3
South-eastern Zone of Ancient Drainage	250	125,000	4,000	3	7,000	6
Eastern Darling Range Zone	253	529,000	29,000	5	81,000	15
Warren-Denmark Southland	254	125,000	8,000	6	17,000	14
Western Darling Range Zone	255	194,000	47,000	24	77,000	40
Southern Zone of Rejuvenated Drainage	257	910,000	16,000	2	47,000	5
South-western Zone of Ancient Drainage	259	541,000	7,000	1	34,000	6
TOTAL		2,856,000	131,000	5	295,150	10

¹Land with a high risk of water erosion includes soils that are currently affected by waterlogging.

Table 14.2: Water erosion hazard by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschenault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Very high to extreme water erosion hazard¹	(ha)	22,000	24,000	7,000	2,000	66,000	9,000
	(%)	4	17	5	4	4	5
High to extreme water erosion hazard¹	(ha)	53,000	39,000	13,000	4,000	161,000	24,000
	(%)	9	27	10	10	9	14

¹Land with a high risk of waterlogging includes soils that are currently affected by water erosion.

Management options

Options can often be implemented as part of an integrated package to combat waterlogging, salinity, flooding, and wind erosion and/or nutrient loss. Management options for erosion problem areas are detailed on pages 240-42 of 'Soilguide' (Coles and Moore 1998). Additional information on the construction of earthworks is available in Keen (2001).

1. **Farm layout:** Realigning fences, tracks and lane-ways to avoid channelling run-off and isolate areas of high erosion risk – see pages 186-187 of the ‘South-West Hydrological Information Package’ (Tille *et al.* 2001).
2. **Maintaining vegetative cover:** Establishment of perennial vegetative cover, maximising productivity of annual crops, retention of stubble and trash in broad-acre crops, use of cover crops and inter-row ground cover in horticulture – see pages 187 and 188 of the ‘South-west Hydrological Information Package’ (Tille *et al.* 2001).
3. **Stock control:** Managing grazing pressure so that paddocks are not denuded and soils are not disturbed by livestock when waterlogged or susceptible to erosion – see page 187 of the ‘South-west Hydrological Information Package’ (Tille *et al.* 2001).
4. **Cross-slope cultivation:** Cropping along the contour or at a slight gradient to slow run-off – page 188 of the ‘South-West Hydrological Information Package’ (Tille *et al.* 2001).
5. **Reduced tillage:** Implementing minimum tillage or no tillage cropping systems to maintain soil stability – see page 188 of the ‘South-west Hydrological Information Package’ (Tille *et al.* 2001) and page 239 of ‘Soilguide’ (Coles and Moore 1998).
6. **Basin tillage, grade furrows and narrow-tined implements:** Suitable cultivation techniques for horticultural crops are discussed by Rose (1997).
7. **Grade and level earthworks:** Constructing level banks, absorption banks, contour sills, grade banks, broad-based banks and interceptor drains to intercept run-off and effectively reduce slope length – pages 189-193 of the ‘South-West Hydrological Information Package’ (Tille *et al.* 2001).
8. **Waterways:** Using well designed waterways to remove run-off safely – page 194 of the ‘South-West Hydrological Information Package’ (Tille *et al.* 2001).
9. **Gully control:** Using gully head sills, flumes, hay bales, drains and gully filling to control and rehabilitate erosion gullies – page 194 of the ‘South-West Hydrological Information Package’ (Tille *et al.* 2001).
10. **Reducing waterlogging:** Saturated soils are more prone to water erosion so reducing waterlogging can also reduce the risk of erosion.

Effectiveness

1. **Farm layout:** Essential for effective management of water erosion.
2. **Maintaining vegetative cover:** Essential for the effective management of water erosion.
3. **Stock control:** Essential for the effective management of water erosion.
4. **Cross-slope cultivation:** Important when cropping on slopes.
5. **Reduced tillage:** Very effective in reducing (but not eliminating) erosion in broadscale cropping areas
6. **Basin tillage, grade furrows and narrow-tined implements:** Very effective in reducing (but not eliminating) erosion in vegetable cropping areas
7. **Grade and level earthworks:** Can be very effective if earthworks are selected to match the land use, topography and soils.
8. **Waterways:** Well designed and maintained waterways are essential for disposing of excess water.
9. **Gully control:** Only applicable where gully formation has already started.
10. **Reducing waterlogging** can contribute to erosion control where waterlogging is a contributing factor.

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ISSUE 14: WATER REPELLENCE (NON-WETTING)

Peter Tille

Extent

Water repellence mainly affects deep sands and sandy duplex soils. The actual extent has not been measured, as this would be a very expensive and time-consuming process. The following estimates are based on the on the qualified Soil Groups allocated to the Department of Agriculture's soil-landscape mapping:

Table 14.1: Water repellence susceptibility by soil-landscape zone in the South West NRM region (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Highly susceptible soils	
			(ha)	(%)
Coastal Dune Zone	211	34,000	13,000	37
Bassendean Zone	212	64,000	43,000	68
Pinjarra Zone	213	182,000	38,000	21
Donnybrook Sunkland Zone	214	69,000	9,000	13
Scott Coastal Zone	215	27,000	10,000	39
Leeuwin Zone	216	51,000	5,000	10
Pallinup Zone	241	6,000	2,000	28
South-eastern Zone of Ancient Drainage	250	125,000	43,000	34
Eastern Darling Range Zone	253	529,000	75,000	14
Warren-Denmark Southland Zone	254	125,000	16,000	12
Western Darling Range Zone	255	194,000	16,000	8
Southern Zone of Rejuvenated Drainage	257	910,000	215,000	24
South-western Zone of Ancient Drainage	259	541,000	175,000	32
TOTAL		2,856,000	660,000	23

Table 14.2: Water repellence susceptibility by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschenault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Highly susceptible	(ha)	97,000	23,000	30,000	4,000	482,000	23,000
	(%)	16	16	23	10	27	13

The largest areas of susceptible soils are in the Southern Zone of Rejuvenated Drainage (zone 257), South-western Zone of Ancient Drainage (259) and Eastern Darling Range (253) totalling over 560,000 ha where Sandy duplex profiles dominate. Other significant areas occur on the Deep sands of the Swan and Scott Coastal Plains with over 100,000 ha of highly susceptible soils.

Impacts

The impacts are summarised by Moore and Blackwell (1998) on page 56 of 'Soilguide'. Water repellence reduces infiltration (especially early in the growing season) and can result in increased run-off. Impacts of reduced infiltration are:

- Lower soil moisture
- Poor crop and pasture germination and establishment
- Poor crop and pasture growth
- Patchy crop performance
- Poor ground cover increasing erosion risk
- Increase in weed establishment
- 'Finger flow' effects, which can lead to rapid movement of nutrients and pesticides beyond the root zone and into the watertable.

Impacts of increased run-off are:

- Increased water erosion risk
- Increased risk of nutrient export
- Potential for pesticide and herbicide run-off
- Concentration of run-off water can lead to rapid point-infiltration (flow fingering) below the root zone that can then recharge watertables.

Management options

1. **Claying:** Addition of clay to topsoil to increase surface area and reduce repellence – see page 63 of 'Soilguide' (Moore and Blackwell 1998, Carter and Hetherington 2002).
2. **Furrow sowing** when cropping to harvest water and ensure even wetting around the seed - see pages 60-62 of 'Soilguide' (Moore and Blackwell 1998) or Blackwell (1997).
3. **Perennial vegetation** reduces problems as there is no annual germination.
4. **Soil wetting agents** lower surface tension.

In addition:

- Lime and gypsum are often mentioned as possible solutions, but have been very disappointing in most trials in WA (Blackwell 1996).
- Repellent soil layers can be diluted with deeper non-repellent soil, but this can lead to a large wind erosion risk and is not a long-term solution (Blackwell 1996).

Effectiveness

1. **Claying:** Best long-term solution (Blackwell 1996). Highly effective on light topsoil containing <3 per cent clay; not very effective on heavier topsoils. A suitable source of clay (dispersible kaolinite) is required close to the soil to be treated (high transport costs).
2. **Furrow sowing:** Easiest for better cropping (Blackwell 1996). Can be effective but increases risks of erosion, herbicide concentration, leaching and waterlogging.
3. **Perennials:** Avoids problem as there is no need for annual germination, although can lead to higher water repellence of infiltrating water
4. **Wetting agents** can be effective, but are too expensive for broadscale agriculture.

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ISSUE 15: WATERLOGGING

Peter Tille

Extent

Waterlogging is most significant in areas of low relief that receive more than 400 mm annual rainfall. Many soils are only affected by subsoil waterlogging which is not readily visible and so the true extent is often under-estimated. This under-estimation particularly applies to perched water tables in permeability contrast soils. Although satellite imagery can be used to assess the extent of waterlogging in any given year, no comprehensive mapping throughout the agricultural area has been undertaken. The following estimates of waterlogging are based on the land units allocated to the Department of Agriculture's soil-landscape mapping.

Table 15.1: Waterlogging risk by soil-landscape zone in the South West NRM Region (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	High to very high risk of waterlogging ¹		Moderate to very high risk of waterlogging ²	
			(ha)	(%)	(ha)	(%)
Coastal Dune Zone	211	34,000	8,000	23	10,000	29
Bassendean Zone	212	64,000	20,000	31	24,000	38
Pinjarra Zone	213	182,000	9,000	5	137,000	75
Donry brook Sunkland	214	69,000	10,000	14	20,000	29
Scott Coastal Zone	215	27,000	12,000	45	19,000	71
Leeuwin Zone	216	51,000	5,000	10	14,000	28
Pallinup Zone	241	6,000	0	0	150	3
South-eastern Zone of Ancient Drainage	250	125,000	4,000	3	14,000	11
Eastern Darling Range	253	529,000	41,000	8	67,000	13
Warren-Denmark Southland Zone	254	125,000	16,000	13	27,000	22
Western Darling Range Zone	255	194,000	16,000	8	19,000	10
Southern Zone of Rejuvenated Drainage	257	910,000	41,000	5	158,000	17
South-western Zone of Ancient Drainage	259	541,000	41,000	8	127,000	23
TOTAL		2,856,000	223,000	8	636,150	22

¹ Land with a high risk of waterlogging has watertables equal to or less than 50 cm for 3-6 months in an average year. These figures include soils that are currently affected by waterlogging as well as soils affected by a combination of salinity and waterlogging.

² Land with a moderate risk of waterlogging has watertables equal to or less than 50 cm for 1-3 months in an average year. Estimates include soils that are currently affected by waterlogging as well as soils affected by a combination of salinity and waterlogging.

Table 15.2: Waterlogging risk by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschenault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Land with high to very high risk of waterlogging¹	(ha)	82,000	28,000	39,000	5,000	129,000	20,000
	(%)	13	19	31	11	7	12
Land with moderate to very high risk of waterlogging²	(ha)	122,000	38,000	64,000	12,000	368,000	40,000
	(%)	20	27	50	29	21	23

Land with high waterlogging risk is widespread on the Scott and Swan Coastal Plains (Zones 213 and 215) and on valley floors in the South-western Zone of Ancient Drainage (259). Significant areas of moderate waterlogging are found in the Southern Zone of Rejuvenated Drainage and the Warren Denmark Southland Zone (257 and 254).

Impacts

The impacts of waterlogging are summarised in Setter and Belford (1990), pages 96-97 of 'Soilguide' (Moore and McFarlane 1998), pages 155-57 of the 'South-West Hydrological Information Package' (Tille *et al.* 2001). Waterlogging can have major effects on crops, pastures and other plants because it deprives the roots of oxygen. It also:

- exacerbates the effects of salinity on plants
- reduces crop and pasture productivity (and can lead to plant death)
- results in patchy crop performance
- contributes to groundwater recharge
- contributes to nutrient export
- increases the risk of water erosion and flooding
- increases the risk of soil structure decline
- provides weed species with a competitive advantage
- reduces the area suitable for horticultural development
- reduces trafficability of the land (machinery and vehicles get bogged).

Management options

Management options can often be implemented as part of an integrated package to combat salinity, flooding, water erosion and/or nutrient loss.

1. **High water use farming systems:** Establishment of high water use pasture, crops and trees upslope to reduce recharge and waterlogging – see pages 111-21 of 'South-West Hydrological Information Package' (Tille *et al.* 2001).
2. **Tolerant crops and pastures:** See pages 159-61 of 'South-West Hydrological Information Package' (Tille *et al.* 2001).
3. **Soil management:** Minimising tillage and applying gypsum to improve water percolation.
4. **Shallow surface drains:** Installing spoon, spinner or W-drains – see page 162 of 'South-West Hydrological Information Package' (Tille *et al.* 2001) and McFarlane *et al.* (1990).
5. **Bedding and mounding:** Installing raised beds to lift plant roots above saturated soil – see page 162 of 'South-west Hydrological Information Package' (Tille *et al.* 2001).

6. **Interceptor drains and banks:** Constructing grade banks or seepage interceptor drains upslope from waterlogged area to divert water away – see pages 163-164 of the 'South-West Hydrological Information Package' (Tille *et al.* 2001) and McFarlane and Cox (1990).
7. **Deep open drains:** Constructing drains (60-250 cm deep) to remove subsoil water – see page 165 of the 'South-West Hydrological Information Package' (Tille *et al.* 2001).
8. **Subsoil drainage:** Installing shallow collector drains, mole channels or tube drains to open drains (60-250 cm deep) to remove subsoil water – see page 165 of the 'South-West Hydrological Information Package' (Tille *et al.* 2001).

Effectiveness

1. **High water use farming systems:** Can be effective in managing waterlogging caused by rising water tables in intermediate or local flow systems. Best used in conjunction with other management options.
2. **Tolerant crops and pastures:** Although primarily an adaptation rather than a control, increased water use on affected areas can lead to reduced waterlogging.
3. **Soil management:** Only applicable where waterlogging is due to surface ponding on dispersive but otherwise well drained soils.
4. **Shallow surface drains:** Effective on heavy soils such as clays and shallow duplexes.
5. **Bedding and mounding:** Results from Bakker *et al.* (1999, 2001, 2002) show increased crop yields on raised beds.
6. **Interceptor drains and banks:** Effective on duplex soils where surface run-off or throughflow in the topsoil is contributing to waterlogging downslope.
7. **Deep open drains:** Effectiveness can be highly variable depending on soil type - most effective on stable, highly permeable soils.
8. **Subsoil drainage:** Can be very effective but only cost efficient in intensive agriculture.

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ISSUE 16: WIND EROSION

Brendan Nicholas

Extent

Wind erosion is most common on loose, dry surface soils (most typically sandy soils) in landscape positions exposed to strong winds. Land management and the amount of ground cover play an important role in determining the erosion that occurs during strong winds.

Most erosion occurs in episodic events. Soil loss may be observed during, and immediately after, a particular erosion event. However the evidence is usually much less clear by the following season. For these reasons it is very difficult to make any meaningful measurement of the current extent. The following estimates of hazard are based on the land units allocated to the Department of Agriculture's soil-landscape mapping.

Table 16.1: Wind erosion hazard by soil-landscape zone in the South West NRM Region (Department of Agriculture 2003)

Zone	Code	Agricultural land (ha)	Very high to extreme wind erosion hazard		High to extreme wind erosion hazard	
			(ha)	(%)	(ha)	(%)
Coastal Dune Zone	211	34,000	4,000	12	22,000	64
Bassendean Zone	212	64,000	12,000	19	42,000	66
Pinjarra Zone	213	182,000	7,000	4	38,000	21
Donry brook Sunkland Zone	214	69,000	1,000	1	18,000	26
Scott Coastal Zone	215	27,000	3,000	11	13,000	48
Leeuwin Zone	216	51,000	300	1	10,000	20
Pallinup Zone	241	6,000	100	2	1,000	17
South-eastern Zone of Ancient Drainage	250	125,000	4,000	3	35,000	28
Eastern Darling Range Zone	253	529,000	6,000	1	103,000	19
Warren-Denmark Southland	254	125,000	1,000	1	29,000	23
Western Darling Range Zone	255	194,000	500	0	22,000	11
Southern Zone of Rejuvenated Drainage	257	910,000	55,000	6	285,000	31
South-western Zone of Ancient Drainage	259	541,000	20,000	4	159,000	29
TOTAL		2,856,000	113,900	4	777,000	27

Table 16.2: Wind erosion by sub-region (Department of Agriculture 2003)

	Area	Peel-Harvey	Leschen-ault	Geographe	Cape to Cape	Blackwood	Warren
Agricultural land	(ha)	613,000	143,000	126,000	43,000	1,758,000	173,000
Soils with very high to extreme wind erosion hazard	(ha)	16,000	2,000	8,000	500	83,000	4,000
	(%)	3	2	7	1	5	2
Soils with high to extreme wind erosion hazard	(ha)	110,000	29,000	38,000	10,000	548,000	42,000
	(%)	18	20	30	24	31	24

The Sandy duplex profiles of the Eastern Woolbelt (Zone 259) comprise the largest areas with a high susceptibility to wind erosion. Significant areas of these soils also occur in the

east (Zones 259, 250, 241). Erosion hazard is also a major concern on dune systems of the Swan and Scott Coastal Plains (zones 211, 212, 215)

Impacts

The impacts of wind erosion are summarised by Moore, Findlater and Carter (1998) on page 211 of 'Soilguide'. Wind erosion has long been recognised as a major land degradation risk in Western Australia. The impacts are:

- Sand blasting damage to crops
- Loss of soil
- Loss of macro and micro nutrients
- Long term loss of productivity
- Loss of pasture seed bank
- Atmospheric pollution
- Burial of infrastructure and engineering structures e.g. fences, drains, yards.

Management options

1. **Windbreaks:** Tree belts have been demonstrated to reduce wind erosion risk
2. **Problem areas:** If the susceptibility of a paddock varies widely, fence to soil type so that susceptible areas can be managed separately.
3. **Land use:** Adjust land use practices so that ground cover is maintained at >50 per cent for all soils

Effectiveness

1. **Windbreaks:** Can be effective. Unlikely that sufficient belts of trees would be planted to provide complete control. Generally used in conjunction with other management options.
2. **Problem areas:** Effective. Most likely to occur where there is a small area that is limiting management options for a larger paddock. A recent development of problem area management is the claying of the soil to reduce the wind erosion risk.
3. **Land use:** Effective. Relies on monitoring of the wind erosion risk of the paddock and adjusting land use practices to maintain adequate cover (e.g. destocking and stubble retention). Seasonal conditions can make it difficult to maintain ground cover at adequate levels. This can include failed crop establishment in a dry year.

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