Salinity Risk in the Corangamite Region, Australia

submitted by

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Declaration of originality

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Peter Dahlhaus

Summary

Classic hydrogeological science, in which observations, measurements and experiments are used to deduce theories, has resulted is a deep understanding of many aspects of salinity processes. The outcome of this approach in Australian dryland salinity studies has been a vast body of scientific work that has resulted in the widespread adoption of two paradigms: 1) that dryland salinity is caused by rising groundwater tables as a result of broad-scale clearing of native vegetation; and 2) that dryland salinity is a threatening process that is a risk to assets.

The Corangamite region in south west Victoria, Australia, has proven to be an ideal landscape in which to test these paradigms using a systems thinking approach to complement traditional scientific methods. The variation in the region's biophysical landscape provides a diverse milieu; the environmental history of landscape changes is well documented; a record of groundwater and salinity monitoring exists; detailed scientific studies have been undertaken; and social policies based on salinity risk have been implemented.

Using this broad range of evidence, this research project has shown that salinity is a permanent and inseparable attribute of the Corangamite region. Primary salinity has episodically existed throughout the Quaternary as evidenced by the landscape record of saline lakes and drainage lines, which were supported by shallow saline groundwater tables. The earliest written historical records noted hydrological changes and attributed them to anthropogenic causes that were contrary to the current axiom. From these records there is no evidence found which supports significant rises in groundwater following widespread land-use change.

Detailed investigations in one landscape reveal that the area of salinised land has continued to expand and new saline discharge areas have emerged, despite the efforts of active salinity management, a decade of below average rainfall, and a general trend of falling watertables. Investigations of the increasing stream salinity in another catchment shows that there has been little discernable effect on groundwater levels following land clearing over the past 150 years. These findings question the validity of the commonly accepted cause (rising watertables)

and effect (land and stream salinisation) model. Alternative salinity models are proposed based on the broad range of data available.

In contemporary risk assessment studies, salinity is universally viewed as a threat to assets. However, salinity risk has both negative and positive impacts, and risk assessment needs to also consider salinity as critical in sustaining the region's internationally important environmental assets. Hence, a systematic, disciplined and rigorous framework for salinity risk management has been developed to protect all classes of assets which are threatened by changes to salinity processes, even those where the salinity itself is the asset. Since it is based on the generic international and national risk management standards it is broadly applicable to all salinity risk management policies.

The recurring theme in this thesis has been to challenge the current salinity process theories, salinity risk assessment methods and salinity risk management dogma in Australia. Testing the current paradigms using evidence from a broad range of disciplines has resulted in new perspectives.

Acknowledgements

This thesis would never have been finalised without the encouragement and generous support of many people. My supervisors Dr Jim Cox and Professor Craig Simmons have been wonderful mentors and deserve acclaim as two of the most patient blokes on Earth. Complying with their research standards has been a lesson I am grateful to have learned.

The Corangamite Catchment Management Authority (CMA) has funded the majority of this research and I sincerely thank Peter Codd for his unwavering support and friendship over the past years. This thesis would not exist without his generous assistance. Thanks to all within the CMA who have been continuously supportive and encouraging, especially: the Chairman, Dr Peter Greig; Chief Executive, Don Forsyth; and colleagues on the Salinity and Soils Operational Portfolio Group - especially the Chair, Ian Crook, and Program Manager, Lucas Oram.

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Datasets have been generously supplied by the Corangamite CMA, Department of Sustainability and Environment and the Department of Primary Industries (and their precursors). Some of this data was modelled by Chris Smitt, Tony Davidson and Frank Lindeman, who had the skills and resources to do so. Martin and Jo Peters, Farmworks Pty Ltd, collected and pre-processed the EM38DD geophysical data at Pittong. Helen Thompson, Andrew MacLeod and Paul Feely at the Centre for eCommerce and Communications (University of Ballarat) constructed the best web-GIS and bore database in the region.

Dr Erica Nathan, Tim Evans, Tony Miner and Cam Nicholson are independent research collaborators whose knowledge of the region is unmatched. Their friendship is highly valued. Thank you to Alice Knight OAM, Kevin Knight OAM, Dr Kay Rodden and Peter Hirth who have been supporters of my research in the Corangamite region for decades. And those collaborators and supporters who have missed a mention here are acknowledged at the end of each of the chapters presented as journal papers.

Family and friends understand that this thesis lies at the end of a long and rocky road. The support of my wife Kris is impossible to underestimate. On those occasions when serious accidents, illnesses and deaths of family members suspended this project, she gave me the encouragement to pick it up again. Els, Roman, Bruce & Jenny, Marianne & Roy, Clifty, Chez & Evie, Nance, Liz & Daryl, Norelle & Peter and many others have been cheering from the sidelines. And two of my mentors, Gerry and Eric, saw the start of the journey but not the end.

1 Introduction

Hydrogeological research is most often based on the scientific method of observation and gathering empirical and measurable evidence to formulate and test a hypothesis. By its nature, the scientific method of observation and experimentation is reductionist in both its subject and scale. However, the limits to reductionism are met within complex systems that are inherently irreducible and require holistic thinking to understand them. 'Big picture' research is more suited to systems thinking, which is founded in the belief that the components of a system can be best understood in the context of the whole, rather than in isolation (Checkland 1981; Skyttner 2006). In other words, the only means to understand why a systematic process persists is to understand its relationship to the entirety of the system, including the components outside of the domain of science.

Although the emergence of holistic thinking dates back to Ancient Greece (Skyttner 2006), systems thinking was formalised in the 1950s with the development of General Systems Theory (von Bertalanffy 1950; Boulding 1956) which connected all types of systems - conceptual, concrete, abstract, natural or anthropogenic. In its application to science, General Systems Theory became Systems Science, the science of integration and synthesis which is capable of being transferred from discipline to discipline. It complements traditional science, rather than replaces it, by helping to unravel the complexity (Weinberg 1975). Traditional analytical thinking reduces the focus of the observer (reductionism), whereas systems thinking expands it (expansionism).

In its application to dynamic systems, Mella (2008) applies five 'rules' to systems thinking: 1) the necessity to observe both the whole and its interdependent parts (seeing both the forest and the trees); 2) the necessity to see the variables beyond those considered significant, as well as their temporal variations; 3) understanding the causes of the variation in all the observed variables; 4) connecting the variables in a chain of causal relations that loops the variations into an interacting system; and 5) specifying the boundaries (both external and internal) of the system under study.

In the context of the above, this thesis loosely adopts a systems thinking approach to research the risk management of land and water salinisation across a broad geographic region. The research includes gathering evidence from beyond the normal hydrogeological science domain, such as historical observations and social policies. Much of this evidence is not easily quantified and therefore the research relies on both qualitative and quantitative data to understand the processes that cause a salinity problem to emerge. This holistic approach may challenge the conventional scientific method traditionally used to understand the nature of salinity. However by adopting this approach new insights and thinking have resulted in revising the perspective of salinity risk and questioning the current approaches to salinity management.

1.1 Background

'Salinity' and 'salinisation' are terms of convenience generally used in the English language to describe the issues or problems associated with the salt content of soil and water (e.g. AFFA 2009). Alternatively, salinity and salinisation are used to refer to an increase in the concentration of salts (e.g. DSE 2009a) or total dissolved solids (TDS) (e.g. Richter and Kreitler 1993) from background levels by any source. Salinity is often assigned two general origins: primary salinity, being the salinisation of land and water by natural physical and chemical processes; and secondary salinity, being that induced by human activities. This distinction has little meaning in situations where the rate of naturally occurring salinity is modified by human changes to the environment, especially when the changes have occurred over centuries.

Salinity is also partitioned into that induced by the development of irrigation, and that which is attributed to environment modifications through dryland agriculture or land clearing, termed dryland salinity (Ghassemi et al. 1995; DSE 2009a). Dryland salinity is the subject of this thesis, since irrigation induced salinity has not been recognised within the geographic region under research.

In the global context, dryland salinity is a well-documented agricultural problem in southern Australia and the Great Plains region of North America. Outside Australia, it occurs extensively in the mid-western states of Montana, North

Dakota and South Dakota of the United States and the prairie provinces of Manitoba, Saskatchewan and Alberta in Canada. Dryland salinity also occurs in Argentina, China, South Africa, Egypt, Turkey, Thailand, the Baltic States, the Commonwealth of Independent States, Iran, India and Pakistan (Abrol et al. 1988; Ghassemi et al. 1995).

Scientific studies of salinity in Australia commenced contemporaneously with the rise of soil conservation awareness in the 1920s and 1930s, mostly from studies in the south west of West Australia (e.g. Wood 1924; Teakle 1938). These studies observed that salt was stored in the landscape and that salinity had been induced by hydrologic imbalance following land clearing for agriculture. Henceforth scientific studies of salinity focused on the hydrologic balance and salt balance in various landscapes (Peck 1978; Peck et al. 1983; Peck and Williamson 1987; Williamson et al. 1987; Macumber 1991). The salinisation of land and water in the Murray Darling Basin and the wheatbelt of south west Western Australia have been the focus for the vast majority of this research (Ghassemi et al. 1995).

In the State of Victoria, the earliest reports on salinity also related the problem to land clearance and adopted a water-balance framework (Holmes et al. 1939; Nathan 1999). The first state-wide survey of salinity by Cope (1958) concluded that the extent of salting (>4,000 ha) was greater than generally realised, and of concern to landholders who considered that the area of salt affected land was increasing. Cope's (1958) observations led him to believe that salts, derived from marine aerosols in rainwater, had accumulated in the soil over geologic time. He argued that before European settlement, the rainwater was being used by trees where it fell, but that after land clearing surplus rainwater was mobilising the soluble salts stored in the permeable A-horizon of soil, causing it to accumulate above an impermeable clay B-horizon at a seepage point downslope or on the valley floor.

By the late 1970s the focus of salinity research had moved from agricultural soil science to hydrogeology, recognising saline groundwater discharge as the main and immediate source of salt (SCA 1978; Jenkin 1979). It was considered that clearing of the native vegetation had led to several metres of groundwater recharge, and the consequent rise in groundwater levels increased the rate of spread of salinity (Jenkin 1983). This resulted in the majority of salinity research in the Victorian drylands throughout the 1980s and 1990s being focused on quantifying the hydrogeologic balance, especially groundwater recharge (e.g. Dyson 1983; Jenkin and Dyson 1983; Macumber 1991; Clifton et al. 1993; Dyson 1993; Reid 1995; Taylor et al. 1995; Clifton 1996; Heislers 1996).

In more recent years salinity research in Australia has broadened to include research into the sources of the salt (e.g. Acworth and Jankowski 2001; Herczeg et al. 2001; Cartwright et al. 2006; Edwards and Webb 2009); sources and residence time of the groundwater (e.g. Herczeg et al. 1992; Bennetts et al. 2006; Petrides et al. 2006); past and current recharge rates (e.g. Cartwright et al. 2007a; 2007b); its relationship to climate (e.g. Rancic and Acworth 2008), palaeoclimate (e.g. George et al. 2008) and climate change (e.g. Cartwright and Simmons 2008).

By the late 1990s some scepticism began to emerge that rising water tables are the single cause of salinity in many of Australia's landscapes (Dahlhaus and MacEwan 1997; Nathan 1998; 1999; Dahlhaus et al. 2000; Acworth and Jankowski 2001; Jones 2001; Fawcett 2004; Wagner 2005; Bann and Field 2006; 2007). Importantly, the basis for this scepticism arose from disciplines outside of hydrogeology, such as pedology (MacEwan and Dahlhaus 1996; MacEwan et al. 1996), environmental history (Nathan 2000), agricultural policy (Tunstall 2005; Wagner 2005), agronomy (Kreeb et al. 1995; Jones 2001), and biology (Bann and Field 2005), as well as within (e.g. Acworth et al. 1997; Cresswell 2003).

However the outcome of the scientific approach in Australian dryland salinity studies has been a vast body of scientific work that has resulted in the widespread adoption of two paradigms: 1) that dryland salinity is caused by rising groundwater tables as a result of broad-scale clearing of native vegetation; and 2) that dryland salinity is a threatening process that is a risk to assets (e.g. NLWRA 2001; Williams 2008). It is these two principles held by the majority of members of the scientific community that are examined in relation to the development of salinity in the Corangamite region, Australia.

1.1.1 The Corangamite region

In this thesis the terms 'Corangamite region' refer to the area of jurisdiction of the Corangamite Catchment Management Authority (CMA) in south west Victoria, Australia (Figure 1.1). The area comprises around 13,340 km^2 of diverse natural landscapes (coast, mountains, plains, lakes), covers all or parts of nine municipalities, and supports a population of around 400,000 inhabitants growing at 5.2 % per year, with manufacturing, tourism, agriculture and forestry as major industries (CCMA 2003)[1].

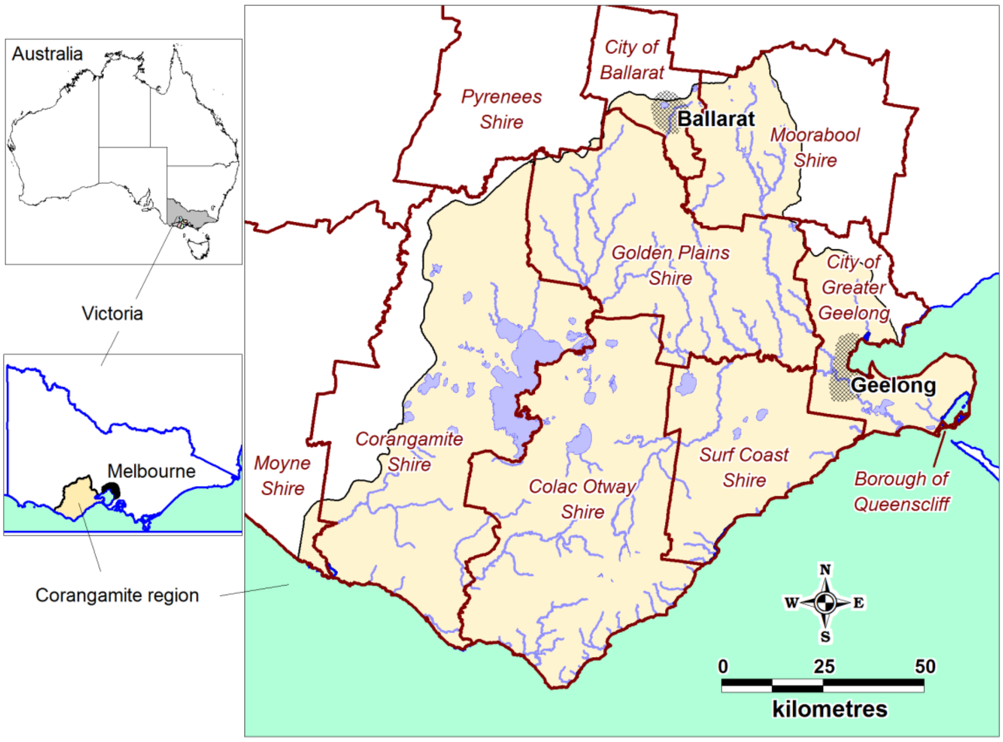

Figure 1.1 Location of the Corangamite region

Dryland salinity impacts on the water quality, agricultural land, environmental assets, urban and rural infrastructure, and cultural heritage assets of the Corangamite region. The most urgent threats are to the urban water supplies of the region's two major provincial cities – Ballarat and Geelong, and to wetlands of international significance listed under the Ramsar Convention and habitats for migratory birds subject to international treaties. In the 1.3 million hectares of the Corangamite region over 17,000 ha of salt-affected land have been mapped and the area continues to expand (Nicholson et al. 2006).

[1] In global terms - an area slightly smaller than Montenegro and larger than Vanuatu, Qatar, Jamaica or the Lebanon

In 2001 the National Land and Water Resources Audit released the Australian Dryland Salinity Assessment 2000 (NLWRA 2001). The predictions for the Corangamite region were dire; with the worst-case scenario suggesting that 48.5 % of agricultural land is at risk from shallow water tables by 2050, costing the region AUD$29 million per year and with over 40 % of the region's wetlands threatened by 2050. Based on the predictions of increasing salinity, the Corangamite region was nominated as one of the priority regions in Australia, under the National Action Plan for Salinity and Water Quality (CoAG 2000).

The main cause of the salinity was assumed to be rising saline groundwater following widespread clearing of native vegetation in the mid to late 19th century for pastoral settlement, agriculture and mining (NLWRA 2001). Since the first regional salinity strategy in 1992 approximately AUD$50 million dollars of government funding has been provided to the region for salinity management, and many millions of dollars in landholder, industry and community contributions. This funding has been provided to establish over 5,000 ha of trees, treat around 1,500 ha of salt affected land, establish over 500 groundwater monitoring bores and support several major research programs (Nicholson et al. 2006).

In accord with the national and state policies, the second generation salinity management plan - *Corangamite Salinity Action Plan 2005-2008* - was prepared, in which the salinity management actions are based on the response of the groundwater systems implicated in the salinity process (Dahlhaus 2004; Nicholson et al. 2006). This is mainly achieved through the establishment of vegetation in areas targeted for recharge or discharge management. Much of the research in this thesis stems from the author's involvement in the preparation of the salinity action plan. The thesis questions the applicability of the assumptions about salinity management, which are perpetrated through the national and state policies, to the management of salinity in the Corangamite region.

1.2 Aims and objectives

The overall aim of this research is to assess salinity risk in the Corangamite region using a holistic ('big picture') systems thinking approach.

To achieve this aim, several objectives are addressed:

- to explore the available data, evaluate the previous work, and understand the biophysical landscapes of the region (Chapter 2)
- to review the occurrence and distribution of salinity in the Corangamite region with the purpose of researching the basis of the assumed link between widespread clearing of native vegetation and the onset of salinity (Chapter 3)
- to research in detail the salinity processes associated with land salinisation, in an area where the salinity threatens an asset (Chapter 4)
- to research in detail the salinity processes associated with stream salinisation, in a catchment where the salinity threatens an asset (Chapter 5)
- to review the assessment of salinity risk with the purpose of developing a rational and holistic approach to salinity risk management (Chapter 6)
- to summarise the research and draw conclusions about the validity of the contemporary approach to salinity management (Chapter 7)

1.3 Organisation of thesis

This thesis comprises seven chapters. The first two chapters are introductory chapters that include an overview of the project and thesis (Chapter 1) and the geographic region (Chapter 2). The following four chapters take the form of journal papers (Table 1.1) that are either published (Chapter 3), in review (Chapter 5) or at the final stage of preparation (Chapters 4 & 6). The final chapter draws together the research components to conclude the thesis.

Chapter 2 has been included to record and review the extent of the data and other sources of evidence that have been used to derive the overall 'big picture' for salinity processes in the Corangamite region. Inevitably this has resulted in some repetition of information, since components of Chapter 2 are repeated as required to provide the regional context for the information presented in the standalone journal papers. While every effort has been made to minimise this, it is nevertheless an inevitable outcome of the thesis structure.

Table 1.1 Journal papers written by the candidate based on this thesis

Journal paper	Status
Dahlhaus P.G., Cox J.W., Simmons C.T. & Smitt C.M. 2008 Beyond hydrogeologic evidence: challenging the current assumptions about salinity processes in the Corangamite region, Australia.	Published *Hydrogeology Journal* **16**: 1283 - 1298
Dahlhaus P.G., Cox J.W., MacEwan R.J., Simmons C.T. & Clark R.M. Increasing land salinisation and falling watertables: assessing 20 years of salinity management in the Pittong region, western Victoria.	In preparation (for submission to *Land Degradation and Development?)*
Dahlhaus P.G., Evans T.J., Nathan E.L., Cox J.W. & Simmons C.T. Groundwater level response to land use change and the implications for salinity management in the West Moorabool River catchment, Victoria, Australia.	Published online in *Hydrogeology Journal* 23rd June 2010
Dahlhaus P.G., Cox J.W. & Simmons C.T. Accentuate the positive: a standard framework for salinity risk management.	In preparation (for submission to *Environment Management?)*

1.3.1 *Journal papers*

1.3.1.1 Paper 1 (Chapter 3)

The first paper - *"Beyond hydrogeologic evidence: challenging the current assumptions about salinity processes in the Corangamite region, Australia"* - reviews the evidence for salinity in the Corangamite region during the Quaternary Period and time of first European settlement. In keeping with a systems thinking approach, the paper uses multiple lines of evidence both hydrogeologic and non-hydrogeologic, to examine the current and historic salinity processes operating in the region. It finds that geomorphic, archaeological and historical records can substantially add value to the scientific investigations and that by including such evidence, the validity of the assumptions about salinity processes in Australian landscapes is challenged. In contrast to the commonly held assumption, the review finds that the clearing of native vegetation has not resulted in rising saline groundwater landscapes in the Corangamite region. Salinity has been an episodic feature of the Corangamite landscapes throughout the Quaternary and was present at the time of the Aboriginal inhabitants and the first pastoral settlement by Europeans. Despite the fact that surface water salinity has increased in some waterways and the area of salinised land has expanded in some landscapes, no recorded evidence can be found which supports significant rises in groundwater following widespread land-use change. In fact, there are many areas in the region where salinity, as an inherent component of the region's landscapes, sustains world-class environmental assets that require discharge from shallow saline groundwater tables to sustain their ecological health. The evidence, drawn from a broad range of disciplines, alludes to the question of whether salinity is in fact a threat or asset and concludes that managing salinity requires an understanding of the specific salinity processes in each landscape.

1.3.1.1 Paper 2 (Chapter 4)

The second paper - *"Increasing land salinisation and falling watertables: assessing 20 years of salinity management in the Pittong region, western Victoria."* - investigates the salinisation of a granitic landscape at Pittong, on the north western edge of the Corangamite region. The area was chosen because it has a history of at least 20 years of management (for which the landholders have been awarded national acclaim) aimed at reducing the extent of salinised land; it has one of the few land salinity monitoring sites in the region; and a lengthy groundwater monitoring record. The investigation integrates the regional geological, geophysical and hydrogeological data; collates the previous salinity mapping and landholder observations; analyses data from a land salinity monitoring site; interprets an extensive electromagnetic geophysical survey; and analyses groundwater monitoring data in relation to rainfall using a time-trend method. The research finds that in this landscape the area of salinised land has continued to expand and new saline discharge areas have emerged, despite the efforts of active salinity management, a decade of below average rainfall, and a general trend of falling watertables. This finding is an apparent contradiction to the current salinity management axiom in Australia, and therefore questions the validity of the commonly accepted cause-and-effect paradigm. A revised model is proposed that implicates deep regional saline groundwater flow, controlled by geological structures, as the point-sources of saline discharge. Implications for salinity management are that the eradication of saline land is not possible at the local scale, but efforts should focus on reducing the spread of salt.

1.3.1.2 Paper 3 (Chapter 5)

The third paper - *"Groundwater level response to land use change and the implications for salinity management in the West Moorabool River catchment, Victoria, Australia"*- examines the connection between the removal of native vegetation, rising watertables and increasing stream salinity that has been established for many catchments across Australia. It finds that in the West Moorabool River catchment on the north eastern edge of the Corangamite region there has been little discernable effect on groundwater levels following land clearing. This is despite that fact that over the past 150 years a significant portion of the catchment has been cleared of dense forest for agricultural development. The research compares historic standing groundwater level records from 1870-71 and 1881 with contemporary measurements recorded in the government bore databases. The data shows that the earliest recorded groundwater levels are well within the seasonal range of values observed today. Hydrogeological data shows that the combination of high recharge rates and excess water available in winter months has been sufficient to maintain high watertables, even under forest cover. By using a systems science approach and drawing together evidence from the history of environmental change, the changes to land and water use, climate records, geology, hydrogeology, and surface water hydrology, a logical explanation for the increasing stream salinity has emerged. This suggests that the combination of increased surface water harvesting, the export of both surface water and low-salinity groundwater from the catchment, and the shift to a drier climate has reduced the stream flows and proportionally increased the amount of saline baseflow. In contrast to the normally accepted axiom, reafforestation as a management strategy to mitigate the rising salinity in the West Moorabool River catchment would seem inappropriate.

1.3.1.3 Paper 4 (Chapter 6)

The fourth paper - *"Accentuate the positive: a standard framework for salinity risk management"*- makes the point that although salinity is widely regarded as a significant geohazard within Australia, there is no nationally consistent approach to salinity risk management. Salinity risk assessment, prediction or management, is limited by the variety of meanings of “risk” in its popular usage. In particular, salinity is universally viewed as a threat and rarely recognised as an asset in the conservation of biological diversity and the security of water for environmental purposes. This paper outlines a framework for salinity risk assessment that has been developed for the Corangamite region, in which both the negative and positive impacts of salinity risk are considered in the broader context. The risk assessment considers both salinity as a threat to assets, and salinity as sustaining the region's most valuable environmental assets. This systematic, disciplined and rigorous approach to salinity risk is based on international and national risk management standards. It has been applied in statutory planning regulations developed in collaboration between catchment managers and local governments to specifically consider environmental values. The standard provides a logical and defendable framework for the assessment of salinity risk that can assist in statutory planning decisions to protect all classes of assets which are threatened by changes to salinity processes, even those where the salinity itself is the asset. In a time of hydrological and climate change, the adoption of a standard risk management framework based is both logical and timely.

1.3.2 *Conference papers or abstracts*

Over the duration of this research project some of the material in this thesis has been published in 10 conference papers and abstracts (Table 1.2). Five of these are core research to this thesis (primary author) and five are aligned to the research in this thesis (contributing author). In addition 21 reports were completed for various projects associated with the research during the period of candidature. These documents are listed in Appendix A and appended in electronic format.

1.4 Summary of the research contribution

When taken together, the recurring theme that links the otherwise disparate chapters in this thesis is that the current salinity process axioms, salinity risk assessment methods and salinity risk management dogma in Australia are inapplicable to the Corangamite region. In general, the current theories have been developed using a traditional reductionist approach, but their application in the Corangamite region does not hold true when examined using an expansionist systems science approach. Testing the theories using evidence from a broad range of disciplines including history, climatology, geomorphology, pedology, hydrology, hydrogeology, environmental management, risk management and environmental planning, results in new perspectives that challenge the current paradigms.

Table 1.2 Conference papers / abstracts written by the candidate based on this thesis

Conference paper /abstract (core to thesis)
Dahlhaus P.G. & Fawcett J. (2008) Salinity without rising watertables: salinity processes and risk assessment in south-west Victoria, Australia. *Salinity, water and society - global issues, local action.* 2nd International Salinity Forum. Adelaide, March 30 - April 4, 2008. 4p (on CD).
Dahlhaus P.G. (2006) A Standard Approach to Salinity Risk Management. *Geological Society of Australia Abstracts* **82**, Australian Earth Sciences Convention, Melbourne July 2-7, 2006 (on CD).
Dahlhaus P.G. and Cox J.W. (2005) Geomorphic and historical evidence of salinity in the Corangamite region, Australia – Implications for current salinity management. *Managing Saline Soils and Water: Science, Technology, and Social Issues.* International Salinity Forum. Riverside, California, April 25-27, 2005. Poster presentation abstracts, pp. 47-50.
Dahlhaus P.G. (2005) Salinity Risk Management. *UrbanSalt 2005 Seminar: Risk, Responsibility and Local Government.* Blacktown Council, Blacktown, Sydney, 13th September 2005.
Dahlhaus P.G. (2004) Characterising groundwater flow systems for salinity management in the Corangamite Region, Australia. *Groundwater Flow Understanding from Local to Regional Scales*, Proceedings XXXIII IAH & 7th ALHSUD Congress, Zacatecas, Mexico, 11–15 October 2004. (on CD).
Conference paper / abstract (aligned to thesis)
Herczeg A., Barton A. & Dahlhaus P. (2008) Hydrochemical methods for rapid assessment of groundwater contribution to Wetlands. *Eos Trans. AGU*, **89**(23), Western Pacific Geophysical Meeting. Supplement, Abstract H34A-01
MacEwan R.J., Dahlhaus P.G. & Fawcett J. (2008) Hydropedology, Geomorphology and Groundwater processes hold the keys to land degradation – Case studies in SW Victoria, Australia. *Proceedings, 1st International Hydropedology Conference*, July 28-31 2008, The Pennsylvania State University, University Park, Pennsylvania, USA. Abstracts, p64.
Barton A.B., Herczeg A.L., Dahlhaus P.G. & Cox J.W. (2007) A geochemical approach to determining the hydrological regime of wetlands in a volcanic plain, south-eastern Australia. *Groundwater and Ecosystems.* Proceedings of the XXXV IAH Congress, 17-21 September, Lisbon, Portugal.
Barton A., Cox J., Dahlhaus P. & Herczeg A. (2006) Groundwater flows and groundwater-surface water interactions in the Corangamite CMA region. *Regolith 2006. Consolidation and Dispersion of Ideas.* Proceedings, CRC LEME symposium, Hahndorf Resort, South Australia, November 2006. http://crcleme.org.au/Pubs/Monographs/Regolith2006.html