EXPLORING THE USE OF WATER MARKETS FOR IMPROVED ENVIRONMENTAL OUTCOMES

Claire Maree Settre

A thesis submitted for the degree of Doctor of Philosophy

The Centre of Global Food and Resources

The Faculty of Professions

The University of Adelaide

September, 2017
I. **Table of Contents**

EXPLORING THE USE OF WATER MARKETS FOR IMPROVED ENVIRONMENTAL OUTCOMES

I. Table of Contents ......................................................................................................................................... i
II. List of Tables .................................................................................................................................................. viii
III. List of Figures ................................................................................................................................................ xi
IV. Abbreviations, Units and Terminology ......................................................................................................... xv
    List of Abbreviations ....................................................................................................................................... xv
    List of Units Used ............................................................................................................................................. xvi
    Useful Terminology ......................................................................................................................................... xvii
V. Abstract .......................................................................................................................................................... xx
VI. Thesis Declaration Statement ...................................................................................................................... xxi
VII. Acknowledgements ...................................................................................................................................... xxii
VIII. Publications and Presentations from this Thesis .......................................................................................... xxiii
    Academic Journal Articles (peer-reviewed) .................................................................................................... xxiii
    Book Chapters (peer-reviewed) .................................................................................................................... xxiii
    Current Working Papers ................................................................................................................................ xxi
    Conference Papers and Seminars ................................................................................................................... xxiv
IX. Additional Publications during Candidature ............................................................................................... xxv
    Academic Journal Articles (peer-reviewed) .................................................................................................... xxv
    Book Chapters (peer-reviewed) .................................................................................................................... xxv

1  **CHAPTER 1: Introduction** .................................................................................................................... 1
   1.1 Water Resources in the MDB .................................................................................................................... 1
      1.1.1 MDB Water Resources ....................................................................................................................... 1
      1.1.2 Water Reform and the Murray-Darling Basin Plan ............................................................................. 3
      1.1.3 Current Policy Platform ..................................................................................................................... 3
      1.1.4 MDB Water Markets ........................................................................................................................... 5
   1.2 Literature Review: Water Markets and Environmental Outcomes ......................................................... 6
      1.2.1 Modelling Water Trade and the Environment ..................................................................................... 6
      1.2.2 Understanding Non-Government Environmental Water Holders ................................................... 8
   1.3 Research Objectives and Questions ......................................................................................................... 9
   1.4 Thesis Methodology and Research Design ............................................................................................... 11
      1.4.1 Quantitative Methodology: Hydro-economic Simulation Modelling ............................................... 12
      1.4.2 Qualitative Methodology: Semi-Structured Stakeholder Interviews and Survey Analysis .............. 14
   1.5 Thesis Structure ....................................................................................................................................... 15
2. **CHAPTER 2: Water Resources and Policy Reform in the Murray-Darling Basin** ............................. 18
CHAPTER 3: Rebalancing the System: Acquiring Water for the Environment through the Market

3.1 Introduction .............................................................................................................................................. 62

3.2 Water Markets and Trade in the MDB ................................................................................................. 64

3.2.1 Water Market Fundamentals ............................................................................................................ 65

3.2.2 Overview of Water Markets in the MDB ....................................................................................... 67

3.2.3 Geographic and Institutional Scope of the Water Market ........................................................... 68

3.2.4 Irrigator Adoption of Water Markets in the MDB ....................................................................... 71

3.2.5 Trends in Australian Agriculture .................................................................................................. 71

3.3 Environmental Water in the MDB ...................................................................................................... 73

3.4 Methods of Reallocating Water to the Environment ......................................................................... 74

3.5 The Rational for Market-Based Water Reallocation ........................................................................ 75

3.5.1 Water-use Efficiency ..................................................................................................................... 75

3.5.2 Cost-effectiveness .......................................................................................................................... 77

3.6 Adaptive Market-Based Reallocation as a Driver of Ecological Health ...................................... 78

3.7 Conditions for the Environment Entering the Water Market .......................................................... 80
3.8 Environmental Water Holders (EWHs) ................................................................. 82
  3.8.1 Environmental Water Holders in the MDB ............................................. 83
3.9 Examples of Existing Environmental Water Markets ............................................. 85
  3.9.1 The Western United States ................................................................. 85
  3.9.2 South-eastern Australia ................................................................. 91
3.10 Challenges to Market-Based Entitlement Recovery ............................................ 94
  3.10.1 Negative Community Perception ....................................................... 95
  3.10.2 Irrigator Preferences for Alternative Recovery Mechanisms ..................... 97
  3.10.3 Third Party Impacts and the Social Impacts of Water Trading ................. 99
  3.10.4 Private Transaction Costs ............................................................... 100
  3.10.5 Groundwater-Surface Water Substitution ........................................... 103
  3.10.6 Entitlement Supply Profiles ............................................................. 104
  3.10.7 Volume as the Metric of Success ...................................................... 105
  3.10.8 Climate Change Risks ................................................................. 105
3.11 Expansion of the Environmental Water Market ................................................. 106
  3.11.1 Water Products for the Environment ................................................ 106
  3.11.2 Environmental Allocation Trade Opportunities in the MDB ................. 108
  3.11.3 CEWH Annual Water Trading Framework ........................................ 110
3.12 Conclusion .................................................................................................. 111
4.  CHAPTER 4: A Century of Intervention in a Ramsar Wetland: the Case of the Coorong, Lower
Lakes and Murray Mouth ............................................................................. 113
  4.1 Introduction ............................................................................................ 115
  4.2 Site Details Overview ............................................................................. 116
  4.3 Water Stakeholders in the CLLMM ......................................................... 117
  4.4 Impact of Water Resource Development on CLLMM ................................. 119
  4.5 History of Infrastructure Interventions in the CLLMM ............................... 122
  4.6 Unsuccessful Infrastructure Interventions ............................................... 125
  4.7 Alternative Infrastructure Proposals ....................................................... 127
  4.8 Discussion and Possible Alternatives .................................................... 128
    4.8.1 The Transition to Sustainability ....................................................... 129
  4.9 Conclusion ............................................................................................. 132
5.  CHAPTER 5: MDB Hydro-economic Modelling Literature Review ...................... 133
  5.1 Introduction ............................................................................................ 135
  5.2 Types of Hydro-economic Models ......................................................... 136
  5.3 Hydro-economic Modelling of the MDB .................................................. 136
  5.4 Agricultural Focused Modelling ............................................................. 138
    5.4.1 Basin Plan Modelling ..................................................................... 143
    5.4.2 Water Trade .................................................................................. 144
CHAPTER 6: Theory, Data and Methodology of Hydro-economic Modelling of Carbon Storage Dynamics ................................................................. 157

6.1 Introduction ............................................................................................................. 158

6.2 Ecosystem Services ................................................................................................... 159

6.2.1 The Ecosystem Service Cascade ........................................................................... 160

6.2.2 Flow Dependent Ecosystem Services ................................................................. 161

6.2.3 Informing Decision-making with Ecosystem Services Analysis ......................... 163

6.2.4 Carbon Storage and Sequestration Ecosystem Service ..................................... 164

6.3 Economics of the HEM ............................................................................................ 166

6.3.1 Conceptual Framework ....................................................................................... 166

6.3.2 Ecosystem Service Valuation Methods, Challenges and Potential for Bias ........ 168

6.3.3 Carbon Storage Valuation ................................................................................... 171

6.3.4 Selection of Discount Rates ................................................................................. 173

6.4 Modelling Case Study ............................................................................................... 174

6.4.1 The Murrumbidgee Catchment ........................................................................... 174

6.5 Model Development and Methodology ..................................................................... 177

6.5.1 Methodology Overview ....................................................................................... 177

6.5.2 Data and Assumptions ......................................................................................... 178

6.5.3 Description of Variables ....................................................................................... 181

6.5.4 Hydrology and Floodplain Inundation Model ..................................................... 184

6.5.5 Carbon Storage Dynamics Model ....................................................................... 187

6.5.6 Carbon Value ....................................................................................................... 194

6.5.7 Water Allocation Price Model ............................................................................ 194

6.5.8 Treatment of Foresight and Water Reallocation Algorithm ................................ 196

6.6 Treatment of Uncertainty ......................................................................................... 198

6.6.1 Sensitivity Testing Methodology ......................................................................... 199

6.7 Conclusion ............................................................................................................... 200

CHAPTER 7: Carbon and Water Market Opportunities in Environmental Water Reallocation: Results of the Hydro-economic Model ......................................................... 201

7.1 Introduction ............................................................................................................ 204
7.2 Baseline River Red Gum Carbon Dynamics and Economic Value ..............................................205
7.3 The Impact of Annual Reallocation to the Environment ..............................................................207
  7.3.1 Long-run Impacts of Annual Reallocation ..............................................................................210
  7.3.2 Annual Reallocation Impact on Water Price .............................................................................211
7.4 Potential to Offset Water Allocation Purchases with Carbon Credit Generation and Sale.212
  7.4.1 Proposed Carbon–Water Trading Strategy ..............................................................................215
7.5 Opportunities to Implement the Proposed Carbon–Water Trading Strategy ..............................216
  7.5.1 Initial Drought Conditions ........................................................................................................218
  7.5.2 Naturally High Flood Events ....................................................................................................218
  7.5.3 Drought Recovery .....................................................................................................................219
  7.5.4 Comparison of Results with Existing Models ..........................................................................219
  7.5.5 A Conceptual Environmental Damage Function .....................................................................219
  7.5.6 Comparison of Reallocation Results .......................................................................................221
7.6 Uncertainty Analysis and Treatment .............................................................................................222
  7.6.1 Sensitivity Testing Results ........................................................................................................225
7.7 Discussion ........................................................................................................................................232
  7.7.1 Potential for a Self-Financing EWH ..........................................................................................233
  7.7.2 Policy Challenges ......................................................................................................................234
  7.8.3 Expansion to Additional Marketable Ecosystem Services .....................................................236
7.8 Study Caveats and Limitations ......................................................................................................237
7.9 Conclusion ........................................................................................................................................239

8 CHAPTER 8: Localism, Community Engagement and 40 cups of Coffee: The Role of Non-
government Environmental Stewards in Water Management in the US and Applications to the MDB .. ..........................240
  8.1 Introduction .....................................................................................................................................242
  8.2 Environmental Water Transfers Background .................................................................................243
  8.3 Literature Review ............................................................................................................................243
  8.3.1 Localism and Social Trust in Resource Management ...............................................................243
  8.3.2 Non-Government Environmental Water Holders .....................................................................245
  8.3.3 NGO EWHs as Stewards of Environmental Water .................................................................247
8.4 Methodology ......................................................................................................................................249
  8.4.1 Qualitative Interviews ...............................................................................................................250
  8.4.2 Quantitative Survey Analysis .....................................................................................................251
8.5 Western US Interview Results: The Role of NGO EWHs .........................................................252
  8.5.1 The 40 Cups of Coffee Principle .................................................................................................253
  8.5.2 Instream Flow Transfer Tools ....................................................................................................255
  8.5.3 Disseminating Information ..........................................................................................................258
  8.5.4 Targeted Action .........................................................................................................................259
B.3.1 Results Summary Table ........................................................................................................306
B.3.2 Long-run Analysis Results ................................................................................................307
B.3.3 Comparison with Permanent Reallocation Strategies .........................................................307
C. APPENDIX C: Estimating the Value of Environmental Water with Ecosystem Service Supply Modelling .........................................................................................................................308
   C.1 Introduction ...........................................................................................................................310
   C.2 Literature Review and ES Supply Theory ..............................................................................311
   C.3 Methodology .......................................................................................................................312
      C.3.1 Overview .......................................................................................................................312
      C.3.2 Modelling and Valuation Assumptions ........................................................................314
      C.3.3 Modelling Ecosystem Service Supply ..........................................................................316
      C.3.4 Valuing Ecosystem Service Supply ............................................................................323
   C.4 Results .................................................................................................................................327
      C.4.1 Baseline Ecosystem Service Supply .............................................................................327
      C.4.2 Ecosystem Service Supply for Environmental Reallocation Conditions ..................329
   C.5 Discussion and Policy Implications .....................................................................................336
   C.6 Conclusion ..........................................................................................................................338
D. APPENDIX D: Monthly Flow Analysis ....................................................................................339
E. APPENDIX E: Supplementary Material from Environmental Water Stakeholder Interviews...342
   E.1 Ethics Approval ....................................................................................................................342
   E.2 Participant Consent Form ......................................................................................................343
   E.3 Participant Information Sheet ..............................................................................................344
   E.4 Sample Interview Talking Points for Semi-Structured Stakeholder Interviews .................346
THESIS REFERENCES ..................................................................................................................348
II. List of Tables

Table 2.1 Demand Management Tools for Freshwater Resources ........................................... 29
Table 2.2 Long-term Water Balance Components in the MDB and Australia .......................... 32
Table 2.3 Rainfall and Runoff Volumes for Historic, Recent and Future Climate Scenarios ... 38
Table 2.4 MDB Water Use, Irrigated Water Use, and Irrigated Agriculture (2015-2016) ........... 41
Table 2.5 Summary of Environmental Trends in the MDB ...................................................... 42
Table 2.6 Characteristics of Phases of Water Policy in the MDB ............................................ 44
Table 2.7 Overview of Significant Water Reforms in the MDB ............................................. 45
Table 3.1 Legal Instruments to Acquire Water for the Environment ......................................... 64
Table 3.2 Water Entitlement and Allocation Naming Conventions across MDB States ............ 68
Table 3.3 Water Trading Activity in the sMDB in 2015-2016 ................................................ 69
Table 3.4 Trends in the Number and Composition of Agricultural Businesses in Australia ...... 73
Table 3.5 Water Recovery Expenditure as Mean $/ML ............................................................ 77
Table 3.6 Environmental Water Acquisition Criteria ............................................................... 82
Table 3.7 Examples of Environmental Water Holders in the MDB ...................................... 83
Table 3.8 Water Recovered, Recovery Budget, and Expenditure for 10 Active Water Trading Sub-basins in the Columbia River Basin from 2003-2010 .............................................. 89
Table 3.9 Summary of Issues Identified with the Current Entitlement Recovery Strategy ........ 95
Table 3.10 Irrigator Preferences for Budget Expenditure on Water Recovery ......................... 98
Table 3.11 Irrigator Willingness to Participate in Alternative Water Sales to the Environment ... 99
Table 3.12 Irrigation District Allocation Transfer Costs between 2009/10 – 2016/17 .................. 102
Table 3.13 Irrigation District Allocation Transfer Costs between 2009/10 – 2016/17 ............... 103
Table 3.14 Irrigation District Entitlement Transfer Costs between 2009/10 – 2016/17 ............ 103
Table 3.15 Water Rights used for the Environment in western US and Australia .................... 106
Table 3.16 Methods, Key Findings and Future Research Required of Literature Examining Allocation Trade for the Environment ......................................................... 109
Table 4.1: Stakeholders of CLLMM Wetland Values and Functions ........................................ 118
Table 4.2: Infrastructure Interventions in the CLLMM .......................................................... 123
Table 4.3: Unsuccessful CLLMM Infrastructure Proposals .................................................... 126
Table 5.1: Partial Equilibrium Agriculturally Focused MDB Hydro-economic Models ............ 139
Table 5.2 General Equilibrium Agriculturally Focused MDB Hydro-economic Models .......... 142
Table 5.3: Environmentally Focused Hydro-economic Models in the MDB ......................... 149
Table 6.1 The Economic of Ecosystems and Biodiversity (TEEB) Ecosystem Service Categories... 160
Table 6.2 Economic Techniques for ES Valuation ................................................................. 169
Table 6.3 The Social Cost of Carbon 2010-2050 ................................................................. 172
Table 6.4 Description of Datasets Used in the HEM ............................................................ 179
Table 6.5 Name, Definition and Range of Variable Indices ................................................................. 182
Table 6.6 Hydrology Model Variable Definitions .................................................................................. 182
Table 6.7 Carbon Storage Dynamics Model Variable Definitions ......................................................... 183
Table 6.8 Carbon Valuation, Water Price and Irrigator Opportunity Cost Variable Definitions .......... 184
Table 6.9 Foresight and Reallocation Model Variable Definitions ......................................................... 184
Table 6.10: Lower Murrumbidgee Environmental Watering Objectives ................................................. 186
Table 6.11 Description of Modeled Ecosystem States and Conditions .................................................... 188
Table 6.12 Uncertainty Matrix Framework. ............................................................................................. 199
Table 7.1 Modelled Water Allocation Purchase Costs and Carbon Credit Benefits ............................... 213
Table 7.2 Descriptive Statistics of Modeled Environmental Water Availability ....................................... 221
Table 7.3 Uncertainty Matrix .................................................................................................................. 224
Table 7.4 Summary of Sensitivity Testing Results for Optimal Reallocations ........................................ 227
Table 7.5 Mean and total volume of water reallocated to the environment for decision horizons of one, two and three years for CP=$30/tCO_2e .................................................................................. 229
Table 8.1 Participant Sector and Number of Participants ....................................................................... 251
Table 8.2 Relevant MDB Irrigator Survey Questions ............................................................................. 252
Table 8.3 Transfer Tools Employed by Non-government Environmental Water Holders ........................ 256
Table 8.4 sMDB Irrigator Preferences (n=1,000) for the Sale of Permanent Water Entitlements in 2015-16 ............................................................................................................................................... 266
Table 8.5 sMDB Irrigator Preferences for Buyers of Permanent Water Entitlements ............................ 267
Table 8.6 Irrigator Willingness to Participate in Water Entitlement Sales to the Federal Government for Environmental Flows in the sMDB in 2008-09, 2010-11 and 2015-2016 .................................................. 269
Table 8.7 sMDB Irrigator Preference for Water Allocation Sales to the Environment in 2010-11 and 2015-16 ............................................................................................................................................... 270
Table 9.1 Summary of Key Thesis Findings ............................................................................................ 278
Table B.1: Mean Carbon Stored in River Red Gums (tCha-1 ± s.e.m) in the Lower Namoi Floodplain in Northern New South Wales .................................................................................................................... 301
Table B.2 Annual River Red Gum Transpiration (mm) between May 2010 and April 2012 with 95% Confidence Intervals for Selected Flooding Sites on the Lower Murrumbidgee Floodplain in Western New South Wales .................................................................................................................... 301
Table B.3 Descriptive Statistics of Baseline Modeled Consumptive Water Availability .......................... 302
Table B.4 Descriptive Statistics of Baseline Modeled Environmental Water Availability ........................ 303
Table B.5 Descriptive Statistics of Baseline Modeled Water Allocation Prices ...................................... 304
Table B.6 Descriptive Statistics for Modeled Floodplain River Red Gum Carbon Storage .................. 305
Table B.7 Baseline Modeled Carbon Storage in Short-run Analysis ...................................................... 307
Table B.8 Baseline Modeled Carbon Storage in Long-run Analysis ....................................................... 307
Table B.9 Difference Between Short and Long-run Analysis ................................................................. 307
III. List of Figures

Figure 1.1 Research Methodology and Design ................................................................. 12
Figure 1.2 Quantitative Methodology: Hydro-economic Simulation Model ......................... 13
Figure 1.3 Qualitative Methodology: Stakeholder Interviews and Survey Analysis .................. 15
Figure 2.1 The Total Economic Value of Water ................................................................... 23
Figure 2.2 Average Annual Blue Water Scarcity from 1996-2005 ........................................... 25
Figure 2.3 The Murray-Darling Basin, Australia ............................................................... 31
Figure 2.4 Total Rainfall Volume (2005-2006) in Australia .................................................. 32
Figure 2.5 Mean Monthly Flow and Rainfall in the MDB for 2013-14 .................................... 33
Figure 2.6 Water-use in the MDB and Whole of Australia in 2004-05 .................................... 34
Figure 2.7 Rainfall Deficits across Australia from January 1997 to December 2009 .............. 35
Figure 2.8 Average Flows at the Murray Mouth from 1980 to 2010 .................................... 36
Figure 2.9 Total Irrigation Water Diverisons and Allocations by State During the Millennium Drought ........................................................................................................... 37
Figure 2.10 Land Use in the MDB ....................................................................................... 40
Figure 2.11 Phases of Water Policy in the MDB ............................................................... 43
Figure 2.12 Annual flow in the Murrumbidgee River at Maude Weir for Current Development Conditions (2009) and Without Development Conditions ......................................................... 47
Figure 2.13 Unbundling of Water Rights ............................................................................ 53
Figure 2.14 Timeline for the Development and Implementation of the Murray-Darling Basin Plan .............................................................. 57
Figure 2.15 Commonwealth Environmental Water Holdings and their Long-term Annual Average Yield as of February 2017 ...................................................................................... 58
Figure 2.16 Federal Progress towards the 2,750GL Water Recovery Target .............................. 58
Figure 2.17 Australian Federal Government Expenditure on Water Recovery Projects ............... 59
Figure 3.1 Australian Catchment Regions with Water Allocation Market Activity in 2015-2016 .... 67
Figure 3.2 Volume of Water Allocation and Entitlement Trade in the sMDB from 1983-2013 ...... 69
Figure 3.3 Net Trade Volumes in the sMDB in 2014-2015 and 2015-2016, Excluding Environmental Trading ...................................................................................................................... 70
Figure 3.4 Adoption of Water Trading by MDB Irrigators ..................................................... 71
Figure 3.5 Trends in Agricultural Businesses in Australia .................................................... 72
Figure 3.6 Overbank Flood Magnitude, Frequency and Impacts ............................................ 79
Figure 3.7 Hydrograph of Flow at Maude Weir with and Without Environmental Water Trade .... 80
Figure 3.8 Net Environmental Allocation Trades in the sMDB 2015-2016 ............................. 84
Figure 3.9 The Columbia River Basin .................................................................................. 88
Figure 3.10 The Colorado River Basin ................................................................................. 91
Figure 3.11 Restoring the Balance Tenders ........................................................................ 93
Figure 3.12 Main Reasons for Irrigators’ Sale or Offer to Sell Water ................................................................. 94
Figure 3.13 MDB Irrigators’ Best-Worst Scores in Response to Statements Regarding Water Reform ............................................................................................................................................. 96
Figure 3.14 MDB Residents Perception of the Likely Effects of the Basin Plan on Economic Outcomes, Community Outcomes and Environmental Outcomes .................................................................................................................. 97
Figure 3.15 Indicative Termination Fees for Goulburn-Murray Irrigation District (CPI adjusted) .......... 102
Figure 3.16 CEWH Environmental Water Trading Framework .............................................................................. 111
Figure 4.1 Coorong, Lower Lakes and Murray Mouth Region .............................................................................. 117
Figure 4.2 Flows over the Barrages and Key Climactic, Policy and Infrastructure Events ..................... 120
Figure 5.1 MDB Hydro-economic Publications by Year .................................................................................... 137
Figure 5.2 The Intersection of Hydro-economic Modelling and Ecological Response Modelling .... 148
Figure 5.3 Conceptual Representation of the Model Linkages between Hydrology, Ecology and Economics in Ecosystem Service HEM .............................................................................................................. 155
Figure 6.1 The Ecosystem Service Cascade ...................................................................................................... 161
Figure 6.2 Flow Dependent Ecosystem Services ............................................................................................ 162
Figure 6.3 The Generation of Flow-dependent Ecosystem Services .................................................................. 163
Figure 6.4 Carbon Pathways in Vegetated Floodplains .................................................................................... 165
Figure 6.5 Carbon Prices in Australia ................................................................................................................ 173
Figure 6.6 Location and extent of Lower Murrumbidgee (‘Lowbidgee’) River Floodplain ....................... 176
Figure 6.7 Conceptual Model Overview and Key Outputs .................................................................................... 178
Figure 6.8 Flood Volumes and Inundation Area for a Vegetated Floodplain .................................................. 187
Figure 6.9 Conceptual River Red Gum Carbon Time Series .............................................................................. 191
Figure 6.10 Conceptual River Red Gum Carbon Sequestration Time series .................................................. 193
Figure 6.11 Observed Water Allocations and Observed and Modelled Water Allocation Prices in the Murrumbidgee .............................................................................................................................................. 195
Figure 6.12 Defining Uncertainty in Modelling ............................................................................................... 198
Figure 7.1 Proportion of Time Desired Return Period for Flooding per Floodplain Area is Exceeded for Baseline Conditions .......................................................................................................................................... 206
Figure 7.2 Modelled Environmental Water Availability and River Red Gum Carbon Storage Trend for Baseline Conditions in the Lowbidgee .................................................................................................................. 206
Figure 7.3 Proportion of Time the Desired Return Period for Flooding per Floodplain Area is exceeded for Baseline and Optimal Reallocation Conditions .................................................................................................................. 208
Figure 7.4 Modelled Environmental Water Availability for Baseline and Optimal Annual Reallocation Scenario .............................................................................................................................................. 209
Figure 7.5 Modelled Consumptive Water Availability for Baseline and Optimal Annual Reallocation Conditions .............................................................................................................................................. 209
Figure C.6 Modelled River Red Gum Floodplain Carbon Storage for Baseline Conditions...........328
Figure C.7 Modelled Native Fish Habitat Suitability Scores for Native In-Channel Specialist (Murray Cod) Fish Under Baseline Conditions ..................................................................................329
Figure C.8 Modelled Additional Annual Flow Required to Prevent the Formation of Favourable Blue Green Algae Conditions under Baseline Conditions .................................................................329
Figure C.9 Modelled Variation in River Red Gum Carbon Storage for Increasing Permanent Reallocations (CP=$23/tCO$_2$e$).................................................................................................330
Figure C.10 Modelled Marginal Increase in the Annual Flow of Carbon Storage Benefits for a Range of Carbon Prices ..................................................................................................................331
Figure C.11 Modelled Marginal Increase in the Annual Flow of Erosion Prevention Benefits for a Range of Avoided Cost Estimates ..................................................................................................332
Figure C.12 Modelled Marginal Increase in the Annual Flow of Blue Green Algae Prevention Benefits for the Average Water Allocation Price ....................................................................................333
Figure C.13 Modelled Marginal Increase in the Annual Flow of Native Fish Habitat Benefit for a Range of Marginal Non-Market Value Estimates ........................................................................334
Figure C.14 Modelled Marginal Increase in the Summed Annual Flow of Ecosystem Services in the Lower Murrumbidgee (Carbon Storage, Blue Green Algae Prevention, Erosion Prevention, Native Fish Habitat) ........................................................................................................................336
Figure D.1 Mean monthly streamflow (ML), Murrumbidgee River at Maude Weir (1985-2009) (calculated)........................................................................................................................................339
Figure D.2 Average Distribution of Monthly Streamflow (ML), Murrumbidgee River at Maude Weir (1985-2009) ......................................................................................................................................341
Figure D.3 Mean Monthly Streamflow (ML), Murrumbidgee River at Maude Weir (2007).........341
### IV. Abbreviations, Units and Terminology

#### List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABARE-BRS</td>
<td>Australian Bureau of Agricultural and Resource Economics and the Bureau of Rural Sciences</td>
</tr>
<tr>
<td>ABARES</td>
<td>Australian Bureau of Agricultural Economics and Science</td>
</tr>
<tr>
<td>ABS</td>
<td>Australian Bureau of Statistics</td>
</tr>
<tr>
<td>ACCC</td>
<td>Australian Competition and Consumer Commission</td>
</tr>
<tr>
<td>ACT</td>
<td>Australian Capital Territory</td>
</tr>
<tr>
<td>BOM</td>
<td>Bureau of Meteorology</td>
</tr>
<tr>
<td>CBWTP</td>
<td>Columbia Basin Water Transaction Program</td>
</tr>
<tr>
<td>CER</td>
<td>Clean Energy Regulator</td>
</tr>
<tr>
<td>CEWH</td>
<td>Commonwealth Environmental Water Holder</td>
</tr>
<tr>
<td>CEWO</td>
<td>Commonwealth Environmental Water Office</td>
</tr>
<tr>
<td>CGE</td>
<td>Computable general equilibrium model</td>
</tr>
<tr>
<td>CICES</td>
<td>Common International Classification of Ecosystem Services</td>
</tr>
<tr>
<td>CLLMM</td>
<td>Coorong, Lower Lakes and Murray Mouth</td>
</tr>
<tr>
<td>COAG</td>
<td>Council of Australian Governments</td>
</tr>
<tr>
<td>CRDWT</td>
<td>Colorado River Delta Water Trust</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific Research and Industrial Research Organisation</td>
</tr>
<tr>
<td>DEWHA</td>
<td>Department of Environment, Water, Heritage and the Arts</td>
</tr>
<tr>
<td>DEWNR</td>
<td>Department of Environment, Water and Natural Resources</td>
</tr>
<tr>
<td>DoAWR</td>
<td>Department of Agriculture and Water Resources</td>
</tr>
<tr>
<td>DoE</td>
<td>Department of the Environment</td>
</tr>
<tr>
<td>DoEE</td>
<td>Department of the Environment and Energy</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>ES</td>
<td>Ecosystem services</td>
</tr>
<tr>
<td>EU ETS</td>
<td>European Union Emissions Trading Scheme</td>
</tr>
<tr>
<td>EWH</td>
<td>Environmental water holder</td>
</tr>
<tr>
<td>EWTF</td>
<td>Environmental water trading framework</td>
</tr>
<tr>
<td>GVAP</td>
<td>Gross value of agricultural product</td>
</tr>
<tr>
<td>GVIAP</td>
<td>Gross value of irrigated agricultural product</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Water Partnership</td>
</tr>
<tr>
<td>HEM</td>
<td>Hydro-economic model</td>
</tr>
<tr>
<td>HSI</td>
<td>Habitat suitability index</td>
</tr>
<tr>
<td>IPCC</td>
<td>Inter-governmental Panel on Climate Change</td>
</tr>
<tr>
<td>IWG SC-CO₂</td>
<td>International Working Group on the Social Cost of Carbon</td>
</tr>
<tr>
<td>IWRM</td>
<td>Integrated water resource management</td>
</tr>
<tr>
<td>MAE</td>
<td>Millennium Ecosystem Assessment</td>
</tr>
<tr>
<td>MDBA</td>
<td>Murray-Darling Basin Authority</td>
</tr>
<tr>
<td>MDB</td>
<td>Murray-Darling Basin</td>
</tr>
<tr>
<td>MDB BWF</td>
<td>Murray-Darling Basin Balanced Water Fund</td>
</tr>
<tr>
<td>MDBC</td>
<td>Murray-Darling Basin Commission</td>
</tr>
<tr>
<td>MDBMCM</td>
<td>Murray-Darling Basin Ministerial Council</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-government organisation</td>
</tr>
<tr>
<td>nMDB</td>
<td>Northern Murray-Darling Basin</td>
</tr>
<tr>
<td>NPWS</td>
<td>National Plan for Water Security</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales</td>
</tr>
<tr>
<td>NWC</td>
<td>National Water Commission</td>
</tr>
<tr>
<td>NWI</td>
<td>National Water Initiative</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>OEH</td>
<td>Office of Environment and Heritage</td>
</tr>
<tr>
<td>OWT</td>
<td>Oregon Water Trust</td>
</tr>
<tr>
<td>PC</td>
<td>Productivity Commission</td>
</tr>
<tr>
<td>PE</td>
<td>Partial equilibrium</td>
</tr>
<tr>
<td>PO</td>
<td>Pareto optimality</td>
</tr>
<tr>
<td>PPO</td>
<td>Potential Pareto optimality</td>
</tr>
<tr>
<td>QLE</td>
<td>Qualified Local Entity</td>
</tr>
<tr>
<td>RTB</td>
<td>Restoring the Balance</td>
</tr>
<tr>
<td>RtB</td>
<td>Restoring the Balance</td>
</tr>
<tr>
<td>SA</td>
<td>South Australia</td>
</tr>
<tr>
<td>SC-CO$_2$</td>
<td>The social cost of carbon</td>
</tr>
<tr>
<td>SDL</td>
<td>Sustainable Diversion Limit</td>
</tr>
<tr>
<td>SEACI</td>
<td>South Eastern Australian Climate Initiative</td>
</tr>
<tr>
<td>sMDB</td>
<td>Southern Murray-Darling Basin</td>
</tr>
<tr>
<td>SRA</td>
<td>Sustainable Rivers Audit</td>
</tr>
<tr>
<td>SRWUIP</td>
<td>Sustainable Rural Water Use and Infrastructure Program</td>
</tr>
<tr>
<td>TC</td>
<td>Transaction cost</td>
</tr>
<tr>
<td>TEEB</td>
<td>The Economics of Ecosystems and Biodiversity</td>
</tr>
<tr>
<td>TLM</td>
<td>The Living Murray</td>
</tr>
<tr>
<td>USC</td>
<td>United States Department of Agriculture</td>
</tr>
<tr>
<td>USED</td>
<td>Upper South East Drainage</td>
</tr>
<tr>
<td>US-EPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>US-FWS</td>
<td>United States Fish and Wildlife Service</td>
</tr>
<tr>
<td>WFF</td>
<td>Water for the Future</td>
</tr>
<tr>
<td>WGCS</td>
<td>Wentworth Group of Concerned Scientists</td>
</tr>
<tr>
<td>WTO</td>
<td>World Trade Organisation</td>
</tr>
<tr>
<td>WUA</td>
<td>Water user association</td>
</tr>
</tbody>
</table>

**List of Units Used**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>AU</td>
<td>Australian dollar$^1$</td>
<td>(~0.75 $US$)</td>
</tr>
<tr>
<td>AF</td>
<td>Acre foot</td>
<td>(1.23 x 10$^6$ litres)</td>
</tr>
<tr>
<td>EC</td>
<td>Electro conductivity</td>
<td>(1 µS/cm)</td>
</tr>
<tr>
<td>GL</td>
<td>Giga litre</td>
<td>(1x10$^9$ litres)</td>
</tr>
<tr>
<td>Ha</td>
<td>Hectare</td>
<td>(1 x 10$^2$ km$^2$)</td>
</tr>
<tr>
<td>ML</td>
<td>Mega litre</td>
<td>(1 x 10$^6$ litres)</td>
</tr>
<tr>
<td>tC</td>
<td>Tonnes of carbon</td>
<td>(1 x 1000kgC)</td>
</tr>
<tr>
<td>tCO$_2$e</td>
<td>Tonnes of carbon dioxide equivalent</td>
<td>(1 x 1000kgCO$_2$e)</td>
</tr>
</tbody>
</table>

$^1$ Unless otherwise indicated all dollar values are in Australian dollars.
### Useful Terminology

<table>
<thead>
<tr>
<th><strong>Term</strong></th>
<th><strong>Definition</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>2800GL Basin Plan hydrological scenario</td>
<td>June 2009 hydrological conditions adjusted for an additional 2800GL environmental water in the MDB.</td>
</tr>
<tr>
<td>Allocation water trade (see also: water allocation)</td>
<td>The temporary (e.g. annual) sale of water ascribed to a water entitlement.</td>
</tr>
<tr>
<td>Appropriation</td>
<td>The abstraction and beneficial use of water from a water resource system. The appropriation date (see: prior appropriation) is set from the first date of appropriation of the water right.</td>
</tr>
<tr>
<td>Bankfull discharge</td>
<td>The flow volume which connects the river channel to the floodplain. Flow greater than bankfull discharge results in floodplain inundation.</td>
</tr>
<tr>
<td>Baseline hydrological scenario</td>
<td>June 2009 hydrological and development conditions in the MDB.</td>
</tr>
<tr>
<td>Catchment water balance</td>
<td>A mathematical representation of all catchment inflows, losses, storages and outflows.</td>
</tr>
<tr>
<td>Commonwealth Environmental Water Holder (CEWH)</td>
<td>A federal agency established by the Water Act (Cwth 2007) responsible for the management of environmental water acquired by the Australian federal government. The water rights managed by CEWH is ‘held’ environmental water (see: environmental water).</td>
</tr>
<tr>
<td>Consumptive water-use</td>
<td>The abstraction of water which results in the permanent removal or diminishment of water from its source. The volume of water ‘taken up’ is the consumptive water-use volume (e.g. domestic water-use).</td>
</tr>
<tr>
<td>Council of Australian Governments (COAG)</td>
<td>A group consisting of the Prime Minister of Australia, the First Ministers of Australian states and territories, and the President of the Australian Local Government Association. COAG is charged with managing matters of national significance that need to be co-ordinated across states and territories (e.g. the Basin Plan).</td>
</tr>
<tr>
<td>Decision horizon (also: planning horizon)</td>
<td>The number of years considered in a forecast of future events and relevant information when making a decision (see also: rolling horizon).</td>
</tr>
<tr>
<td>Demand-based water management</td>
<td>Water management strategies that seek to change the consumptive demand patterns for freshwater through the use of voluntary measures (e.g. education programs), rules and regulation (e.g. water restrictions), and economic instruments (e.g. water markets and water pricing).</td>
</tr>
<tr>
<td>Economic water scarcity</td>
<td>Water scarcity that occurs when a population does not have the necessary monetary or human capital to access volumes of water adequate to meet consumptive demand.</td>
</tr>
<tr>
<td>Ecosystem services</td>
<td>The services provided by the natural environment, which support the survival and well-being of human populations.</td>
</tr>
<tr>
<td>Entitlement water trade</td>
<td>The permanent sale of a water entitlement or water right (see also: water entitlement).</td>
</tr>
<tr>
<td>Environmental asset</td>
<td>Naturally occurring ecosystems or biomes that provides environmental services or functions. (Note that this definition is adopted from the OECD (2005) Handbook of National Accounting and differs from the ABS definition, which requires an asset to have an identifiable owner who derives economic benefit from holding or using the environmental asset (ABS, 2010a).</td>
</tr>
<tr>
<td>Environmental steward</td>
<td>An individual or entity whom engages in the sustainable use and protection of the natural environment and its functions.</td>
</tr>
<tr>
<td>Environmental water</td>
<td>Water designated to maintain, protect or restore ecological character of freshwater ecosystems. In the MDB, environmental water is either rules-based (volume prescribed by water-sharing plans) or held (acquired by an environmental water holder from consumptive water users).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Environmental water holder</td>
<td>An entity, government or otherwise, with a mandate to manage acquired (or 'held') water rights/entitlement for environmental benefit</td>
</tr>
<tr>
<td>Environmental water product (also: environmental water transfer tool)</td>
<td>A water right/entitlement, or aspect thereof, that is acquired on the water market and used for environmental use (see also: water product).</td>
</tr>
<tr>
<td>Environmental water transaction (also: environmental water transfer)</td>
<td>A market style transaction in which an environmental water product is transferred from consumptive use to environmental use.</td>
</tr>
<tr>
<td>Federation drought</td>
<td>A hydrological drought affecting much of Australia from 1897 to 1903.</td>
</tr>
<tr>
<td>Flow-dependent ecosystem</td>
<td>Natural ecosystems dependent upon the provision of freshwater flows to support and maintain ecological function.</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Fresh water stored below the surface of the Earth in the soil and in acquirers.</td>
</tr>
<tr>
<td>High security water entitlement</td>
<td>A water entitlement which reliably yields full allocation volumes in approximately 90-95 years out of 100 in the MDB, with little variation between years except during extreme drought conditions.</td>
</tr>
<tr>
<td>Hydro-economic model</td>
<td>A mathematical model integrating hydrological and economic principles.</td>
</tr>
<tr>
<td>Hydrological catchment (also: drainage basin)</td>
<td>The geographic extent for which all surface water runoff converges to a single low-elevation point. In the MDB, a 'catchment' often refers to one of the 22 sub-catchments of the wider MDB.</td>
</tr>
<tr>
<td>Hydrological indicator site</td>
<td>The 18 environmental assets in the MDB for which environmental watering requirements were quantified for the Basin Plan.</td>
</tr>
<tr>
<td>Long-term average annual yield</td>
<td>The expected long-term average yield from a water entitlement over a 100 year period.</td>
</tr>
<tr>
<td>Low/general security water entitlement</td>
<td>A water entitlement which yields a variable allocation depending on water availability. General security water entitlements provide a LTAAAY of 42-81% and low security yields between 24-35% in the MDB.</td>
</tr>
<tr>
<td>Millennium drought</td>
<td>A prolonged hydrological drought affecting the majority of south-eastern Australia. Prolonged periods of dry conditions were experienced from late 1996 to mid-2010 (BOMb, 2015), and the height of the Millennium Drought was experienced from 2001 to 2009.</td>
</tr>
<tr>
<td>Non-consumptive water-use</td>
<td>The use of water which does not result in the permanent removal or diminishment of water from its source (e.g. in-situ environmental watering)</td>
</tr>
<tr>
<td>Non-government organisation</td>
<td>An organisation, typically non-profit, which is independent from state, federal or international governments.</td>
</tr>
<tr>
<td>Normative framework</td>
<td>A framework or method to help analyse normative trade-offs.</td>
</tr>
<tr>
<td>Over-allocated (also: over-appropriated)</td>
<td>The state of a water resource system when the volume of water rights/entitlements held by consumptive and non-consumptive water users exceeds the long-term average volume of water available for use.</td>
</tr>
<tr>
<td>Physical water scarcity</td>
<td>Water scarcity that occurs when water resource development is approaching or has exceeded sustainable diversion limits, such that there is not enough water to meet all demands.</td>
</tr>
<tr>
<td>Prior appropriation doctrine</td>
<td>The dominant water law applied to the western United States, characterised by “first in time, first in right” abstraction priorities and beneficial use clauses.</td>
</tr>
<tr>
<td>Ramsar Convention</td>
<td>An international treaty identifying internationally important wetlands developed in Ramsar, Iran.</td>
</tr>
<tr>
<td>Regulated river</td>
<td>A river subject to major water resource development such that downstream flows are regulated by major upstream water storage infrastructure.</td>
</tr>
<tr>
<td><strong>Resilience</strong></td>
<td>The ability for a system to resist or recover from perturbation to its original long-term state.</td>
</tr>
<tr>
<td><strong>River Red Gum (also: <em>Eucalyptus camaldulensis</em>)</strong></td>
<td>A large, long-lived Eucalyptus tree species indigenous to Australia. It is commonly found along watercourses and is reliant upon regular flooding in ecologically desirable volumes and frequencies.</td>
</tr>
<tr>
<td><strong>Rolling horizon</strong></td>
<td>In a rolling horizon decision-making approach, the decision maker makes the most immediate decision (e.g. decisions in the first period) based on knowledge of conditions in the present period and an uncertain (e.g. probabilistic or stochastic) forecast of the remaining years in the decision horizon. In the next period, the second period decisions become the most immediate and the decision horizon is pushed out further into the future, and is thus ‘rolled over’.</td>
</tr>
<tr>
<td><strong>Supply-based water management</strong></td>
<td>Water management strategies that seek to increase and more effectively manage the supply of freshwater for consumptive use, including measures such as water treatment plants (e.g. desalinisation), water transport and delivery systems (e.g. pipes, channels), infrastructure construction and upgrades (e.g. dams and weirs).</td>
</tr>
<tr>
<td><strong>Surface-water</strong></td>
<td>Fresh water stored in the surface of the Earth in rivers, streams, lakes and reservoirs.</td>
</tr>
<tr>
<td><strong>Sustainable diversion limit (SDL)</strong></td>
<td>An upper level of water-use that limits the amount of water that can be used for consumptive purposes in the MDB.</td>
</tr>
<tr>
<td><strong>The Commonwealth</strong></td>
<td>The Federal Commonwealth Government of Australia</td>
</tr>
<tr>
<td><strong>The Murray-Darling Basin Plan (also: the Basin Plan)</strong></td>
<td>A co-ordinated approach between state, territory and federal governments to manage water resources in the MDB. The Basin Plan was passed into law in 2012 and the initial sustainable diversion limits will come into full effect in 2019.</td>
</tr>
<tr>
<td><strong>The Paris Agreement</strong></td>
<td>A global agreement on climate change mitigation actions developed during the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change held in Paris, France. Australia ratified the Paris Agreement in 2016 and it entered into force in November of that year.</td>
</tr>
<tr>
<td><strong>Water allocation</strong></td>
<td>The volume of water credited to a water entitlement able to be used in a season, dependent on the total water available in the system and the security of the water entitlement.</td>
</tr>
<tr>
<td><strong>Water entitlement (also: water access entitlement)</strong></td>
<td>The right to an ongoing share of a total amount of water available in a water resource system. Water entitlements yield annual water allocations. Internationally and commonly referred to as a <em>water right</em>.</td>
</tr>
<tr>
<td><strong>Water product</strong></td>
<td>A water right, or aspect thereof, that is sold on the water market. Water products are characterised by the type (e.g. groundwater, surface-water), the duration of the water right exchange (e.g. annual, permanent, 5 year lease), and any other contractual characteristics (e.g. dry-year trigger arrangement). (See also: <em>environmental water product</em>).</td>
</tr>
<tr>
<td><strong>Water user association (also: water user board)</strong></td>
<td>A group of water users, such as irrigators, who combine financial, technical and social resources to manage and maintain a water supply system.</td>
</tr>
<tr>
<td><strong>Water year (also: water accounting year)</strong></td>
<td>The 12 months period commencing each year on the 1st of July.</td>
</tr>
<tr>
<td><strong>Without development hydrological scenario</strong></td>
<td>Modelled hydrological conditions without any water resource development and major water abstraction in the MDB.</td>
</tr>
</tbody>
</table>
V. Abstract

Water resource development has historically proceeded with little consideration for the environment. In the Murray-Darling Basin (MDB) Australia, water resource development has resulted in considerable ecological degradation and a diminishment of flow-dependent ecosystem services (ES). In response, MDB water policy has undergone considerable reform in the past decade, culminating in a commitment to reallocate water from consumptive use back to the environment. This thesis examines potential further use of water markets, and issues associated with this, to provide greater and more efficient environmental flows.

The main question investigated in this thesis was the potential for an environmental water holder (EWH) to use the water allocation market to reallocate water to the environment for improved ecological condition and ES generation. To answer this question, an interdisciplinary mixed-methods approach was employed involving: a) the development of a hydro-economic model that simulates the annual trade decisions of a forward-looking EWH in a MDB sub-catchment; b) 49 qualitative face-to-face interviews across the US and Australia with stakeholders from industry, non-profit and government agencies regarding the role of non-government environmental water holders (NGO EWHs); and c) quantitative survey analysis of 1,000 southern MDB irrigator preferences in 2015-2016 for the sale of environmental water.

Key findings of this thesis show that trading water allocations for the environment can have positive ES benefits by improving floodplain inundation. Under particular hydrological and fiscal conditions, the increase in floodplain carbon storage may be of sufficient market value to offset the cost of environmental water allocation purchases. This indicates a potential carbon-water trading strategy which may provide a novel revenue stream for self-financing EWHs. It was shown that NGO EWHs play a unique role in environmental water reallocation through the provision of flexible and multi-functional water trade arrangements. Results also highlight the importance of social capital in facilitating successful environmental water trades. Lastly, results demonstrate that southern MDB irrigators show a clear preference for the local management of water resources, and in particular NSW and Victorian irrigators rank the federal government among their least preferred buyers of water entitlements. Southern MDB irrigators also demonstrate a clear preference for the use of water allocation trade for the environment.

Key recommendations based on these results include: a) the further judicious expansion of market-based reallocation policies, particularly water allocation trade, in place of continued infrastructure-based reallocation; b) the use of carbon credit generation and sale to cost-effectively finance annual environmental water reallocation; and c) the need to encourage an increased partnership of federal agencies with local and NGO EWHs, in order to increase irrigator participation and sustain local values in environmental water management.
VI. Thesis Declaration Statement

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other 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 has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree. I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. I acknowledge that copyright of published works contained within this thesis resides with the copyright holder(s) of those works. I also give permission for the digital version of my thesis to be made available on the web, via the University’s digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

___________________

Claire Settre

September, 2017
VII. Acknowledgements

The research process for this thesis has been a journey, to say the least. For better or worse, there has never been a dull moment and for all the great times I have many people to thank.

I firstly grateful to my parents, David and Susan Settre. To my mother I owe my fascination with nature and to my father I owe my stubborn sense of justice, both of which have been critical motivations for this thesis.

A most sincere and heartfelt thank you to my primary supervisor Associate Professor Sarah Wheeler. Your guidance has kept me steady through the excited highs and doubtful lows and your consistent honesty has been a beacon on this convoluted path. Thank you for taking a chance on me. An equal thank you to my secondary supervisor Professor Jeffery Connor whose big picture vision has been a driving force for my research. Thank you for pushing me to strive for the best quality outcomes and helping me make the leaps I wouldn’t have chosen to make by myself. Thank you both for the hours of encouragement, writing, reading, and discussion.

Thank you also to everyone who offered me their time and insights over the course of my candidature. I particularly appreciate the input from Dr. Adam Loch, Dr. Alec Zuo, Dr. Juliane Haensch, Dr. David Adamson and Professor Henning Bjornlund. I would also like to sincerely thank Associate Professor Kurt Schwabe at the University of California, Riverside, for hosting me twice during my candidature.

I would like to gratefully acknowledge the financial support provided by The Centre of Global Food and Resources at the University of Adelaide; the Centre of Regulation and Market Analysis at the University of South Australia; and the Endeavour Fellowship program administered by the Federal Department of Education and Training. I am grateful for the support I have received through provided by the Federal Department of Education and Training. This research was also supported by an Australian Research Council Discovery Project (DP140103946). I am sincerely grateful for in-kind support provided by the Commonwealth Scientific and Industrial Research Organisation and the School of Public Policy at the University of California, Riverside.

Lastly, a heartfelt, teary, smile-cry thank you to Glyn Hancock. Your insight and intelligence has helped me develop the courage to focus on my strengths and own my weaknesses. I am endlessly grateful for your unwavering support and calm love.
VIII. Publications and Presentations from this Thesis

Academic Journal Articles (peer-reviewed)


Book Chapters (peer-reviewed)


Current Working Papers


Conference Papers and Seminars


IX. Additional Publications during Candidature

**Academic Journal Articles (peer-reviewed)**

**Book Chapters (peer-reviewed)**