The Status of Research into the Effects of Dryland Salinity on Aquatic Ecosystems

A discussion paper arising from a salinity workshop
in Albury, New South Wales, on 13 December 1999

D.L. Nielsen and T.J. Hillman

Murray-Darling Freshwater Research Centre

Cooperative Research Centre for Freshwater Ecology
Technical Report 4/2000
September 2000

■ RESEARCH ■
COOPERATIVE CENTRE FOR
■ FRESHWATER ECOLOGY ■

The Cooperative Research Centre for Freshwater Ecology improves the health of Australia's rivers, lakes and wetlands through research, education and knowledge exchange. It was established in 1993 under the Australian Government's Cooperative Research Centre Program.

The Cooperative Research Centre for Freshwater Ecology is a collaborative venture between:

- ACTEW Corporation
- CSIRO Land and Water
- Department of Land and Water Conservation, NSW
- Department of Natural Resources, Queensland
- Department of Natural Resources and Environment, Victoria
- Environment ACT
- Environment Protection Authority, NSW
- Environment Protection Authority, Victoria
- Goulburn-Murray Rural Water Authority
- Griffith University
- La Trobe University
- Lower Murray Water
- Melbourne Water
- Murray-Darling Basin Commission
- Sunraysia Rural Water Authority
- Sydney Catchment Authority
- University of Canberra

Ph: 02 6201 5168
Fax: 02 6201 5038
Email: pa@lake.canberra.edu.au
http://freshwater.canberra.edu.au

Printed in September 2000

Nielsen, D. L.
The status of research into the effects of dryland salinity on aquatic ecosystems : a discussion paper arising from a salinity workshop in Albury, New South Wales, on 13 December 1999.

Bibliography.

ISBN 1 876810 12 2.

1. Salinity – Environmental aspects – Australia. 2. Soil salinization – Australia. I. Hillman, T.J. II. Cooperative Research Centre for Freshwater Ecology (Australia). III. Title. (Series : Technical report (Cooperative Research Centre for Freshwater Ecology) ; 4/2000).

631.4160994

Editing and layout: Science Text Processors Canberra, scientex@actonline.com.au
Printing and binding: Elect Printing, Fyshwick, ACT

CONTENTS

List of tables and figures

EXECUTIVE SUMMARY

The Cooperative Research Centre for Freshwater Ecology (CRCFE) sponsored a one-day workshop at the Murray-Darling Freshwater Research Centre, Albury, on 13 December 1999, bringing together water resource managers and researchers to explore research requirements in the face of increased salinisation.

The workshop was prompted by three recent reassessments of the salinity issue, by PMSEIC (1998), MDBC (1999), and CSIRO (Walker *et al.* 1999), and by the fact that the new CRCFE, in its first year of operation, is ideally situated to develop innovative research responses to emerging management problems. The three reports highlight the rapidly increasing influence of dryland salinity (as distinct from groundwater and drainage inputs) in the salinisation of aquatic systems. It results in salt inputs well upstream of irrigation influences, in streams previously unaffected by salinity. It also results in floodplain wetlands being inundated by water of higher base-level concentration of salt which in turn leads to accelerated salinisation from the seasonal cycle of filling and evaporation. Neither of these two issues has been addressed by research.

The workshop identified other knowledge gaps during an examination of past and current research, especially the lack of information about sub-lethal effects of salinity and their influence on ecosystem structure and functions over time.

During the workshop discussions, the following research areas requiring early response were recognised:

- prediction of the effects of salinity on the (sensitive) biota of low-order streams, including their biodiversity and ecological function;
- assessment of the ecological effects of increased salinity and increased rates of salinisation on floodplain wetland systems, particularly ephemeral systems;
- clarification of the sublethal effects of salinity that, through changes to reproduction, recruitment, or metabolic processes, may modify ecosystem function in affected rivers and wetlands.

The workshop pinpointed six areas of research (below) that would address these issues in the short, medium or long term; areas 1, 2, 4 and 5 are of higher priority than areas 3 and 6.

Short to medium term

In the short to medium term, research should aim:

1. to develop and evaluate a database from existing data sets for sites for which there exist both salinity data (including EC) and biological data. This database would maximise the value of resources already invested in collection of background data, and provide a basis for developing testable hypotheses to link salinity with biological responses.
2. to survey a wide range of wetland types and rivers across a broad geographic area to assess their current condition in terms of salinity and biological integrity. This type of study should assist in establishing general relationships between salinity and biological integrity, and in identifying possible future reference sites.

Medium to long term

In the medium to long term, research should:

3. investigate the relationships between salinity and the survival, growth and recruitment of biota, and between salinity and ecological processes in aquatic ecosystems;
4. use field experiments to assess the response of upland stream and lowland floodplain ecosystems to increasing salinity. In lowland floodplain ecosystems, emphasis should be given to exploring the use of drought-resistant flora and fauna in sediments of ephemeral systems as generalisable indicators of response to stress in these systems.

Long-term or ongoing research

Long-term or ongoing research should:

5. establish experimental site(s) for medium-scale controlled experiments linking salinity and ecosystem structure and processes, in laboratory and field studies;
6. identify key taxa on which to focus future research and assessment.

The recommendations from this workshop are being incorporated into project D3 within Program D (Water Quality and Ecological Assessment) of the overall research portfolio of the CRCFE.

Salt in freshwater environments

A review of dryland salinity was presented at the workshop.

The review briefly describes salinity and the causes and results of salinisation of rivers, billabongs and wetlands, focusing on eastern Australia. It outlines aspects of the disposal of saline water from salinised areas. Finally, having mentioned potential effects of salt water on freshwater biota, it summarises what is known of the effects of salinity on aquatic ecosystems.

1. INTRODUCTION

Vast areas of Australia's farm and grazing lands are gradually succumbing to dryland salinity. It is estimated that by the year 2050 an area the size of Victoria will be lost to traditional agriculture (PMSEIC 1998). In 1990 the importance of rising salinity and associated deterioration in water quality within the Murray-Darling Basin was identified as a priority in the Murray-Darling Basin Natural Resources Management Strategy (Crabb 1995). More recently, the Prime Minister's Science, Engineering and Innovation Council (PMSEIC 1998) reviewed the scope of the salinity problem in Australia. In particular, the potentially devastating impact of salinisation on aquatic ecosystems was highlighted.

It is difficult to predict the effects of dryland salinisation at such a large scale on the ecology of the waterbodies that originate, flow through and ultimately drain these areas. How will the chemistry of these waterbodies change? Are there critical thresholds for salt concentration, and how will the biota respond? Is the Australian biota resilient to salt or will there be large-scale changes in species composition? Will biodiversity and ecosystem function be preserved in an increasingly salty world?

We do not know which waterbodies are most at risk: is it the small streams high up in the catchment, the larger lowland rivers, or the permanent and ephemeral wetlands on their floodplain? What tools do we have to protect and restore these systems?

The huge spatial and temporal scales of dryland salinisation mean that if our current best land management practices were fully implemented tomorrow, salinisation would continue to increase in waterbodies throughout Australia. The effect of increasing salt concentrations on a range of freshwater biota has been extensively reviewed (Hart *et al.* 1991; Metzeling *et al.* 1995). However, we have very limited understanding of the ecological consequences of salinisation in Australian freshwaters.

1.1. Study and workshop

To assist in focusing research into the salinisation of freshwater ecosystems, the Cooperative Research Centre for Freshwater Ecology (CRCFE) initiated a study of the scope of the problem. The study had three main objectives:

- to review relevant research that has been completed or is currently being carried out on the effects of dryland salinity on the freshwater biota of Australia (see section 3, page 12);
- to identify critical gaps in understanding about the effects of dryland salinisation on freshwater ecosystems — this was achieved by the workshop described here, bringing together water resource managers and researchers;
- to produce a discussion paper outlining the outcomes of the workshop, identifying knowledge gaps and potential research responses. This technical report is the result.

The workshop was organised with the intention of:

- juxtaposing appreciations of the salinity problem (now and for the future) and existing biological knowledge relevant to an understanding of the ecological effects of salinity;
- enabling managers and researchers to discuss interests and/or needs concerning the ecological effects of salinity on freshwater ecosystems;
- identifying key knowledge gaps and research questions that relate to the effects of dryland salinity on freshwater biota;
- identifying potential research opportunities for the CRCFE, including possible strategic alliances that could provide funds and/or opportunities to exchange knowledge useful for this research.

The following people attended the workshop:

Terry Hillman	CRCFE	Dominique Benzaken	EA
Daryl Nielsen	CRCFE	Felicity Bunny	EA
Rod Oliver	CRCFE	Stuart Blanch	Inland Rivers network
John Whittington	CRCFE	Kevin Goss	MDBC
John Williams	CSIRO	Brian Lawrence	MDBC
Margaret Brock	DLWC	Paul Bailey	Monash University
Patricia Geraghty	DNRE	Bill Williams	University of Adelaide
Tim O'Brien	DNRE	Nigel Warwick	University of New England
Leon Metzeling	EPA, Victoria		

1.2. Future trends

Dryland salinity is a major problem in the Murray-Darling Basin as well as in other parts of Australia, particularly Western Australia, and the impacts of salinity on the terrestrial environment are well known. Less is known about the impacts of salinity on the water quality and biota of river and wetland systems. In 1999 the Murray-Darling Basin Commission audited the current and future threats of salinity to the Murray-Darling Basin. The salinity audit (MDBC 1999) predicts changes in salinity on a gross scale in the Murray-Darling Basin over the next 20 to 100 years. Because the audit uses data from a calibrated groundwater study it cannot readily identify salt processes that are occurring on a local catchment scale, but the data can be used in a predictive capacity across the Murray-Darling Basin.

Table 1. Rivers within the Murray-Darling Basin that are predicted to have salinities exceeding threshold levels in the next 100 years (from MDBC 1999)

	Average river salinity (EC) in years 1998, 2020, 2050 & 2100			
River valley	**1998**	**2020**	**2050**	**2100**
South Australia				
River Murray at Murray Bridge	590*	730*	870*	980*
River Murray at Morgan	570*	670*	790*	900*
Victoria				
Avoca at Third Marsh	1440*	1470*	2220*	2990*
Loddon	870	880	900	970
New South Wales				
Lachlan	530	780	1150	1460
Bogan	730	1500	1950	2320
Macquarie	620	1290	1730	2110
Castlereagh	640	760	1100	1230
Namoi	680	1050	1280	1550
Queensland				
Warrego	210	1270	1270	1270
Condamine-Balonne	210	1040	1040	1040
Border Rivers	310	1010	1010	1010

Notes: 1. Data refer to the end of the system except for those asterisked, which indicate river reaches.
2. Figures for Victoria are flow-weighted.

Within the salinity audit, all salinities are gauged against three thresholds of tolerance:

- *800 electrical conductivity (EC) threshold* — this is the upper salinity limit set by the World Health Organization (WHO) for drinking water. It becomes increasingly difficult to manage irrigation once this level is exceeded; some crops can have reduced yields when irrigated with water even below this level of salinity.
- *1500 EC threshold* — only salt-tolerant crops can be irrigated with water of this salinity; direct biological effects are likely to occur in freshwater ecosystems.
- *5000 EC threshold* — this is generally accepted as the upper limit for freshwater ecosystems. Only highly tolerant freshwater taxa can live in waters above this salinity threshold; crop irrigation is severely restricted.

Table 1 shows the changes in salinity predicted by the audit for rivers in the Murray-Darling Basin for the years 2020, 2050, 2100. Until recently, rising salinity has been expected only in the lower Murray. However, the audit predicts that salinity will rise significantly in other river valleys as well, including those in upland regions. Floodplain wetlands associated with the River Murray are also becoming increasingly threatened by salinity. Currently, about 25% of the lower Murray floodplain in South Australia is influenced by salt. The audit predicts that 30–50% of the lower Murray floodplain in South Australia will be adversely affected within 50 years.

The salinity audit shows that policy change is needed, not only to rescue terrestrial areas from salinisation but also to avoid the salinisation of freshwater ecosystems. The quality of water across the Murray-Darling Basin and its effects on both the aquatic and the terrestrial components of the environment are now considered important.

Four broad options for controlling salinity can be implemented (Walker *et al.* 1999) (Figure 1):

A. no intervention — salinity continues to increase until equilibrium is reached;

B. management strategies are implemented that slow down the rate of increase in salinity; equilibrium occurs more slowly than in option A but with the same damage to the environment;

C. management strategies are implemented that slow down the rate of increase in salinity; equilibrium is reached with less damage to the environment than with option B;

D. management strategies are implemented that reverse the trend in rising salinity.

This indicates that there is a zone of opportunity between options B and C in which management strategies can be implemented to decrease the level of damage that will occur because of rising salinity throughout the Murray-Darling Basin. Key elements of the salinity strategy are:

- integrated catchment management,
- targets and accountability,
- innovation in land use,
- markets for environmental services (e.g. major revegetation works).

A number of federal and state policy initiatives exist that are designed to protect rivers and wetlands from salinisation, but these initiatives need to be underpinned by both research and monitoring programs and to be continually reviewed. There is a need to consider rivers and wetlands as a single unit when setting priorities. On a national scale the extent of salinised areas is unknown and areas that are potentially at future risk need to be identified.

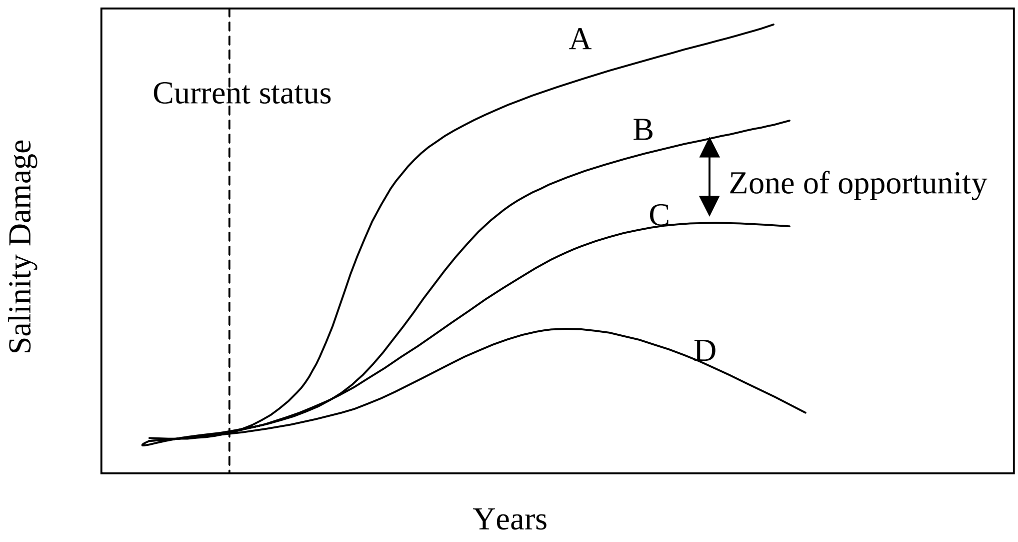

Figure 1. Options for controlling salinity (from Walker *et al.* 1999)

2. RESEARCH RESPONSE

2.1. Existing and possible research

No ongoing research into either the direct toxic effects or the indirect effects of increasing salinity on the biota of freshwater rivers and wetlands was reported at the workshop. However, in Western Australia, long-term monitoring programs are in progress, to detect changes in aquatic ecosystems in salt-affected areas and in areas that may become affected in the future.

A body of recent research by Bailey and James (Bailey 1998; Bailey & James 2000) was identified at the workshop. This research includes an assessment of riverine and wetland R&D needs and contains new information on the salinity tolerances of a significant number of freshwater species; it provides very valuable basic information.

Historically, most of the research effort into salinity has been directed at predicting its effect on agricultural systems. The effects on aquatic ecosystems have largely been ignored. Salinity in aquatic ecosystems is not part of the National Wetlands Research and Development portfolio.

An objective within the Water Quality and Ecological Assessment Program of CRCFE is to develop an ecological basis for determining reference conditions against which to identify damage or change. A number of existing biological databases have associated data for chemical parameters that often include electrical conductivity (EC). Analysis of these data sets may be useful for predicting trends in the effects of salinity on aquatic ecosystems. Existing maps of groundwater can also be superimposed over river and wetland areas. This will help to identify those wetlands at greatest risk. Rivers in which saline stratification can occur during periods of low flow can also be identified. Remotely sensed data have been used in the Upper Kent Catchment, Western Australia, to determine the historical and present distribution of salt-affected land, and to produce maps showing areas of land at risk of future salinisation (Evans *et al.* 1995). It may be possible to use a similar approach to identify aquatic systems likely to become affected in the future.

In the absence of sufficient long-term studies on the relationship between freshwater biota and salt, existing data sets containing both biological data and salinity data should be located and analysed, possibly revealing trends in freshwater ecosystems that are correlated with changing salinity. Also, survey of the biological and saline condition of wetlands and rivers across a broad geographic area may reveal correlations between salinity and biological integrity.

Recommendations

Develop and evaluate a database from existing data sets for sites for which there are both salinity data (including EC) and biological data. This database would maximise the value from resources already invested in background data collection and provide a basis for developing testable hypotheses linking salinity with biological responses.

Survey a wide range of wetland types and rivers across a broad geographic area to assess their current condition in terms of salinity and biological integrity. This study should assist in establishing general relationships between salinity and biological integrity, and in identifying possible future reference sites.

There is a general acceptance that freshwater ecosystems tolerate water of 1000 mg TDS L^{-1}, below which ecological effects are very slight. Taken uncritically, this view could lead to the fallacy that, until that value is reached, freshwater ecosystems are healthy and there will be no adverse effects on the biota or ecosystem. This is especially dangerous because much of the work that produced this view has been done in systems such as lowland rivers where the biota will already have been exposed to significant salt levels. For many taxa, sublethal effects may not be apparent at the community level for some time. There has been limited research into the effects of salinity on the majority of freshwater biota. Of the research undertaken, most studies have investigated macroinvertebrates or macrophytes. Little information is available on other aquatic, semi-aquatic or riparian species (see section 3, Table 2).

For many species, the adult stages are the parts of the life cycle most tolerant of increased salt concentrations. The eggs and larvae of many fauna and the immature propagules of plants may be more susceptible than adults, according to the revised Water Quality Guidelines (ANZECC & ARMCANZ 2000). Many taxa may be able to survive at elevated salt concentrations although reproduction, recruitment and growth of juveniles may be substantially reduced. Aquatic communities can still be diverse in affected systems but the community composition may be altered; salt-resistant taxa (e.g. mosquitoes and some chironomids) may increase in abundance as salinity increases.

The rate of change of salinity in freshwater ecosystems, as predicted by the salinity audit, will be much higher than the rate at which freshwater biota can evolve or adapt. In lowland rivers much of the biota may be salt-tolerant or have mechanisms that allow survival during periods of extreme salt concentrations. Upland rivers potentially have experienced less variation in salinity, and therefore biota in these systems may be less salt-tolerant. Changes in salinity in these upland systems may be too rapid for the taxa to adapt to, and so taxa may be lost from these systems. Communities will then become dominated by salt-tolerant taxa. Research is needed that will investigate the relationship between salinity, survival and recruitment of biota associated with aquatic ecosystems.

There is only limited understanding of how salinity impinges on ecosystem functioning and associated processes, or of how the key drivers of the ecosystem are affected. However, ecological processes may continue even though the community composition changes. For example, decomposition can still occur with different suites of bacteria. Functional groups have been used to monitor the effects of changed hydrological regimes on aquatic plant communities (Brock & Casanova 1997) and the use of such groups may be applicable to studies on the effects of salinity on aquatic communities. If key taxa or groups of taxa can be identified, investigations into salinity can focus on them.

Recommendations

Identify key taxa on which to focus future research and assessment.

Investigate the relationships between salinity and the survival, growth and recruitment of biota, and between salinity and ecological processes in aquatic ecosystems.

2.2. Interaction between salinity and other factors

Part of the Water Quality and Ecological Assessment Program of CRCFE includes the development of tools with which to measure the ecological responses of freshwater ecosystems to stresses.

Currently, managers have little information about the relationship between flow patterns, salt levels and environmental damage. Nor is any information available to show how a combination of changes in flow and salt may affect river and wetland communities synergistically. For systems that are naturally variable in both salinity and hydrology there is no knowledge of how increasing salinity affects the biota or ecosystem integrity. Environmental flows should be a useful tool for managing salinity in aquatic ecosystems, but until the relationship between these three factors is understood there is little that can be done to predict appropriate flows or identify opportunities for the effective disposal of salt-contaminated water with minimal damage to the environment.

If both ecosystem health and salinity can be measured, then actions such as water allocations, river operation, engineering intervention and catchment management programs can be implemented to dilute the salt and increase the health of aquatic ecosystems. These measures and indicators need to be determined by innovative experimental science, which can then be used to underpin management issues on a broader scale.

There is currently no work on ecosystem function or processes that can be used to develop a relationship between river health and salt. Figures 2A, 2B and 2C illustrate conceptual models of the ways in which salinity might affect upland river systems and unregulated or regulated lowland river systems. Field experiments could be designed to assess the responses of upland and lowland river ecosystems to increasing salinity. A particular experimental area could be developed in which the effects of salinity on aquatic ecosystems could be examined at a variety of scales. This would enable researchers to determine salinity's effects on the functioning and processes of aquatic ecosystems.

Recommendations

Use field experiments to assess the response of upland stream and lowland floodplain ecosystems to increasing salinity. In lowland floodplain ecosystems, emphasis should be given to exploring the use of drought-resistant flora and fauna in the sediments of ephemeral systems, as generalisable indicators of response to stress in these systems.

Establish experimental site(s) for medium-scale controlled experiments linking salinity and ecosystem structure and processes, in laboratory and field studies.

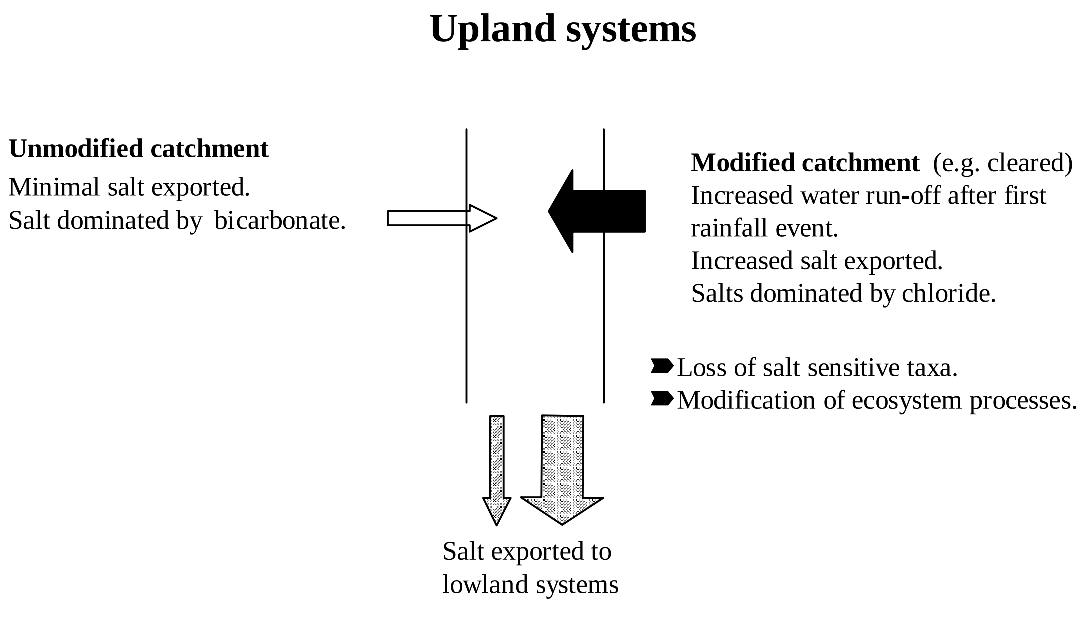

Figure 2A. Conceptual model of salinity effects on upland river systems

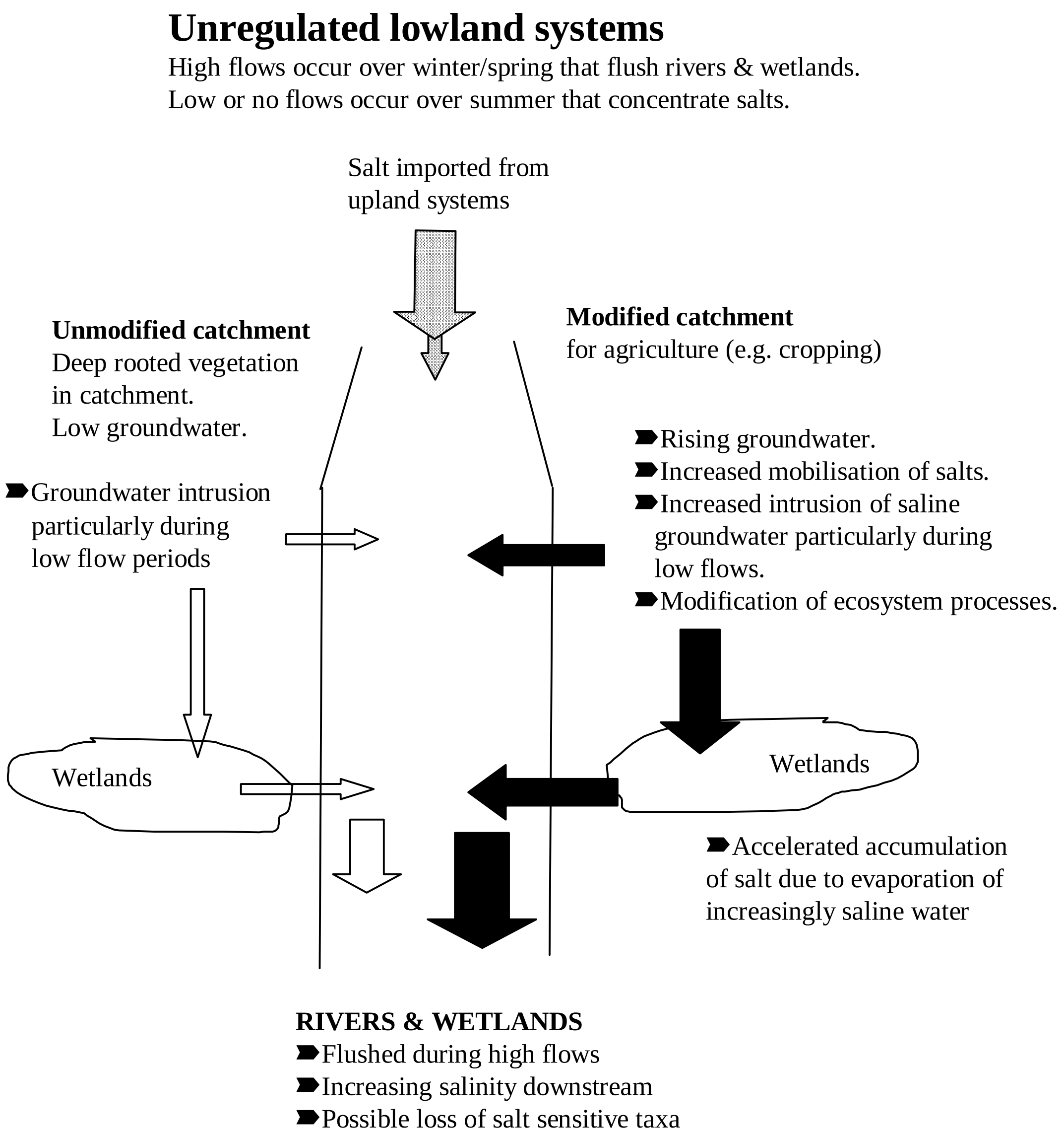

Figure 2B. Conceptual model of salinity effects on unregulated lowland river systems

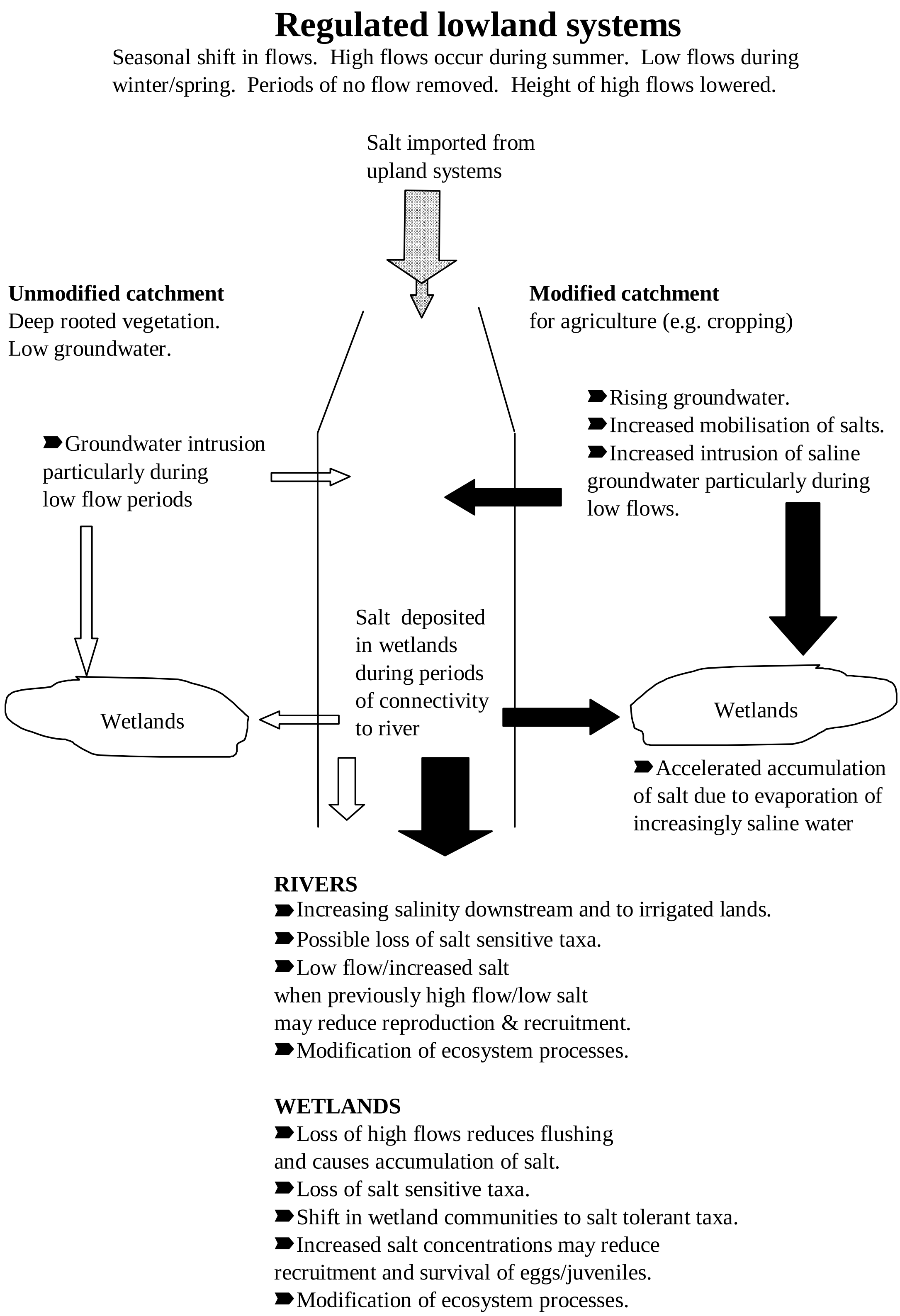

Figure 2C. Conceptual model of salinity effects on regulated lowland river systems

3. SALT IN FRESHWATER ENVIRONMENTS: Review[1] of research on the effects of dryland salinity on freshwater biota

3.1. Salinisation and its possible effects on aquatic ecosystems

The animals of freshwater ecosystems (rivers, wetlands and lakes) can be divided into two groups based on their ability to regulate their internal osmotic concentrations against the external environment. Good regulators are termed euryhaline and can adapt to a wide range of salinities. Poor regulators are termed stenohaline and are restricted only to a narrow range of salinities. Plants are also divided into two groups. Halophytic plants are salt-tolerant. Non-halophytic plants grow best in freshwater, but as salinity increases growth is reduced or they die (Hart *et al.* 1991).

Salinity is a measure of the concentration of salt in the water. This is generally expressed as the total dissolved salts (TDS) in the water, in milligrams of salt per litre (mg/L). Electrical conductivity (EC units = µS/cm) is often used as a surrogate. The relationship between TDS and EC varies between waters with different ionic composition and along the length of a river (Close 1990). Because of this variability, conversion between TDS and EC is not always reliable and should be treated with some caution. However, usually, 1 mg/L = 0.60 EC (Close 1990) or 1 mg/L = 0.68 EC (Hart *et al.* 1991). In this review, the conversion used by Hart *et al.* (1991) is applied.

Changes in salinity can have direct physiological effects on biota in freshwater (particularly through osmoregulation), and can result in change in species diversity. The removal (or addition) of taxa that provide refuge and/or food can then lead to further modification of community structure and function. This review considers changes in salinity from less than 500 mg/L to above 1000 mg/L. This is the range of salinities most likely to be encountered in Australian rivers and wetlands. There is some evidence that ecological effects of salinity are likely to be observed within this range.

Salt enters aquatic systems primarily either from groundwater or from terrestrial material via the weathering of rocks. Some salt may also be transported with wind and rainfall (Baldwin 1996; Williams 1987). The relative contributions of these sources depend on factors such as distance inland, climate and geology (Williams 1987) and cause the ionic composition of water to vary between localities. Bicarbonate is typically the dominant anion in the headwaters of rivers, whereas chloride is the dominant anion downstream. The proportion of sodium to total cations increases with distance downstream (Close 1990). The dominant salt found in the groundwater is sodium chloride (Close 1990).

Under natural river flow conditions, inflows of saline groundwater result in salinities becoming relatively high during drought or low-flow conditions (e.g. in the River Murray; Close 1990). River regulation has reduced the natural variability in flow, and periods of low flow or no flow have been removed. In the River Murray, salinity increases down the length of the river, as does the range of salinities. For example, between 1978 and 1986 the difference between the maximum and minimum salinities above Lake Hume at Jingellic, NSW, was 47 mg/L, whereas at Tailem Bend, South Australia, the difference was 850 mg/L (Close 1990). Before the regulation of the River Murray the range of salinities experienced at any point was potentially much greater than it is now. Salt concentrations in pools in the River Murray during low-flow events may have exceeded 10 000 mg/L (Williams 1999). Pools with salinities greater than 30 000 mg/L have been recorded from the Wimmera River, Victoria, during low-flow periods (Anderson & Morison 1989). During low-flow periods in the Darling River, there are substantial inflows of saline water, caused by the natural groundwater head (Oliver *et al.* 1999).

[1] This review, written by Daryl Nielsen, was presented at the workshop.

There is no evidence that current salinity levels exceed the tolerance of the native biota that is associated with the River Murray (Close 1990; Williams 1999). It has been suggested that the more common macroinvertebrate taxa have a broader range of salt tolerance than rarer taxa (Metzeling 1993).

Under natural flow regimes, wetlands associated with floodplains of lowland rivers are diluted and flushed out with freshwater during high river flows (State of the Rivers Report 1995). Between floods, many billabongs increase in salinity because of evaporation. They also receive saline run-off from local catchments (State of the Rivers Report 1995). Salinities recorded from billabongs associated with the River Murray near Albury–Wodonga have been as high as 1500 mg/L (Hillman 1986), and in experimental mesocosms salinities increased by a factor of three over 10 weeks as evaporation reduced the volume of water (Bailey 1998). Many wetlands are also becoming increasingly influenced by rising saline groundwater.

Salinisation of waterways is not confined to lowland river systems such as the Murray-Darling. Many upland areas and streams across Australia are now becoming increasingly influenced by salinisation. These rivers are usually unregulated and often flow intermittently, with low salinities. During droughts they can shrink to a series of waterholes with relatively high salinity (Boulton & Lake 1990). The dominant anion in these systems is bicarbonate, which has percolated through the soil profile before entering the rivers (State of the Rivers Report 1995).

Deforestation and urbanisation in upland catchments have reduced the retention of water in the soil, increasing erosion and surface run-off (Lake & Marchant 1990). This has increased the amount of surface salts being transported into aquatic systems within these catchments. The dominant anion in these surface salts is typically chloride, and it may cause the ionic ratio in the aquatic systems to change, affecting the biota.

While increases in salinity will potentially have some effect on the biota associated with lowland permanently flowing rivers, there are likely to be greater effects on the biota associated with upland non-regulated low-flow or intermittent rivers. In these systems, periods of higher salinity may exceed the tolerance of the biota.

In many upland areas across Australia, catchments and rivers with increasing salinity have been recorded. Low-order streams in upper catchments, such as the Yass River in NSW (Bek & Robinson 1991; State of the Rivers Report 1995) and Balfes Creek in the Upper Burdekin catchment, Queensland (NDSP fact sheet (a)) are becoming increasingly threatened by salinisation. There have been relatively recent occurrences of salt scalds in the upper catchments of rivers such as the Murrumbidgee (State of the Rivers Report 1995). In many upland catchments salinity is not yet being seen at the soil surface, but the potential exists for more serious problems to develop.

Salt-water intrusion from the sea is also affecting many freshwater ecosystems. In the Northern Territory, saline water intrusion into Sampan Creek, caused by the erosion of tidal channels, now extends 30 km inland and is having a substantial effect on approximately 24 000 ha of freshwater wetlands; a further 50 000 ha is under threat (O'Brien 1999).

Salinity may have indirect effects on the structure of freshwater ecosystems, indicated first by changes in the dominance of plants or animals (Williams 1987). Unnaturally high salinity reduces the diversity of macrophytes, simplifying the ecosystems (Sainty & Jacobs 1990). Loss of habitat complexity will influence the diversity and abundance of associated taxa. For example, in a six-year study, Savage (1979) recorded a change in corixid (water bug) populations in saline lakes in England. The loss of *Myriophyllum spicatum*, as a result of higher salinity, indirectly caused the loss of *Sigara concinna* which requires aquatic vegetation to which to attach its eggs.

Unnaturally high salinity also modifies many of the processes that occur within freshwater ecosystems. Salinity has been shown to reduce the amount of suspended particulate and colloidal matter in the Darling River, allowing increased phytoplankton production (Oliver *et al.* 1999).

3.2. Disposal of saline water and the effect on biota

If the height of the watertable can be reduced, there will be less groundwater intrusion into surface waters (Macumber 1990). However it is also necessary to manage surface water run-off resulting from high rainfall. This not only directly washes sediment and salts into aquatic ecosystems but causes an increase in infiltration of water to the underlying watertable which results in a rise in the groundwater level where it may impinge on rivers and wetlands (Evans *et al.* 1990).

Rising groundwater can be intercepted by using both surface and sub-surface drains. On Kangaroo Island, drains are used to empty the perched watertables caused by high winter rainfall. They carry the water to natural drainage lines before it can seep into the deeper saline groundwater. In this way recharge of the groundwater is reduced (NDSP fact sheet (b)). In irrigated areas, drains are used to lower the watertable. The drainage water is directed into rivers and wetlands, or to artificial evaporation basins.

The disposal of saline water into rivers and wetlands needs careful timing. Saline water dicharged during periods of low flow or no flow can substantially increase the salinity of the receiving water and exceed the tolerance of the resident biota. However, the variability in the physical conditions (for example depth and flow) of the receiving water may modify the effect of the added salinity on its biota (Bailey 1998). The initial pulse of high salinity into the receiving water may be sufficient to affect salt-sensitive animals, but a strategy of variable release, using pulsed discharges, may allow taxa to recover between pulses (Bailey 1998) and prevent nuisance taxa from gaining advantage from continually higher salinities (Winder & Cheng 1995).

Invertebrate communities associated with wetlands may be more sensitive to increasing salinity than those typically associated with lowland rivers (Bailey 1998).

3.3. The biota

Hart *et al*. (1991) and Metzeling *et al*. (1995) have extensively reviewed the effect of increasing salinity on freshwater biota. Much of the work they review has relied on field observation and/or direct toxicological testing. Table 2 summarises what is known of the effects of salinity on the major groups of plants and animals associated with aquatic ecosystems. Very few studies have examined sub-lethal responses to changes in salinity. Field studies have suggested links between the abundance and diversity of biota and increased salt concentrations. Interpretation of the effects of increased salinity can be confounded by other factors such as pollution, river regulation or waterlogging (Froend *et al.* 1987; Williams 1987).

Above a threshold salinity level of 1000 mg/L, direct adverse biological effects are likely to occur in freshwater systems (MDBC 1999). In waters more saline than this, many macrophyte and invertebrate taxa are known to have reduced abundance and diversity. There has been very little investigation of the effects of salinity below 1000 mg/L on recruitment, reproduction or survival of early life stages. Changes in diversity and loss of taxa may not become apparent until a long time has elapsed.

For many species, adult stages are the parts of the life cycle most tolerant to increased salt concentrations. Eggs and larvae of many animals and immature propagules of plants may be more susceptible (ANZECC & ARMCANZ 2000). For example, eggs of many fish may be damaged by high salinity during the time between fertilisation and the post-fertilisation hardening of the egg (T. O'Brien pers. comm.). Hart *et al*. (1991) have suggested that once high levels of salinity are reached recruitment may be reduced. Increased salinity has been shown to inhibit the emergence of resting stages of plants and animals from inundated sediment (Skinner *et al.* in press), which will have an effect throughout wetland and river systems.

Salinity effects may be of secondary importance to some groups of biota. Waterlogging resulting from rising groundwater will cause irreparable damage to the root system of plants well before salinity has an effect (Froend *et al.* 1987). Prolonged waterlogging increases the potential for anaerobiosis (Hart *et al*. 1991; Baldwin & Mitchell 2000). This results in oxygen limitation and the formation of toxicants such as sulfides (Baldwin & Mitchell 2000).

Table 2. Known effects of salinity on major components and characteristics of aquatic ecosystems

Group or characteristic	Tolerance level	Knowledge	References
Bacteria	Unknown	Will probably require substantial increases in salinity to cause significant community changes (Hart *et al*. 1991). Very high salinities may restructure microbial communities and modify nutrient release. However changes in communities could occur unnoticed with little effect on processes such as methanogensis.	Hart *et al*. (1991); Metzeling *et al*. (1995)
Microcrustaceans	Restricted to waters with <1000 mg/L salinity	Freshwater animals appear to be restricted to waters with salinities <1000 mg/L Significant reductions in abundance occur at >1000 mg/L	Hart *et al*. (1991) Bailey (1998)
Rotifers	Unknown	Knowledge of Australian taxa poor. Overseas studies suggest substantial reductions in diversity when salinity is >2000 mg/L. Salinity prevents emergence of rotifers from resting eggs	Green & Mengestou (1991) Pourriot & Snell (1983)
Macroinvertebrates	Some taxa affected by toxicity at salinity >1000 mg/L	The effect of salinity on this group is well researched using both field observations and toxicological tests. Reductions in the abundance of many animals within this group become apparent once salinity is >1000 mg/L. At high salinities nuisance taxa (mosquitoes and chironomids) known to proliferate in degraded systems may increase in abundance	Hart *et al*. (1991); Metzeling *et al*. (1995); Bailey (1998)
Macrophytes	Toxic effects and reduced growth seen at salinity >1000 mg/L	The effect of salinity on this group is well researched using both field observations and toxicological tests High salinities may result in reduced survival of belowground biomass of some taxa, and affect germination of some taxa	Hart *et al*. (1991); Metzeling *et al*. (1995); Bailey & James (2000) Bailey (1998)
Algae	Unknown	The sensitivity of this group is largely unknown. The cyanobacteria *Anabaena circinalis* can adapt to salinities >7000 mg/L after several days exposure	Hart *et al*. (1991); Metzeling *et al*. (1995); Bailey & James (2000). Winder & Cheng (1995)

Table 2 continued

Group or characteristic	Tolerance level	Knowledge	References
Fish	Tolerant of salinity up to 10 000 mg/L	Adults of most fish associated with lowland rivers appear to be tolerant of high salinities. There has been little research on juveniles or egg development.	Hart *et al*. (1991); Metzeling *et al*. (1995)
Amphibians	Unknown	All life stages may be susceptible to increased salinity	Hart *et al.* (1991); Metzeling *et al*. (1995)
Riparian vegetation		Increased salinity will affect non-halophytic plants. Seed germination decreases as salinity approaches 3000 mg/L.	Hart *et al*. (1991)
Waterbirds		This group may not be directly affected. Indirectly, the loss of riparian vegetation, macrophytes and invertebrates may change the distribution and breeding success of many birds.	Hart *et al*. (1991)
Nutrients		Disposal of saline water from lakes may increase PO_4 and total Kjeldahl N and decrease NO_x in the receiving waters. Saline groundwater typically is high in N and low in P.	Kefford (1998)
Chemistry		In upland areas the dominant anion is bicarbonate. Surface run-off will carry salts in which the dominant anion is chloride (the dominant anion in saline groundwater). Changes in the ionic ratio may affect the biota.	
		A decrease in pH has been recorded as salt concentrations increase in wetlands	Bailey (1998)
Turbidity		Increasing salinity above salt concentrations of 200 mg/L will often cause an associated decrease in turbidity. Divalent ions such as Ca^{2+} and Mg^{2+}, present in saline ground-water are effective in flocculating colloidal particles, which results in reduced turbidity.	Oliver *et al*. 1999
		Saline groundwater intrusion into the Darling River has been shown to cause a decrease in turbidity, which improves light penetration and results in increased algal growth and productivity	

4. REFERENCES

Anderson, J.R. & Morison, A.K. (1989) *Environmental Flow Studies for the Wimmera River, Victoria*. Summary report. Arthur Rylah Institute for Environmental Research. Technical report series No. 78.

ANZECC & ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. National Water Quality Management Strategy Paper No. 4. Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

Bailey, P. (1998) *Effects of Increased Salinity on Riverine and Wetland Biota*. Project UM018 Final report. Canberra LWRRDC.

Bailey, P. & James, K. (2000) *Riverine and Wetland Salinity Impacts — Assessment of R&D Needs*. Occasional paper No. 25/99. Canberra, LWRRDC.

Baldwin, D. (1996) Salinity in inland rivers. *Australasian Science* **17**(3), 15–17.

Baldwin, D. & Mitchell, A. (2000) The effects of drying and re-flooding on the sediment/soil nutrient dynamics of lowland river floodplain systems — a synthesis. *Regulated Rivers: Research and Management.* In press.

Bek, P. & Robinson, G. (1991) *Sweet Water or Bitter Legacy. State of the Rivers — Water Quality, New South Wales*. Department of Water Resources, NSW.

Boulton, A.J. & Lake, P.S. (1990) The ecology of two intermittent streams in Victoria, Australia. I. Multivariate analyses of physicochemical features. *Freshwater Biology* **24**, 123–141.

Brock, M.A. & Casanova, M.T. (1997) Plant life at the edge of wetlands: ecological responses to wetting and drying patterns. *Frontiers in Ecology* (eds. N. Klomp & I. Lunt), pp. 182–205. Elsevier Science, Oxford.

Close, A. (1990) River salinity. *The Murray* (eds N. Mackay & D. Eastburn), pp. 127–144. Murray-Darling Basin Commission, Canberra.

Crabb, P. (1995) Managing water resources: seeking unity in the interests of diversity. *Conservation Biodiversity: Threats and Solutions* (eds R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunny & D.P. Silertsen), pp. 162–173. Surrey Beatty & Sons, London.

Evans, F.H., Caccetta, P.A., Ferdowsian, R., Kiiveri, H.T. & Campbell, N.A. (1995) *Predicting Salinity in the Upper Kent River Catchment*. A report from the LWRRDC project, ‘Integrating Remotely Sensed Data with Other Spatial Data Sets to Predict Areas at Risk From Salinity’.

Evans, R., Brown, C. & Kellet, J. (1990) Geology and groundwater. *The Murray* (eds N. Mackay & D. Eastburn), pp. 77–93. Murray-Darling Basin Commission, Canberra.

Froend, R.H., Heddle, E.M., Bell, D.T. & McComb, A.J. (1987) Effects of salinity and water-logging on the vegetation of Lake Toolibin, Western Australia. *Australian Journal of Ecology* **12**, 281–298.

Green, J. & Mengestou, S. (1991) Specific diversity and community structure of Rotifera in a salinity series of Ethiopian inland waters. *Hydrobiologia* **209**, 95–106.

Hart, B.T., Bailey, P., Edwards, R., Hortle, K., James, K., McMahon, A., Meredith, C. & Swadling, K. (1991) A review of the salt sensitivity of the Australian freshwater biota. *Hydrobiologia* **210**, 105–144.

Hillman, T.J. (1986) Billabongs. *Limnology in Australia* (eds P. De Deckker & W.D. Williams), pp. 457–470. Dr W. Junk, Dordrecht.

Kefford, B.J. (1998) Is salinity the only water quality parameter affected when saline water is disposed of in rivers? *International Journal of Salt Lake Research* **7**, 285–300.

Lake, P.S. & Marchant, R. (1990) Australian upland streams: ecological degradation and possible restoration. *Proceedings of the Ecological Society of Australia* **16**, 79–91.

Macumber, P. (1990) The salinity problem. *The Murray* (eds N. Mackay & D. Eastburn), pp. 111–125. Murray-Darling Basin Commission, Canberra.

MDBC (1999) *The Salinity Audit*. Murray-Darling Basin Commission, Canberra.

Metzeling, L. (1993) Benthic macroinvertebrate community structure in streams of different salinities. *Australian Journal of Marine and Freshwater Research* **44**, 335–351.

Metzeling, L., Doeg, T. & O'Connor, W. (1995) The impact of salinisation and sedimentation on aquatic biota. *Conservation Biodiversity: Threats and Solutions* (eds R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunny & D.P. Silertsen), pp. 126–136. Surrey Beatty & Sons, London.

NDSP fact sheet (a). *Groundwater Quality and Occurrence in the Balfes Creek Catchment*. National Dryland Salinity Program.

NDSP fact sheet (b). *Dryland Salinity Management on Kangaroo Island*. National Dryland Salinity Program.

O'Brien, C.C. (1999) Salt water intrusion. *Second Australian Stream Management Conference Proceedings: The Challenge of Rehabilitating Australian Streams* (eds I. Rutherford & R. Bartley), pp. 759–760. Cooperative Research Centre for Catchment Hydrology, Melbourne.

Oliver, R.L., Hart, B.T., Olley, J., Grace, M., Rees, C. & Caitcheon, G. (1999) *The Darling River: Algal Growth and the Cycling and Sources of Nutrients*. Final report to the Murray-Darling Basin Commission.

PMSEIC (1998) *Dryland Salinity and Its Impact on Rural Industries and the Landscape*. Occasional paper No. 1. Department of Industry, Science and Resources.

Pourriot, R. & Snell, T.W. (1983) Resting eggs in rotifers. *Hydrobiologia* **104**, 213–224.

Sainty, G. & Jacobs, S. (1990) Waterplants. *The Murray* (eds N. Mackay & D. Eastburn), pp. 265–273. Murray-Darling Basin Commission, Canberra.

Savage, A.A. (1979) The corixidae of an inland saline lake from 1970 to 1975. *Archiv für Hydrobiologia* **86**, 355–370.

Skinner, R., Sheldon, F. & Walker, K.F. (in press) Animal propagules in dry wetland sediments as indicators of ecological health: effects of salinity. *Regulated Rivers: Research and Management*.

State of the Rivers Report (1995) Murrumbidgee Catchment 1994–1995. NSW Government.

Walker, G., Gilfedder, M. & Williams, J. (1999) *Effectiveness of Current Farming Systems in the Control of Dryland Salinity*. CSIRO Land and Water, Canberra.

Williams, W.D. (1987) Salinisation of rivers and streams: an important environmental hazard. *Ambio* **16**(4), 180–185.

Williams, W.D. (1999) Wetlands, salinity and the River Murray: three elements of a changing environmental scenario. *Rivers for the Future* **10**, 30–33.

Winder, J.A. & Cheng, M.H. (1995) *Quantification of Factors Controlling the Development of* Anabaena circinalis *Blooms*. Research report No. 88. Urban Water Research Association of Australia, Melbourne.

OTHER PUBLICATIONS OF
The Cooperative Research Centre for Freshwater Ecology

The Cooperative Research Centre for Freshwater Ecology publishes a range of books, guidelines, newsletters, technical reports and brochures. These publications can be ordered from the Cooperative Research Centre for Freshwater Ecology at its Albury centre, by phoning 02 6058 2310, or by email to enquiries@mdfrc.canberra.edu.au.

Many reports are also available on our Web site at http://freshwater.canberra.edu.au.

Books

CRC for Freshwater Ecology. 1997. *Living on Floodplains*. Limited copies available.

Brochures

- Billabongs, floodplains and river health
- Chaffey Dam project
- Effects of a drying phase on the ecology of Menindee Lakes
- Environmental flows for the Campaspe River
- Providing an ecological basis for the sustainable management of Menindee Lakes
- Rivers and fish in stress
- Snags: a valuable but scarce resource
- Sustainable rivers: the Cap and environmental flows
- Water forum

Guidelines

Lawrence, I. & Breen, P. 1998. *Design Guidelines: Stormwater Pollution Control Ponds and Wetlands*.

Identification Guides

The CRC for Freshwater Ecology sells 31 different Identification Guides to the Invertebrates of Australian Inland waters, including:

Hawking, J. & Smith, F. 1997. *Colour Guide to Invertebrates of Australian Inland Waters*. ID Guide no. 8. ($24.00)

Hawking, J. 2000. *Key to Keys: A Guide to Keys and Zoological Information to Identify Invertebrates from Australian Inland Waters*. 2nd edn. ID Guide no. 2. ($22.00 + $2.20 postage)

Technical reports

CRC for Freshwater Ecology. 1996. *Managing Collaboration for Scientific Excellence*.

Cottingham, P. 1999. *Scientific Forum on River Condition and Flow Management of the Moonie, Warrego, Paroo, Bulloo and Nebine River Basins*.

Cottingham P., Whittington J. & Hillman, T. 1999. *Riverine Management and Rehabilitation Scoping Study*.

Cullen, P., Whittington, J. & Fraser, G. 2000. *Likely Ecological Outcomes of the COAG Water Reforms*. Also on the Web at http://freshwater.canberra.edu.au (then click Publications; then click Technical Reports)

Growns, J. & Marsh, N. 2000. *Characterisation of Flow in Regulated and Unregulated Streams in Eastern Australia.* Technical report no. 3/2000.

Lawrence, I. 2000. *Factors Determining Algal Growth and Composition in Reservoirs*. Available only on the Web at: http://nemp.aus.net

Ransom, G., Morgan, P., Cullen, P., Allen, D., Sinclair, D. & McGregor, D. 1998. *The Effect of Sewage Phosphorus Loads Using Phosphorus-free Laundry Detergent. Thurgoona Case Study*.

Reid, D., Harris, J. & Chapman, D. 1997. *NSW Inland Commercial Fisheries Data Analysis*.

Scholz, O., Gawne, B., Ebner, B., Ellis, I., Betts, F. & Meredith, S. 1999. *The Impact of Drying on the Ecology of Menindee Lakes*.

Sheldon, F. 1999. *Spencer Regions Strategic Water Management Study*.

Thoms, M.C. 1998. *The Condition of the Namoi River System*.

Thorncraft, G. & Harris, J.H. 2000. *Fish Passage and Fishways in New South Wales: A Status Report.* Technical report no. 1/2000.

Whittington, J. 2000. *Technical Review of Elements of the WAMP Process of the Queensland DNR*.