



Department of  
Primary Industries and  
Regional Development

Digital Library

---

Resource management technical reports

Natural resources research

---

2006

## Natural resource management issues in the Avon River basin

Paul Galloway

Follow this and additional works at: <https://researchlibrary.agric.wa.gov.au/rmtr>



Part of the [Agriculture Commons](#), [Environmental Indicators and Impact Assessment Commons](#), [Environmental Monitoring Commons](#), [Fresh Water Studies Commons](#), [Hydrology Commons](#), [Natural Resources Management and Policy Commons](#), [Soil Science Commons](#), and the [Water Resource Management Commons](#)

---

### Recommended Citation

Galloway, P. (2006), *Natural resource management issues in the Avon River basin*. Department of Primary Industries and Regional Development, Western Australia, Perth. Report 288.

This report is brought to you for free and open access by the Natural resources research at Digital Library. It has been accepted for inclusion in Resource management technical reports by an authorized administrator of Digital Library. For more information, please contact [library@dpiird.wa.gov.au](mailto:library@dpiird.wa.gov.au).

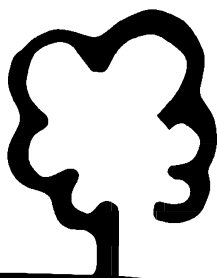


Department of Agriculture  
Government of Western Australia



**NATURAL RESOURCE  
MANAGEMENT ISSUES  
IN THE  
AVON RIVER BASIN**

*Paul Galloway*



March 2006



**RESOURCE MANAGEMENT  
TECHNICAL REPORT 288**

**Resource Management Technical Report 288**

**Natural resource management  
issues in the  
Avon River Basin**

**Edited by Paul Galloway**

**March 2006**



**Department of Agriculture  
Government of Western Australia**



**DISCLAIMER:**

While all reasonable care has been taken in the preparation of the material in this document, the Western Australian Government and its officers accept no responsibility for any errors or omissions it may contain, whether caused by negligence, or otherwise or for any loss, however caused, sustained by any person who relies on it.

© State of Western Australia, 2006

## Contents

	<b>Page</b>
<b>INTRODUCTION</b>	<b>3</b>
ISSUE 1: ACID GROUNDWATER .....	5
ISSUE 2: ACID SULFATE SOILS.....	9
ISSUE 3: DRYLAND SALINITY.....	11
ISSUE 4: FLOODING.....	17
ISSUE 5: NON-WETTING SOIL (WATER REPELLENCE).....	20
ISSUE 6: NUTRIENT LOSS AND EUTROPHICATION.....	22
ISSUE 7: REMNANT VEGETATION DECLINE .....	27
ISSUE 8: SOIL ACIDITY .....	33
ISSUE 9: SOIL FERTILITY DECLINE .....	36
ISSUE 10: SOIL STRUCTURE DECLINE.....	38
ISSUE 11: SUBSURFACE COMPACTION .....	41
ISSUE 12: SURFACE WATER SUPPLY SHORTAGES.....	43
ISSUE 13: WATER EROSION.....	44
ISSUE 14: WATERLOGGING .....	48
ISSUE 15: WIND EROSION .....	51

### ACKNOWLEDGEMENTS

Members of the Department of Agriculture’s Central Region Natural Resource Management team produced this report, which is largely based on Technical Report 244 (Stuart-Street 2003), whose main authors were Angela Stuart-Street, Peter Tille, Brendan Nicholas, Paul Galloway and Heather Percy. Tim Mathwin, Nick Cox, Don Bennett and Eric Wright also contributed to Technical Report 244.

Thanks to the following people who reviewed various sections: Ed Barrett-Lennard, Don Bennett, Paul Blackwell, Bill Bowden, Dan Carter, Neil Coles, Nick Cox, Perry Dolling, Darren Farmer, Chris Gazey, Richard George, Mohammad Hamza, Mark Rivers, Rob Summers and David Weaver, all from the Department of Agriculture.

Steven Wong from the Water and Rivers Commission and Brett Beecham from the Department of Conservation and Land Management also contributed comments.

Thanks also to Phil Goulding, Josh Smith, Damian Shepherd and Dennis van Gool for providing assistance with spatial data analysis.

## INTRODUCTION

This document analyses the intrinsic risk of soil, land and water degradation within the Avon River Basin (ARB). Little data is currently available on actual areas of land affected by various forms of degradation. Instead, we estimate these areas by interpreting the characteristics of soils and landscapes identified during regional land resource surveys. The Department of Agriculture holds such interpretations within its Map Unit Database (Department of Agriculture 2002) and van Gool *et al.* (2001) document interpretation systems. Calculations of potentially affected areas are based on privately-owned agricultural land, as defined by National Land and Water Resources Audit data (NLWRA 2003). Climate variability and local and regional land-use practices will influence the extent to which an issue affects agricultural land.

We arrange 15 natural resource management issues in alphabetical order. Four sections describe each issue:

- 1) **Extent:** Briefly describes the nature of the issue and, where data is available, the ultimate extent that the issue may affect the South West land division. We tabulate the area of agricultural land at risk within each agricultural sub-region of the ARB (Galloway 2004). The Avon Catchment Council and land management groups within the basin may find this useful for assessing NRM issues against assets and for formulating targets.
- 2) **Impacts:** A brief explanation about why the issue is important, and how it affects agriculture and the environment. Citations direct readers to references that provide more detail.
- 3) **Management options:** This describes effective on-ground actions. Where possible, we classify options according to Salinity Investment Framework principles (George and Kingwell 2003) of recovery, containing the problem, or adapting practices to live with the changed environment. Sometimes, the management options are best implemented as a package that contains two or more elements of the SIF principles. At other times, a management option classed as 'adaptation' matures to 'contain' and then 'recovery' over time. In these cases, it is difficult to assign a SIF classification to the management option.
- 4) **Effectiveness:** We summarise the likely effectiveness of each management option and provide references that support the use of management actions/options. Where no supporting references are identified, information on the effectiveness of management actions is not available.

Management options are only effective if adopted. Many options discussed in the following pages are economically, temporally and spatially challenging. A systematic and holistic approach using a variety of options to ameliorate a management problem will often deliver a more permanent fix than any single option.

## References

Galloway P (2004) Agricultural sub-regions of the Avon River Basin. Resource Management Technical Report 284. Department of Agriculture, Perth.

George R, Kingwell R (2003) Draft Salinity Investment Framework - Agricultural Land and Infrastructure. Department of Agriculture, Perth.

NLWRA (2003) National Land and Water Resources Audit land use data theme (data extracted June 2003 from Audit website).

Stuart-Street A (2003) Natural resource management issues: South West Region. Resource Management Technical Report 244. Department of Agriculture, Perth.

van Gool D, Tille P, Moore G (2001) Land evaluation standards for land resource mapping: assessing land qualities and determining land capability in south-western Australia. Resource Management Technical Report 181. Department of Agriculture, Perth.

## ISSUE 1: ACID GROUNDWATER

### Extent

Acid groundwater (pH <4) is common in the WA wheatbelt (Mazor and George 1992), being present in around 20 per cent of bores monitored in the Central Agricultural Region. It occurs in two distinct situations, valley floors of the eastern wheatbelt and on hillside seeps of the western wheatbelt/woolbelt.

Acid groundwater in the eastern wheatbelt is broadly distributed across valley groundwater systems, but appears particularly prevalent near salt lakes. Deep and shallow groundwater systems are both affected. The lowest recorded pH measurements of groundwater in the ARB are 1.4 and 1.8, near the Kulin and Hyden salt lakes, respectively.

Acid groundwater occurs in the western wheatbelt as small hillside seeps. They are common. The lowest recorded pH of 2.3 was encountered in the Westdale area.

McArthur *et al.* (1991) attributed the acidification of groundwater at playa-margin discharge zones in the eastern wheatbelt to ferrollysis, which is the most likely process causing low pH in most wheatbelt groundwater (George, unpublished data and subsequent unpublished analyses by Ghauri). Ferrollysis is the oxidation and hydrolysis of dissolved  $\text{Fe}^{2+}$  (Mann 1983). The process typically leads to the precipitation of red/brown iron oxides at the soil surface. In western wheatbelt areas, groundwater becomes enriched in ferrous iron with close proximity to mafic dykes, resulting in acidity via ferrollysis upon discharge at the ground surface.

The transformation of primary or secondary sulfides to sulfate also generates acid. However, the extent of this process in the eastern wheatbelt is minimal and it may not have contributed to acid generation at all during recent geological times.

In the eastern wheatbelt, acid groundwater has been identified in locations remote from salt lake environments and/or too deep for active ferrollysis to be responsible (see Figure 1). This acidity may be explained though one or a combination of the following:

- Density driven reflux of acidified brines, with acidity possibly maintained due to the exhaustion of buffering agents in the immediate vicinity;
- Acid diffusion in groundwater, from higher concentrations near playas to relatively lower concentrations remote from playas; or
- Residual acidity from rock weathering that has been preserved within valley groundwater systems. This style of acid generation would be analogous to the process currently occurring in the western wheatbelt, and also explains why some catchments have acid groundwater while other nearby catchments do not.

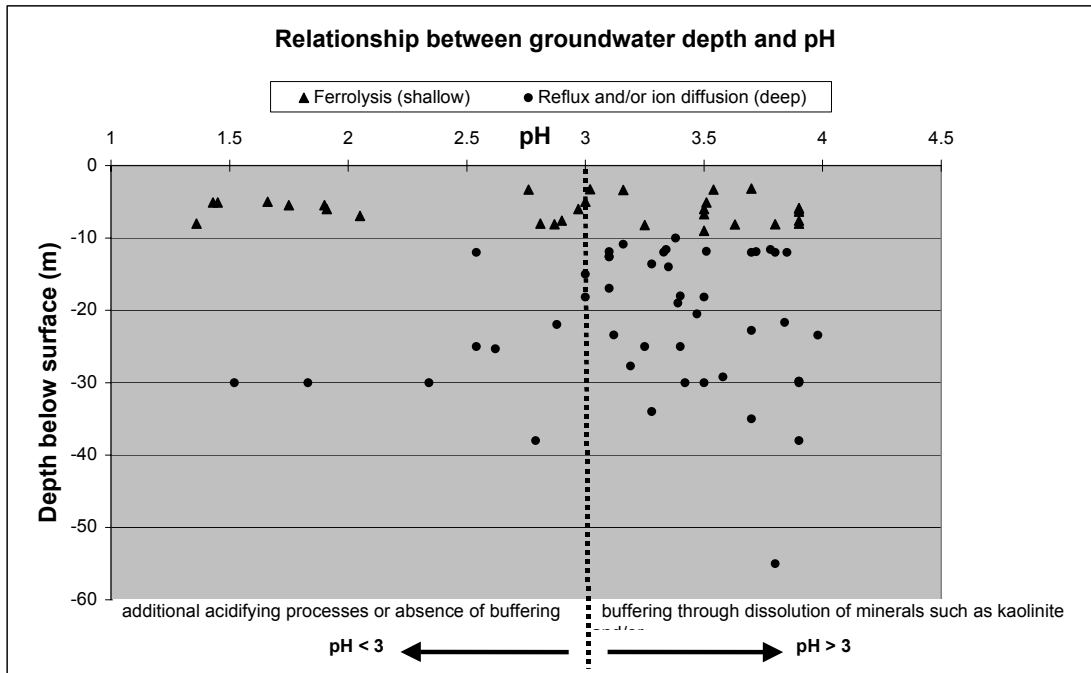


Figure 1: Depth of groundwater and pH influence on 76 bores in the ARB.

## Impacts

Rising watertables cause acid saline water to encroach on the near-surface environment whether drainage occurs or not. Seeps in the western wheatbelt discharge acidic and brackish-saline 'baseflow', though net loads are arguably no different, whether they are artificially drained or not. The impacts of acidity on western seeps have become more apparent following clearing and seep expansion. Increased volumes of acid water may affect streams, ecosystems and soils on- and off-site. In the eastern wheatbelt, diffuse source seepage of acid groundwater increases considerably by drainage and pumping, although flows and loads can be modified using containment strategies.

Corrosive acid groundwater can damage ecosystems and infrastructure, depending on concentration and the time over which the water remains unbuffered. Acid groundwaters are typically saline to hypersaline. They may also contain ions that could pose a public health or environmental threat (e.g. aluminium, lead, copper, cadmium, manganese and other heavy metals and radio-nucleotides). Impacts related to poorly managed discharge of acid groundwater may become more apparent as the adoption of groundwater drainage and pumping practices increases. Naturally acidic water bodies exist throughout the wheatbelt and local ecosystems are suited to those conditions. Increased loads of acidic water may not adversely affect these systems much.

Some of the impacts are outlined below:

Ecosystems not adapted to acidic conditions are at risk of degradation through improper disposal of acid groundwater. Acids in effluent water should be neutralised or reduced.

**On-site/off-site seepage:** Acid groundwater may cause pH shifts in stream ecosystems and irreversible changes in subsoils, potentially affecting production systems.

**Productive uses are limited:** Many industries cannot use acid groundwater due to its pH (e.g. death of fish in aquaculture). Presence of heavy metals and bioaccumulation of contaminants also affect end use.



**Detrimental to built infrastructure:** Metal and some synthetic components used in pumps and desalination equipment are likely to degrade more quickly when exposed to water that is acidic. The life expectancy of concrete is also reduced (e.g. culverts).

## Management options

Effective management of acid groundwater first requires it to be characterised in order to develop a chemical treatment with sufficient neutralising capacity. Treatment systems depend on both flow and load (e.g. acid, metals, salts, etc.). Some forms of acid treatment are less effective when large amounts of iron and aluminium are present, as is often the case in the wheatbelt. Information on managing large volumes of acid groundwater is still being developed.

**Chemical adjustment of pH (Recover):** Limestone, hydrated lime, sodium hydroxide, sodium carbonate or ammonia can be used to treat acid groundwater. There are many advantages and disadvantages of using different chemicals to adjust pH including cost, reaction time, effectiveness, and handling dangers. Residues from chemical treatment need to be disposed of properly.

*Limestone channels and anoxic drains* can be used where acid groundwater must be conveyed over some distance prior to or during treatment. These management options contribute minimal alkaline chemicals to counter acidity.

*Anaerobic wetlands* have organic-rich substrates that exchange dissolved metals. This exchange occurs between the dissolved metals and abundant humic and fulvic acids contained within the substrate (Wildeman *et al.* 1991). Soluble metals are converted to insoluble forms by the anoxic conditions of wetland sediments (Fennessy and Mitsch 1989). Settling of suspended solids occurs from water velocity control of the wetland vegetation (Brooks 1984). Anaerobic conditions also prevent oxidation of sulfides, thus maintaining potentially acidic soil minerals in a benign form.

**Physical barriers (Contain):** Containing acid water by constructing physical barriers can isolate the problem from environmentally sensitive areas. Site investigations and good engineering and construction practices are required for such management, since these barriers can be breached if construction materials degrade or if the design parameters do not account for climatic extremes.

## Effectiveness

Information for treating acid discharges is derived mainly from reported information on acid mine drainage. Virtually no information exists for the treatment of naturally acid groundwater in the quantities present in the ARB. Combinations of management options are common in the treatment of highly acidic effluents. The limitations of effectiveness in acid mine drainage treatment are also likely to apply to acid groundwater.

- 1. Chemical adjustment of pH:** Downstream effects and disposal of residues created during chemical treatment must be considered. Chemical treatment options are ongoing and continuous chemical supply is required for the life of the project.

*Limestone channels and anoxic drains* can become clogged with metal hydroxides due to oxidation and pH increases. Provided water flows fast enough, the abrasive action of the water can dislodge these coatings maintaining some neutralising effects. Addition of limestone to existing deep drains used for salinity reclamation may render them ineffective due to blockage. Water flow velocities in deep drains are too low to maintain an abrasive action on large limestone particles.

*Anaerobic wetlands*: have proved capable of removing iron and producing alkalinity. The primary factor limiting their effectiveness is the slow mixing of the alkaline substrate water with acidic waters near the surface. This slow mixing can be overcome by constructing very large wetlands to provide long retention times (Skousen 1997). This demand on land area is a major impediment to the increased use of this option.

- 2. Physical:** Barriers only hold acidic groundwater and do not produce alkalinity without the addition of neutralising agents. The corrosive properties of detained acid groundwater need to be monitored and tested when evaporation is used to reduce volumes. Care is required when volume reduction via evaporation takes place to prevent accumulation of excessive concentrations of contaminants.

## References

- Brooks RP (1984) Optimal designs for restored wetlands. In *Treatment of Mine Drainage by Wetlands*. Contribution #264. Dept. of Biology, Pennsylvania State University. pp 19-29. University Park, PA.
- Fennessy S, Mitsch WJ (1989) Design and use of wetlands for renovation of drainage from coal mines. In *Ecological Engineering: an introduction to ecotechnology*. WJ Mitsch and SE Jorgensen (eds), pp 232-252. (John Wiley & Sons: New York)
- Mann AW (1983) Hydrochemistry and weathering on the Yilgarn Block, Western Australia - ferrollysis and heavy metals in continental brines. *Geochim. Cosmochim. Acta* 47, pp 181-190.
- McArthur JM, Turner JV, Lyons WB, Osborn A, Thirwall MF (1991) Hydrochemistry on the Yilgarn Block, Western Australia: ferrollysis and mineralisation in acidic brines. Department of Geological Sciences, University College London, UK. *Geochimica et Cosmochimica Acta* 55 (5), 1273-88.
- Mazor E, George RJ (1992) Marine airborne salts applied to trace evapotranspiration, local recharge and lateral groundwater flow in Western Australia. *J. Hydrol.* 139, 63-77.
- Skousen J (1997) Overview of Passive Systems for Treating Acid Mine Drainage. *Green Lands* 27(2), 34-43.
- Wildeman T, Gusek J, Dietz J, Morea S (1991) *Handbook for Constructed Wetlands Receiving Acid Mine Drainage*. (US EPA: Cincinnati, Ohio)

## ISSUE 2: ACID SULFATE SOILS

### 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. Their extent in inland WA is very poorly understood and urgently requires investigation. In addition, it has recently been recognised in South Australia that extensive inland areas featuring saline soils may also be at risk where deep up-wellings of saline, sulfate-rich regional groundwater reach the surface (Fitzpatrick *et al.* 2000). Research into the likelihood of this problem occurring in WA is on-going.

### 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; and
- serious effects on infrastructure including pipes, foundations and road surfaces susceptible to corrosion causing accelerated structural failure.

Within the ARB, examples of acid sulfate soils are increasingly found in association with soil disturbance due to deep and surface water drainage.

### Management options

The key option is to recognise the existence of potential acid sulfate soils and contain the problem by avoiding land disturbance. Field identification is possible by using various soil, water and vegetation indicators (Dairy Industry Development Company 2001). Management depends on the existing quantities of sulfide mineral, acid loads produced, and the area under threat. Options include:

1. Efficient water and drainage management systems
2. Carefully selecting pasture species and effectively managing pastures
3. Fencing off affected areas
4. Revegetating groundwater recharge areas and utilising perennial pastures
5. Establishing tolerant species in scalds to stabilise soil and prevent erosion and acid run-off when it rains
6. Treating acid sulfate-affected land and drainage water (within channels and ponds) by liming (where economical).

## Effectiveness

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

1. Effective watertable management (preventing oxidation) has been the key to the efficient management of acid sulfate soil. Wherever possible, do not drain these soils: avoiding disturbance is always the preferred option. If drainage is necessary, then use broad shallow drains to prevent disturbance of potential acid sulfate soils. Do not use deep drains in areas with acid sulfate soils.
2. Highly productive pastures have been established on land affected by acid sulfate soil, 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 quite difficult to manage.
4. Revegetation with perennials in recharge areas has lowered watertables.
5. Careful species selection has helped to stabilise affected areas, reducing erosion and acidic run-off.
6. Liming may be an uneconomical practice on a broad scale, but on a small area may be effective to neutralise sulphuric acid in soil or water.

## References

- Ahern CR, Ahern MR, Powell B (1998) Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998. Department of Natural Resources, Resource Sciences Centre, Indooroopilly.
- Dairy Industry Development Company (2001) Farming successfully on the acid sulfate soils of the NSW coastal plain. Dairy Industry Development Company (NSW) Ltd.
- Fitzpatrick R, Merry R, Cox J (2000) What are Saline Soils? What happens when they are drained? *Natural Resource Management*, Special Issue June 2000.

## ISSUE 3: DRYLAND SALINITY

### Extent

Western Australia has the largest area of dryland salinity in Australia and highest risk of increased salinity in the next 50 years (Land and Water Australia 2000). The NLWRA states that an estimated 4.3 million hectares (16%) of the South West currently has high potential of developing salinity from shallow watertables. This is predicted to rise to 8.8 million hectares (33%) by 2050 (Short and McConnell 2001).

Within the ARB, western zones most urgently require salinity management, as areas at risk of salinity generally already feature intermittent waterlogging and/or salinity. Without intervention, we expect equilibrium between recharge and discharge to occur between 2010 and 2030.

Valley floors and adjacent footslopes of the eastern wheatbelt comprise the greatest area at risk of salinity. These areas are still productive for traditional cereal rotations but have rising saline watertables within several metres of the surface. However, the rate of watertable rise is lower because recharge rates are lower than further west. Hence, more time is available to implement practices that reverse salinity trends. Without intervention, we expect equilibrium between recharge and discharge to occur between 2030 and 2075.

Seasonal floods and droughts have affected watertable trends in the eastern wheatbelt over recent years. Whilst these events have increased and decreased individual bore levels, groundwater continues a long-term rising trend, with the inevitable conclusion that salinity extent will increase.

Estimates of current salinity and areas at risk of salinity in Table 3.1 derive from Land Monitor (2002) data. A draft Salinity Investment Framework (George and Kingwell 2003) outlines the estimated extent of salinity under different management scenarios. The framework includes the probability of adoption and technical feasibility of management scenarios for each soil-landscape zone.

**Table 3.1. Current extent of salinity and area at risk of salinity in the future in agricultural sub-regions of the ARB (Land Monitor 2002; Department of Agriculture 2002a)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Land presently saline		Land at risk of salinity in the future	
		'000 ha	%	'000 ha	%
South-east Lakes	1,604	98	6.1	399 <sup>A</sup>	24.9
Darling Range	148	3	1.8	24	16.1
Avon Valley	813	47	5.8	195	23.9
Dale/Upper Avon	163	5	3.3	33	20.4
Northern Sandplain	687	35	5.1	209	30.4
Mortlock	1,326	112	8.4	431	32.5
Carrabin	1,794	50	2.8	553 <sup>B</sup>	30.8
Yealering Lakes	661	36	5.6	123 <sup>C</sup>	19.1
Southern Cross	189	3	1.7	60 <sup>D</sup>	31.7
<b>TOTAL</b>	<b>7,387</b>	<b>388</b>	<b>5.3</b>	<b>2,027</b>	<b>27.4</b>

<sup>A</sup> Possible over-estimation caused by Land Monitor mapping that classed upland valleys as high salinity risk, and soil mapping limitations of the Department of Agriculture.

<sup>B</sup> Possible over-estimation due to low relief and incomplete Land Monitor coverage.

<sup>C</sup> Soil mapping limitations.

<sup>D</sup> Likely to be an over-estimation, this area has deep regolith and deep watertables.

## Impacts

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

- **Loss of productive agricultural land:** Salinity leads to poor growth or death of plants, and is most detrimental when combined with waterlogging. Of the 4.3 million hectares (16%) of the South West at risk from shallow groundwater, 81 per cent is agricultural land. Predictions, based on current and perceived land uses, are that shallow watertables and salinity may affect a third of agricultural areas by 2050 (Land and Water Australia 2000).
- **Loss of biodiversity** caused by the detrimental effects of secondary salinity on bushland remnants and wetlands. Twenty-one of 54 wetlands within the agricultural region are potentially at risk of secondary salinisation. In these systems, the shallow perched watertables that contribute to fresh water wetlands are likely to become salt-affected due to rising intermediate and regional saline watertables. Secondary salinity will affect an estimated 1500 plant species, with 450 species possibly subject to extinction. The number of fauna species is likely to reduce by 30 per cent in salt affected areas, and according to Land and Water Australia (2000) "...terrestrial animals will decline significantly. For example, a 50 per cent reduction in the water birds using wheatbelt wetlands is anticipated due to the salinity-induced death of shrubs and trees with onset of salinity."
- **Reduction of available water supplies:** Saprock and perched aquifer resources exist in western areas, whilst eastern zones rely mostly on perched aquifers for good quality water. With continued recharge and salt mobilisation, water bores are likely to begin drawing on expanding saline groundwater systems.
- **Detrimental effects on town sites and infrastructure:** Just under 29,000 km of road and rail networks and up 30 rural towns may be affected. Damage to buildings, recreation facilities and difficulties with public utilities including water supplies and waste management systems are also expected (Land and Water Australia 2000).
- **Increased risk of water erosion:** Denuded and waterlogged topsoil is more susceptible to detachment and transport (Tille *et al.* 2001).

## Management options

Effective management of secondary salinity involves managing salt-affected areas and the broader catchment simultaneously (Moore 1998). Options are outlined below (summarised from Tille *et al.* 1991 and Moore 1998):

1. **Adopting low recharge farming systems:** To replace current agronomic practices with alternative, economically viable systems, that increase evapotranspiration and reduce the amount of water percolating below the root zone. These include:
  - **Improving annual crop and pasture agronomy (Contain):** Improve existing agronomic practices by selecting appropriate species and varieties, applying adequate - but not excessive - fertiliser, controlling weeds, whilst also ensuring that the timing and application of the above techniques follows "best practice".
  - **Using perennial plants (Contain):** Pastures, trees and fodder shrubs capable of growing throughout the year use more water than annual crops

and pastures. They have more extensive root systems that dry out soil profiles better than annuals and they may have access to groundwater. They also transpire more water because they grow all year and often have larger leaf area than annuals.

- **Managing soils with major chemical and/or physical limitations (Contain and Adapt):** Several soils and landscapes have intrinsic attributes that limit productivity and contribute greatly to degradation via recharge and/or erosion. These soil types include Acid yellow sandy earths, Pale deep sands, Shallow gravels, rock outcrops/ bedrock 'highs' and some duplex soils. Such soils and landscapes should be identified and managed according to their productive capacity. This may involve treatment, alternative production, or ceasing production and replanting to indigenous vegetation.
- **Protecting, managing and enhancing remnant vegetation (Contain and Recover).** Protecting and managing remnant vegetation will maintain existing water use under the remnant. Enhancing the quality and area of bushland may reduce groundwater recharge compared to annual plants that the bush replaces.
- **Saltland pastures and crops (Adapt):** Saltland plants can provide some production from what is otherwise generally unusable land. They may increase transpiration and reduce evaporation from the soil surface, thus promoting leaching of salts from the soil surface by rainfall. They may also reduce erosion on salt-affected areas.
- **Aquaculture (Adapt and some Recovery and Containment through associated works):** There is some potential for aquaculture ponds using groundwater drainage from salt-affected areas.

2. **Engineering solutions** are required in addition to increasing water use by plants. These options help to prevent water from recharging and remove saline water from the catchment and include:

- **Managing surface water (Recover and Contain):** Prepare and implement farm and catchment management strategies that incorporate water harvesting, storage and removal, using a range of earthworks. Such earthworks include banks, drains, roaded catchments, dams and natural waterways.
- **Managing groundwater (Recover and Contain):** Deep open or enclosed drains, pumps and siphons can prevent salts from accumulating in the upper soil profile by lowering watertables and allowing rainfall to leach salt. These techniques aim to increase the rate of discharge. However, to function as a system, they must also direct saline effluent to evaporation basins designed to maximise evaporation. To be effective, the entire system must evaporate effluent more efficiently than non-engineered groundwater discharge mechanisms.
- **Evaporation basins and salt harvesting (Adapt and some Recovery and Containment through associated works):** Basins can store saline groundwater until it evaporates (JDA and Hauck 2004). Commercial harvesting of salt from an evaporation basin may be an option.
- **Desalination (Adapt and some Recovery and Containment through associated works):** Converts saline or treated wastewater into water of drinking quality (potable) and for industrial use. Generally, distillation and reverse osmosis (RO) are used for seawater desalination, while RO and electrodialysis are used to desalinate brackish water (Department of Agriculture 2002b). Mineral extraction may be combined with desalination, and the products used by industry, for animal nutrition and as dust suppressants.

## 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):

### 1. Adopting low recharge farming systems:

- *Improve annual crop and pasture agronomy.* Improving agronomic practices to reach maximum theoretical crop yields will only increase water use by about 4 per cent, because increases in biomass production and transpiration are offset by decreased evaporation from the soil surface (Tennant *et al.* 2002). The time over which annuals use water can be maximised by selecting species and varieties suited to environmental conditions, and by good grazing management and effective fertiliser use (Tille *et al.* 2001). Extending the time interval over which annuals can grow will increase the total water they use. However, the efficacy of different varieties to maximise water use depends on the climatic situation in which they are grown. Later-maturing varieties will use more water than early-maturing varieties in long season, high rainfall environments. However, in short season, low rainfall environments this difference is marginal (Tennant *et al.* 2002).
- *Use of perennial plants.* Perennial species reduce recharge caused by summer and autumn rainfall by using this water as it falls. They also dry out the soil profile over summer, creating a soil moisture buffer. Assuming uniform wetting, this buffer must be saturated before recharge can occur. (In practice, recharge can occur via preferred pathway flow even without a saturated soil profile.) Perennials are most effective when used to manage salinity derived from local flow systems. They use more water than annual species in the late spring, summer and autumn, and deeper-rooted perennials (trees) are the highest water users (Tille *et al.* 2001). Lucerne is the main perennial pasture option for recharge management in broadacre situations, although acid soils and low rainfall during establishment can dramatically reduce plant survival. Low rainfall also affects yield.
- *Managing soils with major chemical and/or physical limitations:* Management practices that reduce waterlogging often help combat salinity. Soil management that improves chemical or physical restrictions to plant growth will improve crop water use by allowing greater root exploration, which may dry the soil profile more thoroughly, potentially reducing recharge (Tille *et al.* 2001).
- *Protect, manage and enhance 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 the native vegetation before it was cleared (Moore 1998).

### 2. Engineering solutions:

- *Managing surface water:* Well designed and sited surface-water management structures can reduce waterlogging and subsequently diminish the severity and impact of secondary salinity. They may also contribute to increasing plant water use by improving the conditions for plant growth (Tille *et al.* 2001). Landholders often comment that culvert capacity under public roads is generally too low. This can cause inundation and sedimentation which further add to waterlogging/salinity problems.
- *Managing groundwater:* Drains, pumps and siphons can all contribute to groundwater control. We strongly recommend careful site assessment, design and cost/benefit analysis before implementing these options, because low permeability of materials on many salt-affected areas can reduce their effectiveness.



### 3. Living with salinity:

- *Saltland pastures and crops*: Revegetating saline areas with salt-tolerant species will increase water use and may help lower watertables (Tille *et al.* 2001). Saltland pastures 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). Waterlogging and saline soils often occur together. These sites will require surface water management to reduce waterlogging because many saltbush species do not tolerate waterlogging well.
- *Aquaculture*: The use of saline water for aquaculture is well documented (e.g. in Tille *et al.* 2001). However, operating costs may be prohibitive and there must be plentiful non-polluted water. Acid groundwater (pH <4) is not suitable for aquaculture. Such water is prevalent in valley floors of the north-eastern wheatbelt.
- *Evaporation basins and salt harvesting*: Salt that accumulates in evaporation basins is best stored on-site. Harvesting this salt commercially has only succeeded in isolated cases. Financial viability is unlikely unless a local niche market is identified (JDA and Hauck 2004).
- *Desalination*: Desalination technologies can produce high quality water, but may be costly because they use a lot of energy (Department of Agriculture 2002b). The viability depends on the situation. It may not be cost effective on a small scale.

### References

- Department of Agriculture (2002a) Map Unit Database.
- Department of Agriculture (2002b) [www.agric.wa.gov.au/environment/land/drainwise/options](http://www.agric.wa.gov.au/environment/land/drainwise/options).
- George R, Kingwell R (2003) Draft Salinity Investment Framework - Agricultural Land and Infrastructure. Department of Agriculture, Perth.
- JDA Consultant Hydrologists and Hauck E (2004) Evaporation basin guidelines for disposal of saline water. Department of Agriculture, Miscellaneous Publication 3/2004.
- Kingwell R, Hajkowicz S, Young J, Patton D, Trapnell L, Edward A, Krause M, Bathgate A (2003) Economic Evaluation of Salinity Management Options in Cropping Regions of Australia. National Dryland Salinity Program.
- Land Monitor (2002) Website at [www.landmonitor.wa.gov.au](http://www.landmonitor.wa.gov.au).
- Land and Water Australia (2000) Australian Dryland Salinity Assessment, National Land and Water Resources Audit, Commonwealth of Australia, Canberra.
- Moore G (1998) Soil salinity. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore). Agriculture Western Australia, Bulletin 4343 pp. 146-58.
- O'Connell M, Young J (2002) The Role of Saltland Pastures in the Farming System – A Whole-Farm Bio-Economic Analysis. In 1MPULS> - Draft Discussion Paper of the Saltland Pastures Association.
- Short RJ, McConnell C (2001) Extent and Impacts of Dryland Salinity. Resource Management Technical Report 202, Department of Agriculture, Perth.

Tennant D, Ward P, Hall D (2002) Limitations and opportunities for increasing water use by annual crops and pastures. In Crop updates 2002. Farming systems for sustainability (Compiler: Richard Olive) Department of Agriculture, Perth.

Tille P, Mathwin TW, George RJ (2001) The South West Hydrological Information Package. Understanding and managing hydrological issues on agricultural land in the south west of Western Australia. Agriculture Western Australia, Bulletin 4488.

## ISSUE 4: FLOODING

### Extent

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

Rivers and drainage lines in catchments cleared for agriculture are more prone to flooding than those where the natural vegetation remains. Catchments where land is cultivated regularly are at greatest risk of flooding because of reduced infiltration, which is caused by compaction and hardpan formation. Catchments with increasing areas of salinity and waterlogging experience greater flood peaks, because more of the catchment remains saturated between rainfall events (Bowman and Ruprecht 2000).

There is no consistent mapping of the extent of flooding or flood-prone areas across agricultural regions. Individual events have been tracked by satellite imagery. The Department of Environment produces flood risk maps for populated areas, such as towns, with a history of flooding. Modelling has also been carried out in certain catchments. The following data is based on the flood hazard assigned to land units in the Department of Agriculture’s soil-landscape mapping.

**Table 4.1. Flood hazard in agricultural sub-regions of the ARB (Department of Agriculture 2002a)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Land with a moderate to high risk of flood hazard <sup>A</sup>	
		('000 ha)	%
South-east Lakes	1,604	119	7.4
Darling Range	148	11	7.2
Avon Valley	813	150	18.5
Dale/Upper Avon	163	11	7
Northern Sandplain	687	26	3.7
Mortlock	1,326	233	17.5
Carrabin	1,794	160	8.9
Yealering Lakes	661	21	3.1
Southern Cross	189	7	3.7
<b>TOTAL</b>	<b>7,387</b>	<b>738</b>	<b>10</b>

<sup>A</sup> Land likely to be affected by moving floodwaters at least once in every 10 years.

The above data is as much indicative of those landforms that contribute to the generation of flood events, as being affected by them. An understanding of flood potential can only be determined by tracking actual events and modelling. This is mainly due to the large number of variables that contribute to flood generation, such as landscape formation, storm probabilities, land use and run-off. Even when flood events are recorded and tracked, there is often a general lack of locally-recorded and accurately observed climatic and run-off data to provide information on the processes that occurred to generate such events.

## Impacts

The impacts of flooding include damage to infrastructure, interruption to communication and transport, crop and stock losses, erosion and sedimentation. The impacts are summarised in Tille *et al.* (2001).

## Management options

The agricultural areas are still undergoing immense hydrological change in response to clearing and development. Our understanding and ability to determine the potential impacts of this, as well as ability to develop remedial measures, is greatly hindered by 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 in areas 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 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 these, we need to undertake stream gauging and related modelling on a far greater scale.

To date, our knowledge is based on common sense, supported by observation, which indicates that on a small scale the following tools (described in detail in Tille *et al.* 2001 and Department of Agriculture 2002b) may be effective:

**Lower recharge farming systems (Recover and Contain):** Which are also designed to combat salinity and waterlogging and may reduce the risk of flooding by providing a larger soil water storage buffer.

**Temporary detention (Contain):** Wherever possible by incorporating practices that are generally used to reduce soil erosion, e.g. grade banks and working land on the contour.

**Installation of earthworks and water harvesting schemes (Recover and Contain):** To regulate and reduce run-off from contributing landforms and catchment areas.

**Groundwater drainage schemes (Recover and Contain):** That de-water waterlogged areas between storm events to provide greater soil infiltration capacity.

On a regional scale options may include:

**The use of natural lakes and wetlands (Contain):** To act as detention basins to attenuate flood events.

**Regional scale drainage schemes (Recover and Contain):** That drain land and divert flood flows away from infrastructure to detention and disposal areas.

## Effectiveness

**Lower recharge farming systems:** Have potential to reduce run-off caused by saturation excess and may provide traps for silt to help reduce the flow-on effects of silted culverts and water courses etc.

**Temporary detention:** Is likely to be beneficial in small and moderate storm events. The benefits reduce during severe or prolonged storm events.

**Installation of earthworks:** With water harvesting, this is often a successful option on a local scale. These generally provide significant localised benefits and cause few off-site problems providing schemes are properly designed.

**The use of natural wetlands:** If properly managed, the flow of water through these can benefit flood control, conservation and the community. However, these projects require expert input.

**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.

## References

Bowman S, Ruprecht J (2000) Blackwood River flood risk study. Surface Water Hydrology Science and Evaluation. Water and Rivers Commission, Surface Water Hydrology Report Series Report SWH 29.

Department of Agriculture (2002a) Map Unit Database.

Department of Agriculture (2002b) [www.agric.wa.gov.au/environment/land/drainwise/options](http://www.agric.wa.gov.au/environment/land/drainwise/options).

Tille PJ, Mathwin TW, George RJ (2001) The South West Hydrological Information Package – Understanding and managing hydrological issues on agricultural land in the south west of Western Australia. Agriculture Western Australia, Bulletin 4488.

Water and Rivers Commission (2000) Flooding in Western Australia. Water Facts 13.

## ISSUE 5: NON-WETTING SOIL (WATER REPELLENCE)

### Extent

Non-wetting mainly affects soils with sandy surfaces. Non-wetting is caused by hydrophobic (waxy) organic compounds that coat soil particles. These waxy compounds usually derive from the breakdown of organic matter. Sandy soils are highly susceptible to non-wetting because they have low surface areas so hydrophobic compounds can coat more soil particles. Lupin plant residue is a known source of hydrophobic compounds.

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 qualified soil groups allocated to the Department of Agriculture's soil-landscape mapping:

**Table 5.1. Area of land susceptible to water repellence in agricultural sub-regions of the ARB (Department of Agriculture 2002)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Soils highly susceptible to non-wetting	
		('000 ha)	%
South-east Lakes	1,604	258	16.1
Darling Range	148	29	19.3
Avon Valley	813	207	25.5
Dale/Upper Avon	163	37	22.6
Northern Sandplain	687	9	1.3
Mortlock	1,326	210	15.8
Carrabin	1,794	93	5.2
Yealering Lakes	661	141	21.3
Southern Cross	189	25	13.0
<b>TOTAL</b>	<b>7,387</b>	<b>1,010</b>	<b>13.7</b>

Over 60 per cent of susceptible soils are in the South-east Lakes, Mortlock, and Yealering Lakes, where sandy duplex soils dominate. Another 20 per cent of soils susceptible to non-wetting are found in the Avon Valley sub-region. This is possibly due to high agricultural productivity and wheat-lupin rotations, which exacerbate water repellence. The surprisingly low figures for the Northern Sandplain must be viewed with caution, as large areas of these sub-regions have sandy-surfaced soils.

### Impacts

The impacts of non-wetting soils are summarised by Moore and Blackwell (1998) on page 56 of 'Soilguide'. Non-wetting 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, including delayed and uneven establishment;
- poor crop and pasture growth;
- patchy crop performance;
- poor ground cover increasing erosion risk; and
- an increase in weed establishment.

Impacts of increased run-off are:

- increased water erosion risk;
- increased risk of nutrient export;
- potential for pesticide and herbicide run-off; and
- concentration of run-off water leading to rapid point-infiltration (flow fingering) below the root zone that can then recharge watertables.

## Management options

**Furrow sowing (Adapt):** Create furrows when cropping to harvest water and ensure even wetting around the seed - see pages 60-62 of 'Soilguide' (Moore and Blackwell 1998) and Blackwell (1997).

**Claying (Recover):** Adding clay to topsoil to increase surface area and reduce repellence - see page 63 of 'Soilguide' (Moore and Blackwell 1998, Carter and Hetherington 2002).

**Perennial vegetation (Contain):** Establishing perennials reduces problems, as they can provide better ground cover if managed properly and there is also no annual germination.

**Soil wetting agents (Recover and Contain):** Agents that lower the surface tension of water to increase infiltration are usually added in bands along seeding rows, due to the cost of wetting agents.

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

**Furrow sowing:** The easiest solution for better cropping (Blackwell 1996). Can be effective, but can also increase the risk of erosion, herbicide concentration, leaching and waterlogging.

**Claying** provides the best long-term solution (Blackwell 1996). It is highly effective on topsoils containing less than ten per cent clay. A suitable source of clay (non-saline dispersible kaolinite) is required close to the soil to be treated (high transport costs).

**Perennials:** Avoid the problem, as there is no need for annual germination.

**Wetting agents:** Can be effective but are too expensive for broadacre agriculture.

## References

Blackwell P (1996) Managing water repellent soils. Agriculture Western Australia Farmnote 109/96.

Blackwell P (1997) Furrow sowing on water repellent soils. Agriculture Western Australia, Bulletin 4333.

Department of Agriculture (2002) Map Unit Database.

Moore G, Blackwell P (1998) Water repellence. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore). Agriculture Western Australia, Bulletin 4343 pp. 53-63.

## ISSUE 6: NUTRIENT LOSS AND EUTROPHICATION

### Extent

Phosphorus and nitrogen are the main nutrients that contribute to eutrophication of surface water and groundwater. Nitrogen most often enters groundwater by leaching through sandy soils and surface water via groundwater discharge. Phosphorus most often enters surface waters of the ARB attached to transported clay particles. Nitrogen and phosphorus also commonly enter waterways as nutrients in organic matter. Areas of heavier textured soils left prone to soil erosion may contribute to nutrient export and eutrophication. Soil water and nutrients can reach streams by moving through macropores in soil, thus largely avoiding particles that would normally bind nutrients and buffer against loss.

Nutrient export in the ARB occurs largely by diffuse discharge from agricultural operations or urban developments, but point sources may also be significant locally. These include intensive agricultural developments, effluent from septic tanks, piggeries, sheep holding yards, feedlots, meat processing plants and other industries.

Current estimates are that up to 10 per cent of phosphorus added as fertiliser is lost in drainage and approximately 70 per cent of this comes from previous applications stored in the soil (Harris 1996). Water sampling during spring indicates that phosphorus concentrations are high (between 0.09 and 0.33 mg/L) in the upper Toodyay Brook and the North and East branches of the Mortlock River (Harris 1996). Thus, water quality in these tributaries is poor with respect to phosphorus load. Nitrogen loads are considerably less across the system. For example, sampling carried out from 1997 to 1999 in the North Mortlock and Avon Rivers revealed high total nitrogen loads (1.3-2.0 mg/L) at only a single North Mortlock sampling site (WRC 2000).

Coastal estuaries and inlets of WA are particularly susceptible to eutrophication. The Swan River estuary is the ultimate sink for nutrients sources from the Avon River Basin. However, the ARB is likely to contribute only minor inputs, in the form of phosphorus attached to clay particles, and nitrogen and phosphorus in organic form, compared to industry and urban development on the coastal plain. Deeley *et al.* (1999) provide comprehensive information, and Tille *et al.* (2001) outlined the factors contributing to eutrophication in these areas.

The extent of nutrient loss from agricultural areas is very difficult to measure directly. It may be best determined by a spatial analysis of soil nutrient levels and nutrient retention capabilities, land use, topographical and hydrological attributes. Such an analysis could be calibrated by assessing nutrient levels in the major waterways. However, soil tests are not often conducted at the required spatial and temporal resolution, and the other parameters are usually provided only in terms of broad regional data. Monitoring nutrient loads occurs on some waterways. This monitoring provides an indication of actual nutrient export rates, but the reliability of the results varies with the quality of data collection and analysis, and the intensity of monitoring over time and space.

In the absence of comprehensive soil, land use, topographical and hydrological data, the Department of Agriculture's soil-landscape mapping provides an estimate of the potential susceptibility of soils and landscapes to nutrient export (Table 6.1).



**Table 6.1. Phosphorus loss hazard in agricultural sub-regions of the ARB (Department of Agriculture 2002)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Soils with high to extreme phosphorus export hazard	
		('000 ha)	%
South-east Lakes	1,604	97	4.9
Darling Range	148	22	15.0
Avon Valley	813	156	19.1
Dale/Upper Avon	163	28	17.3
Northern Sandplain	687	39	5.7
Mortlock	1,326	289	21.8
Carrabin	1,794	164	9.2
Yealering Lakes	661	38	5.8
Southern Cross	189	5	2.8
<b>TOTAL</b>	<b>7,387</b>	<b>822</b>	<b>11.1</b>

A large proportion of the Darling Range has a high phosphorus export hazard. The steep slopes and high rainfall contribute to erosion of the loamy soils that have significant levels of phosphorus bound to the clay. The Avon River Management Authority (1993) estimated that the rate of peak stream-flow in the ARB has increased by a factor of 3 to 4 since clearing, and this was largely attributed to clearing. Climatic conditions such as episodic intense or sustained rainfall further increases flow rates and associated movement of pollutants.

### Impacts

The impacts of eutrophication are summarised by Tille *et al.* (2001) and Weaver and Summers (1998). Most of the impacts of nutrient loss and eutrophication occur off-site, and include:

- algal blooms and the formation of algal mats on the water surface;
- waterways that become depleted in oxygen when dead algal matter decomposes, which may lead to the death of fish and crustaceans;
- damage to seagrass meadows in the marine environment due to shading by algal blooms;
- waterway pollution caused by toxins from blue-green algae (*Nodularia*, *Microcystis*, *Ocsillatoria*). These may kill fish, birds and livestock and are a human health hazard;
- closure of waterways 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; and
- loss of groundwater supplies for human use, or more expensive treatment to ensure continued use.

On-site impacts include:

- toxic effects on crops when groundwater with high nutrient levels is used for irrigation;
- toxins from algae contaminating farm water supplies, endangering livestock, and
- toxic levels of nitrates in groundwater, which can endanger livestock.

## Management options

- 1. Monitoring:** Ongoing monitoring of river water quality, particularly in association with known point sources of pollution.
- 2. Fertiliser management (Recover and Contain):** Match fertiliser applications to plant requirements by conducting and correctly interpreting tests of soil, tissue and/or sap, as appropriate (see Farmnotes by Summers in references). Apply fertilisers at the correct time and use appropriate application methods to prevent run-off and leaching.
- 3. Using alternative fertilisers (Recover and Contain):** Include coarse rock gypsum to supply sulphur rather than superphosphate; non-soluble rock phosphate on acid sands on poorly drained areas (most appropriate for coastal plain farm management).
- 4. Soil amendments (Contain):** Improve nutrient retention of soil by preventing soil erosion and by applying amendments to improve the ability of the soil to hold nutrients (e.g. claying sandy soils, increasing organic carbon levels, applying gypsum on gypsum responsive soils to improve infiltration as described in Tille *et al.* 2001)
- 5. Streamlining and filter strips (Recover and Contain):** Fence off and establish buffer strips to filter water flowing overland and protect waterways. The recommended width of the buffer strip varies with land use, soil type, 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).
- 6. Perennials (Contain):** Plant perennial species (pastures, trees and shrubs) to minimise losses from leaching. Perennials access water and nutrients from a greater soil depth over a longer time than annuals, and also reduce the risk of future leaching events by more thoroughly drying out the soil profile, thus creating a buffer to reduce recharge.
- 7. Drainage (Contain):** By reducing waterlogging, plant uptake of nutrients is increased but this may increase nutrient export, depending on design and a range of climatic and soil characteristics (Tille *et al.* 2001).
- 8. Constructed wetlands (Contain):** Wetlands can be constructed to slow water flows, trap sediment and assimilate nutrients. Criteria for their design using examples relevant to the Ellen Brook catchment are presented in Deeley *et al.* (1999).
- 9. On-farm re-use systems (Contain and Adapt):** Manage surface water to harvest and store water and nutrients for use on-farm.
- 10. Control of water erosion (Contain):** Management options are outlined in the Water Erosion section of this document.
- 11. Treating point sources (Contain):** Store, treat and dispose of effluent from piggeries and intensive agriculture (e.g. feedlots) according to accepted guidelines, such as those set out in Dairy Industry Nutrient Strategy working Group (1998) and Latto *et al.* (2000).
- 12. Controlling eutrophication and algal blooms in on-farm water supplies (Contain and Adapt):** Construct silt and manure traps at dam inlets to reduce eutrophication. If an algal bloom forms in dam water, use block alum and barley straw to inhibit algae; or use chemicals such as Simazine and calcium hypochlorite to kill algae. For low algae levels, skim algae and scum off the water surface. Farmnotes on this issue 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; and  
 43/94 Toxic algal blooms.

## Effectiveness

**Fertiliser management:** Highly effective, particularly for phosphorus, with many soils already having moderate to high phosphorus status and thus not requiring additional applications.

**Alternative fertilisers:** Generally effective, when combined with management option 2. Rock phosphate does not release enough phosphorus on most soils but is a good option for acid sands on poorly drained areas on the coastal plain.

**Soil amendments:** Highly effective at reducing phosphorus loads with the added benefit of increasing pasture production.

**Streamlining and filter strips:** Effective but alternative watering points may be required for livestock.

**Perennials:** Effective for grazing systems and between horticultural crops. Perennial buffer strips only 3 metres wide, which have controlled grazing can reduce nutrient and particulate movement by 90 per cent. Substantial increases in animal production have been reported because pasture production is greatly improved at the times when there is a feed gap.

**Drainage:** Effectiveness depends on soil properties and hydrological processes, and may actually 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.

**Constructed wetlands:** Most effective if used to filter run-off from small agricultural catchments rather than from large areas or point sources or where the ratio of wetlands to catchment area is high.

**On-farm re-use systems:** Effective if nutrient-rich waters are used for irrigating crops. Monitor crops and livestock for possible toxicity.

**Control of water erosion:** Refer to Issue 13, Water Erosion.

**Treating point sources:** Highly effective.

**Controlling eutrophication and algal blooms in on-farm water supplies:** Well-designed sediment traps are effective at reducing dam eutrophication. The other methods treat the symptoms of eutrophication, not the cause. These methods may restrict the subsequent use of water.

## References

Avon River Management Authority (1993) Avon River System Management Strategy.  
 Government of Western Australia.

Dairy Industry Nutrient Strategy Working Group (1998) Environmental management for animal based industries - dairy farm effluent. Agriculture Western Australia, Bulletin 4336.

- Deeley DM, Paling EI, Humphries R (1999) Why south western Australian estuaries are highly susceptible to nutrient enrichment. In Proceedings of the International Conference on Diffuse Pollution. International Association of Water Quality, Perth, Western Australia, 16-20 May 1999.
- Department of Agriculture (2002) Map Unit Database.
- Harris TFW (1996) The Avon: an Introduction. Avon River Management Authority.
- Heady G, Guise N (1994) Streamlining - an environmentally sustainable drainage network for the Swan Coastal Plain (Peel-Harvey Catchment). Western Australian Department of Agriculture, Bulletin 4279.
- Latto A, Noonan JD, Taylor RJ (2000) Environmental guidelines for new and existing piggeries. Agriculture Western Australia, Bulletin 4416.
- Tille P, Mathwin TW, George RJ (2001) The South West Hydrological Information Package. Understanding and managing hydrological issues on agricultural land in the south west of Western Australia. Agriculture Western Australia, Bulletin 4488.
- Water and Rivers Commission (2000) Statewide Water Quality Assessment. Website: [www.wrc.gov.au/under/statewqassess/Avon](http://www.wrc.gov.au/under/statewqassess/Avon).
- Weaver D, Summers R (1998) Soil factors influencing eutrophication. Chapter 7.3 in Soilguide: a handbook for understanding and managing agricultural soils (ed. G Moore). Agriculture Western Australia, Bulletin 4343 pp. 243-250.

## ISSUE 7: REMNANT VEGETATION DECLINE

### Extent

#### *Vegetation cover*

Original vegetation remains on only 30 per cent (7.7 million hectares) of Western Australia's Intensive Land-use Zone (ILZ) (Beeston *et al.* 2002) and two-thirds of that is within State-managed forest reserves. Shepherd *et al.* (2002) assessed 40 per cent of remaining vegetation patches across the agricultural zone, and found that almost half were significantly disturbed and 8 per cent were at risk from rising saline watertables. The greatest risk is in the wheatbelt.

Remnant vegetation in the ILZ of the ARB compares unfavourably to the above figures, having poorer representation and less protected in the public reserve system. Over 85% of the ILZ in the ARB is cleared for agriculture, with native vegetation now covering only 1.086 million hectares. Of this remaining vegetation, only 55% (498,000 ha) is in the public estate (Department of Agriculture 2004). This is summarised in Table 7.1.

**Table 7.1. Area of remnant vegetation in agricultural sub-regions of the ARB (Department of Agriculture 2004)**

Agricultural Sub-region	Total area ('000 ha)	All native vegetation ('000 ha)	% of total area remaining as remnant vegetation	Native vegetation on private land (ha)	
				('000 ha)	%
South-east Lakes	2,018	423	21	92	5.7
Darling Range	224	93	42	4	2.6
Avon Valley	833	49	6	13	1.6
Dale/Upper Avon	169	15	9	8	4.7
Northern Sandplain	738	75	10	30	4.4
Mortlock	1,370	76	5	61	4.6
Carrabin	2,033	296	15	218	12.2
Yealering Lakes	679	42	6	24	3.7
Southern Cross	249	71	29	41	21.9
<b>TOTAL</b>	<b>8,313</b>	<b>1,139</b>	<b>14</b>	<b>491</b>	<b>6.6</b>

#### *Vegetation community distribution*

The distribution of vegetation communities is not uniform. Settlers targeted some communities for clearing because they grew on land considered more valuable and productive. Clearing has reduced the extent of some vegetation more than others. Some vegetation communities are currently 'endangered', meaning that they occupy less than 10% of their original distribution. Others are 'vulnerable' to the risks of extinction, meaning that they occupy less than 30% of their original distribution. ANZECC (2000) defined these classifications and the Environmental Protection Authority (2000) subsequently adopted them.

Analysis of data collated by Shepherd *et al.* (2002) concludes that 109 vegetation communities existed in the ARB prior to clearing (Department of Agriculture 2004). Of these, 32 are 'endangered', 41 are 'vulnerable' and only 36 are 'not at risk', according to accepted classifications. This simplistic 'total count' analysis suggests that two thirds of the ARB's vegetation communities are at risk of decline.

This simple analysis takes no consideration of the viability of individual patches. Such complex study is largely beyond the scope of this report, and methods of establishing patch viability are being debated in the ecological sciences fields, since many factors contribute to the viability or otherwise, of patches (see Land and Water Australia 2005, for an introductory discussion). Furthermore, the concept of viability is difficult to define, as viability will mean different things for different species, which will be different again for various suites of species that operate together as an ecological community.

**Vegetation continuity and size of remnants**

The size of remnant patches is one factor that affects their viability and can be analysed. Large patches with small edge to area ratios are more viable than smaller patches with large edge to area ratios, all other factors being equal. Land and Water Australia (2005) have collated ‘general vegetation management guidelines’ that can assist with setting targets and indicators, and these guidelines are a basis for analysing remnant vegetation continuity and patch size in the Avon River Basin.

Land and Water Australia (2005) state that even patches of 0.5 ha can provide valuable and viable habitat. But the consistent minimum patch size (with 20% understorey) for bird habitat is about 10 ha. Furthermore, bigger remnants are more likely to be valuable for larger fauna, with three studies suggesting that areas of 80, 100 and 150 ha were the minimum viable size for larger animals.

The following analysis has set cut-off values at <1 ha, 1–10 ha, 10–100 ha, 100–1000 ha, and >1000 ha, based on the figures derived from Land and Water Australia. The addition of large areas above 1000 ha is included to show the number of very large contiguous remnant patches within each agricultural sub-region of the Avon River Basin (Table 7.2).

It is important to understand that these cut-off values are somewhat arbitrary, since it is impossible to ascribe one size value for a ‘viable’ patch of remnant vegetation. This is so because the measure of viability depends on the purpose for which the vegetation is being retained, managed or enhanced. For example, a population of small and relatively immobile invertebrates, such as spiders, are likely to require a much smaller vegetation patch than a carnivorous mammal with a large ‘home range’.

**Table 7.2. Number of remnants within the Avon River Basin in each size category (Department of Agriculture 2005)**

Agricultural sub-region	Number of remnants in each size category (ha)					Total number of remnants in each sub-region
	<1	1-10	10-100	100-1000	>1000	
Avon Valley	2,122	2,522	586	51	1	5,282
Carrabin	9,470	5,559	1,511	257	32	16,829
Dale/Upper Avon	1,030	1,056	197	22	1	2,306
Darling Range	2,599	3,964	770	106	7	7,446
Mortlock	11,357	3,296	804	103	5	15,565
Northern Sandplain	56	18	7	1	-	82
South-east Lakes	7,470	6,531	1,396	231	50	15,678
Southern Cross	773	600	156	32	7	1,568
Yealering Lakes	2,697	2,605	571	49	3	5,925
<b>Total number of remnants in each category</b>	37,574	26,151	5,998	852	106	70,681

## Note about data sources used in the vegetation analysis

The vegetation analysis uses a different dataset to the other analyses in this document. The spatial coverage is slightly different, but the total coverage of the datasets varies by less than 2 per cent. These differences are considered insignificant. Note that the total area of land in each sub-region and in the ILZ part of the Avon River Basin is used to analyse remnant vegetation, rather than only the agricultural land, since large tracts of remnant vegetation lie in the public estate. This varies from other analyses in this report, which use only the agricultural land within each sub-region, as most degradation hazards mostly affect agricultural land.

## Impacts

Clearing native vegetation reduces biodiversity in several ways. Firstly, removing the plants directly reduces their population size, thereby reducing genetic diversity of those species for their own survival and for genetic stock for productive use by humans. Secondly, clearing also reduces habitat necessary for other species to survive. Such loss may also impact indirectly on species that rely on the species affected by habitat loss. Thirdly, clearing results in fragmented landscapes that have insufficient natural vegetation resources across various landscapes to support viable populations of many species (Beecham 2002). In these fragmented landscapes, populations of species may be isolated and unable to interchange genetic material, hastening population decline.

Clearing land of native vegetation alters hydrological processes by increasing recharge and ultimately, increasing discharge area. This increased discharge area results in secondary salinity, waterlogging and inundation, particularly in lower landscape areas. Such degradation processes often adversely affect remaining native vegetation in and surrounding these discharge areas.

Ongoing vegetation decline can be attributed to the effects of land salinisation, illegal clearing, unsuitable burning regimes, weed invasion, woodcutting, destructive recreational activities, feral animals and poor management of remnants and surrounding agricultural land including inadequate fencing, stock access, spray drift and fertiliser influx.

## Management options

- 1. Corridors (Recover and Contain):** Protect and connect existing remnant vegetation patches by planting indigenous vegetation along paddock boundaries, drainage lines and shelter belts as corridors (Lefroy *et al.* 1991). Corridors should be as wide as practicable to reduce edge effects (Lambeck 1999).
- 2. Fencing remnants (Recover and Contain):** Control grazing in remnants by fencing them off from stock (Hussey and Wallace 1993). Establish alternative shelterbelts for stock protection.
- 3. Planting buffers (Recover and Contain):** Planting buffers around remnants reduces deleterious effects of normal farm management activities on remnants (edge effects). Buffers help minimise weed encroachment and inputs of nutrients and chemicals.
- 4. Weed control (Recover):** Maintaining intact native vegetation canopies and limiting nutrient inputs reduces the competitiveness of weeds in remnant vegetation. Herbicides should only be used with great caution in remnants, as indigenous plants are often susceptible to their effects. Physical removal and scalping the soil surface are acceptable methods of control for some weeds. Farmnotes relating to this include:

- 37/98: Site preparation for successful revegetation
  - 47/98: Weed control for successful revegetation
5. **Strategic revegetation (Recover):** Targeted revegetation to address specific farm and catchment issues, such as groundwater discharge and recharge.
  6. **Rehabilitation of degraded remnants (Recover):** Reseeding or replanting native species, depending on the availability of seed either on adult plants or in the soil (See previously mentioned Farmnotes)
  7. **Controlling feral animals** such as rabbits, foxes, pigs and cats can improve ecological function of remnants and natural regeneration by reducing direct impacts on vegetation and native animals that help fertilise plants and spread seed.
  8. **One-off, or short term management intervention:** Some form of interceptive 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). 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. **Controlling nutrient imbalances in remnants:** 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).
  10. **Spray drift control:** Chemicals sprayed during normal farm operations can damage remnant vegetation if they drift into remnants. Hussey and Wallace (1993) suggest management options.

## Effectiveness

1. **Corridors:** Effectiveness depends largely on the width of the corridor, with wider corridors being more effective than narrower ones to reduce edge effects (Lambeck 1999). Using drainage lines as corridors will help to limit the effects of flooding, trap sediment, provide habitat and stabilise river banks and this may allow the safe disposal of surface water, where necessary. Corridors of indigenous replantings can connect existing remnants, improving the viability of remnants and providing refuges for flora and fauna to live in and migrate through.
2. **Fencing remnants:** Only effective if stock are totally excluded. Even light grazing causes poor recruitment of woodland and understorey species (Lambeck 1999). Fencing to exclude stock allows native understorey to regenerate and can reduce the competitiveness of weeds that out-compete native species in grazed situations.
3. **Planting buffers:** Can effectively minimise adverse affects of normal farm operations such as chemical drift and nutrient inputs (management options 9 and 10). Buffers are also effective at reducing invasion into remnants that are not yet populated by weeds. The minimum recommended width for buffers is 5 metres of densely planted vegetation (Ocktmann and Holt 2000).
4. **Weed control:** Can be effective if closely monitored and controlled appropriately. Long-term ongoing management of weeds is generally required to minimise the deleterious effects of existing weed invasions. One-off weed management will not improve the long term viability of remnants.



5. **Strategic revegetation:** Most effective for salinity management when used in small problem areas such as sandplain seeps. For biodiversity values, direct seeding most closely mimics a functioning ecosystem. However it is rarely possible to completely reproduce a functioning indigenous ecosystem on previously cleared land (Hobbs *et al.* 1993).
6. **Rehabilitation of degraded remnants:** Passive regeneration of vegetation, especially understorey, by excluding stock and other regeneration pressures, can be effective at improving the value of remnants. Actively re-introducing flora species is more difficult, since it requires a higher level of management intervention (by planting seedlings or direct seeding) and one cannot be sure that representative species or genetic stock have been re-introduced.
7. **Controlling feral animals:** Ongoing management is required to effectively control feral species.
8. **One-off, or short term management intervention:** Highly effective if the treatment addresses a known causative agent in the decline of the remnant vegetation. Otherwise, they can be risky management practice that may cause more harm.
9. **Controlling nutrient imbalances in remnants:** Best managed by planting effective buffers.
10. **Spray drift control:** Best managed by planting effective buffers

## References

- ANZECC (2000) National Framework for the Management and Monitoring of Australia's Native Vegetation. Australian and New Zealand Environment and Conservation Council, Department of Environment and Heritage, Canberra.
- Beecham BC (2002) Biodiversity Synopsis Report for the Avon Wheatbelt 2 Interim Biogeographic Regionalisation of Australia (IBRA) Sub-Region. Department of Conservation and Land Management, Perth. Unpublished report.
- Beeston GR, Hopkins AJM, Shepherd DP (2002) Land-use and vegetation in Western Australia. Resource Management Technical Report 250. Department of Agriculture, South Perth.
- Department of Agriculture (2004) Remnant vegetation database. Data extracted by DP Shepherd.
- Department of Agriculture (2003) West Mortlock Catchment Appraisal. Resource Management Technical Report 239. Department of Agriculture, South Perth.
- Environmental Protection Authority (2000) Environmental Protection of Native Vegetation in Western Australia. Clearing of native vegetation, with particular reference to the agricultural area. Position Statement No. 2. Perth.
- Hobbs RJ, Saunders DA, Main AR (1993) Conservation Management in Fragmented Systems. *In*: RJ Hobbs, DA Saunders (eds) Reintegrating Fragmented Landscapes. (Springer-Verlag: New York Inc.)
- Hussey, BMJ, Wallace KJ (1993) Managing your Bushland. Department of Conservation and Land Management, Perth.

- Lambeck RJ (1999) Landscape Planning for Biodiversity Conservation in Agricultural Regions. Biodiversity Technical Paper No. 2. Department of Environment and Heritage, Canberra.
- Land and Water Australia (2005) <http://www.lwa.gov.au/nativevegetation/managing.asp>
- Lefroy EC, Hobbs RJ, Atkins IJ (1991) Revegetation Guide to the Central Wheatbelt. Bulletin 4231, Department of Agriculture, Perth.
- Ocktmann M, Holt C (2000) Vegetation buffer zones. Farmnote 38/2000. Department of Agriculture, Western Australia, Perth.
- Shepherd DP, Beeston GR, Hopkins AJM (2002) Native vegetation in Western Australia : extent, type and status. Resource Management Technical Report 249. Department of Agriculture, Perth.

## ISSUE 8: SOIL ACIDITY

### Extent

Soil acidity is a widespread problem in the South West agricultural area. According to the National Land and Water Resources Audit (2002), 11 per cent or 2.1 million hectares of surface soil within the South West were strongly acid, with pH <4.8. Another 78 per cent or 15 million hectares had pH between 4.8 and 5.5.

Soil acidity is most prevalent in sandy soils with a low capacity to buffer pH change. It occurs naturally in some soils in the south-west of WA and accelerates under some farming practices, including adding acid fertilisers, product removal and leaching of nitrate (Dolling *et al.* 2001). Identifying and ameliorating acidity at the surface has rapidly increased in WA, due in large part to Department of Agriculture extension programs. However, identifying and remediating subsoil acidity (10-30 cm) is still not common among farmers. Cost effective techniques for remediating subsoil acidity are still being developed and trialled. (Chris Gazey, pers comm). Surface and subsurface pH estimates in Table 8.1 are based on the qualified Soil Groups allocated to the Department of Agriculture’s soil-landscape mapping.

**Table 8.1. Extent of acid topsoil and subsoil and soil at high risk of acidification in agricultural sub-regions of the ARB (Department of Agriculture 2002)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Topsoils currently strongly acid (pH <sub>Ca</sub> <4.5 at 0-10 cm)		Subsoils currently strongly acid (pH <sub>Ca</sub> <4.5 at 50-80 cm)		Soils with high risk of subsurface acidification	
		'000 ha	%	'000 ha	%	'000 ha	%
South-east Lakes	1,604	>1	>0.1	1	> 0.1	297	18.5
Darling Range	148	3	1.7	2	1.0	53	36
Avon Valley	813	8	1.0	3	0.4	373	45.8
Dale/Upper Avon	163	1	0.8	1	0.7	93	57
Northern Sandplain	687	10	1.4	64	9.4	356	51.8
Mortlock	1,326	9	0.7	21	1.6	471	35.5
Carrabin	1,794	31	1.7	49	2.8	457	25.4
Yealering Lakes	661	7	1.0	>1	0.1	243	36.8
Southern Cross	189	> 1	0.2	3	1.3	19	10.2
<b>TOTAL</b>	<b>7,387,</b>	<b>70</b>	<b>1.0</b>	<b>145</b>	<b>2.0</b>	<b>2,363</b>	<b>32.0</b>

### Impacts

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

- Increasing the availability of the toxic elements, especially aluminium (manganese toxicity due to low pH has not been observed in WA);
- Decreasing the availability of nutrients such as phosphorus, potassium, calcium, magnesium, molybdenum and copper;
- Reducing the rate of some microbial activity, for example, microbes involved in the decomposition of organic matter that supplies nitrogen, phosphorus and sulphur; and
- Increasing the rate of some fungal activity, resulting in increased diseases of plants, although some fungal diseases can decrease, for example, ‘take all’.

Information is lacking about off-site impacts and further study is required. However, soil 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 soil clay minerals, hence reduced fertility;
- Declining pH of waterways and aquatic environments, and;
- Increased infrastructure cost as a result of increased salinity, waterlogging, flooding and sediment on roads and in drains;

## Management options

Management options are summarised on pages 128-140 of 'Soil Guide' (Moore *et al.* 1998).

1. **Adding alkaline reagents (Recover and Contain):** Adding lime as top dressings (to increase surface soil pH) and by banding or incorporating at depth (to increase subsoil pH) is the major management recommendation. Other alkaline reagents (e.g. fly ash from cement kilns, dolomite) are alternatives.
2. **Reduce rate of acidification (Contain):** Several management methods will reduce the rate of acidification. Firstly, reducing the rate of product removal from the paddock will reduce the rate of acidification by reducing the export of cations (which are replaced by hydrogen ions [acid] in the soil). An example is to restrict the highly acidifying operation of hay cutting to alkaline soils and to distribute hay as feed on to acid paddocks. Secondly, reducing or removing the input of acidifying fertilisers (ammonium-based nitrogen and elemental sulphur) will decrease acidification rates. Thirdly, reducing or stopping nitrate leaching will decrease acidification rates. This can be achieved by reducing or splitting nitrogen applications to the amount crops can realistically use and by planting perennials that draw on nitrate, water and alkaline nutrient reserves from deeper in the soil profile than annual plants are able to.
3. **Plant acid-tolerant species (Adapt):** Species and varieties that can tolerate lower pH can maintain profitability over the short-term. This strategy can be used in conjunction with amelioration.

## Effectiveness

1. **Adding alkaline reagents:** Proven effective and economically viable for surface acidity, and also effective at ameliorating subsurface acidity with time (Tang and Rengel 2001). Surface liming is effective at maintaining appropriate pH in the subsurface if liming occurs before significant acidity develops. The effectiveness of using alkaline reagents to ameliorate subsoil acidity is currently being investigated. Other alkaline reagents are effective, e.g. fly ash from cement kilns, dolomite, but are often not as economically viable, nor are they available in the large quantities required to ameliorate acidity on farming land.
2. **Reduce rate of acidification:** Can be effective as part of an integrated solution, in conjunction with adding alkaline reagents. It is a valuable management tool, but alone is unable to prevent soil acidification.
3. **Plant acid tolerant species:** A short-term measure only, ineffective at reversing acidification as it allows soil acidification to continue to occur.

## References

Department of Agriculture (2002) Map Unit Database.

Dolling PJ, Moody P, Noble A, Helyar K, Hughes B, Reuter D, Sparrow L (2001) Report to the National Land and Water Resources Audit: Soil Acidity and Acidification.

Moore G, Dolling P, Porter B, Leonard L (1998) Soil acidity. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore.) Agriculture Western Australia, Bulletin 4343 pp. 127-140.

National Land and Water Resources Audit (2002)

[http://audit.ea.gov.au/anra/atlas\\_home.cfm](http://audit.ea.gov.au/anra/atlas_home.cfm) Agriculture Assessment 2001

[http://audit.ea.gov.au/anra/agriculture/docs/national/Agriculture\\_Contents.html](http://audit.ea.gov.au/anra/agriculture/docs/national/Agriculture_Contents.html)

Tang C, Rengel Z (2001) Liming and reliming enhance barley yield on acidic soil. *In*: Soil Acidity Research Development and Extension Update 2001. Department of Agriculture, Western Australia. Bulletin 4059 pp 1-4.

## ISSUE 9: SOIL FERTILITY DECLINE

### Extent

The native soils of Western Australia are some of the most inherently infertile in the world. Consequently, the fertility of many agricultural soils has substantially increased by adding chemical fertilisers and organic matter from crop and pasture residues. However, not maintaining soil fertility at recommended levels threatens agricultural productivity.

The rate of potential nutrient decline varies with the type and intensity of land use, because nutrient requirements and product removal vary significantly between agricultural land uses. Agricultural activities can only continue over the long-term if the nutrient status of soils is maintained or improved. Natural inputs and fertiliser additions both replace nutrients exported in agricultural products. While no comprehensive data on the extent of soil fertility decline is available, generalised assessments of farm-gate nutrient balances and organic carbon ranges are available for the South West (Australian Natural Resources Atlas 2001).

**Table 9.1. Generalised assessments of farm-gate nutrient-balance for two broad land-uses within Western Australia's agricultural zone (negative means that inputs < exports; neutral means that inputs = exports; positive means that inputs > exports)**

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

(Australian Natural Resources Atlas 2001.)

**Table 9.2. Estimated area of agricultural land, partitioned by arbitrary ranges of soil organic carbon per cent, in the south-west of Western Australia.**

Soil carbon range	<0.5 %	0.5-0.75%	0.75-1.0%	1-1.5%	1.5-2%	2-4%	>4%	Total area
Area (km <sup>2</sup> )	900	36,400	54,700	61,100	15,800	27,900	4	196,700

(Australian Natural Resources Atlas 2001.)

Erosion events cause acute nutrient loss. Leaching and surface water run-off can also cause substantial losses. Some nutrients are affectively 'lost' when they are fixed in, or to, organic matter and soil minerals, thereby becoming unavailable to plants. The availability of each plant nutrient varies with the pH of the soil. Some become toxic at low pH, others become unavailable. Conversely, some become toxic at high pH and others become unavailable.

### Impacts

Depletion of nutrients from fertile paddocks will eventually reduce yields and decrease the productivity and quality of future crops and pastures. Nitrate leaching causes soil acidification and nitrification of groundwater. Declining fertility is linked to decline in soil structure, increased erosion and secondary salinity. Run-off containing nitrogen and phosphates can pollute waterways and groundwater.

## Management options

Nutrient management has moved soil fertility beyond the 'build up' phase into a 'maintenance' phase over much of Western Australia's intensive agricultural region. Site-specific nutrient management now commonly replaces broad district fertiliser guidelines. Early diagnosis and treatment of soils with marginal nutrient(s) status is likely to be more productive and profitable in the long-term than depleting nutrient reserves for short-term profits.

1. **Monitoring:** Know the nutrient, organic carbon and pH status of the soil.
2. **Make appropriate fertiliser decisions (Adapt):** Base decisions on analyses appropriate to the nutrient or nutrients in question. For example, soil tests may be adequate for some macro-nutrients, whereas tissue tests are likely to be required for some micro-nutrients. Where possible, diagnose marginal or inadequate nutrient status by comparing tissue tests of plants grown in high-nutrient areas such as windrows to tissue tests of plants grown elsewhere across the paddock. The ability to recognise/ diagnose deficiency (and toxicity) symptoms in plants and animals is valuable. Ensure laboratory tests follow standard and accepted practices.
3. **Additions (Adapt):** Add fertilisers and soil ameliorants that supply essential plant nutrients, based on appropriate decision-making processes. Such additions will improve the soil chemically and physically. Use legumes to increase soil nitrogen.
4. **Organic matter content (Recover):** Follow pasture and cropping management recommendations to maintain and build on levels of organic matter.
5. **Soil erosion (Contain):** Reduce or prevent erosion to lower acute losses of nutrients.
6. **Water management (Contain):** Decrease leaching and run-off.

## Effectiveness

1. **Monitoring:** Regular monitoring can identify nutrient imbalances, pH and organic carbon status, which can help determine the appropriate management. Monitoring alone does not solve nutrient decline issues.
2. **Fertiliser decisions:** Anticipate fertility problems so that appropriate and timely steps can be made to address them. Losses become critical when the paddock soils are already marginal or deficient in nutrients.
3. **Soil 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, to soils.
4. **Organic matter content:** Soil organic matter can be maintained or improved by maximising pasture and crop residues (within stubble management capabilities).
5. **Soil erosion:** Improved pastures and stubble residues provide effective ground cover protection for soil, reducing erosion risk.
6. **Water management:** Crops and pastures fertilised correctly use more water than those that are nutrient deficient.

## References

Australian Natural Resources Atlas (2001) Farm Gate Nutrient Balances.  
[www.audit.ea.gov.au/ANRA/land](http://www.audit.ea.gov.au/ANRA/land).

## ISSUE 10: SOIL STRUCTURE DECLINE

### Extent

Soil structural instability affects about 3.5 million hectares of the South West agricultural region (Hunt and Gilkes 1992). Crusting and hardsetting is most common in medium and fine textured surface soils with clay content between 10 and 35 per cent. A high proportion of such soils in WA have inherent chemical properties deleterious to stable structure, with high exchangeable sodium percentages (sodic soils), Ca:Mg ratios that decrease with depth down the profile and low organic matter content. Management practices strongly influence structural decline. These variables preclude the collation of comprehensive data on the actual extent of soil structure decline. Estimates in Table 10.1 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 10.1. Susceptibility of soils to structural decline in agricultural sub-regions of the ARB (Department of Agriculture 2002)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Soils with high susceptibility to structural decline		Soils with moderate and high susceptibility to structural decline	
		('000 ha)	%	('000 ha)	%
South-east Lakes	1,604	<1	<0.1	287 <sup>A</sup>	17.9
Darling Range	148	-	-	2	1.4
Avon Valley	813	1	0.2	49	6.0
Dale/Upper Avon	163	-	-	1	0.9
Northern Sandplain	687	<1	< 0.1	22	3.2
Mortlock	1,326	2	0.2	80	6
Carrabin	1,794	6	0.3	239	13.3
Yealering Lakes	661	-	-	17	2.6
Southern Cross	189	< 1	0.2	61	32.0
<b>TOTAL</b>	<b>7,387,</b>	<b>10</b>	<b>0.1</b>	<b>758</b>	<b>10</b>

<sup>A</sup> Anecdotal evidence and local experience suggest that the area at moderate risk is an over-estimate.

The most extensive areas susceptible to structural decline are in the Carrabin, Mortlock and South-east Lakes sub-regions. Although the most susceptible areas identified are listed only as 'moderate' risk, significant degradation is likely to have occurred due to past higher tillage and stocking practices.

### Impacts

Soil structure decline can affect the productive capacity of agricultural land in the following ways:

- *Reduced infiltration* results in less plant available water, which adversely affects yield.
- *Poor workability* increases the cost 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 affects crop growth by restricting the oxygen supply in the rooting zone.
- *Reduced trafficability* can affect the timing of operations, such as spraying and seeding.

See Needham *et al.* (1998) for further details.

Some impacts of soil structure decline may cause limited off-site degradation. Reduced infiltration increases run-off from the soil surface. Where run-off water and eroded material enter streams, increased sedimentation and eutrophication may result. If run-off water does not reach flowing streams and also does not infiltrate, it will accumulate in depressions and evaporate, causing secondary salinity over time. The off-site degradation issues caused by soil structure decline are most likely to be realised in higher rainfall and higher relative relief areas (Zones 256 and 257). Remedying soil structure decline in these areas is most likely to deliver public benefits.

### Management options

The principal strategy to maintain good structure in surface soils is to reduce the impact of deleterious management practices. Remedial management to restore soils with degraded structure to good condition may precede this strategy (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).

General options include:

1. **Monitor** and assess current condition using the methods listed in the above references.
2. **Minimise tillage (Recover and Contain)** 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 stock damage and trampling (Contain)** by reducing stock numbers on susceptible soils when they are wet.
4. **Increase organic matter (Recover)** as a food source for soil biota that improve structure and to provide a long-term binding agent
5. **Retain stubble (Recover and Contain)** to protect against raindrop impact.
6. **Apply gypsum (Recover)** to increase clay flocculation and improve the calcium status of the soil.
7. **Deep ripping (Recover)** plus gypsum application is necessary if the soil is also compacted.

A combined package using some or all of the above components has been developed for soils of the eastern wheatbelt (Hamza and Anderson 2002, 2003; Hamza and Penny 2002).

### Effectiveness

Minimising tillage by direct drilling has significant economic advantages to cultivation/seeding operations on susceptible soils in the northern wheatbelt (Blackwell *et al.* 2001). The benefits of no-till are 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). These experiments suggest that rainfall

infiltration rates increase as yield increases. The benefits extended several seasons after treatment in heavier soils.

No-till sowing increases infiltration significantly compared to multiple tillage. This reduces the potential for water erosion significantly on some soils but may increase the potential for recharge (see Bligh 1998).

## References

- Blackwell P, Nicholson D, Jones M (2001) No-till wheat trial results, on hardsetting valley floor loams at Morawa and Mullewa 1995.
- Bligh K (1998) Contour no-till sowing minimises water erosion. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore). Agriculture Western Australia, Bulletin 4343 p. 239.
- Department of Agriculture (2002). Map Unit Database.
- Hamza M, Penny S (2002) Treatment of compacted soils in the Eastern wheatbelt. Farmnote 26/2002, Department of Agriculture, Western Australia.
- Hamza MA, Anderson W (2002) Improving soil fertility and crop yield on a clay soil in Western Australia. *Aust. J. Agric. Res.* **53**, 615-620.
- Hamza MA, Anderson W (2003) Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. *Aust. J. Agric. Res.* **54**, 273-282.
- Hoyle F (2001) The role of cover cropping in renovating poor performing paddocks: a case study. In Crop updates 2001: Farming systems. Department of Agriculture, Western Australia.
- Hunt N, Gilkes B (1992) Farm Monitoring Handbook. The University of Western Australia.
- Needham P, Moore G, Scholz G (1998) Soil structure decline. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore). Agriculture Western Australia, Bulletin 4343 pp. 64-79.

## ISSUE 11: SUBSURFACE COMPACTION

### Extent

Subsoil compaction can occur in different soil types and climatic conditions. However, susceptibility is reduced in strongly structured soils, well-drained soils with high organic matter content and in drier regions where 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 is 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 highly susceptible to subsurface compaction in agricultural sub-regions of the ARB (Department of Agriculture 2002)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Soils with high subsurface compaction susceptibility	
		('000 ha)	%
South-east Lakes	1,604	408	25.4
Darling Range	148	78	53.0
Avon Valley	813	327	40.1
Dale/Upper Avon	163	80	48.8
Northern Sandplain	687	400	58.2
Mortlock	1,326	693	52.2
Carrabin	1,794	727	40.5
Yealering Lakes	661	289	43.7
Southern Cross	189	27	14.1
<b>TOTAL</b>	<b>7,387</b>	<b>3,031</b>	<b>41.0</b>

This analysis indicates that a large part of the ARB has soils that are susceptible to subsurface compaction. Nearly half of the area at risk lies in the Carrabin and Mortlock sub-regions where uniform coarse-textured soils dominate. In terms of potential impact, the Northern Sandplain has the greatest proportion of soils at risk.

### Impacts

The main cause of subsoil compaction on tilled soils is wheeled vehicular traffic, especially heavy machinery. Compaction can also occur due to trampling by stock, particularly on wet soils, and the development of plough pans. The principles are summarised by Needham *et al.* (1998).

Subsoil compaction influences plant growth by:

- decreasing soil pore size and continuity;
- decreasing root penetration and density;
- reducing access to moisture and nutrients; and
- predisposing the crop to waterlogging and soil pathogens.

The effect of compaction on crop growth is complicated by different responses from various species and cultivars.

## Management options

Ameliorating subsurface compaction can greatly increase yield (Jarvis and Porritt 1985).

1. **Deep Ripping (Recover):** Deep cultivation can loosen subsurface layers. See page 124 of 'Soilguide' (Needham *et al.* 1998) for a decision tree on managing subsurface compaction using deep ripping.
2. **Controlled traffic (Adapt and Contain):** Still in development. This has become a practical option 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 (Contain):** Defer grazing, reduce stocking rates or remove stock altogether from soils at risk, particularly when susceptible soils are wet (Needham *et al.* 1998).

## Effectiveness

1. **Deep ripping:** Useful for many compacted soils. Important complementary management involves applying or incorporating gypsum at the time of deep ripping to re-aggregate the ripped soil. Deep ripping is not recommended alone (Needham *et al.* 1998). On duplex soils where the topsoil is > 30 cm deep the soil responds similarly to uniform coarse textured soils. Where the A horizon is <30 cm deep subsoil properties may override any deep ripping effects (see Hamza and Anderson 2002, 2003).
2. **Controlled traffic:** Benefit relates to confining traffic to tramlines and avoiding compaction between the tramlines (Blackwell 1988). The confinement of compaction to tramlines has the benefit of increasing the effectiveness of deep ripping. Benefits also include reduced overlap, saving on inputs (Blackwell 1998).
3. **Stock control:** 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 can help reduce the degree of structural damage to fragile surface soils (Needham *et al.* 1998).

## References

- Blackwell P (1998) Controlled traffic for reduced compaction and inputs. Crop Updates 1998. Data retrieved February 2002, from:  
<http://www.agric.wa.gov.au/cropupdates/1998/cereals/traffic.htm>.
- Department of Agriculture (2002) Map Unit Database.
- Hamza MA, Anderson W (2002) Improving soil fertility and crop yield on a clay soil in Western Australia. *Aust. J. Agric. Res.* **53**, 615-620.
- Hamza MA, Anderson W (2003) Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. *Aust. J. Agric. Res.* **54**, 273-282.
- Jarvis RJ, Porritt SE (1985) Soil compaction and its effect on wheat yield. Australian Field Crops Newsletter **20**, 122-25.
- Needham P, Moore G, Scholz G (1998) Subsurface Compaction. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore). Agriculture Western Australia, Bulletin 4343 pp. 116-124.

## ISSUE 12: SURFACE WATER SUPPLY SHORTAGES

### Extent

Low rainfall has the greatest impact on rural water supply, as it is the origin of all on-farm water supplies. The Northern Sandplain, Carrabin, Mortlock, Southern Cross, Yealering Lakes and South-east Lakes sub-regions are the most affected due to a combination of variable rainfall, generally below 350 mm/yr, high evaporation rates (upwards of 1800 mm/yr) and catchments containing large areas of land affected by salinity.

Tille *et al.* (2001) outlined seven factors that influence surface water supply shortages:

- Unseasonally low rainfall, with compounding effects over consecutive years;
- Poor water quality caused by salinity, acidity or other pollutants;
- Lack of run-off in small catchments, on highly permeable soils, where dense vegetation remains and where tillage has decreased and cropping is the dominant land-use;
- Insufficient harvesting structures, such as roaded catchments and banks;
- Inadequate capacity of water harvesting and storage structures;
- Sedimentation of water storage structures after erosion events; and
- Losses during storage due to evaporation and leaking storage structures.

### Impacts

Acute water shortages in the ARB mostly affect rural communities, the agricultural industry and infrastructure. Ecosystems present prior to European settlement had adapted to cope with large seasonal variations. However, other degradation processes have degraded natural surface water storages, thus making low rainfall years problematic for native flora and fauna. For example, the extent and volume of perennial pools in waterways has reduced because of increased sedimentation. Some pools now dry up in low-rainfall years.

Agricultural impacts include:

- Reduction or dispersal of livestock to match water availability;
- Death of livestock through bogging in dam sediments at low water levels;
- Increased costs to farm businesses and the community caused by greater use of the central water supply scheme;
- Damage to roads caused by carting water for stock and households. Such damage increases the cost of road maintenance and thus shire rates, and decreases amenity for those living on degraded roads;
- Reduction in area or crop failure, particularly those irrigated from locally-sourced water;
- Increased costs to farm businesses through forced sales, water carting and reduced production;
- Decreased amenity for rural communities, caused by declining quality of parks, gardens and sports grounds.

## Management options

1. **Appropriate water supply planning, risk analysis and regular review (Recover):** Ensuring that water supplies meet the needs of the farming enterprise by good design, and construction of infrastructure.
2. **Correctly locating water supply and storage structures (Recover)** to reduce the chance that rising saline watertables will affect them and to improve performance of water supply schemes by generating run-off from small rainfall events.
3. **Maintaining existing water supply structures (Recover)** by regularly de-silting storage structures and maintaining banks and roaded catchments to harvest water.
4. **Implementing integrated landcare techniques (Recover)** to improve water harvesting, while addressing recharge, water and wind erosion and waterlogging.

## Effectiveness

The management options were developed through research, demonstration and land owner experience. They can greatly improve farm water supply schemes. However, the level of input from professional water supply planners often determines the implementation of effective and reliable water supplies.

## References

Tille PJ, Mathwin TW, George RJ (2001) The South West Hydrological Information Package - Understanding and managing hydrological issues on agricultural land in the south west of Western Australia. Agriculture Western Australia, Bulletin 4488.

## ISSUE 13: WATER EROSION

### Extent

The nature of soils, landforms and vegetative cover, in conjunction with land management practices and heavy rainfall events, determines erosion distribution. Sheet and rill erosion most commonly occurs on steep land that has been heavily grazed or cultivated over the spring and summer, leaving the soil surface exposed and prone to erosion when rain falls. Gully erosion occurs where surface water concentrates into flowlines, such as natural depressions, sheep and wheel tracks, cultivation and rip lines, and coalescing rills. The most severe erosion events occur during heavy rainfall when soils are bare and loose due to cultivation or grazing. Accelerated erosion also occurs on areas affected by salinity and waterlogging, as these areas are less able to sustain plant growth that can protect the surface soil from raindrop impact and scouring by run-off.

Hilly landscapes of the ARB are most seriously affected by soil erosion, especially in the higher rainfall areas under management practices of conventional cultivation (several passes) and stubble burning.

While severe gully or rill erosion may leave long-term scars on the land 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 largely disappeared from the erosion site by the following season. In these circumstances, telltale signs are deposits of sediments down-slope of the eroded areas. These deposits often accumulate around fences, trees and shrubs at lower paddock margins.

The following estimates of erosion hazard are based on the land units allocated to the Department of Agriculture's soil-landscape mapping:

**Table 13.1. Water erosion hazard in agricultural sub-regions of the ARB (Department of Agriculture 2002)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Soils with very high to extreme water erosion hazard <sup>A</sup>		Soils with high to extreme water erosion hazard <sup>A</sup>	
		('000 ha)	%	('000 ha)	%
South-east Lakes	1,604	6	0.4	40	2.5
Darling Range	148	8	5.4	12	7.9
Avon Valley	813	33	4.1	62	7.7
Dale/Upper Avon	163	8	5.0	8	5.0
Northern Sandplain	687	10	1.5	27	3.9
Mortlock	1,326	38	2.9	77	5.8
Carrabin	1,794	47	2.6	82	4.6
Yealering Lakes	661	8	1.2	23	3.6
Southern Cross	189	< 1	0.2	1	0.6
<b>TOTAL</b>	<b>7,387</b>	<b>158</b>	<b>2.1</b>	<b>336</b>	<b>4.5</b>

<sup>A</sup> Land with a high risk of water erosion includes soils that are currently affected by waterlogging.

Across the ARB, the average soil loss through sheet erosion ranges from 6.6 t/ha/yr in the wheatbelt to 9.8 t/ha/yr in the woolbelt (George 2001). Sheet and rill erosion is evident in some western areas, especially in steeper catchments of the Dale, Avon and West Mortlock. In the wheatbelt, erosion is most common below large rock outcrops, mallet hills and breakaways, especially on hardsetting loams or clays.

Table 13.1 shows that areas with a very high to extreme erosion hazard are the steeper landscapes of the Darling Range, Dale/Upper Avon and Avon Valley. These sub-regions also have significant areas of high erosion hazard. Mortlock, Carrabin and Yealering Lakes sub-regions have significant areas at high risk of water erosion.

## 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, waterways, culverts and roads, which may exacerbate flooding and salinity by obstructing flow lines;
- contributes to eutrophication of water bodies;
- reduces trafficability of paddocks; and
- can threaten infrastructure such as roads and fences.

## Management options

Water erosion is often best managed as part of an integrated package that also combats waterlogging, salinity, flooding, wind erosion and nutrient loss. Management options are detailed on pages 239-242 of 'Soilguide' (Coles and Moore 1998) and pages 186-194 of the 'South West Hydrological Information Package' (Tille *et al.* 2001).

1. **Farm layout (Recover and Contain):** Realigning fences, tracks, stock watering points, gateways and laneways to isolate areas of high erosion risk and to avoid channelling run-off.
2. **Maintaining vegetative cover (Recover):** Prevent erosion by establishing perennial vegetative cover, maximising productivity of annual crops, retaining stubble and trash in broadacre crops, and using cover crops, to maintain adequate vegetative cover.
3. **Stock control (Contain):** Manage grazing pressure so that paddocks are not denuded and soils are not disturbed by livestock when waterlogged or susceptible to erosion.
4. **Cross-slope cultivation (Contain):** Crop along the contour or at a slight gradient to slow run-off.
5. **Reduced tillage (Recover and Contain):** Improve soil stability by converting to minimum or no tillage cropping systems.
6. **Soil conservation earthworks (Recover and Contain):** Intercept run-off and effectively reduce slope length by constructing contour sills, grade banks, broad-based banks and interceptor drains.
7. **Waterways (Recover and Contain):** Remove run-off safely using constructed or natural waterways.



8. **Gully control (Recover and Contain):** Control and rehabilitate erosion gullies with gully head sills, flumes, hay bales, drains and gully filling.
9. **Reducing waterlogging (Recover and Contain):** Reduce waterlogging to reduce erosion risk, as saturated soils are more prone to water erosion.

### Effectiveness

1. **Farm layout:** Essential for the 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 broad-acre cropping areas.
6. **Soil conservation earthworks:** Essential, if earthworks are correctly designed and selected to match the land use, topography and soils.
7. **Waterways:** Well-designed and maintained grassed waterways are essential for disposing of excess water.
8. **Gully control:** Only applicable where gully formation has already started.
9. **Reducing waterlogging:** Can contribute to erosion control where waterlogging is a contributing factor.

### References

Coles N, Moore G (1998) Run-off and water erosion. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore). Agriculture Western Australia, Bulletin 4343 pp. 223-242.

Department of Agriculture (2002) Map Unit Database.

Tille PJ, Mathwin TW, George RJ (2001) The South West Hydrological Information Package – Understanding and managing hydrological issues on agricultural land in the south west of Western Australia. Agriculture Western Australia, Bulletin 4488.

George RJ (2001) WA soil erosion under investigation. *Journal of Agriculture* Vol. 42, Department of Agriculture, Western Australia.

## ISSUE 14: WATERLOGGING

### Extent

Waterlogging is most significant and frequent in areas of low relief and in low landscape positions that receive more than 400 mm annual rainfall (western ARB). Many soils are only affected by subsoil waterlogging which is not readily visible and so the true extent is often underestimated (all areas). In the lower rainfall areas of the ARB, very large areas face high risk of waterlogging due to poor internal drainage characteristics of duplex soils and low gradients that cause poor external drainage. However, the actual occurrence is less frequent than in higher rainfall areas because rainfall events delivering water in excess of internal and external drainage capabilities rarely occur.

Although satellite imagery can be used to assess the seasonal extent of waterlogging, no comprehensive mapping has been conducted across the agricultural area. The following estimates are based on the land units allocated to the Department of Agriculture's soil-landscape mapping. The risk analysis is based on the methods of van Gool *et al.* (2001)

**Table 14.1. Waterlogging risk in agricultural sub-regions of the ARB (Department of Agriculture 2002)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Land with high to very high risk of waterlogging <sup>1</sup>		Land with moderate to very high risk of waterlogging <sup>2</sup>	
		('000 ha)	%	('000 ha)	%
South-east Lakes	1,604	80	5.0	401	25.0
Darling Range	148	6	4.1	14	9.2
Avon Valley	813	40	4.9	179	22.0
Dale/Upper Avon	163	5	3.0	28	17.1
Northern Sandplain	687	8	1.1	82	11.9
Mortlock	1,326	65	4.9	349	26.3
Carrabin	1,794	49	2.7	422	23.5
Yealering Lakes	661	28	4.2	93	14.1
Southern Cross	189	6	3.0	51	27.2
<b>TOTAL</b>	<b>7,387</b>	<b>345</b>	<b>4.7</b>	<b>1,717</b>	<b>23.3</b>

### Impacts

The impacts of waterlogging are summarised on pages 155-157 of the 'South West Hydrological Information Package' (Tille *et al.* 2001), pages 96-97 of 'Soilguide' (Moore and McFarlane 1998) and Setter and Belford (1990).

Waterlogging can have major effects on plants, farm productivity and landscape functionality because it:

- deprives the roots of oxygen;
- exacerbates the effects of salinity on plants;
- reduces crop and pasture productivity;
- 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 some weed species with a competitive advantage;
- reduces the area suitable for horticultural development; and
- reduces trafficability of the land (machinery and vehicles get bogged).

## Management options

Management for waterlogging is best implemented as part of an integrated package to combat salinity, flooding, water erosion and/or nutrient loss.

1. **High water use farming systems (Contain and Adapt):** Reduce the incidence and/or severity of waterlogging periods by planting high water use pasture, crops and trees upslope of areas prone to waterlogging. This action may also reduce recharge. See pages 111-121 of the 'South West Hydrological Information Package' (Tille *et al.* 2001).
2. **Tolerant crops and pastures (Adapt):** Plant crops and pastures tolerant to waterlogging - see pages 159-61 of the 'South West Hydrological Information Package' (Tille *et al.* 2001).
3. **Soil management (Recover and Contain):** Increase water percolation through the soil profile by improving soil structure – see section on soil structure decline.
4. **Shallow surface drains (Recover and Contain):** Install spoon drains, spinner drains or W-drains to remove surface water - see page 162 of the 'South West Hydrological Information Package' (Tille *et al.* 2001) and McFarlane *et al.* (1990).
5. **Bedding and mounding (Contain):** Install raised beds to lift plant roots above saturated soil - see page 162 of the 'South West Hydrological Information Package' (Tille *et al.* 2001).
6. **Interceptor drains and banks (Contain):** Divert water away from waterlogged areas by constructing grade banks or seepage interceptor drains upslope - see pages 163-164 of the 'South West Hydrological Information Package' (Tille *et al.* 2001) and McFarlane and Cox (1990).
7. **Deep open drains (Contain):** Remove subsoil water with open drains (60-250 cm deep) - see page 165 of the 'South West Hydrological Information Package' (Tille *et al.* 2001).
8. **Subsoil drainage (Contain):** Install 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:** Effectiveness varies according to the system and seasonal variation. Such systems can dry out the profile and contribute to reduced incidence or severity of waterlogging in future years. They are best used in conjunction with other management options.
2. **Tolerant crops and pastures:** This is primarily an adaptation to changed environmental conditions. Increased water use by plants can marginally reduce waterlogging extent and severity.

3. **Soil management:** Effective only where waterlogging is due to surface ponding on 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 through-flow in the topsoil contributes to waterlogging downslope.
7. **Deep open drains:** Effectiveness is variable and depends on soil type. Deep open drains are most effective where they intercept highly permeable layers in stable soils.
8. **Subsoil drainage:** Can be very effective but usually only cost efficient in areas of intensive agriculture.

## References

- Bakker D, Hamilton G, Tipping P, Spann C, Rowe D (1999) Results of improved soil management and cropping systems for waterlog-prone soils - 1998 season. Agriculture Western Australia. Resource Management Technical Report 191.
- Bakker D, Hamilton G, Houlbrook D, Spann C (2001) Improved soil management and cropping systems for waterlog-prone soils - Results of the 1999 season. Agriculture Western Australia Resource Management Technical Report 194.
- Bakker D, Hamilton G, Houlbrook D, Spann C (2002) Improved soil management and cropping systems for waterlog-prone soils - Results of the 2000 season. Department of Agriculture Resource Management Technical Report 229.
- Department of Agriculture (2002) Map Unit Database.
- McFarlane DJ, Cox J (1990) Seepage interceptor drains for reducing waterlogging and salinity. *Journal of Agriculture Western Australia* **31**, 66-69.
- McFarlane DJ, Negus T, Ryder A (1990) Shallow drains for reducing waterlogging and salinity on clay flats. *Journal of Agriculture Western Australia* **31**, 70-73.
- Moore G, McFarlane D (1998) Waterlogging. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore). Agriculture Western Australia, Bulletin 4343 pp. 94-107.
- Setter T, Belford B (1990) Waterlogging: how it reduces plant growth and how plants can overcome its effects. *Journal of Agriculture Western Australia* **31**, 51-55.
- Tille PJ, Mathwin TW, George RJ (2001) The South West Hydrological Information Package - Understanding and managing hydrological issues on agricultural land in the south west of Western Australia. Agriculture Western Australia, Bulletin 4488.
- van Gool D, Tille P, Moore G (2001) Guidelines for assessing land qualities and determining land capability in south-west Western Australia, Resource Management Technical Report 181. Agriculture Western Australia.

## ISSUE 15: WIND EROSION

### Extent

Wind erosion is most common on loose coarse, dry surfaced soils (most typically sandy soils) in landscape positions exposed to strong winds (such as crests).

Most erosion occurs in episodic events. Evidence of wind erosion is usually observable during and immediately after a particular event, but is usually much less clear by the following season. Therefore, it is very difficult to measure the current extent of erosion. The following estimates of hazard are based on the land units allocated to the Department of Agriculture's soil-landscape mapping.

**Table 15.1. Wind erosion hazard in agricultural sub-regions of the ARB (Department of Agriculture 2002)**

Agricultural Sub-region	Area of agricultural land ('000 ha)	Soils with very high to extreme wind erosion susceptibility		Soils with high to extreme wind erosion susceptibility	
		('000 ha)	%	('000 ha)	%
South-east Lakes	1,604	125	7.8	265	16.5
Darling Range	148	<1	0.2	35	23.9
Avon Valley	813	15	1.9	228	28.0
Dale/Upper Avon	163	3	1.8	53	32.2
Northern Sandplain	687	33	4.8	101	14.8
Mortlock	1,326	28	2.1	291	21.9
Carrabin	1,794	21	1.2	235	13.1
Yealering Lakes	661	24	3.7	212	32.0
Southern Cross	189	<1	<0.1	43	22.7
<b>TOTAL</b>	<b>7,387</b>	<b>251</b>	<b>3.4</b>	<b>1,465</b>	<b>19.8</b>

The South-east Lakes, Yealering Lakes and Northern Sandplain have the greatest areas that are highly susceptible to wind erosion. The low rainfall here contributes to a greater risk of inadequate stubble or pasture cover over summer and autumn, which greatly increases the susceptibility of a landscape to wind erosion.

### Impacts

The environmental and agricultural impacts of wind erosion can include the following (from Moore *et al.* 1998 and Penny 1999):

- Loss of soil;
- Loss of macro and micro-nutrients;
- Long-term loss of productivity;
- Loss of pasture seed bank;
- Atmospheric pollution;
- Sand blasting damage to crops;
- A reduction in rooting depth;
- Soil structure decline;
- An increase in the mortality of newborn sheep and recently shorn sheep; and
- Soil accumulating around fences.

## Management options

Land management and the amount of ground cover play a major role in determining the amount of erosion that occurs during strong winds. Droughts exacerbate wind erosion. Wind erosion can be managed by strategies aimed at reducing wind speed below the threshold or by reducing the amount of exposed loose soil, or both (Penny 1999).

**Windbreaks (Contain):** Tree belts can reduce wind erosion risk (Cleugh 2003).

**Maintain at least 50 per cent vegetative cover (Recover and Contain):** Adjust land use so that ground cover is maintained at above 50 per cent for susceptible soils.

**Management strategies (winter cropping and summer grazing):** Help to achieve this is summarised by Carter (1996, 2002) and Findlater and Riethmuller (1993).

**Problem area management (Contain):** If the susceptibility of a paddock varies widely, fence to soil type, so that problem areas can be managed separately.

**Management of livestock (Recover):** Ensure that watering points, gateways, feedlots, etc. are not sited on susceptible soil types.

## Effectiveness

**Windbreaks:** Can be effective, although it is unlikely that sufficient belts of trees could be planted to provide complete control. Generally used with other management systems.

**Maintain at least 50 per cent vegetative cover:** Effective. Relies on risk monitoring of paddocks and adjusting land use practices (e.g. destocking). Seasonal conditions (such as drought) can make it difficult to maintain ground cover at adequate levels.

**Problem area management:** Effective. Most likely where there is a small area limiting management options for a larger paddock. Claying soil is a recent development.

**Management of livestock:** Effective if numerous entry and exit points to paddocks are established and water points are duplicated across paddocks. This could be combined with feeding of stock (when required) close to preferred water point locations to encourage usage.

## References

- Carter D (1996) Preventing wind erosion. Agriculture Western Australia, Farmnote 35/96.
- Carter D (2002) The amount of stubble needed to reduce wind erosion. Agriculture Western Australia, Farmnote 67/2002.
- Cleugh H (2003) Trees for shelter - windbreaks for Australian farms. RIRDC, Canberra.
- Department of Agriculture (2002) Map Unit Database.
- Findlater PA, Riethmuller GP (1993) No-till sowing machinery to control wind erosion. Agriculture Western Australia, Farmnote 61/96.
- Moore G, Findlater P, Carter D (1998) Wind erosion. In 'Soilguide - A handbook for understanding and managing agricultural soils' (ed. G Moore). Agriculture Western Australia, Bulletin 4343 pp. 53-63.
- Penny SA (1999) Yilgarn Land Management Manual. Department of Agriculture, Merredin.