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Water Resource Protection in Australia: Water Quality and Quantity as a Feature of Agricultural Land Management Systems

EH Graham Centre Monograph No. 2

Kathleen H Bowmer

EDITED BY
Edward H Clayton and Helen M Burns

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April 2012

For updates to this publication, check http://www.dpi.nsw.gov.au/ or http://www.grahamcentre.net/

Published by the **NSW Department of Primary Industries**, a part of NSW Department of Trade and Investment, Regional Infrastructure and Services.

First published April 2012

ISBN 978 1 74256 242 1

Cover design and photo by: Sharon Kiss, NSW Department of Primary Industries

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Citation:
Bowmer KH (2011). EH Graham Centre Monograph No. 2: Water Resource Protection in Australia: Water Quantity and Quality as a Feature of Agricultural Land Management Systems. Ed by EH Clayton and HM Burns, EH Graham Centre for Agricultural Innovation, Wagga Wagga, NSW. Available at: http://www.csu.edu.au/research/grahamcentre/

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FOREWORD

The aim of our Monograph series is to provide an in depth review of topics relevant to agricultural systems in southern Australia.

Stubble management was identified as an important research, development and extension priority when the Graham Centre alliance between Charles Sturt University and NSW Department of Primary Industries was established in 2005.

The current Monograph considers the benefits (ecosystems services) and potential costs of human activity in the context of stubble farming systems.

The first Graham Centre Monograph “Stubble Retention in Cropping Systems in Southern Australia: Benefits and Challenges” examined the positive and negative outcomes from the adoption of stubble retention in south-eastern Australia. That Monograph focused on issues of stubble retention in a changing climate, where adaption to change and maintaining ground cover are increasingly important.

This current Monograph “Water Resource Protection in Australia: Water Quality and Quantity as a Feature of Agricultural Land Management Systems”, presents a framework for setting policy and planning priorities to protect water quantity and quality; compares the role of stubble farming systems with other management methods; and explores the links between adoption of stubble farming systems and trends in river health.

This Monograph provides important insights into the impacts of agricultural practices on river health, which will influence policy and investment priorities to protect Australian water resources from the potential impacts of agriculture.

Professor Deirdre Lemerle
Director, EH Graham Centre for
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Editors

ACKNOWLEDGEMENTS

Professor Kathleen Bowmer was a Research Fellow with the EH Graham Centre in 2009 and the Charles Sturt University Institute for Land, Water and Society in 2010. She was hosted by Charles Sturt University School of Agricultural and Wine Sciences during her part-time employment from 2008 to 2011. Several catchment managers and water utility operators completed surveys and provided useful discussion for this monograph; they must remain anonymous for ethical reasons. The EH Graham Centre's mixed farming systems group, especially Professor Len Wade and Dr Tom Nordblom, provided ideas and commentary during numerous workshops. The encouragement of Professor Deidre Lemerle is appreciated. Ms Karryn Hann provided research support**.**

Dr Phil Price, Professor Helen Ross, Dr Tom Nordblom, Dr John Williams, Mr Len Kennedy, Mr George Warne, Mr John Francis and Mr Greg Bugden provided personal insights or made substantial improvements to the manuscript.

Portions of this monograph have been/will be published in condensed and revised format in:
The Australasian Journal of Environmental Management (abridged version of Part 1 of the Monograph); and The Journal of Hydrology (2011) **43**, 176-185 (expanded version of Part 3 of the Monograph).

EXECUTIVE SUMMARY

This monograph was initiated as part of an investigation of the benefits (ecosystem services) and potential costs of stubble farming systems. This information is required to underpin the choices for investment in planning, whether in improved farming systems or in infrastructure and water treatment technology, and to justify further research and investment in stubble farming systems. The ultimate objective is to compare the benefits and costs of stubble farming in Australia with alternative management methods to protect water quality, water quantity and hydrological change downstream.

Part 1 of this monograph develops the framework for setting policy and planning priorities to protect water quantity and quality. Part 2 describes alternative management options and the comparative role of stubble farming systems compared with other management methods. Part 3 explores the links between adoption of stubble farming systems and trends in river health to see whether causative links can be established.

Part 1: Policy and planning priorities in water resource protection

Three stakeholder classes are used as a basis for ranking the significance of water quality and quantity issues in Australia. Rankings, assessed as priorities for management intervention and investment, are derived from views of several leading natural resource and water utility managers, supplemented by a review of the literature. The stakeholder groups are (1) rural and irrigation (this includes riparian rights to access water known in Australia as ‘stock and domestic supply’); (2) urban water used for drinking and industry including power generation; and (3) aquatic ecology and ecosystem resilience (this includes water for aesthetic, spiritual, recreational and cultural purposes). Water characteristics used for the significance assessments are: salinity; acidity; nitrogen and phosphorus; carbon; turbidity; micro-pollutants; pathogenic organisms; volumetric water availability and hydrological flow patterns.

Trends over the last decade show a reduction in concern for salinity, reflecting the effects of a drying climate in lowering groundwater levels; while investment in treatment technology has reduced the impact of eutrophication. Increased priority is allocated to micro-pollutants and pathogens that are associated with intensive re-use of water for drinking and uncertainty about impacts on human health. In the latter category, reduction of pesticide use is countered by increased risks from water recycling and poorly understood impacts of new pharmaceutical and industrial pollutants.

Part 2: Management methods

The off-farm downstream benefits and costs of stubble farming systems are reviewed and compared with alternative management options for protection of water quality and quantity. The management options are assessed under categories of (1) prevention (including watershed protection methods); (2) interception (such as the use of salinity evaporation ponds, protection of the riparian zone and use of wetlands for effluent treatment and stormwater interception; and (3) treatment (such as disinfection and filtration). The many benefits of stubble farming systems include reduction in turbidity and associated pollutants through effects in reducing hillslope erosion, and reduction in concentration of salt in run-off through water retention in the landscape. The effects of stubble farming on the water cycle and on the groundwater profile at local and catchment scale is a knowledge gap.

Part 3: Links between land use and river health

Stubble farming has increased in Australia over several decades with claims of improved productivity, landscape stability and environmental benefit, yet recent audits show a dramatic and general decline in river health. Explanations for this apparent anomaly are explored. The link between stubble farming and downstream water quality and quantity is confused by effects of climate change and variability, other agricultural and riparian land-use changes, effects of introduced species, lag times and effects of scale. Additionally, cost-benefit analysis is complicated by changing perceptions of the value attributed to the aquatic environment.

Assessing the value of ecosystem services provided by stubble farming could be aided by the use of environmental indicators (such as vegetation cover), modelling, ecological risk assessment, and farmer-based sustainability initiatives.

Integrated catchment management is a particular responsibility of regional natural resource management groups and catchment management authorities in Australia. The strengthening of local, regional and catchment-scale approaches is advocated. This includes the re-integration of land management and governance with water management and planning. It is encouraging that some farmers are themselves developing systems to optimise trade-offs between on-farm activities and ecosystem service benefits; these initiatives are commended.

Prognosis

Land management systems in general, and stubble farming systems in particular, are important drivers of water resource condition but the integration of land and water management appears to have been downplayed and under-funded in recent years. Links between land use and downstream water quality and ecosystem resilience are difficult to quantify because of the interaction of many confounding factors. Also substantial past investment in water treatment technology has enabled urban Australians to access safe water for drinking and industry, to some extent removing the pressures for greater investment in watershed protection. It is timely to revisit the catchment-based approach to landscape sustainability and resilience in Australia. In this context the provision of ecosystem services by stubble farming systems needs to be recognised, quantified and valued. Overall the ecosystem benefits reviewed here provide a rationale for increasing rather than reducing stubble-farming practices, and in investment in research to develop mechanical methods for stubble management.

KEYWORDS

Water balance, aquatic ecology, complexity, optimisation, ecosystem services, water quality, hydrology, integrated catchment management, conservation farming, stubble, zero tillage, minimum tillage, watershed protection, valuation.

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ABC	Australian Broadcasting Commission
ABS	Australian Bureau of Statistics
ANRA	Australian Natural Resource Atlas
ANZECC	Australian and New Zealand Environment Conservation Council
APSIM	Agricultural Production Systems Simulator
ARMCANZ	Agricultural and Resource Management Council of Australia and NewZealand
AWA	Australian Water Association
BC2C	Biophysical Capacity to Change
BTEX	Benzene, toluene, ethylbenzene and xylene
CAT	Catchment Analysis Tool
CERAT	Coastal Eutrophication Risk Assessment Tool
COAG	Council of Australian Governments
CMA	Catchment Management Authority
CMC	Victoria Catchment Management Council
CMSS	Catchment Management Support System
CRC CARE	Co-operative Research Centre for Contamination and Remediation of the Environment
CRC WQT	Co-operative Research Centre for Water Quality and Treatment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWR	Centre for Water Research
DAFF	Australian Government Department of Agriculture Fisheries and Forestry
DECC	NSW Department of Environment and Climate Change
DECCW	NSW Department of Environment, Climate Change and Water
DLWC	NSW Department of Land and Water Conservation
DNR	NSW Department of Natural Resource
DPI	Victoria Department of Primary Industries
DPC	Queensland Department of the Premier and Cabinet
DSE	Victoria Department of Sustainability and Environment
DWE	NSW Department of Water and Energy
EPA	(Victoria) Environmental Protection Agency; (NSW) Environmental Protection Authority
GFSF	Groundwater Flow Systems Framework
GHD	Gutteridge Haskins & Davey
GRDC	Grains Research & Development Corporation
HNCMA	Hawkesbury-Nepean Catchment Management Authority
IACSEA	Independent Advisory Committee on Socio-Economic Analysis
ICM	Integrated Catchment Management
LASCAM	Large Scale Catchment Model
MDBA	Murray-Darling Basin Authority
MDBC	Murray-Darling Basin Commision
MDBMC	Murray-Darling Basin Ministerial Council
NCCARF	National Climate Change Adaptation Research Facility
NCGRT	National Centre for Groundwater Research and Training
NDSP	National Dryland Salinity Program
NHMRC	National Health and Medical Research Council
NLWRA	National Land and Water Resources Audit
NRC	NSW Natural Resource Commission

NRCP	National River Contaminants Program
NRM	Natural Resource Management
NRMMC	Natural Resource Management Ministerial Council
NWPASS	National Working Party on Acid Sulphate Soils
NWC	National Water Commission
OECD	Organisation for Economic Co-operation and Development
OEH	NSW Office of Environment & Heritage
PC	Productivity Commission
PERFECT	Productivity, Erosion and Run-off Functions to Evaluate Conservation Techniques
PRISM	Practical Index of Salinity Models database
SANTFA	South Australian No-Till Farmers Association
SCRA	Standing Committee on Regional Australia
SEWPC	(Department of) Sustainability, Environment ,Water, Population and Communities
SIF	Salinity Investment Framework
SKM	Sinclair Knight Merz
SOE	State of the Environment
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WANTFA	Western Australian No-Tillage Farmers Association
WQRA	Water Quality Research Australia

1. PART 1: POLICY AND PLANNING PRIORITIES

1.1. Abstract

The relative importance of quality and quantity parameters in protecting water resources and river health in Australia was assessed by consultation with senior planners and managers, and supplemented by a review of the literature. Stakeholder groups considered were: rural and irrigation; drinking and industry; and ecosystem resilience, including recreation and aesthetics. Water characteristics selected were: salinity; acidity; nitrogen and phosphorus; carbon; turbidity; micro-pollutants; pathogenic organisms; volumetric water availability and hydrological flow patterns. Trends show a reduction in concern for salinity reflecting the effects of a drying climate in reducing groundwater levels (from the late 1990s); while investment in treatment technology has reduced the impact of eutrophication. Increased priority is allocated to turbidity and to micro-pollutants and pathogens. In the latter category, reduction of pesticide use is countered by increased risks from water recycling and poorly understood impacts of new pharmaceutical and industrial pollutants. Future challenges for water resource protection and planning are discussed.

1.2. Introduction

This monograph was initiated as part of an investigation of the benefits in terms of downstream ecosystem services and potential costs of stubble farming systems in Australia, to underpin decisions on land-use planning and investment.

Throughout the monograph stubble farming systems implies farming that involves retaining stubble on the surface for its water retention and soil erosion reduction benefits. Agronomists also term these ‘stubble retention systems’, which may also include the retaining of stubble until it is removed with ‘a late burn’ just prior to sowing. Reference to ‘conservation farming’ includes both reduced and zero-tillage, with or without stubble retention.

Stubble is plant residue left in the field after harvest, including stem, leaf and glumes or pods. Stubble can be removed by burning, baling as hay, or incorporated into the soil using cultivation.

Conservation farming practices are used on about 70 million hectares worldwide (approximately 46% in Latin America, 37% in the United States and Canada and 13% in Australia). Future demand for cereals from increasing population growth creates challenges to crop the soil continuously while limiting degradation (West, 2004). In Europe run-off and soil erosion are major environmental threats and on-farm adoption of soil and water conservation measures is the subject of a recent special issue of the Land Use Policy Journal (de Graff et al., 2010). Adoption of stubble farming systems has increased rapidly in Australia during the last ten years (Llewellyn and D'Embden, 2010). Further information is provided by state-based no-till farming groups (SANTFA, 2011;WANTFA, 2011).

This monograph on off-farm benefits and costs supplements a recent review of on-farm benefits of stubble farming systems in Australia, such as improved profitability, rainfall capture, soil structure and reduced energy consumption (Scott et al., 2010). Off-farm downstream benefits of stubble farming are assumed to include protection of water quality and the health of rivers and streams through retention of water associated with soluble pollutants such as salt and nitrates and reduction of run-off of soil and particulate matter associated with phosphorus. Additional benefits could include reduced risks of algal blooms, protection of aquatic habitat and ecological food webs, improved aesthetic value, and reduced costs of water treatment for irrigation and urban use. Costs might include water pollution with herbicides and reduction in yield of available water.

Information about off-farm benefits of stubble farming is required for a full cost-benefit analysis:

- to estimate and justify investment in research, new technology, and operating costs to establish crops under large stubble loads without burning;
- to support decisions about the best mix of instruments to maintain or encourage adoption of stubble systems;
- to investigate the role of stubble farming as a strategy for the protection of water quality, either in general, or in pollution-prone 'hotspots'; and
- to provide information to national and regional planners, policy makers and natural resource managers about the relative benefits of investment in various methods for watershed protection or water treatment.

Information about off-farm costs is required:

- to assess the potential impact on water quality of pesticide and herbicide use, which may increase with adoption of stubble farming methods; and
- to assess the implications of water retention in the landscape on the sustainable yield of water, and on catchment-based water balance.

The ultimate objective is to compare the benefits and costs of stubble farming in Australia with alternative management methods, including land-use planning options used in watershed protection, interception in the riparian zone, and water treatment methods with a focus on the effects on water quality, water quantity and hydrological change downstream. This requires an overview that crosses both disciplinary expertise and agency responsibilities. Consequently, prior to specifically investigating the role of agricultural land management systems, a framework was developed to value a range of water quality and quantity characteristics and to assess the current effectiveness of a range of planning and management options.

1.3. Priority setting

Priority setting is important for achieving effective investment of public funds for water resource protection, either directly or through incentives or market-based approaches. But how should this be done?

A review of examples from the recent literature shows diverse objectives:

- for catchment action planning (NSW DECC, 2009; NSW NRC, 2005; NRC, 2010);
- for public involvement in setting new guidelines for drinking water (NHMRC, 2010; Simpson and Stratton, 2011);
- for assessing attitudinal trends on the importance of the environment (NSW DECC, 2010); and
- for setting research agendas (Lovett et al., 2000; CSIRO, 2007a).

Many reviews are concerned with setting environmental priorities or management options (e.g. Lovett et al., 2000; Davies et al., 2010; NLWRA, 2002; NSW DECC, 2009; NWC, 2010a). Scales range from river reach to catchment to national level, with rural and urban concerns generally treated separately. Methodologies include expert scientific analysis, survey of the selected stakeholders and formal public consultation, usually as separate processes. Exemplars of socio-economic integration include the scoping study on the social impacts of a return of environmental flows to the River Murray (Hassall and Associates et al., 2003) and the contribution to the national debate about developing options for recycling drinking water (Simpson and Stratton, 2011).

1.4. Framework that includes stakeholder needs

Generally examples of socio-economic integration indicate a need for better stakeholder engagement in collaborative planning, as recommended by the National Water Initiative. Consequently a framework for priority setting was developed for this monograph that considers stakeholder needs as well as expert opinion.

Stakeholder groups selected for this monograph were: rural and irrigation (this includes riparian rights to access water known in Australia as ‘stock and domestic supply’); urban water used for drinking and industry; and aquatic ecology and ecosystem resilience (this includes water for aesthetic, spiritual, recreational and cultural purposes). Quality characteristics selected were: salinity, acidity, nitrogen (N), phosphorus (P), carbon, turbidity, micro-pollutants and pathogens. Water quantity considerations include volumetric water availability and hydrological flow patterns.

Key issues were investigated by interviews with natural resource managers, supplemented by a review of the literature review and media reports. The issues are summarised in Table 1 as current priorities for investment and retrospective and prospective trends. This informs Part 2 of this report where emerging challenges are foreshadowed as a prerequisite for developing priorities for water planning and management into the future.

1.5. Catchment types and stakeholder classes

1.5.1. Rural use and irrigation

The high ranking attributed to water quantity for rural use and irrigation in regulated rivers in Table 1 reflects the substantial economic benefits of water for consumptive purposes in rural and urban Australia (MDBA, 2010b; Meyer et al., 2005), together with a decade of drought that might be expected to put pressure on irrigation production. Several factors are softening the impact of water scarcity: the substantial recent ‘buyback’ of water from irrigators (Productivity Commission, 2010); evidence that production is only marginally reduced by drought (ABS, 2010); and the benefits of water trading in increasing flexibility and profitability for irrigators (NWC, 2010c). Conversely, the cap on Sustainable Diversion Limits foreshadowed in the proposed Basin Plan (MDBA, 2011) is expected to increase concerns about water scarcity in the future.

Table 1. Relative importance of water quality and quantity priority issues to selected stakeholder groups - retrospective trends, current importance and prospective trends.

	Rural and Irrigation[1]			Drinking and Industry			Ecological Resilience		
Priority issues	Retro	Current	Pros	Retro	Current	Pros	Retro	Current	Pros
Salinity	↓	M	↑	↓	M	↑	↔	L	↔
Acidity	↔	L	↑	↔	L	↔	↑↑	M	↑
N and P	↓	L	↑	↓	L	↑	↔	H	↑
Carbon	↔	L	↔	↔	M	↔	↔	L	↔
Turbidity	↓	L	↑	↓	H	↑↑	↓	H	↑
Micro-poll.	↔	M	↑	↑↑	H	↑↑	↑↑	H	↑
Pathogens	↔	L	↑	↑↑	H	↑↑	↔	L	↔
W Quantity	↑	H	↑↑	↑↑	H	↑↑	↑↑	H	↑↑
Hydrology	↔	L	↑	↔	L	↔	↑↑	H	↑

[1] Retro = water quality importance retrospectively, Pros = water quality importance prospectively, Current = water quality importance currently (L = Low, M = Medium, H = High). Trends are indicated by arrows.

1.5.2. Drinking and industry

The high rating for water quantity attributed to drinking water and industry (Table 1) reflects the priority allocated to ‘critical human needs’ in the recent drought. High ratings for turbidity, micro-pollutants and pathogens reflect public concerns about recycling and the safety of water quality for drinking. However, while the demand for good quality drinking water for cities, towns and industry remains high, recent access to alternative water sources, particularly desalination and cross-catchment piping has reduced the potential risk of water scarcity, at least in coastal cities.

Hoang et al. (2009) report that the operating capacity of desalination plants in Australia is 294ML/day, the capacity of plants under construction is 976 ML/day and proposed plants will produce a further 925 ML/day. Current use is 153ML/day for potable water and 141 ML/day for industry, rising in 2013 to an estimated 1734 ML/day and 461 ML/day, respectively. In major cities, seawater desalination is projected to increase ten-fold from 45GL/year in 2006 to over 450GL/year in 2013.

Piping from rural to urban Australia has progressed rapidly over the last few years. Major projects include the 70km Sugarloaf Pipeline from the Goulburn River in Victoria to the Sugarloaf Reservoir, a Melbourne storage (Victoria DSE et al., 2007). Pipelines from Melbourne to Geelong (Victoria), Tantangarra to the Murrumbidgee in Canberra (ACT), Shoalhaven to Sydney (NSW) and the south-west Yarragadee Aquifer to Perth (WA) have been reviewed by the Productivity Commission (Productivity Commision, 2008). A new pipeline in northern Victoria will connect Raywood and Sebastian to the Bendigo Water supply to provide a higher level of water security and improved quality (Coliban Water, 2010).

Many rural communities have a relatively poor capacity for water and sewerage treatment compared with larger regional centres and cities. Infrastructure Australia reports that water utilities and regional towns are failing to produce a safe water supply and the Productivity Commission is currently reviewing water recycling and stormwater management, including water security in towns and villages (Productivity Commission, 2011). Studies cited by the Local Government Association of Queensland found that 18% of water providers had high to very high risks for maintenance of drinking water quality and safety (Hepworth, 2010) and in

NSW only 83% of the population served by non-metropolitan Local Water Utilities received water that complied with the microbiological requirements of the Australian Drinking Water Guidelines (Crampton and Ragusa, 2010; NSW DWE, 2009).

1.5.3. Aquatic ecology and ecosystem resilience

Concern about the ecological condition of rivers and estuaries has intensified through a decade of drought and competition for scarce water resources. Audits of river condition summarised recently by Schofield (2010) show that the health of many rivers and estuaries is poor and declining. Recent policy guidelines for water planning (COAG, 2009) reflect a growing recognition that aquatic systems need protection against threats that could lead to ecosystem decline beyond a threshold of resilience.

Estuaries and near-shore ecosystems are ranked highly. Some are threatened assets such as the Great Barrier Reef or coastal systems with limited ocean water exchange, such as Moreton Bay, the Gippsland Lakes, the Wallis and Myall lakes, Lower Murray Lakes and Coorong, and the Peel-Harvey Inlet. Harris (2006) describes the irreversible loss of seagrasses as a critical component of marine and brackish aquatic ecosystems. A key threat is the substantial proportion (about 70%) of all effluent produced by cities that is discharged to coastal waters (Thomas et al., 1997).

The general public are alert to the need to maintain ecosystems for future generations (NSW DECC, 2010). Water is being allocated to the environment through water sharing plans, buyback arrangements and imposition of caps on consumptive use, but valuation of the benefits and the concept of over-allocation is contentious (Davis, 2009). Consequently ecosystem resilience received a high ranking for water quantity and hydrological patterns (Table 1). Several water quality characteristics are also ranked highly, reflecting a strong link between ecosystem health and water remaining fit for irrigation, human consumption, and recreation and tourism.

Water for aesthetic, spiritual, recreational and cultural purposes is included in the aquatic ecology stakeholder group. The increasing value of tourism is described in several reports (ABS, 2010; Dyack et al., 2007). For example the Great Barrier Reef, one of the globe’s most iconic natural ecosystems, contributes over $5.4 billion to the Australian economy through tourism and fishing industries but is threatened by diffuse pollution of nitrogen, phosphorus, sediment and pesticides and by drainage of natural wetland filtering systems (Pittock, 2010).

It should be noted that there is a perception by some communities and social scientists that planning is unfairly dominated by biophysical approaches to aquatic ecology (Alston and Mason, 2008). There is growing recognition of the importance of social inclusiveness in planning (Cullen, 2006; NWC, 2011). The need for improved indigenous consultation is again noted in the National Water Initiative third biennial review (NWC, 2011, Executive Summary, page 9), and the special challenges of indigenous participation are described by Jackson (2008) and Jackson et al.(2010).

1.5.4. Overall assessment of benefits from investment

Clearly there is overlap between the stakeholder categories. For example, a decline in ecosystem integrity and eventual collapse will ultimately result in deterioration in water quality to the extent that utility is affected. Also, although recreation, aesthetics, fishing and tourism might be seen as utilitarian functions, they are dependent on the maintenance of a resilient ecosystem, and therefore aquatic resilience and recreation and aesthetics are combined in the following literature review. Syme and Nancarrow (2008) in recognising this overlap, promote a 'Water Benefits Accounting and Assessment' methodology that is based on the overall subjective benefit that people derive from water. They define 'Water Benefits' as the ways in which water promotes well-being in both utilitarian and non-utilitarian ways, acknowledging that the same volume of water can deliver multiple benefits as it moves through a catchment.

1.6. Water quality characteristics

Rankings of water quality characteristics in Table 1 are current, reflecting the impact of water scarcity over the last decade together with advances and implementation of treatment technology and changes in public expectations. A broad overview was obtained from the following literature: OECD (2008) on Australia's environmental performance; ABS (2010) on water use in Australia; MDBA (2010b) on the socio-economic context and water requirements in the Murray-Darling Basin; Bates et al. (2011) on freshwater biodiversity in response to climate change; Marsden and Pickering (2006) on costs and opportunities for urban water; Young (2009), NSW DECC, (2009; 2010) and NSW OEH (2010) on cost of non-point pollution; and Cornish and Pratley (1987) on effects of tillage and conservation farming. Sources of information on the downstream effects of land use on water quality include ARMCANZ and ANZECC (2000); Hunter et al. (1995); Williams et al. (1998); Bowmer (1998); and Victoria CMC (2007). Sources of information on specific individual water quality and quantity parameters are provided in the following sections.

1.6.1. Salinity

Salinity occurs naturally in Australia, but the clearing of native vegetation has caused subsoil salt to come to the surface in many areas. Dryland salinity is enhanced when deep-rooted native vegetation is replaced with shallow-rooted annual crops and pastures that use less water, causing the water table to rise, bringing salt with it. Irrigation salinity occurs when over-watering causes saline groundwater to reach the surface by capillary rise, with salt deposited when the water evaporates. The Australian Bureau of Statistics estimates current annual costs at A$130 million in lost agricultural production and at least A$40 million in loss of environmental assets (ABS, 2010). The National Land and Water Resources Audit found up to 5.7 million hectares of land and 24 of 74 assessed river basins at risk from salinity (NLWRA , 2002). Beresford et al. (2001) quotes the area at risk at over 15 million hectares nationwide, and over 6 million hectares in WA, where the Wheatbelt region has some of the worst examples of dryland salinity in the world. The most significant off-site impact of dryland salinity is the salinisation of freshwater rivers, which affects all water users and the aquatic environment.

Rural and irrigation salinity

Chassemi et al. (1995) reviewed the occurrence, treatment and costs of dryland and irrigation salinity in Australia. Eberbach (1998) described the management of salt-affected soils, suggesting that consumers of agricultural products should contribute more to restoration. Irrigated crops are damaged at high concentrations of salt, and soil dispersion causes impermeability (Bond and Smith, 2006). Also subsurface water contaminated with salt will ultimately devastate irrigation systems unless it can be leached below the root zone. Consequently, irrigators are highly dependent on up-stream catchment managers to provide a clean water source and to reduce salt loads in run-off water. Although use of groundwater for irrigation has substantially increased as surface water access has been restricted, understanding of salinity in groundwater systems is poor. There are also special issues of high salinity arising from oceanic saltwater intrusion in the Burdekin irrigation system as a result of groundwater extraction (Narayan et al., 2007).

Drinking and industry

In a Salinity Audit conducted in 1999, the Murray-Darling Basin Ministerial Council found that salinity in the Murray River exceeds World Health Organisation levels for potable water for about 10% of the year and predicted that the Macquarie, Namoi, Bogan, Lachlan and Castlereagh Rivers will exceed the standard threshold of 800 electrical conductivity (EC) units for potable water within 50 years (MDBMC, 1999). Some of these rivers were predicted to exceed the 1500 EC threshold for irrigation within 100 years. An inter-governmental agreement determined that electrical conductivity (EC) targets for drinking water in the Murray River at Morgan, near the border of SA with NSW and Victoria, must not exceed 800 EC units for 95% of the time. These targets drive salt reduction programs in states and catchments up-stream. Without this amelioration it is estimated that salinity in the River Murray will exceed drinking water standards for nearly 150 days per year by 2020.

In this 1999 assessment it was also reported that some rivers are particularly vulnerable to increases in salinity. For example salinity levels in the Murrumbidgee River were increasing at between 0.8% and 15% per year, depending on whether measurements are made up-stream or downstream of major irrigation off-takes. In August 2001 the Murray-Darling Basin Ministerial Council launched the Basin Salinity Management Strategy and in 2010 reported on current levels of salinity in the Basin (MDBA, 2010c). The effects of salinity management by interception schemes was estimated to give a benefit in EC units at Morgan of between 831 EC units in October 2008 to about 295 EC units in June 2009. Modelling showed that, without salinity management, salinity at Morgan would have been in the range of 1200 to 1430 EC units. Such levels that would have been destructive to most irrigated plantings in that part of the Murray River.

Salt also damages infrastructure including roads and buildings, and corrodes pipes in cooling power stations. Healey (2009) reports that infrastructure in 30 towns in WA and 60 in Victoria are at risk from shallow saline water tables; about 34% of state roads are damaged by salinity in NSW, costing about $9 million per year; and 500 km of main roads are damaged by salinity in WA. Bugden (1999) describes damage to roads, footpaths, sewerage systems housing and industry in Wagga Wagga, NSW.

Aquatic ecology

The effect of salinity on freshwater biodiversity was reviewed by Kefford et al. (2007). Risk factors for sensitive species are being developed. In general, sudden rises and falls are more detrimental than gradual changes. The effects of dryland salinisation on the shift of wetlands from fresh to saline or hypersaline status in south-west WA has been reviewed by Sim et al. (2007). Saltwater intrusion is a threat in some estuaries, caused less by increasing loads of salt in inflowing rivers and streams than by reduction in flow caused by reduced rainfall, interception and extraction of water by expansion of land-based activities such as afforestation, farm dams and peri-urban development.

Ranking and trends

As indicated in Table 1, rural and irrigation, and drinking and industry are allocated a medium rating for salinity. The Natural Heritage Trust and Prime Minister's National Action Plan for Salinity and Water Quality that invested $1.4 billion in twenty-one priority catchments over seven years was suspended in 2008, reflecting general perceptions that salinity is, at least for the moment, under control. Also the emphasis previously given to salinity and the underpinning science has been questioned (McDonald, 2007; Marohasy, 2003; Marohasy, 2010). A recent audit of the Murray-Darling Basin shows that dryland and irrigation salinity has declined together with export of salt into rivers that are sources of drinking water (MDBA, 2010c).

The low ranking for salinity impacts on ecological resilience (Table 1) reflects the relative tolerance of aquatic ecological processes to salinity.

Overall, retrospective trends show a steady or declining score, reflecting a decade of drought conditions that, in much of southern Australia over the last decade, has reduced run-off and lowered ground water levels (even though reduced flows, i.e. lower dilution, tend to oppose these benefits through increasing salt concentration). However, recent floods over most of Australia may reverse this decline and mobilise salts that have accumulated in the floodplains over the last decade. Consequently prospective trends are scored as potentially increasing in importance.

1.6.2. Acidity

Rural and irrigation

Costs of soil acidification in NSW, measured as agricultural production foregone, are estimated at 25 times the costs of dryland soil salinity, and increasing (NSW OEH, 2010). Acidification of surface water is caused by run-off from agricultural areas where ammonia-based fertilisers are applied, with an increasing trend towards depressed pH (ANZECC, 2000). It could also be caused by acid water leaching below crop root zones, eventually finding its way into streams as base flow, although evidence is lacking (P. Price pers. comm.). Chartres (1998) describes increased run-off and erosion as the major off-site effect of acidification in agricultural production systems, although there is little published work on this topic. In areas with naturally acid and shallow soils such as the sandstone plateaux north and south of Sydney further acidification may deplete the soils' buffering capacity, leading to leaching of toxic aluminium, iron and manganese into waterways.

Drinking and industry

According to Australian Water Quality Guidelines (SEWPC, 2011: pH Factsheet) drinking water should be between pH 6.5 and 8.5 based on the need to reduce corrosion and encrustation in pipes and fittings. Also chlorine disinfection efficiency is reduced above pH 8.0, though monochloramine disinfection requires a pH between 8.0 and 8.4. The taste and feel of water is also affected by pH in combination with other physical characteristics such as total dissolved solids, temperature and hardness. Acid or alkali is added to adjust pH if necessary, so to date declining pH has not been a major concern for urban water used for drinking and industry.

Aquatic ecology

The formation and exposure of sulphur-rich sediments within river systems are indirect effects of water scarcity caused by increasing diversion up-stream and by reduced base flow in rivers, which is in turn caused by declining groundwater levels, combined with sulphates present in saline waters. Exposure of these sediments to the atmosphere is a major problem for the Ramsar-listed Lower Lakes in the Murray and for an increasing number of other wetlands (Akerman, 2008). The newly exposed sediments may lead to serious environmental problems including acidification, mobilisation of heavy metals, anoxia and the production of noxious gases such as hydrogen sulphide. Sulphidic sediments have often been thought of only as a coastal phenomenon but are now known to be common inland (Hall et al., 2006).

Ranking and trends

Acidification of surface waters is probably increasing as a result of soil acidification. Under the heading '*Sleepers that may become future threats'*, Hamblin (2001, p. 130) notes that '*acidification of soils has been largely overlooked , as has the problem of managing sodic soils, both of which cover vast areas of Australia and contribute as much or more to poor water quality, secondary salinity and loss of ecosystem function as does clearing. These problems are sleepers because they have not been elevated to the position of political concern enjoyed a decade ago by algal blooms or currently by salinity'*.

In a later State of the Environment Report, Gleeson and Dalley (2006) comment that soil acidity affects about half the total area of agricultural land (8-10 times more land than salinity), and projects a two-fold increase by 2016. In NSW, State of the Environment monitoring and evaluation over the last decade shows that soil acidity, together with carbon content and structure, has deteriorated (NSW DECCW, 2009). Similarly, the Victorian Index of Stream Condition (Victoria DPI, 20107) report on concerns about deteriorating trends while several NSW Catchment Action Plans (e.g. Murrumbidgee CMA, 2011; Hawkesbury-Nepean CMA, 2008) rate acidic soils as emerging priority issues.

However, the risks to run-off water quality from soil-based acidification is probably small compared with the effects of drying on sulphur-rich sediments. The risks posed by sulphidic sediments may be ameliorated by the imposition of a new cap (the Sustainable Diversion Limit) foreshadowed in the Murray-Darling Basin Plan (MDBA, 2011). The recovery of 3000-4000GL long-term average volume proposed for return to the environment had pre-election bipartisan support for 'buyback of water from willing sellers'. This target volume has proved too ambitious and contentious, but the November 2011 revision to the Plan proposes a return of 2750 GL of water to the environment, which is still expected to ameliorate the acid sulphate sediment problem to some extent. Prospective impact is still listed as increasing because of the mid-term projections of climate drying into the future.

1.6.3. Elements that fuel the food web (Nitrogen, Phosphorus, Carbon)

Nutrient enrichment, particularly with nitrogen and phosphorus, stimulates the growth of aquatic plants and algae. This may be a direct problem, or indirectly when decay and breakdown may deplete oxygen levels in the water, killing fish and disrupting the aquatic food chain. Throughout the world the process of nutrient enrichment (eutrophication) has accelerated with more intensive land use and fertiliser application, and increasing discharge of stormwater, sewage, detergents and industrial effluents (Bowmer, 1981). Algal (cyanobacterial) blooms cost the Australian community between $180-240 million per annum with the costs shared by urban water users, dryland farmers and irrigators in approximately equal proportions (Lovett et al.,, 2000).

Australian agricultural industries contribute to pollution through high levels of crop fertiliser use, especially nitrogen, and nutrients generated and concentrated by a large livestock population, exacerbated by poor management of animal excrement (OECD, 2008). Intensive rural industries have also proliferated and need sophisticated waste management systems (Bowmer and Laut, 1992).

Nutrient export from point and diffuse sources were reported for the Murray-Darling Basin (Banens et al.,2000). Cropping (which was not further differentiated into stubble farming and cultivated crops) was responsible for just over 50% of the total phosphorus emissions in the Basin and 31% of the total nitrogen emissions, although comprising less than 10% of land use. Unimproved pasture was 61% of land use, generating 12% of the phosphorus and 46 % of the nitrogen. Urban and point sources provided only 1-2% of the emissions.

Bolger and Stevens (1999) found that groundwater contamination with nitrates in Australia is widespread, in some cases affecting both shallow, unconfined and deeper aquifers. Sources include extensive grazing, dairying, and agricultural fertiliser applications, intensive rural industries, septic tanks and naturally occurring nitrogen-fixing vegetation.

Carbon is an essential element in the food web but excessive quantities from poorly treated sewage effluent or intensive rural industries can create anaerobic conditions that kill fish. ‘Black water’, resulting from dissolved organic matter released when flood waters drain into river systems, is another source of carbon (NSW Primary Industries, n.d.). Natural, catchment-derived organic matter is an important factor in increasing the costs of water treatment (CRC WQT, 2005).

These pollutants exist in a range of forms: organic, adsorbed onto particles and dissolved; and biological availability is complicated by different rates of release and uptake. Interception by filtering is useful for particulate forms but is less effective for dissolved material.

Rural and irrigation

Although algal blooms do not generally create major problems for flood irrigators, high pressure and trickle systems require good water quality. Back-flushing of filters and growth of algal and bacterial slimes in piping systems can substantially increase the operating costs of these more sophisticated irrigation systems, which will be impacted upon by the rapidly increasing cost of power.

Stock watering and unregulated supplies ('stock and domestic') are vulnerable to algal blooms. As these sometimes contain toxins, the consequences may be significant if alternative sources of water, such as clean ground water supplies, are not available.

Drinking and industry

Algal blooms are a major symptom of nutrient enrichment and can cause problems through production of odours, toxins and filter clogging (Bowmer, 1981; Bowmer et al., 1992; Jones, 1994a; Jones, 1994b; Oliver and Ganf, 2002). Associated bacterial slimes can block filters and delivery equipment, requiring expensive maintenance to avoid sloughing and blockage. Taints, odours and toxins are a problem for drinking and industrial use of water and require carbon filtration or more expensive dissolved air flotation for removal (Farmerie, 2005; Hitzfeld et al., 2000).

Dissolved carbon compounds can react with disinfectants to form carcinogenic compounds that interfere with charcoal treatment to remove odours and toxins, and cause growth of bacterial biofilms in pipes. Catchment processes to reduce carbon have been studied in Victoria and SA (CRC WQT, 2005).

Nitrate contamination of groundwater is widespread in Australia, exceeding maximum of 10mg/L recommended by the Australian Drinking Water Guidelines in many areas, with some areas by nearly ten-fold (Bolger and Stevens, 1999). They recommend a change in research focus from point sources, which are more easily regulated, to broad diffuse sources that require more complex management.

Aquatic ecology

Algal blooms are fuelled when increases in concentrations of nitrogen and phosphorus coincide with other suitable conditions such as reduced water flow and light climate. The subject was reviewed in a Special Issue of the Australian Journal of Marine and Freshwater Research (Jones, 1994b) and by a Senate Standing Committee (Australian Government, 1992). Algal blooms became a prominent problem in Australia in the early 1990s, when major blooms in the Darling River, Peel Harvey Estuary and Queensland reservoirs triggered the development of algal management plans at all levels of government. More recently algal blooms have affected over 800km of the Murray River (Lauder, 2009).

Lakes can exist in two forms: clear and dominated by seagrasses, or turbid and dominated by algal blooms, the latter form features oxygen depletion in the sediments and loss of biodiversity. Once the lake is flipped out of the seagrass dominated state by input of nitrogen from the catchment, return is difficult or impossible. Under the heading '*A dying shame — Australian coastal freshwater lakes*', Harris (2006) describes the demise of seagrass beds, their role in promoting the breeding of fish and benefits in maintaining nutrient cycling processes.

Ranking and trends

Nitrogen and phosphorus were ranked as lower importance across ‘rural and irrigation’ and ‘drinking and industry’ in Table 1, perhaps reflecting a comment by a natural resource manager interviewed for this monograph that, *‘People have learnt to live with the algal bloom problem, through a range of avoidance, management and treatment strategies’*. For example, many towns and cities have invested in treatment technologies such as dissolved air flotation and charcoal filtration to remove algal odours and toxins, and comprehensive response strategies have been developed by state agencies and utility managers.

Interestingly, research has demonstrated that flow, stratification and light penetration, not nutrient availability alone, are the triggers for blooms in south-eastern Australian rivers (Davis and Koop, 2006). Perceptions that water scarcity and micro-pollutants are increasing in importance may also contribute to the relatively lower scores for nitrogen and phosphorus.

1.6.4. Turbidity (eroded particles)

Turbidity has long been recognised as a characteristic feature of Australian inland waters. High turbidity levels in Australian rivers reflect the effects of human disturbance in agriculture, the vulnerability of cultivated and heavily grazed soils to erosion and the effects of European carp - an introduced fish which increases turbidity by roiling the water as it stirs up sediments in search of food (Bowmer, 1981; Bowmer, 1982; Douglas, 1967; Hart, 1986).

The National Land and Water Resources Audit (NLWRA, 2001) gives a catchment-scale comparison of hillslope, gully and rill erosion. Several parameters (rainfall erosivity, woody cover, slope, and slope length and soil type) were used to determine susceptibility to soil erosion in a series of maps. The Audit reports that downstream costs from turbidity are as large as those due to salinity and concludes that investment in soil management to reduce erosion will provide a more rapid return than activities to control dryland salinity. Table 2 presents data from this national assessment of the loss of soil by water-borne erosion. Sheetwash is the dominant erosion processes in Queensland, gully erosion dominates over much of southern Australia, and stream bank erosion is a problem particularly in Victoria. Contemporary soil erosion is higher in the north of Australia reflecting natural processes. The Australian Natural Resource Atlas reports that sheetwash erosion is three times the natural rate of soil loss (ANRA, 2001).

Table 2. Australian soil erosion rates.

Erosion rate	Tonnes/ha/yr	Proportion of lands (%)
Low	< 0.5	39
Medium	0.51 - 9.9	50
High	> 10	11

Source: (ANRA, 2001)

Erosion rates provide information on loss of soil that may be deposited as sediment as it settles in a river channel. Turbidity (suspended fine solids carried in the flow) increases through sediment suspension in wind-induced and turbulent conditions. Because both sediments and turbidity can carry adsorbed pollutants, the impact of erosion on water quality is complex and difficult to interpret.

Rural and irrigation

Turbidity is an expensive problem for pressurised irrigation systems because of the infrastructure and energy costs of filtration and back-flushing. These can sometimes exceed the costs of the water purchased by the farmer.

Drinking and industry

Fine suspended particles that cause turbidity are able to adsorb pollutants such as herbicides, chlorinated hydrocarbon pesticides, petroleum hydrocarbons, and phthallic acids (Bowmer, 1982; Bowmer et al., 1998). Adsorption affects biological availability, transport downstream and costs and effectiveness of treatment processes. Turbidity also increases the costs of water treatment for consumptive use and interferes with disinfection by UV treatment and chlorination (Conway and Miller, 2010).

As noted earlier, the role of turbidity in affecting algal blooms is also important, both through reducing light availability in standing waters and reservoirs, which benefits buoyant cyanobacteria (Oliver and Ganf, 2002); and in transporting adsorbed phosphorus, associated mainly with eroded soil particles (Edgar et al., 2007).

New turbidity standards are proposed by the National Health and Medical Research Council but are being challenged by water utilities (WQRA, 2010). Estimated over 20 years to 2020, the costs of a 5% increase in turbidity and sedimentation in rivers and streams of the Murray-Darling Basin was $256 million and $154 million net present value, respectively (Bryan and Marvanek, 2004). This is considerably higher than the costs attributed to salinity.

Aquatic ecology

The physical effects of turbidity in intercepting light were studied in detail by Kirk (1979). Interception of sunlight can damage ecosystems; shading that affects submerged plants in estuaries, lakes and river systems can have compounding effects on water quality leading to a non-reversible decline. Harris (2007, p. 150) comments that ‘E*stuarine and coastal systems are strongly non-linear in their response to nutrient loads; the resulting hysteresis is common. Once pushed from a seagrass-dominated to a phytoplankton-dominated state recovery is difficult. Shallow lakes show very similar state shifts and there is anecdotal evidence for a similar response in Australian rivers’.*

Two examples of damaged aquatic ecosystems include Lake Mokoan in Victoria, a large shallow lake that became extremely turbid, and was eventually drained (Conole et al., 2005) and the Lachlan River in NSW (Roberts and Sainty, 1996). A changing light climate can clog biofilms, disrupt the food web, and damage bottom-rooting river plants, as well as coral (Pittock, 2010) and seagrasses (Harris, 2006). The threat to biodiversity increases when turbidity is combined with the regulation of rivers to create constant flow (Watts et al., 2009).

Ranking and trends

A low ranking for turbidity for rural and irrigation stakeholders in Table 1 reflects the past dominance of flood and furrow irrigation, which are insensitive to turbidity, together with relatively good irrigation water quality supplies. In future, the increasing adoption of more sophisticated irrigation systems raises the importance of clear water to avoid high costs of filtration. A high ranking for drinking and industry reflects the high costs of treatment and increasing pressures on urban water supplies.

A high ranking for ecological resilience reflects concerns about the impact of sediments on seagrasses in near-shore coastal waters such as Port Phillip Bay, Brisbane River and Moreton Bay, and Perth Coastal Waters (Fox et al., 2007). The Great Barrier Reef has a high value to tourism estimated at over \$A5.4 billion per annum (Garnaut, 2011) and the Queensland Government's new Environmental Risk Management Plans to manage sediment and herbicides (Queensland DPC, 2008) have created public unrest and protest (Kennedy, 2010).

In case studies in south-eastern Australia, Rustomji and Pietsch (2007) found that catchment erosion rates are beginning to decline as gullies stabilise. However the process of sheet erosion remains highly important where dry landscapes are exposed to heavy rain. Bushfires in the vicinity of major cities have also caused problems for water treatment especially in Canberra (Daniell and White, 2005) and Melbourne (Hellier and Stevens, 2007). Turbidity is likely to increase in importance for all water users and for the environment because it is associated with transport of phosphorus and a range of adsorbed micro-pollutants and is expensive to treat.

1.6.5. Micro-pollutants

Rural and irrigation

Although pesticides have been widely used in Australian agriculture and herbicides are still used for aquatic weed control in irrigation supply and drainage systems (Bowmer et al., 1998), current practice sees a much reduced use and restriction to herbicides that break down quickly, such as acrolein. On-farm recycling of irrigation water in the Murrumbidgee Irrigation Areas was investigated and found to be safe for crops (Bowmer and Weerts, 1987). Micro-pollutant concentrations found to exceed safety guidelines in irrigation waters are summarised in the Australian State of the Environment Report (Ball et al., 2001). Few instances of damage from accidental pollution of water have been proven but intentional contamination, as shown by the recent case of tomato and vegetable poisoning in Bowen, Queensland, can be expensive (Callinan, 2010). There is also a concern about validating claims for ‘clean and green’ produce, which is a strong imperative for trade (Hamblin, 2001).

Drinking and industry

Recent public health concerns include:

- the occurrence of pathogens (*E. coli*, *Cryptosporidium*, *Giardia* and viruses) in drinking water from desalination plants (Aikman, 2010a, 2010b);
- viruses, pharmaceutical and immuno-suppressant compounds in water recycled for drinking in south-east Queensland (Lawrence et al., n.d.; Roberts and Murphy, 2008);
- potential impacts of endosulfan and atrazine from forested catchments in Tasmania (Bleaney and Pullinger, 2010);
- claims of carcinogenic effects of macadamia fungicides in Queensland (Dayton, 2009); and
- microbiological contamination of rural drinking water (Crampton and Ragusa, 2010).

A wide range of micro-pollutants occur in drinking water in Australia. They include endocrine disruptor chemicals, heavy metals, synthetic industrial organic compounds, volatile organic compounds, pesticides and metabolites, algal toxins, disinfection by-products, radionuclides, pharmaceuticals, estrogenic and androgenic hormones, antiseptics, perflurochemicals and nanoparticles (Falconer, 1999; Falconer et al., 2006; Kookana et al., 2007; Khan, 2010; CRC WQT, n.d.).

As noted by Khan (2010), although most micro-pollutants are reduced by advanced treatment processes, many chemicals are not measurable so concentrations must be derived from theoretical calculations. A National Health and Medical Research Council committee has set out new limits for 140 pesticides in drinking water guidelines to be considered by governments and, not surprisingly, water utilities are concerned about costs of monitoring (Bita, 2010).

Increased recycling of wastewater has raised concern about the potential risk to human health. A survey of 5 Australian cities in 2007 found that half the 3000 respondents would be unwilling to drink recycled water, although 74% would be prepared to drink recycled water if they could be assured of its safety (Lampard et al., 2010).

Discharge waters from coal seam gas are a new source of pollution. BTEX compounds (benzene, toluene, ethylbenzene and xylene), which are potentially carcinogenic, have recently been found in exploration wells in the Darling Downs of Queensland (Fraser and Barrett, 2010), delaying approval on the development of the industry. The National Water Commission have recently recommended a precautionary approach to development, noting the substantial benefits of the industry to Australia and potential extraction of about 300 GL per year of low quality water, compared with current extraction of about 540 GL per year from the Great Artesian Basin (NWC, 2010b).

Aquatic ecology

Pesticide run-off and ecological impact from irrigated systems was studied for a mixed rice and summer cropping system in the Murrumbidgee Irrigation Areas (Bowmer et al., 1998; Korth et al., 1995). Although eco-toxicology tests showed some synergistic effects from a cocktail of herbicide and pesticides residues, effects were localised and minor. Reviews of the impact of pesticides from cotton farming systems of northern NSW (Bowmer et al., 1995) showed that damage to riverine aquatic ecology such as fish kills could not be attributed to water contamination and an extensive monitoring program also provided reassurance that pesticides were not responsible for fish kills.

Recycling, and application of withholding periods before drainage water is released, can successfully manage contamination with rice pesticides (Quayle, 2005). In the cotton industry water recycling on-farm together with other integrated pest control methods and genetically modified cotton cultivars has reduced pesticide contamination (Cox Inall Communications, 1998). Also the Australian Pesticides and Veterinary Medicines Authority recently cancelled the registration of endosulfan, one of the most persistent cotton pesticides. Nevertheless guidelines for the safety of aquatic life to pesticides are up to an order of magnitude smaller than for drinking water and irrigated crops. The potential effect of herbicides and other pollutants on the Great Barrier Reef was noted previously, in Section 1.5.3.

Industrial pollutants are also an important legacy of industrial processes, including leaking fuel dumps, munitions plants, livestock dips, refineries and landfills. Elevated dioxin levels in Sydney Harbour have contaminated sediments and resulted in restriction on fishing to avoid ingestion of potential carcinogens (Davies, 2010). In Australia, the Co-operative Research Centre for Contamination and Remediation of the Environment) specialises in risk assessment and remediation technologies (CRC CARE, n.d.).

Ranking and trends

The medium ranking for micro-pollutants for rural and irrigation stakeholders in Table1 reflects the difficulty of managing risk, the expense and logistics of monitoring, and concerns about maintaining the reputation of clean food products for consumers and the export market. This is despite Australia’s well-developed registration and approval processes.

A high score for drinking and industry reflects public concerns for health safety, especially when water is recycled, and uncertainties about the toxicological impact of emerging categories of widely occurring pollutants. This is despite advances in recent water treatment technology that have substantially reduced the risks (Khan and Roser, 2007).

Although many inland communities currently drink water that has been recycled indirectly through river dilution and transport, direct recycling is contentious, with policy bans in NSW, Victoria and SA In Queensland restrictions apply until dams fall below 40% of capacity. Concerns are likely to increase as pressure for water recycling grows. The recent position statement from the National Water Commission noted that water recycling, including that for drinking, can provide a significantly greater proportion of Australia’s future urban supplies (NWC, 2010e).

Conversely, pressure on urban supply and recycling in major urban cities has been reduced by large investments in capital infrastructure and operating costs in desalination and by cross-catchment transfer from rural to urban systems, through and across regions. Rural communities are less able to afford expensive technology and continue to live with poorer water quality and water restrictions. This issue remains a challenge for the future.

The high ranking attributed to micro-pollutants in ecosystem resilience in Table 1 reflects potential damage to icon sites, notably the Great Barrier Reef. Industrial pollution is also topical with high cost of clean-up and long-term consequences for ecology.

The overall rankings in Table 1 show an increase in importance of micro-pollutants, both retrospectively and prospectively. The OECD performance review of Australia (OECD, 2008, p. 25) comments that that '*There is a dearth of policy-relevant information about trends in the use of pesticides and about the levels of pesticide residues in food, organisms and ecosystems'*. The vulnerability of land and utility managers to liability from micro-pollutants and pathogen contamination adds to the problem.

1.6.6. Pathogens

Rural and irrigation

Irrigation with urban effluents and land spreading of biosolids from treated sewage is widely practised in all cities in Australia ((Po et al., 2005; Victoria EPA, 2004). Guidelines underpin the safety of irrigation practices for commodities and grazing animals (SEWPC, 2011).

The recent incidence of deaths in Europe from a new strain of *E. coli* on bean sprouts (Anon, 2011), although still under investigation, is likely to raise vigilance about public health risks for food. Such incidences justify the raised ranking for prospective trends for pathogens indicated in Table 1.

Drinking and industry

Discharge of waste to rivers and re-use of water for drinking is a major driver of concern for public health (Lampard et al., 2010; O'Toole, 2011). Re-use schemes can use treated sewage, but also stormwater and industrial wastewaters. Effluent from industries processing food products (e.g. abattoirs or wineries) need to be treated to remove nutrients and oxygen demand.

Topical issues include:

- the occurrence of pathogens (*E. coli*, *Cryptosporidium*, *Giardia* and viruses) in drinking water from unprotected catchments and from desalination plants (Aikman, 2010b);
- viruses, pharmaceutical and immuno-suppressant compounds in water recycled for drinking in south-east Queensland (Roberts and Murphy, 2008).

Water scarcity and population growth are driving change. Large investment in capital infrastructure and operating costs, such as desalination and cross-catchment transfer, has reduced pressure on water supply in major urban centres. However, rural communities are unable to access desalination or afford other expensive technology and face water quality and water restriction issues. Many local water utilities receive water that does not comply with the microbiological requirements of the Australian Drinking Water Guidelines (Productivity Commission, 2011).

Aquatic ecology

Pathogens can be a problem for recreation and commercial fishing. Infection of aquatic organisms is found in water subject to sewage and urban effluent discharge. For example, pathogens found in shellfish include the bacteria Salmonella and Clostridium, and viral diseases such as hepatitis B. However, cooking kills the bacteria and denatures the toxin (Barnes and Mann, 1991). Australian Water Quality Guidelines (SEWPC, 2011: Vol. 3

Section 9.4) describe the effects of pathogens on aquaculture, and also provide guidelines for the protection of human consumption of aquatic foods. These are based on the notion of acceptable daily intake of contaminants. A range of pathogens and naturally occurring algal and bacterial toxins have killed fish in Australia waters, although the overall risk is assessed as low in Table1.

1.7. Water quantity

1.7.1. Volumetric water availability

Impacts of climate change and variability

The effect of climate variability and change on catchment water balance is a critical issue in Australia. In Western and south-eastern Australia 'step changes' to a drier climate and dramatic effects on run-off have been observed in the last decade. For example, a 20% reduction in rainfall between 1997 and 2005 resulted in a 60% reduction in Perth's water supply catchment (Wentworth Group, 2006, using data from the Water Authority of WA). Rainfall run-off ratios have declined in the last decade of drought because of the combined effects of soil warming, changing seasonality of rainfall, bushfires and land-use change, including interception by farm dams and afforestation (Van Dijk et al., 2006). Into the future the shared water resources in the Murray-Darling Basin are predicted to decline further, in spite of recent rainfall (CSIRO, 2010). Potential increases in afforestation driven by carbon credit policies are foreshadowed as a further threat to water availability in river systems (Wentworth Group, 2009).

During the decade of drought a conservative approach to storing water for critical human needs was adopted so that dam releases of stored water for broad-scale irrigation are only made once the supply for 'critical human needs' (drinking, industry and stock watering) is secured. This has reduced water available for the environment and for irrigators, particularly those holding 'general security' licenses. In rural Australia the Labor policy '*Water for the Future*' allocated \$3.1 billion for buyback of water from willing sellers and \$5.8 billion for investment in irrigation infrastructure (Rudd and Albanese, 2007). Further rebalancing of consumptive and environmental water allocations is foreshadowed in the proposed Murray-Darling Basin Plan, which is now in a phase of public consultation (MDBA, 2011). The impact of these changes is likely to be substantial, particularly when the ongoing costs of infrastructure maintenance and social disruption are considered (MDBA, 2010b).

Dryland farmers have also suffered badly in the last decade and much of southern Australia has been declared eligible for exceptional circumstances provision (DAFF, 2007). Many cities have invested in re-use strategies, and new expensive sources of water including desalination and piping across catchments, as discussed earlier, in Section 1.6.

Ranking and trends

The high priority for water quantity across all stakeholders identified in Table 1 clearly reflects the decade of drought experienced in southern Australia and the projections of water scarcity into the future. A stronger emphasis on water for critical human needs reflects the growing urban demand through population increase. Increasing concerns into the future also reflect impacts of reduced catchment inflows on estuarine systems through increased risk of seawater intrusion (OzCoasts, 2010) and effects of increased groundwater pumping on aquifer salinisation (NWC, 2010d). In the regulated Murray-Darling system the demise of the Coorong, Lower Lakes and Murray mouth as described by Lamontagne et al. (2004) have attracted special attention because of the politics of accessing water from up-stream states (COAG, 2008; Kingsford et al., 2011; Wentworth Group, 2008).

1.7.2. Hydrological patterns

Aquatic ecology

In highly regulated rivers, changes in patterns of flow include reversal of seasonality up-stream of irrigation off-takes and reduced occurrence of pulsing flows that are required to maintain ecosystem diversity and functionality (Watts et al., 2009). Reduction of flow downstream of irrigation off-takes, loss of longitudinal connection of rivers caused by weirs and barrages, and loss of lateral connection through capture of and storage of water are detrimental to aquatic resilience. Occasional mid-level floods are needed to achieve over-bank flow for wetlands, floodplains and forests (Young et al., 2001; Hillman, 2008). For example the demise of red gum forests was reviewed recently in NSW (NSW NRC, 2009) and recommendations for conservation have resulted in major disputes about loss of regional employment. Cold water pollution is another feature of impoundment in some regulated rivers.

Extraction from unregulated rivers is also a concern for ecosystem resilience and estuarine condition through effects on flow patterns and volumes. Macro Water Sharing Plans provide some protection for natural features of streams and estuaries in NSW (NSW Office of Water, 2010).

Ranking and trends

As shown in Table 1, hydrological changes are ranked low across rural and irrigation and drinking and industry stakeholders. This is because, until recently, impacts have been overshadowed by issues of water scarcity.

A high rank was awarded to ecological resilience because of the major effects of aseasonal flows caused in highly regulated rivers by extraction for irrigation, and reduction in flow downstream of irrigation systems. However, as noted by one of the utility managers interviewed for this monograph, ‘S*ome loss of ecological condition must be accepted as inevitable in entrained rivers’*, a philosophy also reflected in the terminology ‘working rivers’ coined by Murrumbidgee Irrigation Ltd (Hillman, 2008).

Undoubtedly some detrimental features of hydrological change can be ameliorated through purchase of water for specific environmental assets; rules for water sharing, trading and access; removal of unnecessary weirs; multi-level off-takes to reduce cold water storage releases; and investment in fish ladders. However, into the future, the biggest improvement is likely to come from substantial investment in water buyback, now in progress (NWC, 2010a).

1.8. Summary of current priorities

As indicated in Table 1, water quantity, turbidity, micro-pollutants, pathogens and nutrients received high priority rankings, although not across all stakeholder groups. This assessment generally accords with audits and guidelines reported in the literature.

1.8.1. Audits

In accord with the National Land and Water Resources Audit assessment, turbidity appears to be of greater importance than salinity (NLWRA, 2002). Results differ from those reported by the National Rivers Contaminants Program (Lovett et al., 2000) in which catchment and river manangers were canvassed for their views about the most important river contaminants at a national scale. Salinity and nutrients were listed as most important in the ATECH report (Lovett et al., 2000), followed by sediment, then (of approximately equal status) organic matter, heavy metals, pesticides, acidification, temperature and 'other' (turbidity and sediments were not separated). Noteworthy omissions by Lovett et al. (2000) are micro-pollutants and pathogens that are important for public perception and safety of drinking water. The ATECH reviewers (Lovett et al., 2000) did not reveal criteria for deriving the priorities, nor investigate the needs for different water users and for protection of ecological assets.

The NSW Department of Environment and Climate Change (NSW DECC, 2009) ranked the importance of pollutants from diffuse sources in NSW after analysis for social, economic and environmental consequences and geographic occurence (whether common or local). In comparing these scores with our results in Table 1, it should be noted that turbidity was not included in the NSW DECC report, although sediment was. Results were as follows:

- Overall, nutrients and sediment received high scores, pathogens, toxicants and salinity achieved medium scores, and acid sulphate soils were low. When analysed for social consequences, pathogens were scored highly because of impacts on human health, recreational amenity and contaminated aquatic food.
- Pathogens again received high scores for economic consequences.
- For environmental consequences, high scores were attributed to nutrients, sediment, salinity and acid sulphate soils. Listed impacts of nutrients include stimulation of plant growth and algal blooms, and choking of waterways. Sediments impact on habitat and spawning areas. Salinity scores reflect reduced biodiversity and direct toxic effects. Acid sulphate soils cause fish kills, reduced biodiverstiy and increase the availability of toxicants.

A further insight into current priorities is given in a review of stakeholder perspectives of research needs (CSIRO, 2007 aa). After analysing interviws and questionnaires from 180 people in 100 organisations it was found that there was a high degree of agreement about the important issues for more than 20% of the respondents. Percentage of respondents nominating various issues were:

- impact of climate change and variability on water availability (43%);
- managing surface and groundwater resources (34%); and
- the effect of changes in land use on water yields (17%).

In the section on managing water quality priorities were:

- nutrients/sediments (14%);
- salinity (14%);
- groundwater /surface water contamination (12%);
- acidification (11%); and
- agricultural chemicals (17%). (Note that pathogens and other micro-pollutants are not listed).

1.8.2. Guidelines

Benchmarks and guidelines for groundwater protection, diffuse and point sources, sewerage systems, effluent management for intensive rural industries, and water recycling are set by the Natural Resource Management Ministerial Council (SEWPC, 2011)). Drinking water guidelines are set by the National Health and Medical Research Council (NHMRC, 2011).

The NHMRC is currently engaging in a public consultation process on proposed new guidelines for microbial safety of drinking water to include viral and protozoan pathogens. Monitoring of water quality is expensive and has been restricted, making it difficult to assess progress and trends. Also many micro-pollutants and pathogens are extremely difficult to measure, so preventative risk management procedures using multiple barriers is an appropriate strategy for protection of public health. '*The greatest risks to consumers of drinking water are pathogenic micro-organisms. Protection of source and treatment areas are of paramount importance and must never be compromised'* (NHMRC, 2010, page3). The role of watershed protection and the role of benign conservation farming practices is the focus of Part 2 of this monograph.

1.8.3. Indicators

Indicators for assessing the condition of aquatic ecosystems have been reviewed (Fairweather and Napier, 1998; Bennett et al., 2002). In Victoria a range of indicators are weighted and added to give an overall index of stream condition (Victoria DPI, 2010) while the Murray-Darling Basin Sustainable Rivers Audit (MDBC, 1998) uses fish, hydrology and macro-invertebrates as the key indicators. These and other assessments reviewed by Schofield (2010) show that many aquatic environments are degraded, raising questions about the relative impact of water scarcity compared with other pressures such as the effects of introduced species, population growth and changes in land use.

1.9. Recommendations on priority setting

1.9.1. Need to consider interactions between stressors

For convenience and simplicity three stakeholder groups and nine water characteristics were selected for review. A problem of this approach is that it is the *combination* of various stressors that affect the utility of the water or demise of river and estuarine health. For example the development of an algal bloom can be affected by many factors including weir-pool or river-reach residence time (water quantity and flow regime), phosphorus or nitrogen availability, the light climate (turbidity) and temperature. In recognition of these interactions, the water quality guidelines adopted by NRMMC (SEWPC, 2011) are underpinned by a risk-based framework.

Similarly, damaging pollutants discharged from coastal cities and changing hydrological patterns (limited ocean water exchange) interact to threaten near-shore and coastal ecosystems where the loss of seagrasses, a critical component of marine and brackish aquatic ecosystems, is often irreversible (Harris, 2006). Moreton Bay, the Gippsland Lakes, the Wallis and Myall Lakes, the Lower Murray Lakes, and the Peel-Harvey Inlet are affected., The Great Barrier Reef, which contributes over $5.4 billion to the Australian economy (Garnaut, 2011) is also threatened by diffuse pollution of nitrogen, phosphorus, turbidity, sediment and pesticides together with loss of natural wetland filtering systems (Pittock, 2010).

Effective priority setting requires integration, adaptability and public participation. The required cross-disciplinary approaches are not aided by disciplinary boundaries, by separation of rural and urban water management, or by separating land management and water resource planning. As noted by Hamblin (1998, p. 4)) in developing a short list of indicators for State of the Environment, *'the greatest challenge is developing the most suitable trade-off responses when several pressures interact'*.

Systems approaches and frameworks that can help with this problem have been available for some time. For example, Clayton and Radcliffe (1997) provide a text on sustainability that integrates social cultural (ethics and equity), economic and environmental factors; Newell et al. (2005) provide a template for integrating across social and environmental disciplines; and multi-criteria analysis and multi-objective optimisation methods are described by Hajkowitz (2007) and Xevi and Khan (2005), respectively.

Risk-based frameworks and modelling are also useful in integrating threats (McCarthy, 2007) and have been successfully trialled in Australia (Pollino and Henderson, 2010). Another approach is the use of indicators, sometimes weighted before addition, to integrate the combined effect of threatening processes on catchments or to give an easily understood asseessment of stream or river condition (Davies *et al.*, 2010; Victoria DPI, 2010).

1.9.2. Need to avoid over-simplification

Planners need to be wary of 'single issue' priorities that have been a feature of Australian natural resource management and investment. For example, in the last decade, media attention and investment priorities have focused, in sequence, on salinity, algal blooms, water scarcity, environmental needs, public health safety from re-use of water for drinking, and water for food security. There are several problems with adoption of these dominant single issues:

1. Simplistic benefit-cost analysis applied to separate user groups may miss opportunities for synergy. For example, Syme and Nancarrow (2008) define 'Water Benefits' as ways in which water promotes well-being in both utilitarian and non-utilitarian ways, acknowledging that the same volume of water can deliver multiple benefits as it moves through a catchment. Hamstead (2007) also comments on the misconception that water is used either for environmental or productive environmental purposes, when both can occur.
2. Highly specific and targeted investments can quickly become redundant. For example, current priorities are heavily coloured by a decade of drought and there is danger that recent flooding may change priorities for salinity and the need for reallocation of environmental water will be reduced. However, a continuing drought in southern Australia is predicted (CSIRO, 2010), reinforcing the need to re-balance the water extracted for consumptive use relative to that reserved for the environment. This exposes

an inevitable tension between public short-term political expediency and the need for a longer-term view.

3. Adaptability in priority setting is needed to cope with changes that include new scientific knowledge, especially on ecological resilience; effects of climate change and variability; new market-based approaches to water trading and infrastructure; new investment in water-use efficiency infrastructure; adoption of new technology such as aquifer storage recovery and desalination; emergence of new industries such as coal seam gas; new policies on water interception and carbon pricing; increased re-use of water for drinking; and changing public perceptions, especially on public health and environmental values. Adaptive management frameworks are available to support priority setting and decision making and have been used widely, for example by Baldwin et al. (2009) and Tan et al. (2010).

1.9.3. Need to integrate land use with water quality planning

Agricultural land use affects water quality and the health and resilience of downstream aquatic ecosystems, although the relationship is complex (Bowmer, 2011). More than thirty years ago Mitchell and King (1980, p. 1) provided an analysis of the research needs required to *'adjust and manage land use in a catchment so that as far as possible appropriate quality and quantity of water and suitable distribution through the year can be ensured at minimum cost to the community'*. However, land-water interactions have been downplayed by Australian water managers in recent years, reflecting an emphasis on water treatment technology ('end-of-pipe solutions') and over-riding concerns, until recently, about water scarcity. A re-integratation of land and water management through catchment-based approaches is advocated (Bellamy et al., 2002; ; Griffith, 2009; Hamstead et al., 2008). Insights into decision making for land management practice and adaptation to change are provided by Pannell and Vanclay (2011).

In Australia there is renewed interest in the benefits of watershed protection (Eichner, 2010). As noted earlier, the National Health and Medical Research Council are currently engaging in a public consultation process on proposed new guidelines for microbial safety of drinking water that advocates the use of multiple barriers (NHMRC, 2010).

1.9.4. Need for community involvement

There is growing recognition of the importance of social inclusiveness in planning (Cullen, 2006; NWC, 2011). For example, the demise of consultation process in the proposed Basin Plan has resulted in a move to involve more local input (SCRA, 2011). The demand for more environmental water is particularly contentious. There are many advantages in community involvement - broad consultative group can enrich expert knowledge, set priorties for limited volumes of water, find innovative, local solutions, and provide consensus on monitoring regimes to demonstratete environmental benefit.

Support for social and economic analysis in environmental decision making is available in Australian texts (e.g. Harding, 1998; Tisdell, 2010), in guidelines provided to support water planning in NSW (IACSEA, 1998), and in trials of profiling methodology (Hassall and Associates et al., 2003). An internet portal has recently been developed (Tan et al., 2010) that provides aids to select practical guides and tools for collaborative and integrated planning and priority setting. These include stakeholder analysis, indigenous engagement, socio-economic impact assessment, best practice for managing climate risk, participatory mapping and deliberative multi-criteria evaluation.

1.10. Future challenges

Assessments in Table 1 reflect the effects of climate change and variability, and recent changes in patterns of supply and demand for water. Lowered groundwater levels have reduced the impacts of salinity, although this may be reversed following the recent floods which are expected to recharge groundwaters in all but the south-west of Australia (MDBA, 2010c).

Although a reduction in run-off and erosion has reduced pressures for investment in nutrient, turbidity and sediment control over the last 10 to 15 years, assessment scores remain high and are likely to increase because of the move to pressurised irrigation systems and accompanying high costs of treatment for filtration and energy. Eutrophication, reflected in occurrence of algal blooms, remains of moderate concern. Even though many cities and towns have invested in plants to treat cyanobacterial odours and toxins, unregulated stock and domestic supplies remain vulnerable. Increased public concern about the safety of drinking water and pressures for re-use has raised the importance of micro-pollutants and pathogens.

Notwithstanding recent widespread rainfall over much of Australia in the spring and summer of 2010, CSIRO (2010) predicts a continuing drought in southern Australia. This reinforces the need to rebalance the water extracted for consumptive use relative to that reserved for the benefit of the environment. The proposed Murrray-Darling Basin Plan (MDBA, 2011) foreshadows a substantial (2750 GL) reduction in the cap on consumptive use (the Sustainable Diversion Limit).

Large increases in environmental water licences in regulated rivers will provide challenges and opportunities for river operations. For example, in wetter times a premium on water storage is expected as both environment and irrigation farmers store (‘carry-over’) water over several years. Reduced irrigation demand may also ameliorate the aseasonality of flow above irrigation off-takes and provide opportunities for pulsing flow for ecological advantage.

Water quality in Australia is an indicator of catchment management and land use. Integrated Catchment Management (ICM) was piloted in Australia by the Murray-Darling Basin Commission using targets for protection of assets (Williams et al., 2004). However, the ICM approach seems to have been overtaken recently, perhaps reflecting dominant concerns with water scarcity and climate variability. Reviewers of natural resource governance (Bellamy et al., 2002; Campbell and Schofield 2007; Griffith, 2009) argue that it is time to re-integrate the management of land and water through catchment-based approaches. The Water Planning Tools Project and lessons on collaborative planning (Tan et al., 2008; Tan et al., 2010) provide support for participative water planning in the future.

Water for drinking and industry imposes a critical demand for quantity and quality that is leading to large investments in infrastructure and improved treatment technologies. However, rural farms and many small towns are unable to afford these improvements and rely on watershed processes, use of rainwater tanks, or access to groundwater bores to maintain a water supply, often of doubtful quality, for domestic and stock watering purposes.

The inherent value of healthy aquatic ecosystems and importance of water-dependent recreation and tourism are increasing. Aesthetic and cultural values of water are important to the Australian public as demonstrated by choice modelling (Bennett et al., 2008; Morrison and Bennett, 2004) and by new approaches to water valuation that capture subjective non-utilitarian priorities (Syme and Nancarrow, 2008). As noted in the biennial review of the National Water Commission, indigenous needs and consultation in planning remain a challenge (NWC, 2009a; NWC, 2011).

In a recent article titled '*Water is the Key to Sustainability*', Jeffery and Cribb (2010) argue that it is time to consider a national effort to increase water storage within the landscape: '*Our dams store only two drops of 100 that fall. Our landscape can potentially store 10 times or more. The universal theme is to save water and build soil carbon*'. The role of stubble retention systems in meeting this aim will be discussed in Part 2 of this monograph.

1.11. Conclusions

Clearly, developing a priority-setting framework for water resource protection requires that biophysical considerations should be better integrated with socio-economics. Notably the effect of public expectation on driving or restricting the implementation of policy should be considered. These issues are complex, difficult and sometimes contentious. Examples include attitudes to re-use of water for drinking in cities and rejection of the Basin Plan by some rural communities. To their credit, planners and governments are responding to these challenges. Fortunately, in Australia, a wide range of tools is being developed and sharing of knowledge and experience is enhancing collaborative approaches to planning.

The restrictions on water availability and increasing need for food and fibre in Australia and globally (Cribb, 2010) will promote greater efficiency in use of rural and irrigation water. Consequently it is important to take a big picture view of all the options for management, using regional, catchment or hillslope scale analysis (as well as a national approach undertaken above) to inform on-ground planning. More information on the range of management options available is presented in Part 2 of the current Monograph.

2. PART 2: MANAGEMENT METHODS WITH A FOCUS ON STUBBLE FARMING SYSTEMS

2.1. Abstract

The off-farm downstream benefits and costs of stubble farming systems are reviewed and compared with alternative management options for water resource protection (quality and quantity) in Australia. Individual quality characteristics considered include salinity, acidity, nitrogen, phosphorus, carbon, turbidity, sediment, micro-pollutants and pathogenic organisms. Water quantity is considered in terms of catchment water balance and hydrology, including seasonality and flow peaks. The management options are assessed under categories of prevention (including watershed protection methods), interception (such as the use of salinity evaporation ponds and protection of the riparian zone) and treatment (such as disinfection and filtration). The many benefits of stubble farming systems include reduction in turbidity and associated pollutants through effects in reducing hillslope erosion and reduction in salt load through water interception in the landscape. More information is required on the effects of stubble farming on the water cycle and on the groundwater profile at the local and catchment scales. This monograph concentrates on off-farm benefits (ecosystem services) and costs from stubble farming; but both on- and off-farm analyses are required to optimise policies and investment in land use.

2.2. Objectives

The significance of individual water quality and quantity parameters to different water users in Australia was collated in Part 1 of this monograph. The objectives of Part 2 of the monograph are:

- to compare the full range of options for management of water quality;
- to collate information on the benefits (ecosystem services) and costs of stubble farming systems;
- to consider the outlook for water resources; and
- to explore the role of stubble farming systems in coping with changing risks and demands for water quality and quantity compared with opportunities and investment in other management options.

2.3. Management options

Management options are separated into three methods as follows:

- prevention - land management for watershed protection;
- interception of pollutant before it reaches the river or natural wetlands or water sensitive urban design; and
- treatment solutions (such as filtration and disinfection) used immediately prior to consumptive use.

2.3.1. Prevention

The valuation of ecological goods and services for watershed restoration was recently reviewed (Thurston et al., 2009) and watershed management for drinking water protection was advocated by (Davis, 2008). As noted by Ford (2010), effective watershed management can substantially reduce operational and capital expenditure for drinking water treatment by providing better raw water quality; and the risk to public health is reduced by providing the first barrier in a multiple barrier chain. A key point here is that prevention through regulated land use and management is far cheaper than treatment to clean up polluted water.

In Australia some metropolitan catchments are managed and/or audited to protect urban drinking water quality and municipal use. For example, public health risks from C*ryptosporidium* and G*iardia* in Sydney drinking water in 1999 led to a CSIRO audit of the catchment and development of land-use planning guidelines; a sixth independent biennial report has recently been completed (NSW DECCW, 2010). New guidelines have recently been released for landholders living in water supply catchments in Victoria under the logo 'F*rom the source to the glass, it's a shared responsibility'* (Eichner, 2010).

The principles of watershed protection in Australia have evolved into strategies and programs for Integrated Catchment Management, Total Catchment Management and Whole Catchment Planning (Bellamy et al., 2002). Standards and targets are set for Catchment Action Plans in NSW emphasising sustainability and resilience (NSW NRC, 2005).

There is also growing recognition in Australia that the long-term sustainability and utility of riverine and estuarine systems requires that the ecosystem be protected. As pointed out by Rutherford et al. (2000) it is easy, quick and cheap to damage natural aquatic ecosystems but hard, slow, expensive, and sometimes impossible, to return them to their original state. Therefore the emphasis should be on avoiding damage in the first place, especially for rivers and streams that are currently in good condition. For highly-regulated 'working' or 'entrained' rivers there is still a need to maintain the resource in a productive condition, avoiding degradation and irreversible decline in quality (Hillman, 2008).

2.3.2. Interception

Interception methods include the use of salinity evaporation basins and the use of filtration capacities of riparian vegetation and wetlands for intercepting eroded particles and associated pollutants. For example, pumping of groundwater and diversion to evaporation basins along the Murray River prevents the discharge of about 162,000 tonnes of salt as part of a salinity trading scheme between three states (Chassemi et al., 1995).

Hart (1986) reviewed the role of particulate matter (turbidity and suspended particles) in the transport and fate of pollutants (nutrients, heavy metals and organic compounds). Many pollutants are quickly adsorbed in turbid water so are effectively intercepted by grass buffer strips and riparian vegetation. There is extensive international literature on the use of natural and constructed wetlands to intercept pollutants (e.g. Hammer, 1990; Kadlec and Knight, 1996). Natural wetlands are used for removal of biochemical oxygen demand, suspended solids and nutrients, including nitrogen, at lower construction and operating costs compared with constructed systems. In Australia the use of Water Sensitive Urban Design integrates wetlands and green spaces with water cycle management for stormwater, including aquifer storage and recovery. A comprehensive national guide and case studies have been prepared by the Joint Steering Committee for Water Sensitive Cities (BMT WBM Pty Ltd, 2009).

Major investments have protected river banks against erosion by fencing and providing off-river watering points for stock. Additionally many Catchment Authorities and regional groups have protected and restored riparian revegetation through a range of incentives and on-ground community programs such as Land and Water Management plans, Landcare, the Natural Heritage Trust and Caring for our Country (e.g."*Celebrating five years of achievement"* NSW

CMA, 2010). Innovative techniques continue to be trialled. For example, in ‘Natural Sequence Farming’ the construction of a ‘chain of ponds’ can avoid incision of the landscape by streams and create a freshwater lens above saline groundwater (Andrews, 2006), but the method remains highly controversial because of potential impacts downstream.

2.3.3. Treatment

Treatment of drinking water in Australia is generally sophisticated and effective (GHD, 2005) and is well-serviced by professional, industry and research associations such as the Australian Water Association, the Water Services Association of Australia, the Barton Group and Water Quality Research Australia. However, many Australian inland towns and villages drink recycled water indirectly, and in larger cities the pressure to recycle effluents for direct drinking is creating challenges because of public concerns about the safety of treatment processes. Also, as noted in Part 1 of this monograph, treatment for smaller centres is less sophisticated and may be deficient, especially where high turbidity and algal blooms are frequent (Productivity Commission, 2011).

2.3.4. Choice of approach

Clearly, the greater the value placed on in-stream ecosystem protection the greater the importance of the preventative and interception methods. However, benefits and values of in-stream water quality for aesthetic, spiritual, recreational and indigenous purposes (and corresponding justification for investment in management) are more difficult to quantify than benefits and costs of interception or of technological solutions for treatment prior to consumptive use. There is also a question about whether communities are prepared to forgo a decline in in-stream water quality and aesthetics even if treatment for consumptive use is available and affordable.

Management interventions for each priority water quality parameter are listed under classification of prevention, interception and treatment in the following sections. The relative effectiveness of management options and the role of stubble farming systems are summarised in Table 4.

2.4. Salinity

2.4.1. Prevention

As salinity effects on water resources are primarily a groundwater issue, an understanding of groundwater flow systems is essential to assessing the risks to landscapes through rates of infiltration of water to groundwater stores (‘recharge’). Although salinity was assessed as a lower priority than turbidity and micro-pollutants/pathogens in Table 1, a return to above average rainfall conditions could increase the risk of salinity in river systems reaching previous high levels (MDBA, 2010c). However, in spite of recent massive flooding in eastern Australia in late 2010 and early 2011, this risk should be considered in the context of climate change projections to a drier state in southern Australia (CSIRO, 2010). Improved modelling frameworks described above and a recent large investment in a National Groundwater Initiative (NCGRT, 2010) should help to improve planning, management and adaptation.

Deep-rooted and perennial crops, agro-forestry, timber shelter-belts, double or opportunity cropping, pasture phases and other methods, including engineering solutions, are well-recognised strategies used in Australia to prevent the rise of groundwater to the soil surface. Various modelling programs, reviewed by Robins (2004) for Land & Water Australia's National Dryland Salinity Program, are being used at catchment level to determine hotspots for intervention. The models include BC2C (Biophysical Capacity to Change), CATSALT, CAT (Catchment Analysis Tool), MODFLOW, HYDRUS-2D, FLUSH (Framework for Land Use and Spatial Hydrology) and FLOWTUBE and are targeted at deep-rooted crops and trees rather than stubble farming adoption specifically.

Other planning tools are now available to help manage the risk of salinity and set priorities for intervention (for a full list of models see Table 5 in Part 3 of this monograph). Those specific to salinity are listed below:

- *The Groundwater Flow Systems Framework* (GFSF) better predicts the behaviour of groundwater in response to recharge, and provides resource managers working at local and regional scales, with a means for achieving a consistent approach to managing and preventing salinity. The response of groundwater flow systems to changing climate and land management are described at local, intermediate and regional scales with increasing lag times, from less than a year to centuries (Walker et al., 2003).

- *The Salinity Investment Framework* (SIF) sets priorities for investment in salinity repair. Four main classes of natural assets are identified: biodiversity, water resources, agricultural land, and rural infrastructure (e.g. towns and roads). Priorities are set, based on three main criteria: the value of the natural asset, the threat to it, and the feasibility of options available for protection (George et al., 2005).

- *The Practical Index of Salinity Models* (PRISM) is a CD ROM of over 90 tools, models and frameworks for planning (NDSP, 2003).

- *Optimisation of water and salt models*. Methods to optimise reductions in salinity while maintaining water run-off are available (Nordblom et al., 2006, 2009, 2010, 2011; Stirzaker et al., 2002;Vertessy et al., 2003). Demonstrations are based on the optimisation of land use (tree planting and lucerne) but principles could be applied to other land uses, including stubble farming.

The lowering of near-surface groundwater levels in inland irrigation areas are reported by Coleambally Irrigation Co-operative, Murrumbidgee Irrigation Ltd and Murray Irrigation (e.g. (Murray Irrigation Ltd, 2007). This may reflect a combination of improved water-use efficiency, restriction of flood agriculture to more impermeable soils and greatly reduced rainfall. Optimisation of subsurface drainage systems (Ayars et al., 2007), novel infiltration (net recharge) trading systems (Whitten et al., 2005), and soil water and groundwater management decision support systems (Humphreys et al., 2006) have also helped to overcome irrigation salinisation.

2.4.2. Interception

Salt interception schemes are large-scale groundwater pumping and drainage projects that intercept saline water and dispose of it, usually by evaporation. For example, 50,000 hectares of farmland in the Wakool Tullakool Sub Surface Drainage Scheme are protected by pumping an average of 14,600 ML of saline water each year, preventing its gradual movement into the Wakool, Niemur and Murray Rivers. The NSW Government acknowledges the value of the interception scheme and currently pays 30% of its annual operation and maintenance costs (Murray Irrigation Ltd, 2006). As part of the Murray-Darling Basin Commission Salinity and Drainage Strategy the three states of NSW, Victoria and SA have pumped about 55 GL of saline water from aquifers each year since 1978 and kept at least 550,000 tonnes of salt out of the river (MDBC, 2006).

2.4.3. Treatment

Desalination technology, based on reverse osmosis, is being increasingly in Australia but is too expensive for small rural towns or for irrigation supplies. In 2008 it was estimated that the total volume of water desalinated was about 300 ML/day with a projection of a seven-fold increase by 2013. Mining and coal seam gas industries are also beginning to adopt reverse osmosis methods for desalination (Hoang et al., 2009; Anon, 2010). The National Urban Water and Desalination Plan is supporting cities and towns to reduce reliance on rainfall by investing in desalination, water recycling and stormwater projects. The program includes two new research centres in Perth, WA, and Brisbane, Queensland (SEWPC, 2010).

2.4.4. Role of stubble systems

Assessment of the benefits of stubble systems for salinity management requires a good understanding of the water cycle at paddock and catchment level. Stubble farming sytems generally compare favourably with tillage because of improved water retention in the root zone, so reducing capillary rise, salt deposition at the surface and run-off. Reduced evaporation would be expected to reduce the volume of capillary rise, but it could also lead to increased deep drainage to groundwater. An advantage of tillage is that it disrupts capillary pathways. More knowledge about the direction and scale of these effects and their interaction is needed. Some work has been initiated by the Grains Research and Development Corporation, but at the paddock, rather than catchment scale (GRDC, 2011).

The model Agricultural Production Systems sIMulator (APSIM) has been used to predict the effects of alternative farming systems on leakage of water below the crop root zone and to calculate the allowable leakage from a catchment to avoid salinisation (McCown et al., 1996).

2.5. Acidity

2.5.1. Prevention

There are two main causes of acidification: (i) broad scale acidification under agriculture due to leaching of anions and net export of cations in farm produce; and (ii) the site-specific issues arising from sulphidic sediments that are oxidised to acids on exposure to air.

Soil acidity affects 8 to 9 times more land than dryland salinity, equivalent to about half the total area of agricultural land in Australia (Gleeson and Dalley, 2006). To raise the pH of all soils to above 5.5 Australia would need to apply 66 million tonnes of lime per annum, compared with application of an estimated 2 million tonnes in 2001 (NLWRA, 2002). Alternative management options include avoiding leaching of nitrogen below the plant root zone by timing nitrogen fertiliser application to meet plant demand, avoiding long fallows, retaining crop residues rather than burning, replacing cations removed in agricultural commodities, and improving soil organic matter levels (Beeton et al., 2006).

Soil acidity is a particular problem in many low-lying regions where the clearing of mangrove swamps and the exposure of iron sulphide in acid sulphate soils to the atmosphere results in highly acidic water (Baldwin and Fraser, 2009). Recent rain and water purchase for the environment is expected to assist in preventing exposure of sediments in the Coorong and Lower Murray Lakes (MDBA, 2010a). The National Strategy for the Management of Coastal Acid Sulphate Soils (NWPASS, 2000) aims to map all affected soils and avoid draining wherever possible.

Impacts of acid sulphate soils listed by the Cooperative Research Centre for Contamination and Remediation of the Environment, (CRC CARE, 2009) include damage to aquatic ecosystems and fish kills, damage to commercial fisheries, and corrosion of concrete footings of buildings and bridges. Several issues contribute to acidity in water so that a diversity of prevention methods is required.

2.5.2. Interception

Since saline groundwater is the principle source of sulphate for inland waterways some wetlands might be protected by banks or by preventing the entry of sulphate-reducing bacteria. However, interception is not a useful technique for dealing with acidity. Reinstating periods of low or no flow into regulated waterways will minimise the accumulation of potentially harmful amounts of sulphidic sediments. Returning high flows at appropriate times will flush salts and acid, scour sediments and dilute affected waterways, as well as protect wetland sediments from saline groundwater by providing a freshwater lens (Baldwin and Fraser, 2009).

2.5.3. Treatment

Digging up sediments for treatment is very expensive, while broadscale acidity treatment with lime, dolomite and other ameliorants is possible, but also expensive. A better strategy is to permanently re-flood the soils to prevent them forming fresh acid, which is underway at a national demonstration site at East Trinity, near Cairns, in Queensland (CRC CARE, 2009).

2.5.4. Role of stubble systems

As noted in the Australia State of the Environment Report (Beeton et al., 2006), some $9.5 million was supplied to improve soil condition through the National Action Plan for Salinity and Water Quality, and the Natural Heritage Trust. However, the continuing, broadscale soil acidification under current agricultural systems has received little attention compared with salinity, and the potential benefits of retaining crop residues (i.e. stubble farming) in mitigating acidification have not been assessed.

2.6. Nitrogen, phosphorus and carbon

2.6.1. Prevention

Urban and rural sources both contribute to contamination with nitrogen and phosphorus, although agricultural run-off is the dominant or substantial source in most catchments (ANRA, 2001). In reviewing the management of algal blooms in Australia, Edgar et al. (2007) report that the biggest agricultural contribution of phosphorus to rivers is naturally derived and strongly associated with soil erosion.

Surface erosion (sheet and rill) is especially important in areas of high rainfall intensities such as the tropics, and where soil tillage is intensive. Over 85% of the sediment-bound phosphorus in Queensland is derived from hillslope erosion, whereas gully (subsoil) and river bank erosion dominates in south-eastern Australia (ANRA, 2001). Consequently, the avoidance of surface soil exposure and erosion is particularly important in reducing pollution of water resources by nitrogen, phosphorus and carbon in the high rainfall areas of Australia.

Sewage treatment plants and stormwater were major point sources of nutrient inputs in the early 1990s (GHD, 1992) but their impacts on fresh and coastal water have been much reduced by re-use and recycling (Radcliffe, 2004) and by the adoption of Water Sensitive Urban Design principles (BMT WBM Pty Ltd, 2009).

Recent research in the National Eutrophication Management Program (Davis and Koop, 2006) shows that nitrogen, rather than phosphorus, can be critical in the development of algal blooms in Australian inland rivers. Nitrogen and the amount of light can influence the species of algae that constitute the bloom. Nitrogen is expensive to remove from sewage, especially for small towns that rely on treatment ponds to remove it before returning effluent to river systems. Nitrogen can be removed in more sophisticated plants such as Canberra’s Lower Molonglo Water Quality Control Centre, but costs of removal are high.

2.6.2. Interception

Nitrogen is not readily intercepted by riparian vegetation and therefore the opportunity for prevention and importance is increased. Forestry and stubble farming systems that use relatively little fertiliser and retain water in the landscape are potentially important mechanisms for water quality protection. Interception by wetlands can be useful to remove nitrogen by processes of nitrification in aerobic zones followed by de-nitrification in anaerobic conditions (Kadlec and Knight, 1996).

Phosphorus is persistent in sediments, and because it is substantially present in the particulate form, it can be intercepted by filtration in the riparian zone. The use of riparian strips to intercept and filter nutrients and to stabilise river banks has been a focus of research and investment by Land & Water Australia (Lovett, 2004) and by several NSW Catchment Management Authorities (NSW OEH, 2010). Particulate phosphorus is also managed by reducing stream bank erosion through controlling rates of rise and fall of water in regulated rivers, providing off-river watering points for stock, and managing grazing to avoid development of erosion tracks. The dissolved form of phosphorus and dissolved organic carbon cannot be easily intercepted.

2.6.3. Treatment

Copper sulphate is used in reservoirs of SA in an attempt to treat early stages of algal blooms. The toxic effects of such approaches limit their use to artificial storages. Activated carbon is a cheap and efficient method for toxin and odour removal from drinking water (Westrick, 2008), and many rural towns now have activated-carbon filters to deal with these water quality problems. PhosLock is a modified clay that can spread over the water to mop up phosphorus, taking the bound phosphorus with it as it sinks. It is a commercial product of Phoslock Water Solutions Ltd. (Douglas, 2007; Phoslock Water Solutions, 2010).

2.6.4. Role of stubble systems

Stubble systems may reduce gully formation and associated sediment export to rivers through diffusing the intensity of run-off events. Compared with tillage systems, stubble farming systems are expected to also provide substantial benefits in protecting rivers from particulate phosphorus contamination that arises from surface run-off. Precision fertiliser application methods and use of slow-release fertiliser granules will help prevent eutrophication by reducing nutrient sources.

Carbon is important and beneficial for fuelling the food web, but has detrimental effects on water quality and treatment when present in excessive concentrations through the formation of odours, toxins and carcinogenic disinfection by-products (CRC WQT, 2005). Stubble farming systems are expected to maintain soil carbon compared with tillage systems (Scott et al., 2010), and as export of both particulate and soluble dissolved material will be reduced through water retention in soil, stubble systems are likely to provide a substantial benefit for water quality. As noted above, there is also evidence that under stubble farming there may be higher levels of phosphorus (and likely dissolved organic carbon) at the soil surface, which, under intense rainfall, may result in contamination of the stream network. In most situations this is likely to be far outweighed by the benefits of stubble in reducing particulate erosion.

2.7. Turbidity (eroded particles)

2.7.1. Prevention

The National Land and Water Resources Audit Advisory Council describes the relative importance of hillslope (sheetwash and rill), gully and riverbank erosion in adding sediments to streams in different Australian catchments (NLWRA, 2001). Hillslope erosion is highest in Queensland, gully erosion dominates over much of south-eastern Australia and streambank erosion is particularly a problem in eastern Victoria. As gully erosion is the main source of sediment loading in south-eastern Australian rivers (NSW OEH, 2011b; Olley and Scott, 2002; Prosser et al., 2001a) it has been a main target for preventative investment strategies. However, evidence from field stratigraphy, optical dating and hydraulic modelling shows that incised gullies are beginning to stabilise, showing a phase of landscape recovery (Rustomji and Pietsch, 2007). The software tool, SedNet, has been used to determine the sources, stores and fluxes of material at river reach scale and identify priorities for investment to meet downstream targets for suspended sediment loads (Lu et al., 2004).

The avoidance and management of bushfires has become a major issue in managing downstream water quality in Australia, especially for cities such as Melbourne, Victoria, (and to a lesser extent for Canberra, ACT, and Sydney, NSW). Cities with protected catchments generally do not filter water before supply, and are therefore vulnerable to the effects of ash and sediment run-off (Anon, 2009).

Stubble farming is an important option in maintaining vegetative cover to reduce sheet and hillslope erosion (see Section 2.7.4). It may also reduce overland flow volumes and velocity and thereby reduce the run-off from intense storm events that lead to gully erosion.

2.7.2. Interception

The use of riparian rehabilitation for interception of eroded particles has been investigated in an extensive program coordinated by Land & Water Australia (Lovett, 2004). In a review of SedNet applications Wilkinson and Kennedy (2007) describe a case study for the Murrumbidgee River catchment in NSW in which 80% of suspended sediment load is derived from 20% of gully erosion sites. SedNet was used to target the investment of about $1 million for a riparian vegetation program to reduce sediment load by 30% at Wagga Wagga (a key inland city in the Murrumbidgee catchment).

Generally riparian vegetation is much less effective in interception where flow (and thus particulate load) is concentrated, as its trapping capacity is quickly exceeded. Riparian vegetation is of most use in trapping particulates from broadscale hillslope erosion (P. Price, pers. comm.).

A method for the Rapid Appraisal of Riparian Condition (Jansen et al., 2004) has been used in the Murrumbidgee River, in NSW, and Murray, Goulburn, La Trobe and Burdekin Rivers in Victoria. The objective was to determine riparian condition and priorities for river restoration.

2.7.3. Treatment

Turbid water is a major problem for Australian inland rivers, and the cost of treatment escalates when algae are also present. Ahmad (2005) describes the various treatment methods, including conventional gravity sedimentation, micro-sand embedded flocculation, and the most sophisticated and advanced treatment, dissolved air flocculation and flotation. There are more than 30 dissolved air flocculation and flotation plants in Australia (GHD, 2005).

2.7.4. Role of stubble systems

A major benefit of stubble farming systems is reduction in sediment load and suspended particles (turbidity) through reduction of hillslope erosion and retention of water in the landscape. Benefits at paddock scale have been demonstrated by early experiments and modelling using PERFECT (Freebairn and King, 2003; Freebairn et al., 1993; Freebairn et al., 1986; Littleboy et al., 1992) and APSIM (Connolly et al., 1999; McCown et al., 1996a). However, in some regions paddock scale mitigation processes are confounded by gully and bank erosion. Modelling (SedNet) has been used to identify the sources and flux of sediments at river reach scale (Lu et al., 2004; Wilkinson and Kennedy, 2007) and the use of riparian vegetation for interception has been investigated in an extensive program by Land & Water Australia (Lovett, 2004). Links between sediment dynamics, riparian vegetation and aquatic ecology were explored in the Ovens River by Derose et al. (2005).

Long-term experiments in Queensland (Thomas et al., 2007) and NSW (Felton et al., 1995) showed a general relationship between reduction in soil loss and increased cover. In the

Greenwood and Greenmount sites of Queensland soil losses were 31 and 49 t/ha for bare soil compared with 1 and 3 t/ha for no tillage and 3 and 6 t/ha for stubble mulch, respectively (Thomas et al., 2007). The dramatic benefits of stubble mulch on reducing soil loss are shown in Table 3 for demonstration sites at Gunnedah, NSW (NSW DLWC, 1979). Run-off from long-term tillage sites in NSW at Ginninderra and Wagga Wagga showed greatly reduced sediment run-off from direct drill sites compared with conventional and reduced tillage (Harte et al., 1985). Hence stubble farming can be a major preventative measure for turbidity and sediment.

Tracer technology has suggested that gully erosion dominates hillslope surface soil erosion in south-eastern Australia (Olley and Scott, 2002; Prosser et al., 2001b). Stubble systems are expected to reduce run-off flow intensity, potentially providing a benefit in gully erosion control, as well as in reducing hillslope run-off.

Table 3. The effect of stubble treatments on erosion losses at demonstration sites, Gunnedah, NSW**.**

Soil type and slope	Soil loss (t/ha/yr) Conventional Tillage	Stubble Incorporation	Stubble Mulch
Colluvial clay; 5-8% slope	270	110	10
Colluvial clay; 1-2% slope	76	51	12
Self mulching clay; 1-2 % slope	60	24	12

Source: NSW DLWC, 1979.

2.8. Micro-pollutants

Micro-pollutants in water include natural compounds such as algal toxins and dioxins from bushfires; brominated fire retardants; organic compounds that are disinfection by-products, heavy metals and organics including hormones and their analogues from waste treatment and septic system discharges, pharmaceuticals, antiseptics, perflurochemicals and nanoparticles, industrial discharges; metal and oil pollutants from urban run-off; and agricultural pesticides (Falconer, 1999; Falconer et al., 2006; Kookana et al., 2007). Consequently a diverse range of preventative, interception and treatment actions is required.

Groundwater pollution from industrial sites (e.g. leaking fuel dumps, munitions plants, livestock dips, refineries and landfills) and BTEX compounds from coal seam gas hydraulic fracturing (‘fraccing’) are new threats (NWC, 2010b).

2.8.1. Prevention

Strategies to protect waterways in urban areas include the capture and filtration of stormwater using wetlands and Water Sensitive Urban Design approaches for stormwater and hard surface run-off (BMT WBM Pty Ltd, 2009). Increasingly, infrastructure planning for safe effluent disposal is a challenge for planning authorities in peri-urban areas.

In rural areas effluent disposal guidelines are available for intensive rural industries such as piggeries, beef feedlots, food processing industries, tanneries and wineries (SEWPC, 2011). Some irrigation industries were once notorious for pollution of water with persistent pesticides such as endosulfan, but a range of ameliorating actions including recycling on-farm and use of genetically modified pest-resistant varieties have reduced or eliminated much pesticide use and contamination (Cox Inall Communications, 1998).

The Great Barrier Reef catchment is an example of an approach to control diffuse source pollution of several herbicides, including atrazine and diuron from sugarcane, cotton and other agricultural industries. A Reef Plan has been developed that requires 650 graziers and 1000 cane farmers to adopt an environmental risk management plan. This provides room for individual innovation and supports the use of techniques such as grass strips, controlled traffic to reduce compaction and sediment loss, and precision application of herbicides and shielded sprayers. The new Reef Plan is provided as an exemplar for managing diffuse pollution that is threatening about 400 near-shore ‘dead zones’ internationally. It is said to strike the right balance with targets, voluntary measures, incentives, regulations, monitoring, enforcement and funding (Pittock, 2010).

Regulation of land use and management of wastes and flows from potential sources of pollutants are key issues. Once in the environment many of these pollutants are almost impossible to recapture, as they are either dissolved or of very small particle size.

2.8.2. Interception

Effective management of the riparian zone and use of filter strips contributes to protection of rivers and estuaries from many pesticides and other pollutants that are hydrophobic and adsorbed onto particulate matter. Farmers in many areas are now able to access support for the capital costs of off-river watering for stock and for fencing to protect river banks (e.g. NSW NRC, 2010; Victorian Government, 2010). Grass filter strips and dense riparian vegetation with ground litter can intercept shallow overland flow and remove adsorbed pollutants through physical trapping, absorption to foliage or infiltration. This mechanism is much less effective where flow is concentrated, in gullies and waterways.

2.8.3. Treatment

A review prepared for State of the Environment Report (Rae, 2006) lists a range of compounds that become environmental risks throughs recycling of water for drinking. They include low concentrations of endocrine disruptors such as phthalates (used in plastics), pharmaceutical drugs and their metabolites, cosmetic materials and natural hormones. However, in a recent study, Lampard et al. (2010) found that exposure to five chemicals in raw wastewater (a synthetic oestrogen, musk fragrance, a phthalate, atrazine herbicide, and NDMA — a disinfection by-product) was several orders of magnitude below the estimated daily intake associated with other exposures, notably food. Also, most micro-pollutants are removed by advanced treatment processes (Khan, 2010). Unfortunately not all communities have access to sophisticated or well-maintained treatment systems (Hepworth, 2010; Productivity Commission, 2010), and there is still community concern and mistrust about the health risks associated with recycling water for consumption (Rae, 2006).

2.8.4. Role of stubble systems

In a recent review of the protection of water sources in Australia (AWA, 2010), several authors and water utility practitioners emphasise the importance of catchment management for protection of drinking water and advocate the use of best practice management that includes minimum input of pollutants. Stubble farming systems are advocated as benign land uses in that pesticide use is mainly knockdown herbicides such as diquat, paraquat and glyphosate that are quickly adsorbed and inactivated in soil; and run-off is minimised (West, 2004). Counter views are that: herbicide use may be increased when tillage is no longer effective as a weed control method; herbicide resistance leads to use of increased quantities of active ingredient and the use of a much wider spectrum of herbicide chemistries; and pesticides are needed for some pests (such as snails in SA) which are best controlled on bare soil. Also it is now recognised that glyphosate is not inactivated quickly in all soil types, and even when adsorbed it can be released later with deleterious consequences (Eberbach and Douglas, 1983). More benign land uses than stubble farming are available, for example, pastures with native vegetation shelter belts if grazing is managed properly, but if an area is already developed for cropping, then stubble farming certainly has potential advantages (P. Price, pers. comm.).

2.9. Pathogens

2.9.1. Prevention

Sources of pathogens include stormwater and sewer overflows, stock with direct access to waterways, stormwater run-off, leakage of poorly functioning septic systems and industrial wastewaters, especially those from processing industries, such as abattoirs and wineries. Any of these may carry bacteria and viruses that can cause disease. Consequently prevention rests on planning and regulation of drinking water supply catchments (Davis, 2008) and development and audit of land-use planning guidelines (NSW DECCW, 2010; Eichner, 2010).

The debate around proposals such as the Toowoomba recycling scheme in Queensland, provides a good example of the intensity of feeling that can arise when re-use is considered. In this case, after much debate and a referendum, the community rejected sewage recycling as an option. The growth of large urbanised populations has exacerbated the problem as new sources of raw water are increasingly distant from these centres.

In some cases the requirement for re-use of wastewater has been driven by the local communities' desires to avoid discharge of their effluent to local waterways or the ocean, although the level of treatment employed would often mean that the effluent is cleaner than the receiving body of water (L. Kennedy, pers. comm.).

Use of 'third pipe systems' that separate water to be used for gardening and toilet flushing avoids the discharge of effluent into rivers and streams. Such schemes (e.g. Rouse Hill in Sydney and Forest Hill in Wagga Wagga, NSW) are normally only considered when sources of raw water suitable for potable water production are inadequate. The cost of producing and distributing effluent suitable for urban re-use is usually far greater than the cost of producing potable water if a suitable source is available. Costs are substantial because a stand-alone additional treatment system and distribution network is required over and above the potable system.

Examples of recycling in Australia include: in SA the Bolivar sewage treatment plant in Adelaide where effluent is used in a large market garden area; in Victoria, Melbourne Water's Werribee Farm where several thousand hectares of land is irrigated with primary-treated sewage to produce fodder for grazing animals, and Coliban Water in Bendigo where sewage is pumped to a large goldmine some distance from the city; and BHP Billiton in Wollongong, NSW, which uses effluent from Sydney Water's Sewage

Treatment Plants. Many c ouncils also use treated sewage to water golf courses, parks, cemeteries and playing fields (L. Kennedy, pers. comm.).

2.9.2. Interception

Wetlands and riparian vegetation are partially effective in reducing pathogen loads in natural streams or effluent pathways. They are particularly useful for treating urban stormwater (e.g. Hamer, 1990).

The various State and Territory Governments within Australia have gradually tightened environmental discharge standards for wastewaters, with the effluents now usually cleaner than their receiving streams. However, these bodies have not paid the same attention to urban or rural stormwater run-off, with the exception of some requirements regarding erosion controls and gross-pollutant traps. Certainly in urban situations, stormwater contains far more microbiological contaminants and nutrients than is being discharged from the communities' sewage effluent streams. Although presently not being utilised to any extent, such large volumes of available water offer potential if they could be economically harvested, treated and stored, without the attached stigma that waste streams attract (L. Kennedy, pers. comm.).

2.9.3. Treatment

Treatment occurs at entry of effluents in waterways, often by exposure to natural UV radiation in sewage treatment lagoons and sometimes by more sophisticated methods, such as UV radiation, as practiced Albury City Council in NSW. Modern treatment technologies, including membrane filtration followed by reverse osmosis, produce a sterile product superior in many ways to the potable water currently used as town water supplies. Treatment methods are reviewed by Thomas et al. (1997) and Burn (2011).

Safety of drinking water at point of consumption is the objective. A central treatment plant, using disinfectants such as chlorine or chloramine, prevents the growth of biofilms in delivery pipes (GHD, 2005).

2.9.4. Role of stubble systems

Animal wastes from grazing livestock are significant sources of pathogens to water supplies (Cox et al., 2005; NHMRC, 2010), which is why many urban catchments have strict land use restrictions (Apte and Batley, 2011). Juvenile cattle and pigs, and adult and juvenile sheep are sources of Cryptosporidium in drinking water supples (NSW DECCW, 2010).

Stubble systems are beneficial in watersheds that are to be protected for drinking water quality because they retain soil particles that are associated with bacteria and viruses and are generally not subject to intensive grazing by livestock. Such systems are part of the multiple barrier or catchment-to-tap approach adopted by major urban water utilities and Catchment Management Authorities in Australia.

2.10. Water quantity and hydrology

In spite of the recent floods, water scarcity, growing populations, and increased need for food continue to drive efficiency in water use (Cribb, 2010). '*A national effort is needed to increase the store of water in the landscape*' (Jeffery and Cribb, 2010).

2.10.1. Prevention

Stubble farming systems provide both public and private benefits. Rainfall capture and retention is a major on-farm benefit of stubble farming systems that is recognised by both farmers and researchers (Scott et al., 2010). There is also increasing evidence that vegetation cover provided by these systems is critical for maintaining the local water cycle through suppression of surfaces temperatures, in turn reducing drying, run-off and ultimately erosion (Kravčík et al., 2008).

2.10.2. Interception

Thomas et al. (2007) reviewed the data on retention of water by stubble farming systems in south-east Queensland, using mean fallow efficiency (gain in soil water as a proportion of fallow rain) as a key indicator. Results comparing run-off from stubble farming and tillage systems across Queensland, were inconsistent. However, deep drainage and leaching was generally greater for no tillage and stubble retention than for conventional tillage or stubble removal. This raises the question of whether stubble farming could increase deep drainage and salinity.

In some situations retention of water in surface soils could indirectly reduce base flow to rivers through reduction of ground water discharge. The combined effects of decreased base flow in streams and groundwater pumping could substantially reduce stream flow in Australians rivers (Evans, 2007). Conversely there is some evidence that deep drainage could be increased by stubble retention compared with conventional tillage systems. Clearly this is an important information gap in quantifying the role and contribution of stubble farming to catchment water balance.

2.10.3. Treatment

Several management interventions are available to maintain run-off and river flow while reducing the amount of salt and pollutants reaching rivers and groundwater. The Co-operative Research Centre for Irrigation Futures used a conceptual water balance approach (reported in Chartres and Williams, 2006) to develop a suite of options that includes:

- reducing consumptive water extraction;
- improving river flow regime by trading, regulation and improved dam management;
- reducing groundwater extraction that provides base flow to rivers;
- managing subsurface drainage to avoid accumulation of salt in the root zone;
- improving irrigation water use efficiency on farm;
- increasing surface water re-use in irrigation and urban situations; and
- managing landscapes to maintain run-off while reducing the amounts of salt and pollutants reaching rivers and groundwater.

Costing these options requires an understanding and quantification of the water cycle. The Regional Water Resource Assessment (NWC, 2007) and Sustainable Yields Project (CSIRO, 2008) provide quantitative information on water balance at catchment scale for several regions. The latter includes trends and projections for different emission scenarios and land-use change. The reliability of these audits is limited by uncertainty about unregulated tributary inflows and soil-water balance. Furthermore, they do not distinguish different land-use contributions to the water cycle.

Recommendations on water balance reporting for Australian water authorities are given by SKM (2005). These water balances do not separate the various classes of environmental water: (i) that are specifically allocated by planning and legislation; (ii) that are obtained by purchase; or (iii) that are left in the river after consumptive use. The National Water Initiative demands a better understanding of the water cycle and the sources and uses of water at a catchment scale so that appropriate planning and policy can be developed and implemented (NWC, 2009).

2.10.4. Role of stubble systems

The ecosystem service benefits and downstream consequences of stubble farming systems (as well as other land-use options such as afforestation) might be approached by analysing the relative importance of public and private investments and returns. For example, water retention in the paddock is a private benefit while reduction in water flow downstream is both a public cost to the environment and a private cost to other consumptive users, including town and city drinking water and amenity, irrigation, industry, and tourism.

2.11. Stubble farming benefits: summary

A summary of current management options (i.e. protection, interception or treatment) is given in Table 4. Stubble farming systems are effective in reducing hillslope erosion and therefore in preventing turbidity and associated adsorbed phosphorus and other pollutants reaching water resources. Direct beneficiaries are recreational water users, through reduction in algal blooms and improved aesthetics, and consumptive water users (irrigation, industry and urban supplies), through reduced costs for water treatment and filtration. The environment is also a direct beneficiary.

The effects of stubble farming in reducing turbidity and phosphorus in surface waters (and maybe in buffering of acidity in some areas) undoubtedly contributes to aquatic ecosystem health and sustainability but many other confounding factors are involved. The multiple confounding factors makes it difficult to attribute benefits either specifically or quantitatively. As noted earlier, it is generally accepted that technological solutions to achieve acceptable water quality for consumptive use are extremely expensive compared with alternative measures of water quality protection by catchment management (Davis, 2008). Stubble farming systems provide public and private benefits in water quality that are potentially large and long-term, compared with technological solutions for water treatment. However, in Australia some water treatment solutions have already been implemented, and so are ‘sunk funds’.

Stubble farming systems may be effective in reducing loads of soluble materials, such as salt and nitrogen, through greater retention of water in the landscape (reduced ‘leakiness’) while other contaminants such, as eroded particles, sediment, and adsorbed material, including phosphorus and pesticides, are retained through reduced erosion. There is potential that improved soil structure over time as a result of stubble farming could reduce leakiness, but conversely retention of more water on and within the soil could lead to greater leakiness. More information is required to resolve this issue.

Reduced peak flow under stubble farming systems may provide a benefit through reduction of gully and subsoil erosion, particularly in southern Australia. This needs to be substantiated through research.

The main downstream cost of stubble farming systems is reduction in available water to the environment and other downstream users as a result of increased water retention in the stubble-retained area. Assessment of benefit or cost depends on the basis for comparison of water balance, for example: prior to European settlement, currently (including stubble farming versus other cropping systems), or by projecting scenarios for climate change into the future. The adoption of carbon credits for agricultural soils could encourage the expansion of stubble farming systems, so increasing landscape water retention and capacity for dryland production of food and fibre.

2.12. Planning implications

2.12.1. Changing priorities

As noted earlier, emerging challenges in water resource planning include increasing demand for food and fibre, continuing water scarcity through climate change, emphasis on water for the environment and water transfers from rural to urban centres. Water scarcity in the Murray-Darling Basin is leading to controversial proposals for the development of irrigated agriculture in northern Australia (CSIRO, 2009) and Tasmania (Denholm, 2010).

These challenges create an increasing demand and competition for water at a time of increasing scarcity. Consequently leading natural resource managers, when interviewed in 2009-10 (i.e. before the recent flooding of 2010 and 2011) agreed that water scarcity considerations have dominated water quality concerns. However, as noted earlier, the latest draft government planning guidelines (COAG, 2009) recognise that, above a certain threshold of water extraction for development, the loss of ecosystem integrity through water scarcity could threaten the utility of the water through deterioration in water quality. In addition loss of ecosystem integrity would also be undesirable for aesthetic and cultural reasons.

Emphasis in earlier decades on stubble farming systems to reduce erosion and pollution (watershed protection through management of diffuse sources) now seems to be overtaken by emphasis on point source nutrient control, control of land clearing and establishment of riparian strips. For example, the recent Victorian River Health Report Card reports that since 2002, over 7,000 km of riparian fencing and 469 km of bank stabilisation works were undertaken (Victorian Government, 2010). In NSW the recent review of Catchment Action Plans emphasises that the primary role of Catchment Management Authorities is to enhance the condition of native vegetation (NSW NRC, 2010).

Because of over-riding concerns about water scarcity there is a risk that the downstream benefits of stubble farming systems to water quality are being taken for granted or are not recognised. Although stubble retention reduced the yield of grain by up to 20% in one long-term trial at Harden, NSW (Kirkegaard et al., 2010), many farmers promote advantages of the system. Potential costs in the adoption of stubble farming systems include specialist equipment for sowing accurately into stubble, changed fertiliser requirements, changes to weed and pest management, and potential for reduced yields. However, for some farmers these costs are mitigated or exceeded by increases in long-term yield, increased protein levels, increased cropping reliability in a variable climate, reduced input costs and operator time (WANTFA, 2011).

Quantification of the benefits of stubble farming systems would assist in increasing adoption. Furthermore, resource managers may need to renew the emphasis on the benefits of stubble farming systems and develop targeted incentive programs to increase adoption so that ecosystem service benefits can be captured.

2.12.2. Incentives for provision of ecosystem services

Ways to change land-use practice and farmer behaviour have been reviewed in many workshops and publications over the last decade (e.g. Kent, 2000; Haszler, 2001; Hajkowicz et al., 2003). A Fenner conference was dedicated to the theme *Agriculture for the Australian Environment*, and a concurrent workshop across the regions was summarised as follows. '*One of the main outcomes of the workshops was recognition for those farmers prepared to take the risk. Recognition will take many forms ranging from financial to emotional. A key requirement is recognition from urban consumers. Such recognition is difficult to engender but must develop to ensure that innovative practices become the norm rather than the exception. A sustainable agriculture levy may be one way of ensuring sufficient funds are available as well as developing an understanding of agricultural issues in urban communities'* (Wilson, 2003, p. 8).

A summary of financial incentive mechanisms, including benefits, disadvantages and examples of applications, was prepared for Catchment Management Authorities by Comerford and Binney (2004). Mechanisms include grants, stewardship payments; cost sharing, auctions and tenders, subsidies, rate relief and tax concessions. Proctor et al. (2007) list a similar range of incentives, adding social recognition to affirm and promote local leaders and desired practices, regulation to restrict certain activities, and provision of information on benefits.

Pannell (2008) describes the use of incentive payments in two broad ways: (i) to encourage people to trial, and subsequently adopt, new practices that are believed to be in their best interest already, and also benefit the environment, and (ii) to compensate people for adopting practices that result in net costs to the adopters, but which benefit the environment and the broader community. If it is recognised that there is some loss of yield through adoption of stubble systems then compensation of type (ii) is required and needs to be large enough to cover not only the financial shortfall between new and traditional land-use options, but also a risk premium to maintain the changes in the longer-term and a further incentive to prompt them into action. Pannell calls this 'bait'.

In a recent comprehensive review Cocklin et al. (2007) consider the conditions under which farmers can provide ecosystem services as well as being producers of food and fibre. They found that many landholders would be drawn to an initiative that gives recognition, support and financial assistance, rather than use of market-based mechanisms, with 'command and control' regulation as a last resort. A price premium for produce through an eco-labelling scheme is one option, but is difficult to implement. Direct financial assistance is advocated, as an increasingly attractive option for landholders and an urgent imperative for Australian governments.

Of course the use of such incentives, presumably funded by taxpayers, will also require auditing, compliance and reporting. Most leading growers are averse to this approach. The widespread adoption of conservation farming across southern Australia (there are some important differences in the north) suggests that for these farmers any costs are outweighed by the benefits. This is likely to continue given that the costs of inputs (fuel, fertiliser, chemicals, and operator time) are rising faster than the value of grain and conservation farming reduces the costs of the inputs. Adoption of stubble farming systems has been variable and there are still problems to be overcome, including weed, pest and disease control, managing large amounts of stubble at sowing, and poor efficacy of pre-emergent herbicides (P. Price, pers. comm.).

A final consideration is that there is increasing interest in the social functions of water in Australia (non-economic commodities such as culture, spirituality, recreation, health and aesthetics). Australia’s market-based approaches to water policy have tended to under-value these assets.

2.13. Recommendations

1. Land management systems in general, and stubble farming systems in particular, are important drivers of water resource condition, but the integration of land and water management appears to have been down-played and under-funded in recent years (Griffith, 2009). A recent review of the state of natural resources management in Australia (Campbell and Schofield 2007,) suggests that it is timely to revisit the catchment-based approach to landscape sustainability and resilience in Australia. In this context the provision of ecosystem services by stubble farming systems needs to be recognised and valued.
2. Measurements are needed of the water balance in stubble farming systems and contribution to ‘leakiness’ at catchment scale. Little information is available on effects of stubble farming systems on groundwater. If retained stubble significantly improves water infiltration, under what conditions and in which locations might this increase groundwater recharge? This may be desirable in areas which are fresh-water sources with local groundwater flow systems that enhance fresh stream flow, but quite undesirable in areas with rising saline groundwater tables threatening to scald low-lying land and/or pollute local streams.
3. Patterns of land use (including stubble farming systems) should be overlain with potential erosion and salinity hotspots, determined by modelling, to assess the role of land-use systems in reducing erosion.
4. Optimisation of ground cover and stubble load and characteristics is needed for erosion prevention in different landscapes and climate. While land-use optimisation methods for forestry and salinity management have been developed (e.g. Nordblom et al., 2009), a similar approach is needed for stubble farming systems, including a broader range of water quality characteristics.
5. Methods for integrating downstream ecosystem services with on-farm profitability should be demonstrated in selected case studies. As noted in an evaluation of sustainable agriculture outcomes from regional investment (RM Consulting Group, 2006, p. 18) the most common deficiencies in regional plans was the matching of land use to capability and soil health condition targets. ‘*An increasing emphasis on land-use capability in*

regional planning would support regions in decision making when considering trade-offs from conservation and production activities'. Based on interviews with 180 stakeholders from over 100 organisations (CSIRO, 2007a, p. 4) provides a select list of research priorities that include *'an improved understanding of landscape function as a basis for investing in integrated outcomes, including biodiversity, water yields, water quality goals and sustainable and management practices, and making informed trade-offs'.*

6. Although complex, the valuation of in-stream water quality for aesthetic, spiritual, recreational and indigenous purposes is important. These values (and corresponding investment strategies) are more difficult to quantify than costs of technological solutions for dealing with declining water quality treatment, such as reverse osmosis, other filtration methods or disinfection. There is also increasing evidence that communities are not prepared to accept a decline in in-stream water quality and aesthetics, even if treatment for consumptive use is available and affordable. More information is needed to assess the value of ecosystem services from stubble farming systems, and the balance of public and private investment required to meet expectations.

This part of the monograph has explored the qualitative off-farm benefits and costs of stubble farming systems downstream, compared with other management options for protecting or treating water. Other on-farm public and private benefits (not considered here) need to be included in a full analysis. Public benefits of retention of stubble in farming systems include carbon sequestration in soil, reduction in air pollution caused by stubble burning, and reduced risk of wind erosion compared with traditional farming systems and cultivation. Private on-farm benefits include operating profit margin and capacity to withstand climate change and variability.

The original impetus for this project was the potential threat to stubble farming practices through the impacts on human and environmental health caused by burning of stubble. Overall the ecosystem benefits reviewed here provide a rationale for increasing rather than reducing stubble farming practices, and in investment in research to develop mechanical methods for stubble management.

Table 4. Effectiveness of stubble farming in relation to management options for maintaining water resource protection.

Parameter	Main Management Options			Role of stubble sytems
	Protection	Interception	Treatment	
Micro-pollutants/ pathogens	Land-use planning and audit in drinking water catchments	Appearance of some micro-pollutants in near-shore waters suggests interception is not sufficient	Sophisticated systems available but public trust is low	+ve; benign land use to be promoted where drinking water is harvested (e.g. use of non-persistent herbicides with low toxicity). Intensive animal grazing can be avoided
Turbidity Sediment Phosphorus	Erosion control through avoidance of bare and cultivated soil	Stream bank and gully erosion are major issues. Management of riparian zone (fencing and planting) can help when P is adsorbed to particles	Filtration , dissolved air flotation; expensive	Large +ve especially in high rainfall zones through reducing particulate erosion
Nitrogen	Reduced and targeted fertiliser use, liming	Interception by riparian zone ineffective for dissolved N	Some sewage treated using methanol or biological methods	+ve through reduced run-off
Carbon	Gypsum treatment can reduce run-off for sodic soils	Improvements to riparian zone (fencing and planting) can help; little effect on dissolved forms of C. Dilution of blackwater used where river operations permit	Treatment by ozonation and disinfection; concerns about carcinogenic bi-products	Neutral; carbon build-up expected but soil structure improvement should ameliorate carbon export through reduction in run-off
Acidity	Fertiliser placement and liming can help	na	Avoid exposure of acid suphate sediments (water purchase for the environment)	Improvement of soil condition and prevention of nitrogen fertiliser leaching regarded as important but effectiveness not assessed
Salinity	Control of water balance by afforestation and deep-rooted perennials	Evaporation basins, but only for point discharges; ineffective for diffuse sources	Desalination for urban supplies adopted; increasing; expensive	Both –ve and +ve; some costs possible due to groundwater rise through deep drainage. Generally beneficial through landscape interception of water.
Water quantity	Plans to licence farm dams, forestry and floodplain harvesting	Consumptive extraction is being adjusted through new caps; drainage reduced through on-farm recycling and improved water-use efficiency	na	Large –ve; overall downstream water yields reduced; need to consider production efficiency for food and fibre compared with irrigation systems
Hydrology	Rules about ‘take’ and trade to protect patterns of flow	Base flow in rivers maybe dependent on groundwater management	na	Uncertain (both +ve and -ve); may reduce volumes available for the environment and downstream users; flattened hydrographs may reduce erosive power of run-off

3. PART 3: LINKS BETWEEN LAND USE AND RIVER HEALTH WITH A FOCUS ON STUBBLE FARMING SYSTEMS

3.1. Abstract

Stubble farming has increased in Australia over several decades with claims of improved productivity, landscape stability and environmental benefit, yet recent audits show a dramatic and general decline in river health. This part of the monograph explores explanations for this apparent anomaly. Many confounding factors complicate interactions between land use and river condition and may disguise or over-ride the potential benefits of adoption of stubble farming systems or other improvements in agricultural practice. These factors include climate change and variability; land-use changes, including an increase in bushfires, growth of farm dams and afforestation; lag times between land-use change and expression of benefits in river systems; use of inappropriate scale that disguises local benefit; variations in the extent of ecosystem resilience; impacts of river regulation; impacts of introduced species; and changes in public perception and values. The use of modelling to understand complexities in the relationship between land-use change and river condition is reviewed. The strengthening of local, regional and catchment-scale approaches is advocated. This includes the re-integration of land management and governance with water management and planning. It is encouraging that some farmers are themselves developing systems to optimise trade-offs between on-farm activities and ecosystem service benefits. This needs to be supported and extended.

3.2. Approach

Australian agencies have encouraged the adoption of stubble farming systems to achieve both private on-farm and public off-farm benefits. The potential benefits (ecosystem services) and costs measured by effects on water quality and quantity characteristics are described in Parts 1 and 2 of this monograph.

In this part of the monograph the links between adoption of stubble farming systems and trends in water resource condition are explored to see whether causative links can be established. This information is required to underpin the appropriate investment in government and regional planning, whether in improved farming systems or other methods.

The Australian Bureau of Statistics reports that adoption of stubble farming systems has increased in Australia over the last few decades. In 2007-8 about 40,000 businesses (53%) used zero-till methods over 17 million hectares (ABS, 2009). This hides a big difference between regions, with generally low adoption in the north and very high adoption in WA. Expert agronomists claim over-riding benefits of stubble farming and zero tillage. For example, in a recent invited keynote address at the prestigious Fenner Conference Pratley (2006, Slide 27) reports that '*conservation farming has revolutionised soil health, water use efficiency, and landscape stability to give both productivity gains and environmental benefits*'; and (Smith, 2009), a previous Director-General of Agriculture for Victoria, in defending agricultural systems against 'green myths', describes adoption of zero-till as a good example of Australian innovation and sustainability. Yet, as explored in more detail later in this report, recent audits generally show a dramatic deterioration in river health.

Part 3 of the monograph will:

- review recent audits of river health;
- provide a framework to describe links between river health and trends in land use;
- investigate the apparent anomaly between aquatic ecosystem decline and improved land use, including the adoption of stubble farming systems;
- review approaches for attributing benefits to stubble farming systems; and
- review methods for incorporating ecosystem benefits of land use in planning and practice.

3.3. Audit of river health

Substantial national and community investments have been made in Australia through public investment in Landcare, the Natural Heritage Trust, the National Action Plan for Salinity and Water Quality, and Caring for our Country. This may reflect ideals of catchment care to protect natural assets such as rivers, wetlands, estuaries and associated aquatic ecosystems but, in general, environmental condition appears to be deteriorating. The National Land and Water Resources Audit Advisory Council found that nutrient concentrations exceeded acceptable standards in 43 of Australia's 246 river basins, turbidity was excessive in parts of 41 basins and salinity exceeded standards in 24 basins (NLWRA, 2002). Soil erosion and in-stream turbidity has a particularly strong impact on water quality in much of eastern Australia and under the heading 'opportunities for improved management' a range of deteriorating quality issues are listed in the audit. These include: salinity (affecting 1% of the agricultural land); increasing soil acidity (threatening production on 25% of the land); water-borne soil erosion (i.e. hillslope, gully and riverbank erosion); and soil and nutrient redistribution and loss.

The National Water Commission (NWC, 2007) reported on the condition of river and wetland health in June 2005 to provide a baseline of river condition at the start of the National Water Initiative reform process. The Framework for the Assessment of River and Wetland Health is based on 6 key indices which are aggregated to produce an index between 0 (severely degraded) and 1 (pristine). Most relevant to this review are: (i) the index of catchment disturbance that covers the effects of land use and vegetation cover on run-off of sediments, nutrients and other contaminants to rivers and wetlands, and (ii) the index of hydrological disturbance that recognises the importance to aquatic ecosystem function of surface flow and groundwater.

In summary, 10% of river length was identified as severely impaired, having lost at least 50% of the aquatic invertebrates species expected to be present; more than 95% of the river length assessed in the Murray-Darling Basin had an environmental condition that was degraded; 30% of river length in the Basin was substantially modified from the original condition; and all reaches and catchments in the Basin had disturbed catchments and modified water quality. It was concluded that many parts of the Basin are threatened by multiple stresses; principally land-use changes, damaged riparian vegetation, poor water quality and modified hydrology. More recently the Murray-Darling Basin Sustainable Rivers Audit assessed ecosystem health using fish condition, macro-invertebrate and hydrology condition (Davies et al., 2008, 2010). Of 45 valleys, 30 were rated as being in very poor condition and another 12 as poor. In a recent collation of river and estuarine condition audits Schofield (2010) also reports a general widespread decline.

3.4. Framework for interactions

The increased adoption of stubble farming systems, together with claims of associated ecosytem benefits, seems to be at odds with the observed general decline in condition of catchments, rivers and streams. This reflects the complexity of other pressures on river health and 'confounding factors' that may over-ride the potential benefits of stubble farming systems in Australian landscapes.

A conceptual framework that illustrates the complexity of interactions and separates cause and effect is given in Figure 1. Factors that impose stress on rivers and wetlands (stressors or pressures) are linked to symptoms of degradation (or responses) through the buffering capacity (condition-fragility or resilience) of the ecosystem. Symptoms reflect the combination of stress intensity and the buffering capacity or resilience of ecosystems.

A similar framework (Pressure State Response and Implications) was used in State of the Environment reports (Hamblin, 1998). This review is focused on the dryland agricultural land-use components highlighted in the diagram, and specifically on trends in stubble farming systems as a subset of agricultural land-use. The diagram also shows the effects of irrigation and urban pressures, illustrating the complexity of attributing water quality characteristics to specific land-use changes. This will be discussed later.

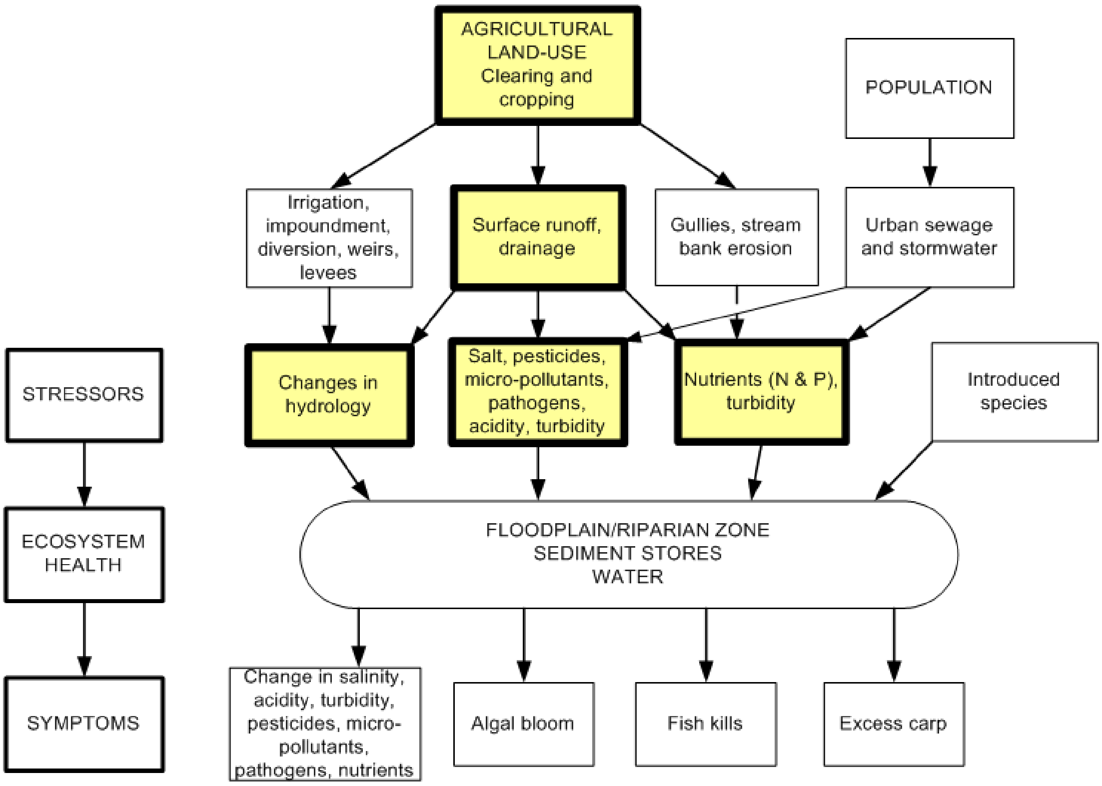

Figure 1. Changes in land-water systems through urban and agricultural stressors and symptoms shown by aquatic systems (modified from Cullen and Bowmer, 1995).

3.5. Confounding factors

Benefits that can be ascribed to stubble farming are difficult to separate from other 'confounding' factors that impact on downstream water quality, quantity and biological diversity. The detrimental impacts and changes in other factors that may improve river health are discussed in the following sections.

3.5.1. Detrimental impacts on river health

Detrimental effects on river health include:

- *Reduction in rainfall.* In spite of recent flooding over much of Australia (October 2010 to January 2011) a continuing drought and reduced run-off is predicted in southern Australia (CSIRO, 2010).
- *Land-use changes.* Water retention by stubble and other farming systems is compounded by other water interception practices, and is additional to interception from forestry plantations (about 2000 GL/yr more in evaporation than would be used in dryland agriculture), farm dams (1600 GL/yr), stock and domestic activities (1100 GL/yr), and overland flows that are harvested from floodplains (900 GL/yr). The volume of water intercepted by these activities totals almost a quarter of all entitlements (SKM et al., 2010). Van Dijk et al. (2006) also describe the risks to shared water resources in the Basin, and the effects of bushfires.
- *Diversion of water.* Water extraction from both unregulated and regulated (dammed) streams and rivers has had a major impact on aquatic ecology and river health, which has been exacerbated by a decade of drought. For the Murray-Darling Basin, specifically the long-term average shortfall of water for environmental needs is estimated to be 67-81 % of the total available surface water, equivalent to between 3000-7000 GL per annum (MDBA, 2010a).
- *Changes in patterns of flow and connection.* In highly-regulated rivers, changes in patterns of flow include reversal of seasonality up-stream of irrigation off-takes and reduced occurrence of pulsing flows that are required to maintain ecosystem diversity and functionality (Watts et al., 2009). Loss of longitudinal connection of rivers caused by weirs and barrages and loss of lateral connection through capture and storage of water are detrimental to aquatic resilience. Occasional mid-level floods are needed to achieve overbank flow for wetlands, floodplains and forests (Hillman, 2008; Young et al., 2001). The demise of red gum forests was an example reviewed recently in NSW (NSW NRC, 2009). Cold water pollution is another feature of impoundment in some regulated rivers. Extraction from unregulated rivers is also a concern for ecosystem resilience and estuarine condition through effects on flow patterns and volumes. Macro Water Sharing Plans (NSW Office of Water, 2010) provide some protection for natural features of streams and estuaries in NSW.
- *Acid sulphate soils.* Acid sulphate benthic sediments, an emerging issue in the Murray-Darling Basin, are an indirect result of water scarcity caused by drought, extraction of water up-stream, and reduced base flow in rivers caused by declining groundwater levels (Akerman, 2008; Hall et al., 2006; Lamontagne et al., 2004; Lamontange et al., 2006; McCarthy et al., 2006).
- *'Blackwater'.* Drainage water returning to rivers after flooding, which is rich in organic matter and organic sediments, can deoxygenate the water, disrupting food webs and killing fish (NSW Primary Industries , n.d.).

3.5.2. Changes that may improve river health

Countering these detrimental effects are changes that are likely to improve river health, including:

- *Improvements in water quality* through interception of pollutants in the riparian zone. Many pollutants are quickly adsorbed in turbid water (Hart, 1986) and are effectively intercepted by grass buffer strips and riparian vegetation. There is an extensive international literature on the use of natural and constructed wetlands to intercept pollutants (e.g. Hamer, 1990; Kadlec and Knight, 1996). In Australia, major investments have protected river banks against erosion by fencing and providing off-river watering points for stock. Many Catchment Authorities and regional groups have protected and restored riparian revegetation through a range of incentives and on-ground community programs such as Land and Water Management Plans, Landcare, the Natural Heritage Trust and Caring for our Country (e.g. NSW CMA, 2010).

3.5.3. Challenges for interpretation

Futher challenges for interpretation of the relationship between land use and river health include:

- *Other management interventions.* A range of land-use and riparian interception options presented in Table 4 may be used to improve river health, making it difficult to isolate the effects of stubble farming systems.
- *Variation in ecosytem resilience.* Depending on their resilience, individual ecosystems, streams and rivers or reaches are expected to differ in their vulnerability to stressors (Figure 1). 'Regime shifts' (Folke et al., 2004) and 'hysterisis', or the loss of ecological function through irreversible change (Harris, 2006) are functions of diversity as well as effects of pollutants and climate change.
- *Lag time*. The effect of lag time between land-use change and impact on river condition has several consequences, both positive and negative. Problems created by earlier land-use practices and impacts such as stock trampling, clearing, fire and rabbits will mask the effects of more recent improvements (Scott and Olley, 2003; Starr et al., 1999). Even with a reduction in sediment sources, fine particulate material in lowland rivers continue to be mobilised for many years after the impact event (Norris et al., 2001). In contrast, comparison of erosion by optical dating shows that erosion has been stabilised over recent decades in a south-eastern Australian catchment (Rustomji and Pietsch, 2007). This 'landscape recovery' is attributed to vegetation growth along gully floors that traps substantial amounts of sediment high in the landscape, reducing sediment catchment yields (Zierholz, 2001).
- *Irreversible effects.* Some effects may also be irreversible, at least within human timescales. For example, much of the gully-eroded sediments now in southern river channels have since been stablised by strategic re-vegetation and native plantings.
- *Scale.* Obviously, benefits achieved at a local scale or in specific geographic areas might be disguised in national and regional scale assessments. For example, in the Murray-Darling Basin, 80% of the water harvested originates in 3% if the catchment and 90% of soil erosion occurs in 20% of the catchment (NLWRA, 2001). Also, as noted previously, sediment delivery to rivers and streams is dominated by hillslope erosion in tropical and subtropical cereal growing areas (NLWRA, 2001) while gully erosion dominates in the southern cereal belt (Olley and Scott, 2002; Prosser et al., 2001b). Although long-term demonstration sites in southern regions show dramatic amelioration of erosion by stubble farming systems compared with conventional

tillage systems at the paddock scale (Harte et al., 1985; NSW DLWC, 1979), the benefits are likely to be overwhelmed by gully sediment sources.

- *Dilution.* The effects of stubble farming on soil water retention and water quality need to be considered because, while pollutant loads from stubble farming systems may be reduced in run-off, the concentration of pollutants could increase. This increase in concentration might be further magnified during drought by reduction in surface flow, river base flow, and up-stream tributary flows.

A cost-benefit analysis is also complicated by different local perceptions of value of river and wetland health and by contrasts in rural and urban outlooks. For example, a community survey '*Who cares about the environment*' (NSW DECC, 2010) found that rural people showed much more interest in river pollution and health than did urban people.

The National River Contaminants Program (NRCP) Strategic Plan (Lovett et al., 2000) canvassed the views of catchment and river managers about the most important national-scale river contaminant issues. The objective of the NRCP (Edgar and Davis, 2007) was to understand where contaminants were coming from, how they were transported in river systems, what transformations occur during transport, and the ultimate fate and impacts of river contaminants on water quality, aquatic life and the riverine ecosystem overall (i.e. a biophysical assessment). However, recent approaches to valuation of river condition and utility provide a broader outlook on ecosystem service benefits that include socio-economics as well as biophysical approaches. In choice modelling approaches Bennett et al. (2008) have demonstrated that urban communities are prepared to pay for availability and access to rivers and wetlands; and Morrison and Bennett (2004) showed that people are prepared to pay substantial increases in costs of food and taxes to maintain characteristics of healthy ecosystems.

3.6. Approaches to integration and optimisation of land and water management

3.6.1. Indicators of landscape condition

A key set of 29 indicators for the land was recommended for Australian State of the Environment report (Hamblin, 1998). A report card format was developed across six threatening processes: accelerated erosion, changes to natural habitats, hydrological disturbances, the introduction of exotic biota, disturbance of nutrient and salt cycling, and anthropogenic pollution. Indicators were selected to reflect pressures, current condition and human response for each process. The central role of vegetation (cover, extent and condition) was identified in many of the proposed indicators because of its critical role in erosion control, nutrient cycling, habitat and maintenance of hydrological balance.

Fewer than 10 indicators in the recommended full list of 61 were sufficiently developed to be useable without further research effort. Most challenging research was listed as '*the nature of the effects of more than one threatening process on environmental conditions*' and '*the most sustainable trade-off responses when several pressures affect various environmental domains*.' (Hamblin, 1998, p. 4).This reflects the concerns raised in this monograph about isolating the effects of stubble farming from other impacts, and conversely, in assessing the benefits as well as any threats).

In the 2006 Australia State of the Environment Report (Beeton et al., 2006) it is disappointing to note that there was no data to indicate significant changes in the effectiveness of responses to the condition of the land (Gleeson and Dalley, 2006). The 2011 Report is currently being prepared.

3.6.2. Modelling

A main problem in ascribing downstream benefits and costs to stubble farming practices is that the relationship between cause (stubble farming compared with conventional tillage systems) and effect (environmental benefit or cost downstream) is difficult to quantify. As noted in Section 3.5.3, a generalised approach is problematical because of time lags and differences at regional and local scale. Various modelling approaches have been used to dissect and integrate the complex relationships. A snapshot of some of the extensive literature on modelling land use and water interactions is given in Table 5. Reviews of these and other models are available in the literature (Arancibia et al., 2007; Letcher et al., 1999, 2002; NSW DECC, 2009; Singh and Frevert, 2002; Williams et al., 1998)

Unfortunately, most of the applications listed in Table 5 are focused on salinity, nutrient management or water interception through afforestation or ecosystem response modelling. Some separate different land uses but do not differentiate between conventional tilled and stubble farming systems.

Approaches to optimise water quality and quantity from adoption of different land uses, and for stubble farming systems specifically, are considered in the following section. These approaches are needed to support planning decisions about where investments and incentives may give best return for ecosystem services.

3.6.3. Risk and sustainability

An Ecological Risk Assessment Framework or Bayesian Network modelling (Hart et al., 2007; Hart and Pollino, 2009) shows promise for application in specific catchments. Bayesian decision networks use multiple, known relationships to help identify which of many factors are likely to have the most impact on the outputs of interest (in this case, stubble farming versus conventional farming systems, and effects on downstream water quality, aquatic life and ecosystem integrity).

The Sustainability Dashboard is a software application developed by the Sage Farmer Group (Pattinson and Day, 2007) that can be used by farmers to generate a visual report of the key indicators of the condition of their land and associated business. It also includes a reflection on the ability of farmers to maintain ecosystem services, described as clean water and sequestration of carbon. The farmers also include a water budget: '*where you get your water from and how much water coming onto your property actually leaves it*' and, as noted by the Sage Farmer Group *'these measures seek to better understand the ecosystem impact of your water use'* (Pattinson and Day, 2007, p. 6).

Decisions about the trade-off between the benefits of a leaky landscape (more water downstream) and a non-leaky one (more on-farm water retention and less downstream pollution) will need analysis at a local or regional level. Case studies are needed to demonstrate the off-farm optimisation of ecosystem services and on-farm profitability through partnerships between farmers, agronomists, and catchment and natural resource managers and agencies.

3.6.4. Regional governance

In Australia, 56 Catchment Management Authorities and Natural Resource Management Regional Groups and Boards have been developed through government investment and allocated responsibility for safeguarding water quality and environmental assets. However, their degree of autonomy, capacity to raise funds and reporting relationships seems to be highly variable and sometimes uncertain (Campbell and Schofield, 2007). The framework established in NSW seems to be more effective than in other states. This may be the result of an independent Natural Resources Commission that sets standards and targets at state level and audits Catchment Action Plans (NSW NRC, 2005).

In a recent review of Australia's natural resource management governance systems Ryan et al. (2010) list ten principles for managing future challenges, including: continuity and stability; subsidiarity (devolving decisions to the lowest level); integrated goal setting; a systems approach to match governance to the nature of the problem; investment in relationships across organisations; managing for resilience of both ecosystems and communities; development of knowledge and innovation; accountability and transparency; and adaptability. Notably 'holism' (planning to address whole systems) is advocated. '*All organisations and activities that impact on natural resources need to be considered. Within government, planning departments and planning decisions should be more included in NRM governance. Water plans and agencies need to be better integrated with land management plans and agencies' (*Ryan et al., 2010, p. *v).*

Similarly, in a recent review of the progress of Catchment Management Authorities in NSW, Commissioner John Williams comments that 'w*e now understand that the processes operating in a landscape are essential for providing goods and services — clean air , water, food, fibre and biodiversity — and that our management should be aiming to maintain the integrity of these processes, rather than return the landscape to an impractical pre-development state*' (NSW NRC, 2010, p. 1).

3.7. Conclusions

Links between land use and downstream water quality and ecosystem resilience are difficult to quantify because of the interaction of many confounding factors. Substantial past investment in water treatment technology has enabled urban Australians to access safe water for drinking and industry, and to some extent has removed the pressures for greater investment in watershed protection.

However, many rural Australians are still dependent on healthy watersheds and rivers for water quality. There is also the threat of collapse in the state of some aquatic ecosystems that could damage aesthetics, biodiversity and resilience. Choice modelling has shown that Australians value these features highly.

The Sustainability Dashboard is commended as a holistic approach to integration that has the advantage of being developed by farmers themselves. As noted by the Sage Farmer Group (Pattinson and Day, 2007, p. 6) '*the provision of clean water and the maintenance of environmental flows and flooding regimes are important, but there are no easily applied* *measures of water-based ecosystem services. Water balance is proposed as a proxy'*. The framework now needs to be populated with data.

Regional groups, such as Catchment Management Authorities, Regional Natural Resource Management Groups and community organisations, such as Landcare, are appropriate for integration and optimisation of land use that considers both on-farm profitability and off-farm ecosystem service benefits and impacts. As noted in recent reviews (Campbell and Schofield 2007, ; Griffith, 2009; NSW NRC, 2010; Ryan et al., 2010) the capacity, authority and resourcing of these regional groups needs to be strengthened in Australia. It is encouraging to note that a recent report on the State of the Catchments in NSW (NSW OEH, 2010) provides condition and trends for land capability and soil condition at sub-catchment level, including erosion, salinity, acidity, carbon and soil structure. Riverine ecosystem condition is also described in detail, although the links to land management are not explicit.

Audits such as the National Land and Water Resources Audit and State of the Environment reporting do not generally consider stubble farming systems separately from grazing or cropping using conventional systems. In view of potential benefits of stubble farming systems this seems to be an obvious information gap.

A catchment-based approach to landscape sustainability and resilience in Australia is advocated. In this context the provision of ecosystem services by stubble farming systems needs to be recognised, quantified and valued.

Table 5. Summary of models used in land and water interactions.

Model	Focus	Notes	References
-Land use to target water and salt yields	Stream salinity	Model optimizes stream water yield and salinity for different land uses including forestry. Applied in Macquarie catchment, NSW. Could be adapted to stubble systems and water quality benefits.	Nordblom et al. (2006)
2CSalt	Stream salinity and water yield	One dimensional surface water model. Can predict differences in impact of land-use change between locations with different soils and climate. Finer scale than BC2C	Gilfedder et al. (2007)
AQUALM	Sediment, nutrient and water yield	A model to assist planners designers and managers; used in the upper Murrumbidgee catchment, NSW. Moderate complexity	Letcher et al. (2002)
BC2C	Stream salinity and water yield	Biophysical Capacity to Change. Uses a groundwater flow systems approach to predict regional effects of afforestation and other land-use changes on annual water yield, groundwater recharge and salinity.	Dawes et al. (2004); Zhang (2002)
CATSALT	Stream salinity	Can be linked to tributary models such as IQQM, REALM and BigMod to determine end-of-catchment streamflow and salt exports. A modelling framework that combines rainfall-run-off modelling techniques with climate variability, land-use efficiency, topographic modelling, salinity hazard and salt outbreak mapping to investigate the effects of land use on water and salt balance.	Tuteja et al. (2003)
CERAT	Estuary	Coastal Eutrophication Risk Assessment Tool estimates the amounts of nutrients and sediments exported from urban development, deforestation and agriculture. The estuary models assess the potential impact of these exports on the water quality, micro-algal biomass and seagrass abundance in the estuary	Dela-Cruz and Scanes, (2010)
CLASS	Salinity and water yield	Catchment Scale Multiple Landuse Atmosphere Soil Water and Solute Transport used to predict climate and land-use effects at paddock, hillslope and catchment scale. Seven tools included or solute balance, vegetation growth modelling, recharge, discharge and stream flow routing.	Tuteja et al. (2004)
CMSS and Win CMSS	Catchment scale land-use planning and nutrient export	Catchment Management Support System. Uses nutrient export coefficients for different land uses to estimate annual diffuse nutrient loads for smaller catchments. Note that in larger catchments in-stream processes such as sedimentation, assimilation and stream bank erosion begin to dominate over catchment sources. Cropping does not separate conventional and stubble farming systems. Accredited estimation tool for the National Pollutant Inventory.	Cuddy et al. (1994); eWater CRC (n.d.b); Young et al. (1996)
CREAMS	Pesticide and nutrient run-off	Chemical Run-off and Erosion from Agricultural Management Systems.	Arancibia et al. (2007)
Diffuse source water pollution estimator	Nutrients in streams	Estimates changes in water pollution loads (total nitrogen, total phosphorus) for developments of up to five hectares.	NSW DECC (2009)
FLOWTUBE	Stream salinity	Salt transport model to route salt through Victorian river networks. Demonstrated for optimising forestry in the Loddon Catchment.	Hekmeijer and Dawes (2003)
FLUSH	Stream salinity	Extends PERFECT to larger land areas and sub-catchments.	Van Dijk et al. (2004)

Table 5. Summary of models used in land and water interactions (Continued).

Model	Focus	Notes	References
GUEST	Soil erosion	Griffith University Erosion System Template. Calculates soil erodibility using a daily time step model.	Misra and Rose (2005)
IHACRES	Stream flow	IHACRES is a catchment-scale rainfall-streamflow modelling methodology used to characterise the dynamic relationship between rainfall and stream-flow, using rainfall and temperature (or potential evaporation) data to predict stream-flow. Applicable at small experimental catchments to basin scale using times steps of minutes, days or months.	Letcher et al. (2002)
IQQM	Stream salinity and water yield	Integrated Quantity-Quality mode developed to model salinity in NSW rivers and used for developing quantity. Currently the model is used for water quantity modelling rather than water quality (with the exception of salinity).	Simons et al. (1996)
LASCAM	Stream flow and water quality	Large Scale Catchment Model. Used to predict the long-term impact of land use and climate change on daily trends of stream flow and water quality (salt sediments, nutrients) used in the Swan and Avon River systems in WA - for catchments up to 140 000 km^2	CWR (2006); Sivapalan et al. (2002)
Leakiness Calculator	Property planning and water yield	An index that monitors the leakiness of grazed, arid and semi-arid landscapes for sediments using remote sensing and Digital Elevation Models. It is sensitive to the spatial patchiness of vegetation cover and allows analysis of trends. To date only applied to grazed rangelands in the Burdekin catchment.	Ludwig et al. (2007)
LUOS	Stream salinity and water yield	Land Use Options Simulator. Predicts water yield and stream salinity at property to catchment level. Incorporates several toolkits to evaluate ecosystem services, including carbon sequestration, soil and nutrient retention.	NSW OEH (2011a)
MUSIC	Urban stormwater	Used in Melbourne Water and Brisbane City council for design of stormwater systems and to support Water Sensitive Urban design planning	eWater Ltd CRC (n.d.a)
PERFECT	Sediment run-off and water yield	Productivity, Erosion and Run-off Functions to Evaluate Conservation Techniques. Provides outputs of water balance, yield, erosion and cover but is a one dimensional model that simulates a single point in the landscape without any consideration of lateral surface or subsurface flow - only applicable to field scale.	(Littleboy et al. (2003)
PRISM	Salinity	Practical Index of Salinity Models Database. Provides information on over 90 tools, models and frameworks	DAFF (2002)
SedNet	Sediment and nutrient run-off	Movement of sediments downstream will be complicated by the filtration effects of riparian vegetation and the effects of deposition and erosion in the river itself. SedNet has been used to isolate and integrate these processes to demonstrate hotspots of sediment sources from gully and hillslope erosion in the Murrumbidgee and Burdekin catchments, respectively.	Bartley et al. (2004); Prosser et al. (2001a); Prosser et al. (2001b)
Source Catchments	Sediment and nutrient load.	Previously Watercast/E2. Applicable for catchment sizes of a few square km to 100,000km^2, designed for experienced modellers and catchment managers	Cook et al. (2009)
TITAN	Land use and reservoir protection	Threshold Indicator Taxa Analysis. An index of reservoir vulnerability to algal blooms for managing reservoirs and catchments (main application comparing grazing land with afforestation in Queensland).	Leigh et al. (2010)
TOPOG	Sediment and water yield	Developed by CSIRO and the CRC for Catchment Hydrology. A 3-D digital terrain model for application to smaller catchments, generally <1km^2. Predicts the hydrological consequences of land-use change and associated water yield, sediment and nutrient movement.	CSIRO (2007b)

4. RECOMMENDATIONS

The recommendations are drawn from Parts 1 to 3 of the monograph to provide a consolidated list.

4.1. Priority setting and decision making

4.1.1. Socio-economics needed

Clearly, developing a priority-setting framework for water resource protection requires improved integration of biophysical and socio-economic considerations; notably, the effect of public expectation on driving or restricting the implementation of policy should be considered. These issues are complex, difficult and sometimes contentious. Examples include attitudes to re-use of water for drinking in cities and rejection of the proposed Basin Plan by some rural communities. To their credit, planners and governments are responding to these challenges. Fortunately, in Australia, a wide range of tools is being developed and sharing of knowledge and experience is enhancing collaborative approaches to planning. The portal developed by the Water Planning Tools Project (2011) is recommended.

4.1.2. Need to consider combinations of stressors

For convenience and simplicity three stakeholder groups and nine water characteristics were isolated for review, but a problem of this approach is that it is the *combination* of various stressors that affect the utility of the water or demise of river and estuarine health.

As noted by Hamblin (1998, p. 4), in developing a short list of indicators for State of the Environment reporting, '*the greatest challenge is developing the most suitable trade-off responses when several pressures interact*'.

4.1.3. Systems approaches needed

Effective priority setting requires integration, adaptability and public participation. The required cross-disciplinary approaches are not aided by disciplinary boundaries, by separation of rural and urban water management, or by separating land management and water resource planning.

Systems approaches and frameworks that can help with this problem have been available for some time. For example, Clayton and Radcliffe (1996) provide a text on sustainability that integrates social, cultural (ethics and equity), economic and environmental factors; Newell et al. (2005) provide a template for integrating across social and environmental disciplines; and multi-criteria analysis and multi-objective optimisation methods are described by Hajkowitz, (2007) and Xevi and Khan (2005), respectively.

Another approach is the use of indicators, sometimes weighted before addition, to integrate the combined effect of threatening processes on catchments or to give an easily understood assessment of stream or river condition (Davies et al., 2010; Victoria DPI, 2010).

4.1.4. Need to value ecosystem services

The valuation of in-stream water quality for aesthetic, spiritual, recreational and indigenous purposes is complex but important. These values (and corresponding investment strategies) are more difficult to quantify than costs of technological solutions for dealing with declining water quality treatment, such as reverse osmosis, other filtration methods, or disinfection. Also there is increasing evidence that communities are not prepared to accept a decline in in-stream water quality and aesthetics, even if treatment for consumptive use is available and affordable. More information is needed to assess the value of ecosystem services from stubble farming systems and the balance of public and private investment required to meet expectations.

4.1.5. 'Single issue priorities' should be avoided

Planners need to be wary of 'single-issue' priorities that have been a feature of Australian natural resource management and investment. For example, in the last decade, media attention and investment priorities have focused in sequence on salinity, algal blooms, water scarcity, environmental needs, public health safety from re-use of water for drinking, and water for food security. There are several problems with adoption of these dominant single issues:

- Simplistic benefit-cost analysis applied to separate user groups may miss opportunities for synergy. For example, Syme and Nancarrow (2008) define 'Water Benefits' as ways in which water promotes well-being in both utilitarian and non-utilitarian ways, acknowledging that the same volume of water can deliver multiple benefits as it moves through a catchment. Hamstead (2007) also comments on the misconception that water is used either for environmental or productive environmental purposes, when both can occur.

- Highly specific and targeted investments can quickly become redundant. For example, current priorities are heavily coloured by a decade of drought and there is danger that recent flooding may change priorities for salinity, and the need for re-allocation of environmental water will be reduced. However, a continuing drought in southern Australia is predicted (CSIRO, 2010) reinforcing the need to re-balance the water extracted for consumptive use relative to that reserved for the environment, and exposing an inevitable tension between public short-term political expediency and the need for a long-term view.

- Adaptability in priority setting is needed to cope with changes that include new scientific knowledge, especially on ecological resilience; effects of climate change and variability; new market-based approaches to water trading and infrastructure; new investment in water-use efficiency infrastructure; adoption of new technology such as aquifer storage recovery and desalination; emergence of new industries such as coal seam gas; new policies on water interception and carbon pricing, increased re-use for drinking; and changing public perceptions, especially on public health and environmental values. Adaptive management frameworks are available to support priority setting and decision making (e.g. Baldwin et al., 2009; Tan et al., 2010).

4.2. Biophysical research gaps

4.2.1. Mapping pattern of land use at appropriate scale

Stubble farming systems are not generally considered separately from grazing or from cropping using cultivated systems in audits such as the National Land and Water Resources Audit and State of the Environment reporting. In view of potential benefits of stubble farming systems this seems to be an obvious information gap.

Patterns of land use (including stubble farming systems) should be overlain with potential erosion and salinity hotspots determined by modelling to assess the role of land-use systems in reducing erosion.

4.2.2. Optimisation of land use for water quality protection

Risk-based frameworks and modelling are useful in integrating threats (McCarthy, 2007) and have been successfully trialled in Australia (Pollino and Henderson, 2010). More use of these appraoches should be made to untangle the compexities and links between land use and water qaulity protection.

Optimisation of ground cover including stubble load and characteristics is needed for erosion prevention in different landscapes and climate. Land-use optimisation methods have been developed for forestry and salinity management (Nordblom et al., 2009) and a similar approach is needed for stubble farming systems and a broader range of water quality characteristics.

4.2.3. Water balance and leakiness

While some information is becoming available (GRDC, 2011), more measurements are needed of the water balance in stubble farming systems and contribution to ‘leakiness’ at catchment scale.

Little information is available on effects of stubble farming systems on groundwater. If retained stubble significantly improves water infiltration, under what conditions and in which locations might this increase groundwater recharge? This may be desirable in areas which are fresh-water sources with local groundwater flow systems such that fresh stream flow is enhanced, but quite undesirable in areas with rising saline groundwater tables threatening to scald low-lying land or pollute local streams. As noted by Stirzaker (2000) targets for infiltration to prevent salinisation in surface will need to be specific to landscapes and catchments; and winter dominant rainfall in southern cropping systems results in leaching that is well short of targets to protect against salinisation.

4.2.4. Sustainability Dashboard

The Sustainability Dashboard is commended as a holistic approach to integration that has the advantage of being developed by farmers themselves. The application can be used by farmers to generate a visual report of the key indicators of the condition of their land and associated business and includes a reflection on the ability of farmers to maintain ecosystem services.

Trade-offs between the benefits of a leaky landscape (more water downstream) and a non-leaky one (more on-farm water retention and less downstream pollution) needs to be analysed at a local or regional level.

4.3. Planning and governance

4.3.1. Need for increased emphasis on land-use capability in regional planning

Methods for integrating downstream ecosystem services with on-farm profitability should be demonstrated in selected case studies. As noted in an evaluation of sustainable agriculture outcomes from regional investment (RM Consulting Group et al., 2006) the most common deficiency in regional plans was the matching of land use to capability and soil health condition targets.

Also, based on interviews with 180 stakeholders from over 100 organisations, CSIRO (2010b, p. 30) provides a select list of research priorities that includes *'an improved understanding of landscape function as a basis for investing in integrated outcomes, including biodiversity, water yields, water quality goals and sustainable and management practice, and making informed trade-offs'.*

4.3.2. Need to integrate water and land-use planning

There is renewed interest in the benefits of watershed protection (Eichner, 2010). The National Health and Medical Research Council are currently engaging in a public consultation process on proposed new guidelines for microbial safety of drinking water that advocates the use of multiple barriers. '*Pathogenic micro-organisms are regarded as the largest threat to drinking water supplies*' (NHMRC, 2010, p. 3*).*

Agricultural land use affects water quality and the health and resilience of downstream aquatic ecosystems, although the relationship is complex (Bowmer, 2011). More than 30 years ago Mitchell and King (1980, p. 40) provided an analysis of the research needs required to '*adjust and manage land use in a catchment so that as far as possible appropriate quality and quantity of water and suitable distribution through the year can be ensured at minimum cost to the community*'. However, land-water interactions have been downplayed by Australian water managers in recent years, reflecting an emphasis on water treatment technology ('end of pipe solutions') and over-riding concerns (until recently) about water scarcity. A re-integratation of land and water management through catchment-based approaches is advocated. (Insights into decision making for land management practice and adaptation to change are provided by Pannell and Vanclay (2011).

4.3.3. Need to strengthen regional groups

In Australia, 56 Catchment Management Authorities and Natural Resource Management Regional Groups and Boards have been developed through government investment and allocated responsibility for safe-guarding water quality and environmental assets; although their degree of autonomy, capacity to raise funds and reporting relationships seems to be highly variable and sometimes uncertain (Campbell and Schofield, 2007). In NSW the framework seems to be better established than in other states with an independent Natural Resources Commission that sets standards and targets at state level and audits Catchment Action Plans (NSW NRC, 2005).

Regional groups, such as Catchment Management Authorities, Regional Natural Resource Management Groups and community organisations such as Landcare are appropriate for integration and optimisation of land use that integrates both on-farm profitability and off-farm ecosystem service benefits and impacts. As noted in recent reviews, the capacity, authority and resourcing of these regional groups needs to be strengthened (Campbell and Schofield, 2007; Griffith, 2009; NSW NRC, 2010; Ryan et al., 2010). It is encouraging to note that a recent report on the State of the Catchments in NSW (NSW OEH, 2010) provides condition and trends for land capability and soil condition at sub-catchment level, including erosion, salinity, acidity, carbon and structure. Riverine ecosystem condition is also described in detail but the links to land management are not explicit.

In a recent review of Australia's natural resource management governance systems Ryan et al. (2010) lists ten principles for managing future challenges that include continuity and stability; subsidiarity (devolving decisions to the lowest level); integrated goal setting; a systems approach to match governance to the nature of the problem; investment in relationships across organisations; managing for resilience of both ecosystems and communities; development of knowledge and innovation; accountability and transparency; and adaptability. Notably 'holism' (i.e. planning to address whole systems) is advocated.

4.3.4. Need for community involvement

There is growing recognition of the importance of social inclusiveness in planning (Cullen, 2006; NWC, 2011). For example, the demise of consultation process in the proposed Basin Plan has resulted in a move to involve more local input through the Windsor Inquiry (SCRA, 2011). T the demand for more environmental water is particularly contentious. Advantages of community involvement are that people can enrich expert knowledge, set priorties for limited volumes of water, find local innovative solutions and agree on monitoring regimes to demonstratete environmental benefit.

Support for social and economic analysis in environmental decision making is available: in Australian texts (e.g. Harding, 1998; Tisdell, 2010); in guidelines provided to support water planning (IACSEA 1998, reviewed by Baldwin et al., 2009); and in trials of profiling methodology (Hassall and Associates et al., 2003). Tan et al. (2010) have recently developed an internet portal that provides aids to select practical guides and tools for collaborative and integrated planning and priority setting. These include stakeholder analysis, indigenous engagement, socio-economic impact assessment, best practice for managing climate risk, participatory mapping and deliberative multi-criteria evaluation.

4.4. Need for a full analysis

The restrictions on water availability and increasing need for food and fibre in Australia and globally (Cribb, 2010) will promote greater efficiency in use of rural and irrigation water. Consequently it is important to take a ‘big picture’ view of all the options for management using regional, catchment or hillslope scale analysis (as well as a national approach undertaken above) to inform on-ground planning.

As noted previously more than 30 years ago by Mitchell and King (1980, p. 52) *‘While it is claimed the simplest solution to catchment solutions lies in water treatment because the technology is now so advanced, such technology is still not completely effective, can be extremely costly, and maybe subject to human error. An important area of research is the comparison between the efficiency of water treatment and the efficiency of a range of land-use control measures and their various combinations’*. This remains an important topic today.

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