

**Identifying and Managing Soil Salinity
at Multiple Spatial Scales on
King Island, Tasmania**

Neil Meadows B. For. Sci.



University of Tasmania

School of Earth Sciences and School of Agricultural Science

September 2008

A Research Thesis submitted to fulfil the requirement
of the Degree of Master of Science.

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution, and to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference is made in the text of this thesis.

Authority of Access

This thesis is to be made available for limited copying or loan in accordance with the Copyright Act of 1968.

Signed

Neil Meadows

Abstract

Soil salinity is a major determinant of agricultural productivity in many regions of Australia. Soil salinity is also spatially variable. This thesis examines the application of electromagnetic induction geophysical techniques and coincident soil sampling to (1) represent the areal extent and magnitude of soil salinity on the agricultural areas of King Island, Tasmania, (2) constitute its major causes; and (3) address mitigation strategies.

An automated electromagnetic induction meter used in the vertical dipolar mode (EM31v) was used to capture apparent total soil conductivity data over 15,420 Ha of the island. A total of 447 soil samples were obtained from sixty-one soil sample holes typically to 350 cm below surface. Ordinary least squares-based regression methods were used to predict average EC_e at the soil sample sites using the conductivity data (EC_a) assessed by the EM31v ($R^2 = 0.76$, p -value = 0.0001). A local, exponential semi-variogram kriging model was developed to interpolate average EC_e to 350 cm depth across the surveyed area. An analysis of geographic information layers, further terrain modelling, and climatic estimates of salt accessions were used to isolate the geological, geomorphological and climatic determinants of soil EC_e on the island.

Across the island the major source of salt is from west coast generated sea spray. Down to 350 cm, the highest average soil conductivity (EC_e of 8 dS/m and above) were found to occur in soils formed on Proterozoic granite, Proterozoic shale and undifferentiated Quaternary sediments. A long-term climate prediction, compelled by climate change forecasts of less rainfall to flush salt from these lithologies by 2030, is that the risk of salinisation in these areas will increase (by 10 %). Terrain morphology was found to be a good predictor of high EC_e on Proterozoic shale, but was found to be unrelated to EC_e on other lithologies. More generally, high EC_e in soils formed on granite were observed to occur at the valley floors and toward the crests of hills. Elevation and geological data were used to estimate the spatial location of high EC_e to 350 cm depth across the entire island (103,000 hectares).

At the landscape scale, hydrogeology was considered to be a potential determinant of elevated soil EC_e . Soil EC_e at valley floors and drained wetlands is associated with salt deposition by capillary action from shallow, highly saline water tables. On sloping land, the lateral flow of groundwater is expressed as saline seepage at break-of-slope areas.

At a finer scale, areas of low permeability subsoil restrict water percolation in several of the island's soil types, causing the development of perched water tables and localised near surface salinity. High surface salinity levels, compared to levels at 50 cm depth, occur without attendant high groundwater levels in some soil types. In these instances, it is suggested that topsoil compaction by livestock has reduced topsoil hydraulic conductivity, reducing the flushing of salt from the topsoil. Under these conditions increased surface and topsoil salinisation is exacerbated by evaporation, however, more research would be required to confirm this theory. If proven, the predicted drop in flushing rains due to climate change is likely to exacerbate this style of salinisation in the future.

Previous soil salinity mapping programs on King Island have been undertaken at the land system scale, thus assuming that characteristics within land system units are homogeneous. Assessed against the results shown in this thesis, the assumption of land system uniformity is shown to be incorrect. Salinity management decisions based on prior land system salinity maps may also have been incorrect.

The soil EC_e maps produced in this thesis may be used to improve sustainable farm management on the island. The maps are currently being used in the development of an Environmental Management System for landholders on the island.

Acknowledgements

Thank you to my supervisors Garry Davidson and Richard Doyle.

Thank you to those that gave their time, support and advice while I was in the field, in the laboratory, processing data, and writing and printing this thesis:

Mark Curtin, Fraser Hopwood, Melanie Kelly, Matthew Miller, Robert Musk, Sheri Parsons, Kim Portlock, James Reid, Adam Uytendaal, Dan Warfe, and Brett Whelan.

Thank you to the farmers of King Island and the King Island Natural Resource Management Committee Inc., in particular Ken Baker and Donald Graham. I hope this thesis can help you in your NRM.

Thank you to my parents and my family Jen, Charlie and Edith.

Table of Contents

<i>Declaration</i>	ii
<i>Abstract</i>	iii
<i>Acknowledgements</i>	v
<i>Table of Contents</i>	vi
<i>List of Figures</i>	viii
<i>List of Tables</i>	xi
<i>List of Maps</i>	xii
Chapter 1. Introduction.....	1
1.1. The problem of scale.....	2
1.2. The study area and the purpose of this thesis	4
1.3. Thesis structure	7
Chapter 2. Australian dryland salinity formation and detection	8
2.1. Causes of salinisation at the macro- and upper meso-scales	8
2.2. Causes of salinisation at the lower meso- and micro-scales	13
2.2.1. Salinisation due to a high water table	14
2.2.2. Salinisation without a high water table	15
2.3. Measuring salinity by electrical conductivity	17
2.3.1. Measurements in the laboratory.....	17
2.3.2. Measuring and mapping salinisation	18
2.4. Sources of salt	22
2.4.1. Rainfall (and evaporation)	22
2.4.2. Sea Spray	23
2.4.3. Weathering.....	23
2.5. Political history and salinity management programs	27
Chapter 3. The climatic and geophysical characteristics of King Island and previous salinity investigations.....	30
3.1. Climatic features and rainfall.....	30
3.2. Geology and geomorphology.....	32
3.3. Soil mapping units	34
3.3.1. Soil on the highland plateau.....	34
3.3.2. Soils on the plains country	39
3.3.3. Swamp soils	41
3.3.4. Soils on the dunes	41
3.4. Groundwater Flow Systems.....	42
3.5. Vegetation	46
3.6. Previous salinity investigations and mapping.....	46

Chapter 4. Detailed aims, materials and methods	51
4.1. Thesis aims.....	51
4.2. EM Survey	52
4.2.1. Kriging EC _a	56
4.2.2. Terrain modelling.....	58
Chapter 5. Results.....	60
5.1. Climatic Observations.....	60
5.2. EM survey.....	60
5.2.1. Terrain Modelling	63
5.3. Lake Flannigan.....	65
5.4. Egg Lagoon.....	69
5.5. Yellow Rock	73
5.6. Currie	83
5.7. South Road.....	87
Chapter 6. Discussion	91
6.1. Reliability of the EM31 for salinisation mapping.....	91
6.2. Variability of salinisation within land systems	92
6.2.1. Groundwater flow systems (GFS)	95
6.3. Biophysical determinants of salinisation	97
6.3.1. Climatic determinants	97
6.3.2. Geological and soil determinants.....	101
6.4. Salinisation models on the various geomorphic landforms	103
6.4.1. The highland plateau.....	104
6.4.2. The undulating plains and slopes.....	105
6.4.3. The Yellow Rock River basin.....	106
6.4.4. The drained swamps	108
6.4.5. The near-coastal dunes.....	110
6.5. A summary of macro- and meso-scale salinisation on King Island.....	111
6.6. Micro-scale salinisation on King Island	112
6.7. Scale and salinisation management – issues to consider	118
Chapter 7. Conclusions.....	123
References.....	130
Appendix A: Soil Sample Site Locations, Depth to Rock and Groundwater Salinity on King Island.....	140
Appendix B: Soil Texture and Salinity	142
Appendix C: Salinity Trends with Increasing Soil Depth	154
Appendix D: Linear Correlation Analysis and Model Parameter Statistics for EC _a and EC _e	162
Appendix E: Regression Analysis and Model Parameter Statistics – Salinity and Terrain Profile Curvature on Different Geological Units at 160 m Pixel Scale	163
Appendix F: Regression Analysis and Model Parameter Statistics – Salinity and Terrain profile Curvature on Different Geological Units at 80 m Pixel Scale .	165

List of Figures

Figure 1: The various scales at which salinisation and its management occur.....	3
Figure 2: King Island is situated along the western margin of Bass Strait.....	5
Figure 3: A map of King Island (TASMAP, 1997).	6
Figure 4: A schematic representation of the hydrologic cycle and salinisation in a Western Australian catchment (Bettenay <i>et al.</i> 1964).	9
Figure 5: GFS are broadly classed as local, intermediate or regional.	12
Figure 6: A typical salinity profile of soil exposed to high and salty groundwater (adapted from Ayres and Westcot 1976).	15
Figure 7: A typical salinity profile of a soil unexposed to a high water table (Jenkins 1982).	16
Figure 8: Electrical current in soil and water can follow three pathways as originally described by Rhoades <i>et al.</i> (1989): (1) in solid soil and water, (2) in water only, and (3) in the solid soil only.	19
Figure 9: The concept of GFS is the foundation of salinity risk assessment and subsequent salinity management (Robins <i>et al.</i> 2003).....	28
Figure 10: Mean annual rainfall across Tasmania (Source: BOM 2006).	31
Figure 11: Monthly rainfall averages at Currie and Pan A evaporation predicted from the Bureau of Meteorology (BOM 2008).....	31
Figure 12: Bedrock geology map of King Island. The numbers in the figure refer to sample plot numbers in Berry <i>et al.</i> (2005).	33
Figure 13: The relief of King Island above sea level (m).	35
Figure 14: Geology of King Island including the distribution of unconsolidated materials (adapted from Calver <i>et al.</i> 2005).	36
Figure 15: King Island's surface drainage pattern and land parcels.....	37
Figure 16: Soil mapping units of King Island (Stephens & Hosking, 1932).....	38
Figure 17: Pegarah fine sandy-loam soil map unit comprise 370 km ² of the island (adapted from Stephens and Hosking 1932).	39
Figure 18: Naracoopa sand soil map unit comprise 106 km ² of the island (adapted from Stephens and Hosking 1932).....	40
Figure 19: Lappa sand soil map unit comprise 257 km ² of the island (adapted from Stephens and Hosking 1932).	41
Figure 20: Taroona sand soil map unit comprise 81 km ² of the island (adapted from Stephens and Hosking 1932).	42
Figure 21: The three major groundwater flow systems on King Island (Latinovic <i>et al.</i> 2002).	44
Figure 22: Vegetation communities of King Island (Source: Tasmanian Vegetation Mapping Program, Department of Primary Industries and Water).....	47
Figure 23: Land systems containing areas of salinity on private freehold land (Grice, 1995).	49
Figure 24: Land systems containing areas of salinity (King Island Natural Resource Management Committee 1998).....	50
Figure 25: The EM31v mounted on an ATV.	52

Figure 26: The linearity of the EM31 response. The solid line represents the non-linear characteristics of the EM31 on soil of high ground conductivity (note the logarithmic scale). The dashed line represents corrected conductivity (adapted from McNeill 1980a).	53
Figure 27: The relative response of the secondary conductivity signal from the EM31 (adapted from McNeill 1980a).....	54
Figure 28: The rotary action drill used for soil sampling.	55
Figure 29: An example of a variogram model with some of the variogram parameters shown (adapted from Golden Software 1999).	57
Figure 30: VESPER fits a variogram model to the collected data within the search neighbourhood to predict a value for an estimation point (Minasny <i>et al.</i> 2005).....	58
Figure 31: Monthly rainfall at Currie post office during the study period and predicted average Pan A evaporation from the Bureau of Meteorology (B.O.M. 2008). ...	60
Figure 32: The number of groundwater samples assessed on King Island and their salinity class (Hart 1974).	61
Figure 33: Relationship between average EC_e at the numbered soil sample drill sites and EC_a , on King Island assessed by the EM31.....	63
Figure 34: Soil salinity classes and contours at the Lake Flannigan site.....	67
Figure 35: Proterozoic granite outcrops on the eastern shoreline of Lake Flannigan..	68
Figure 36: Soil salinity classes and contours at Egg Lagoon.....	72
Figure 37: Contour map showing the change in topography at 1 m intervals draped over the salinity classes.....	77
Figure 38: Terrain modelling from DEMs is a good predictor of the broad scale salinity pattern associated with soil derived from Proterozoic shale but is a poor predictor of salinity on the undifferentiated Quaternary sediments.....	79
Figure 39: Depth and salinity of groundwater along a 2.7 km transect located toward the bottom of the Yellow Rock catchment.	80
Figure 40: Depth to groundwater trends in the lower Yellow Rock catchment (King Island Natural Resource Management Committee 2005).....	82
Figure 41: Soil salinity classes, drainage and 1 m contours at the Currie site.....	85
Figure 42: Soil salinity classes and contours at the South Road site.....	89
Figure 43: Estimates of salinisation around Yellow Rock River by: (a) Grice (1995), (b) in this study; and (c) by the King Island Natural Resource Management Committee (1998).	93
Figure 44: The volume of sodium molecules contained within different sized sea spray during 2001 at Cape Grim on the Tasmanian mainland (Ayres <i>et al.</i> 1999).	98
Figure 45: Rates of aerosol deposition from west coast generated sea spray following the findings of de Leeuw <i>et al.</i> (2000).....	99
Figure 46: Salinity storage and slope position on Proterozoic granite at Lake Flannigan and Proterozoic shale at South Road. In this case, topsoil is the top 50 cm of soil.....	103
Figure 47: Salinisation model for the Nugara sandy-loam, Naracoopa, Lappa and Tarroona sands occurring on the slopes and undulating plains. The red and blue colours represent comparisons of high and low salt content, respectively.	106
Figure 48: Salinisation model in the Yellow Rock River basin (below 20 m ASL).	107
Figure 49: Salinisation model for the Swamp soils at Reedy Lake (Lake Flannigan). Refer to Figure 48 for the causes of salinity at the meso-scale in the basin.	109
Figure 50: Salinisation model for the Swamp soils at Egg Lagoon. Refer to Figure 48 for the causes of salinity at the meso-scale in the basin.	109

Figure 51: Salinisation model for the Pleistocene old dune and Holocene new dune systems on King Island. 110

Figure 52: Soil sample sites that exhibited unconventional salinity profiles..... 115

Figure 53: A theoretical salinisation model occurring at the micro-scale in King Island soil..... 117

List of Tables

Table 1: Catchment classification of salinisation based on GFS characteristics (Coram 1998).	11
Table 2: Commonly used conversion factors for EC _{1:5} to EC _e (Taylor 1993).....	18
Table 3: Land system salinity classification criteria (Grice, 1995).	48
Table 4: Groundwater salinity classes (Hart 1974).	56
Table 5: Classes of soil salinity assigned to EC _e predictions (Taylor, 1993).....	56
Table 6: A comparison between the critical attributes associated with the GFS on King Island as listed in Latinovic <i>et al.</i> (2002) and as measured in this study....	96
Table 7: A summary of the causes of salinisation (from Chapter 2)	104
Table 8: Associations between the geology and soil units on King Island and the occurrence of highly saline soil (>8 dS/m).	111
Table 9: A summary of the causes of soil salinity at multiple spatial scales on King Island.....	123

List of Maps

Map 1. King Island soil apparent conductivity, 0 - 350 cm depth June 2005.....	62
Map 2. King Island predicted average soil salinity between 0 - 350 cm depth on 15,420 hectares.....	64
Map 3. Lake Flannigan - Predicted average soil salinity at 0 - 350 cm depth June 2005...	66
Map 4. Egg Lagoon - Predicted average soil salinity at 0 - 350 cm depth June 2005.....	70
Map 5. Yellow Rock - Predicted average soil salinity at 0 - 350 cm depth June 2005.....	74
Map 5a. Yellow Rock – Soil and groundwater salinity and depth (cm).....	75
Map 6. Currie - Predicted average soil salinity at 0 - 350 cm depth June 2005.....	84
Map 7. South Road - Predicted average soil salinity at 0 - 350 cm depth June 2005.....	88
Map 8. The likelihood of encountering very- and extremely-saline soil between 0 - 350 cm depth.....	112