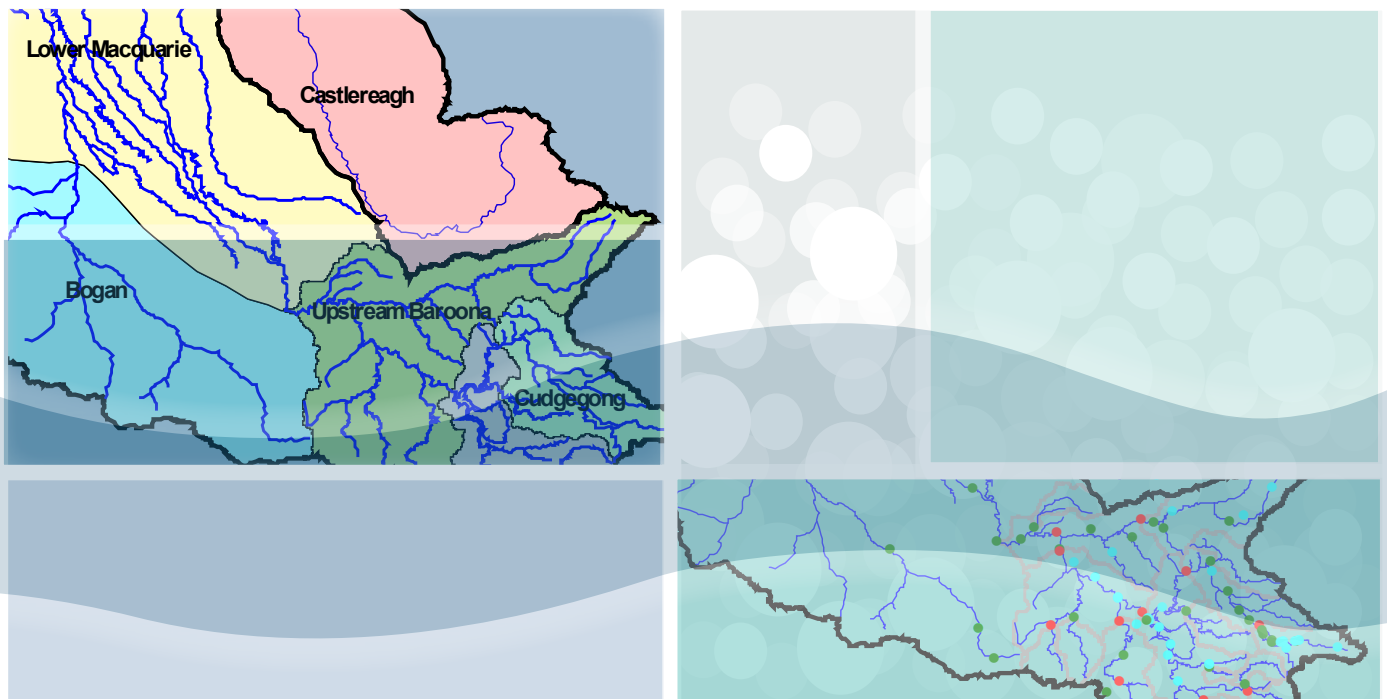


# Instream salinity models of NSW tributaries in the Murray-Darling Basin

Volume 4 – Macquarie River Salinity  
Integrated Quantity and Quality Model



**Publisher**

NSW Department of Water and Energy  
Level 17, 227 Elizabeth Street  
GPO Box 3889  
Sydney NSW 2001  
**T** 02 8281 7777 **F** 02 8281 7799  
information@dwe.nsw.gov.au  
www.dwe.nsw.gov.au

***Instream salinity models of NSW tributaries in the Murray-Darling Basin  
Volume 4 – Macquarie River Salinity Integrated Quantity and Quality Model***

April 2008

ISBN (volume 4) 978 0 7347 5920 7

ISBN (set) 978 0 7347 5198 0

**Volumes in this set:**

In-stream Salinity Models of NSW Tributaries in the Murray Darling Basin

Volume 1 – Border Rivers Salinity Integrated Quantity and Quality Model

Volume 2 – Gwydir River Salinity Integrated Quantity and Quality Model

Volume 3 – Namoi River Salinity Integrated Quantity and Quality Model

Volume 4 – Macquarie River Salinity Integrated Quantity and Quality Model

Volume 5 – Lachlan River Salinity Integrated Quantity and Quality Model

Volume 6 – Murrumbidgee River Salinity Integrated Quantity and Quality Model

Volume 7 – Barwon-Darling River System Salinity Integrated Quantity and Quality Model

**Acknowledgements**

Technical work and reporting by Richard Beecham, Mark Burrell and Robert O'Neill.

**This publication may be cited as:**

Department of Water and Energy, 2008. *Instream salinity models of NSW tributaries in the Murray-Darling Basin: Volume 4 - Macquarie River Salinity Integrated Quantity and Quality Model*, NSW Government.

© State of New South Wales through the Department of Water and Energy, 2008

This work may be freely reproduced and distributed for most purposes, however some restrictions apply. Contact the Department of Water and Energy for copyright information.

Disclaimer: While every reasonable effort has been made to ensure that this document is correct at the time of publication, the State of New South Wales, its agents and employees, disclaim any and all liability to any person in respect of anything or the consequences of anything done or omitted to be done in reliance upon the whole or any part of this document.

DWE 07\_089\_1

## Contents

	<b>Page</b>
1. Introduction.....	1
1.1. purpose of report.....	1
1.1.1. Report structure .....	1
1.1.2. Related reports.....	2
1.2. Historical background to work .....	2
1.2.1. 1988 Salinity and Drainage Strategy.....	2
1.2.2. 1997 Salt trends .....	3
1.2.3. 1999 Salinity Audit .....	3
1.2.4. 2006 Salinity Audit .....	3
1.3. Current policy framework.....	4
1.3.1. MDBC Integrated Catchment Management.....	4
1.3.2. Murray-Darling Basin Ministerial Council Cap on water diversions.....	4
1.3.3. Murray-Darling Basin Ministerial Council Basin Salinity Management Strategy	4
4	
1.3.4. Catchment Action Plans .....	5
1.3.5. NSW Water Sharing Plans .....	6
1.3.6. NSW Salinity Strategy .....	6
1.3.7. NSW Environmental Services Scheme .....	6
1.3.8. CMA Incentive schemes .....	6
1.4. DWE Model framework .....	7
1.4.1. Objectives of modelling .....	7
1.4.2. Modelling requirements .....	7
1.4.3. Strengths and Limitations.....	8
1.5. Staged Model Development .....	10
1.5.1. Stage 1: Model QA and Data Audit .....	10
1.5.2. Stage 2: Initial model development and data and model evaluation .....	10
1.5.3. Stage 3: Model calibration and scenario modelling .....	11
2. The Macquarie-Bogan-Castlereagh System.....	12
2.1. Physical Features of the Catchment.....	12
2.1.1. General .....	12
2.1.2. Stream network .....	14
2.1.3. Hydrometeorology.....	15
2.1.4. Groundwater interactions. ....	19
2.1.5. Land Use .....	20
2.2. Water Resource Management.....	22

2.3.	Salinity in catchment .....	22
3.	Salinity data .....	25
3.1.	Available data .....	25
3.2.	Data used for inflow estimates and model evaluation .....	26
3.2.1.	Exploratory analysis of data .....	27
4.	The Macquarie IQQM.....	33
4.1.	Quantity Model.....	33
4.1.1.	Chifley System .....	33
4.1.2.	Macquarie System .....	35
4.1.3.	Inflows and calibration .....	36
4.1.4.	Storages .....	36
4.1.5.	Extractive demands .....	37
4.1.6.	In-stream demands .....	37
4.1.7.	Peer Review.....	46
4.2.	Quality Assurance of quality model .....	47
4.2.1.	QA Test 1: Update base quantity model.....	47
4.2.2.	QA Test 2: Initialise salinity module with zero salt load .....	47
4.2.3.	QA Test 3: Constant flow and concentration .....	48
4.2.4.	QA Test 4: Variable flow and constant concentration .....	48
4.2.5.	QA Test 5: Flow pulse with constant concentration .....	48
4.2.6.	QA Test 6: Salt pulse with constant flow .....	49
4.3.	Quality assurance conclusions .....	49
5.	Salt inflow estimates and evaluation.....	50
5.1.	Initial estimate .....	50
5.2.	Evaluation Method.....	54
5.2.1.	Model configuration .....	54
5.2.2.	Selection of evaluation sites .....	54
5.2.3.	Data quality performance measures .....	56
5.2.4.	Model result performance measures.....	57
5.3.	Evaluation of Initial Salinity Audit Estimates .....	59
5.3.1.	Windamere Dam.....	59
5.3.2.	Station 421019: Cudgegong River @ Yamble Bridge .....	60
5.3.3.	Station 421025: Macquarie River @ Bruinbun .....	61
5.3.4.	Burrendong Dam .....	63
5.3.5.	Station 421001: Macquarie River @ Dubbo .....	63
5.3.6.	Station 421127: Macquarie River @ Barooka .....	65
5.3.7.	Station 421090: Macquarie River @ Marebone Weir.....	66
5.3.8.	Station 421012: Macquarie River @ Carinda .....	67

5.3.9.	Discussion of results from evaluation of results from simulation with Salinity Audit relationships .....	69
5.4.	Salinity Model calibration .....	70
5.4.1.	Methods (General).....	70
5.4.2.	Windamere Dam.....	71
5.4.3.	Station 421019: Cudgegong River @ Yamble Bridge .....	72
5.4.4.	Station 421025: Macquarie River @ Bruinbun.....	74
5.4.5.	Burrendong Dam .....	76
5.4.6.	Station 421001: Macquarie River @ Dubbo .....	77
5.4.7.	Station 421127: Macquarie River @ Barooka .....	80
5.4.8.	Station 421090: Macquarie River @ Marebone Weir.....	83
5.4.9.	Station 421012: Macquarie River @ Carinda .....	84
5.5.	Validation of results.....	85
5.5.1.	Continuous salinity records .....	85
5.5.2.	Comparison of calibrated salt loads with Salinity Audit salt loads .....	86
5.6.	Model suitability for purpose.....	87
5.6.1.	Baseline .....	88
5.6.2.	Land use management scenarios .....	89
5.6.3.	Water management scenarios .....	89
6.	Baseline Conditions scenario .....	106
6.1.	Baseline Conditions .....	106
6.2.	Results .....	108
7.	Conclusion and recommendations .....	116
7.1.	Conclusion .....	116
7.2.	Recommendations on model improvements.....	116
7.3.	Recommended future data collection .....	117
7.3.1.	Main stream salinity data .....	117
7.3.2.	Inflow salinity data.....	117
7.3.3.	Storages and other supporting data.....	118
7.4.	Model uncertainty and recommended use of model results.....	118
8.	References.....	120

Appendix A. Table of salinity data in Macquarie River System

Appendix B. Comparison of initial estimate with Salinity Audit Results

Appendix C: Model Details

## Figures

	<b>Page</b>
Figure 1.1. Relationship of Basinwide and Statewide policies and plans .....	7
Figure 1.2. Applications and linkages of DECC and DWE models at different scales.....	9
Figure 1.3. Stages of model development .....	10
Figure 2.1. Relationship of Macquarie and Castlereagh catchments to Murray-Darling Basin.....	12
Figure 2.2. Cities and towns in Macquarie-Bogan-Castlereagh catchments.....	13
Figure 2.3. Major regions of Macquarie Catchment .....	14
Figure 2.4. Average annual rainfall in Macquarie-Castlereagh-Bogan catchment .....	16
Figure 2.5. Average monthly rainfall at Dubbo 1890-2000. ....	16
Figure 2.6. Residual mass curve of rainfall at Dubbo .....	17
Figure 2.7. Annual rainfall at Dubbo 1975-2000 .....	17
Figure 2.8. Average annual Class A Pan evaporation in Macquarie-Castlereagh Valley (1973-1995)	18
Figure 2.9. Types of river reach with respect to groundwater interaction.....	19
Figure 2.10. Hydraulic connection between rivers and groundwater.....	20
Figure 2.11. Landuse in Macquarie-Bogan-Castlereagh catchment.....	21
Figure 2.12. Dryland salinity occurrences in Macquarie-Bogan-Castlereagh catchment (mapped pre-1999).....	23
Figure 2.13. Modelled average annual salt export rates (tonnes/km <sup>2</sup> ) from Macquarie River catchments. ....	24
Figure 3.1. Location and record length size for discrete EC data stations .....	25
Figure 3.2. Location and record length for continuous EC data stations .....	26
Figure 3.3. Median salinity versus median flow for inflow sites with discrete EC data.....	27
Figure 3.4. Median salinity along main stream .....	28
Figure 4.1. Schematic of Chifley System IQQM .....	34
Figure 4.2. Schematic of Macquarie System IQQM .....	35
Figure 4.3. Distribution of modelled annual average (1975-2000) inflows and losses in Cudgegong region of Macquarie Valley. ....	39
Figure 4.4. Distribution of modelled annual average (1975-2000) inflows and losses in Upper Macquarie region of Macquarie Valley .....	40
Figure 4.5. Distribution of modelled annual average (1975-2000) inflows and losses in Burrendong Dam to Baroona region of Macquarie Valley .....	40
Figure 4.6. Distribution of modelled annual average (1975-2000) inflows and losses in Lower Macquarie region of Macquarie Valley .....	41
Figure 4.7. Modelled storage in Macquarie System IQQM .....	42

Figure 4.8. Modelled average annual irrigation diversions (GL/year; 1975-2000) for Cudgegong region.....	43
Figure 4.9. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Upper Macquarie Region.....	44
Figure 4.10. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Burrendong to Barooka Region .....	44
Figure 4.11. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Lower Macquarie Region.....	45
Figure 4.12. Distribution of nodes for ordering in-stream and environmental flow requirements.....	46
Figure 4.13. (a) Inflows and resultant EOS flows; (b) Salt load inflows and EOS salt loads .....	49
Figure 4.14. (a) Salt load inflows and EOS salt loads; (b) Concentration inflows and EOS concentration.....	49
Figure 5.1. Geographic representation of 1999 Salinity Audit schematic of inflows and balance points .....	51
Figure 5.2. Inflow catchments used for 1999 Salinity Audit .....	51
Figure 5.3. Calculating resultant concentration from two tributaries.....	54
Figure 5.4. Location of evaluation sites .....	56
Figure 5.5. Station 421019: Cudgegong River @ Yamble Bridge; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.....	61
Figure 5.6. Station 421025: Macquarie River @ Bruinbun; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity .....	62
Figure 5.7. Station 421001: Macquarie River @ Dubbo; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity .....	64
Figure 5.8. Station 421127: Macquarie River @ Barooka; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.....	66
Figure 5.9. Station 421090: Macquarie River @ Marebone Weir; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.....	67
Figure 5.10. Station 421012: Macquarie River @ Carinda; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.....	68
Figure 5.11. Derivation of flow versus concentration LUT from exceedance curves.....	70
Figure 5.12. Procedure to calibrate salt inflows from residual catchments.....	71
Figure 5.13. Non-exceedance curve for observed versus simulated salinity for calibrated model at Windamere Dam .....	72
Figure 5.14. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421019: Cudgegong River @ Yamble Bridge.....	73

Figure 5.15. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421025: Macquarie River @ Bruinbun .....	75
Figure 5.16. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421001: Macquarie River @ Dubbo.....	79
Figure 5.17. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421127: Macquarie River @ Baroona.....	82
Figure 5.18. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421090: Macquarie River @ Marebone Weir .....	83
Figure 5.19. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421090: Macquarie River @ Carinda.....	85
Figure 5.20. Windamere Dam storage volume and concentration data.....	90
Figure 5.21. Station 421019: Cudgegong River @ Yamble Bridge flow and concentration data .....	90
Figure 5.22. Station 421025: Macquarie River @ Bruinbun flow and concentration data .....	91
Figure 5.23. Burrendong Dam storage volume and concentration data .....	91
Figure 5.24. Station 421001: Macquarie River @ Dubbo, flow and concentration data .....	92
Figure 5.25. Station 421127: Macquarie River @ Baroona, flow and concentration data .....	92
Figure 5.26. Station 421090: Macquarie River @ Marebone Weir .....	93
Figure 5.27. Station 421012: Macquarie River @ Carinda observed flow and concentration.....	93
Figure 5.28. Simulated versus observed concentration at Windamere Dam, using Salinity Audit relationships. ....	94
Figure 5.29. Simulated versus observed salinities at Station 421019: Cudgegong River @ Yamble Bridge, using Salinity Audit relationships. ....	94
Figure 5.30. Simulated versus observed salinities at Station 421025: Macquarie River @ Bruinbun, using Salinity Audit relationships.....	95
Figure 5.31. Simulated versus observed salinities at Burrendong Dam, using Salinity Audit relationships.....	95
Figure 5.32. Simulated versus observed salinities at Station 421001: Macquarie River @ Dubbo, using Salinity Audit relationships. ....	96
Figure 5.33. Simulated versus observed salinities at Station 421127: Macquarie River @ Baroona, using Salinity Audit relationships.....	96
Figure 5.34. Simulated versus observed concentration at Station 421090: Macquarie River @ Marebone Weir, using Salinity Audit relationships.....	97
Figure 5.35. Simulated versus observed concentrations at Station 421012: Macquarie River @ Carinda, using Salinity Audit relationships. ....	97
Figure 5.36. Simulated versus observed salinity at Windamere Dam, using calibrated relationship..	98
Figure 5.37. Simulated versus observed salinity for Station 421019: Cudgegong River @ Yamble Bridge, using calibrated relationships.....	98
Figure 5.38. Simulated versus observed salinity for Station 421025: Macquarie River @ Bruinbun, using calibrated relationship. ....	99
Figure 5.39. Simulated versus observed salinity for Burrendong Dam, using calibrated relationship.	99

Figure 5.40. Observed versus simulated concentrations for Station 421001: Macquarie River @ Dubbo using calibrated relationship. ....	100
Figure 5.41. Observed versus simulated concentrations for Station 421127: Macquarie River @ Baroona, using calibrated relationships .....	100
Figure 5.42. Observed versus simulated concentrations for Station 421090: Macquarie River @ Marebone Weir, using calibrated relationships. ....	101
Figure 5.43. Observed versus simulated concentrations for Station 421012: Macquarie River @ Carinda using calibrated relationships. ....	101
Figure 5.44. Continuous observed versus simulated salinities for station 421019: Macquarie River @ Carinda using calibrated relationships. ....	102
Figure 5.45. Continuous observed versus simulated salinities for station 421019: Macquarie River @ Bruinbun using calibrated relationships. ....	102
Figure 5.46. Continuous observed versus simulated salinities for Macquarie River downstream of Burrendong Dam using calibrated relationships. ....	103
Figure 5.47. Daily read observed versus simulated salinities for Macquarie River @ Dubbo using calibrated relationships. ....	103
Figure 5.48. Continuous observed versus simulated salinities for station 421001: Macquarie River @ Dubbo using calibrated relationships. ....	104
Figure 5.49. Continuous observed versus simulated salinities for station 421127: Macquarie River @ Baroona using calibrated relationships. ....	104
Figure 5.50. Continuous observed versus simulated salinities for station 421090: Macquarie River @ Marebone Weir using calibrated relationships. ....	105
Figure 5.51. Continuous observed versus simulated salinities for station 421012: Macquarie River @ Carinda using calibrated relationships. ....	105
Figure 6.1. Frequency of exceedance of simulated salinity for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda. ....	111
Figure 6.2. Frequency of exceedance of simulated salinity for Baseline Conditions scenario on days with salinity observations (1/5/1975-30/4/2000), compared with salinity observations for Macquarie River @ Carinda. ....	111
Figure 6.3. Frequency of exceedance of simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda. ....	112
Figure 6.4. Frequency of exceedance of simulated salt load for Baseline Conditions scenario on days with salinity and flow observations (1/5/1975-30/4/2000), compared with salinity observations for Macquarie River @ Carinda. ....	112
Figure 6.5. Frequency of exceedance of simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda. ....	113
Figure 6.6. Frequency of exceedance of simulated flow for Baseline Conditions scenario on days with flow observations (1/5/1975-30/4/2000), compared with observed flow for Macquarie River @ Carinda. ....	113
Figure 6.7. Cumulative simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda. ....	114

Figure 6.8. Cumulative simulated flow for Baseline Conditions scenario for days with observed flow, and observed flow (1/5/1975-30/4/2000) for Macquarie River @ Carinda.....114

Figure 6.9. Cumulative simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda. ....115

Where:  $\eta$ ,  $\lambda$  are salt load relationship parameters  $SL_{\_}$ ,  $Q_{\_}$  are shown in Figure B.8.1. Figure B.8.1. Schematic for calculating net salt load inflow from residual catchments in IQQM.....132

## Tables

	<b>Page</b>
Table 2.1. Average annual flows in Macquarie (1890 – 2000) .....	18
Table 2.2. Land use statistics for Macquarie-Castlereagh-Bogan catchment.....	21
Table 3.1. Stations at inflow points with discrete and continuous EC data, with results of preliminary screening .....	28
Table 3.2. Stations at evaluation points with discrete EC data, with results of preliminary screening	29
Table 3.3. Stations at evaluation points with continuous EC data, with results of preliminary screening .....	30
Table 3.4. Cumulative distribution statistics of screened EC data sets .....	31
Table 4.1. Function of in-stream ordering nodes in Macquarie System IQQM.....	38
Table 4.2. Flow mass balance report for Macquarie IQQM, 1993/4 Cap Scenario for 1975-2000. ....	47
Table 4.3. Flow mass balance comparison report for Macquarie IQQM after including salt modelling .....	47
Table 4.4. Salt mass balance report for Macquarie IQQM, 1993/4 Cap Scenario with zero salt inflows .....	48
Table 5.1. Salt inflow model parameters for gauged catchments.....	52
Table 5.2. Salt inflow model parameters for residual catchments.....	53
Table 5.3. Results of performance measures for observed versus simulated salinities in Windamere Dam using Salinity Audit relationships .....	60
Table 5.4. Distribution of flow with discrete EC across flow ranges and months for Station 421019: Cudgegong River @ Yamble Bridge.....	60
Table 5.5. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 421019: Cudgegong River @ Yamble Bridge .....	61
Table 5.6. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 421019: Cudgegong River @ Yamble Bridge.....	61
Table 5.7. Distribution of flow with discrete EC across flow ranges and months for Station 421025: Macquarie River @ Bruinbun.....	62
Table 5.8. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 421025: Macquarie River @ Bruinbun.....	62
Table 5.9. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 421025: Macquarie River @ Bruinbun .....	63
Table 5.10. Results of performance measures for simulated versus observed concentrations at Burrendong Dam using Salinity Audit Relationships.....	63

Table 5.11. Distribution of flow with discrete EC across flow ranges and months for Station 421001: Macquarie River @ Dubbo.....	64
Table 5.12. Comparison of statistics within flow ranges of <i>all observed flows versus observed flows on days with discrete EC</i> data during evaluation period for Station 421001: Macquarie River @ Dubbo.....	64
Table 5.13. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 421001: Macquarie River @ Dubbo.....	65
Table 5.14. Distribution of flow with discrete EC across flow ranges and months for Station 421127: Macquarie River @ Baroona .....	65
Table 5.15. Comparison of statistics within flow ranges of <i>all observed flows versus observed flows on days with discrete EC</i> data during evaluation period for Station 421127: Macquarie River @ Baroona .....	65
Table 5.16. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 421127: Macquarie River @ Baroona.....	66
Table 5.17. Distribution of flow with discrete EC across flow ranges and months for Station 421909: Macquarie River @ Marebone Weir.....	66
Table 5.18. Comparison of statistics within flow ranges of <i>all observed flows versus observed flows on days with discrete EC</i> data during evaluation period for Station 421909: Macquarie River @ Marebone Weir .....	67
Table 5.19. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 421909: Macquarie River @ Marebone Weir .....	67
Table 5.20. Distribution of flow with discrete EC across flow ranges and months for Station 421012: Macquarie River @ Carinda .....	68
Table 5.21. Comparison of statistics within flow ranges of <i>all observed flows versus observed flows on days with discrete EC</i> data during evaluation period for Station 421012: Macquarie River @ Carinda .....	68
Table 5.22. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 421012: Macquarie River @ Carinda.....	69
Table 5.23. Calibrated flow versus salinity relationship for Windamere Dam inflows .....	71
Table 5.24. Results of performance measures for simulated versus observed salinities in Windamere Dam using calibrated relationship .....	72
Table 5.25. Calibrated flow versus salinity relationship used for inflows in residual catchment R4...73	
Table 5.26. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421019: Cudgegong River @ Yamble Bridge.....	73
Table 5.27. Calibrated flow versus salinity relationship for inflows in residual catchment R1 .....	74
Table 5.28. Calibrated flow versus salinity relationship for inflows in residual catchment R3 .....	75

Table 5.29. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421025: Macquarie River @ Bruinbun .....	75
Table 5.30. Target Calibrated flow versus salinity relationship for net inflows to Burrendong Dam .....	76
Table 5.31. Calibrated flow versus salinity relationship for inflows in residual catchment R3 .....	77
Table 5.32. Results of performance measures for simulated versus observed concentrations at Burrendong Dam using calibrated relationships.....	77
Table 5.33. Calculated flow versus salinity relationship for salt inflows from catchment Station 421059: Buckinbah Creek @ Yeoval .....	78
Table 5.34. Calibrated flow versus salinity relationship for inflows in R5/6/7.....	78
Table 5.35. Calibrated flow versus salinity relationship for inflows in residual catchment R5/6/7.....	79
Table 5.36. Calibrated flow versus salinity relationship for inflows in residual catchment R5/6/7.....	79
Table 5.37. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421001: Macquarie River @ Dubbo .....	79
Table 5.38. Calculated flow versus salinity relationship for inflows from Station 421055: Coolbaggie Creek @ Rawsonville .....	80
Table 5.39. Calculated flow versus salinity relationship for inflows from Station 421042: Talbragar River @ Elong Elong.....	81
Table 5.40. Calibrated flow versus salinity relationship for inflows in residual catchment R8/R9 .....	81
Table 5.41. Calibrated flow versus salinity relationship for inflows in residual catchment R8, R9 .....	82
Table 5.42. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421127: Macquarie River @ Baroona.....	82
Table 5.43. Flow versus salinity LUT for Ewenmar Creek in the calibrated model.....	83
Table 5.44. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421090: Macquarie River @ Marebone Weir .....	84
Table 5.45. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421090: Macquarie River @ Carinda.....	85
Table 5.46. Comparison of calibrated average annual salt loads with Salinity Audit, and Audit as modified.....	87
Table 5.47. Summary of comparisons of simulated versus observed salt loads .....	89
Table 6.1. BSMS Baseline (01/01/2000) conditions for water sharing.....	107
Table 6.2. Crop types, proportions, and irrigation factor .....	108
Table 6.3. Simulated results of salinity and salt load for MDBMC BSMS Baseline, using calibrated relationships applied to 1/1/2000 conditions model, based on analysis of daily results 01/05/1975-30/04/2000.....	109

Table 6.4. Simulated results of salt loads for MDBMC BSMS Baseline, using calibrated relationships applied to 1/1/2000 conditions model, based on analysis of annual results 01/05/1975-30/04/2000.....	109
Table 6.5. Statistics of observed data for flow, salinity and salt load (1975-2000) at Macquarie River @ Carinda.....	110
Table 7.1: Main stream priority sites for discrete and continuous salinity data collection .....	117
Table 7.2: Tributary stream priority sites for discrete and continuous salinity data collection.....	117
Table B.8.1. Salt transport model results compared with Audit results .....	130

# 1. Introduction

## 1.1. PURPOSE OF REPORT

The purpose of this report is to document the results of work carried out to develop a Macquarie River Salt Transport Model. This model was developed to meet the needs of the Murray-Darling Basin Salinity Management Strategy (Basin Strategy – BSMS see Section 1.3.3.1) and the NSW Salinity Strategy (SSS). This report is intended primarily for an audience with a technical and/or policy background concerned with salinity management

The model substantially increases the salinity modelling capability by NSW for salinity management in the Murray-Darling Basin (MDB), and represents the best available interpretation of salinity processes in these NSW Rivers. The geographic scope of the work is extensive, covering an area of about 600,000 km<sup>2</sup>. The model can assess in-stream effects of water sharing policies, as well as working jointly with the 2CSalt model to assess in-stream salinity and water availability effects of land use and management. These effects can be assessed at a daily time scale for a 25-year period at key locations within the Macquarie River Basin. The model can also link with other models to assess effects at key locations in the Darling River and/or Murray River.

### 1.1.1. Report structure

This modelling has taken place against a historical background of basin wide salinity management, which is discussed in Section 1.2. A number of basin wide and state-wide natural resource management policies are relevant to salinity management and the need for this model. The modelling requirements are clearly set out in Schedule C of the Murray Darling Basin Agreement. The policies are discussed in Section 1.3, with a focus on Schedule C in Section 1.3.3. This model is one of a suite of models and decision support systems that have been developed for salinity management, and this is discussed in Section 1.4. The steps taken to develop this model are discussed in the final section of this chapter.

The processes affecting salinity behaviour in a catchment are influenced by many physical factors, and the most important of these are described in Chapter 2. Whereas the actual salinity behaviour is best described by data, and the data available to characterise this behaviour is described in Chapter 3. The salt transport model was developed using a daily water balance model as the platform. The Macquarie Integrated Quantity Quality Model (IQQM) has been used for water resource management for several years in the NSW, and was converted to the salt transport model in this project. The software used for the model was thoroughly tested and enhanced to eliminate any technical faults. The Macquarie IQQM and software testing is described in Chapter 4.

Estimating salt loads entering the river system is the key task to develop a model that will reliably estimate in-stream salinity behaviour so that it is suitable for the intended purpose. The results of existing and calibrated estimates are documented in Chapter 5. The calibrated model is intended to be used evaluate scenarios, the most important of which is a baseline condition (described in Section 1.3.3), as well as impacts of changing land use, management, and water sharing. The results for the baseline condition are reported and discussed in Chapter 6. The development of models for salinity management is a comparatively new field of work in the MDB, when compared to water balance modelling. The Schedule C foresees the need to improve estimates in light of both limitations of the current work, additional data, and improved technical capability of the scientific organisations. An assessment of the limitations of the model, and some recommendations for future improvement are discussed in Chapter 7.

### **1.1.2. Related reports**

This report is one of seven similar reports for each of the major NSW tributaries of the MDB. The reports are:

- Volume 1 - Border Rivers (jointly with Queensland);
- Volume 2 - Gwydir River;
- Volume 3 - Namoi and Peel Rivers;
- Volume 4 - Macquarie, Castlereagh and Bogan Rivers;
- Volume 5 - Lachlan River;
- Volume 6 - Murrumbidgee River; and
- Volume 7 - Barwon-Darling River.

Each tributary report is complete and self-explanatory; describing what was done for each stage of the model development. However, these descriptions have been kept brief to ensure the report content is more focused on information and results specific to that tributary. Note that this report primarily summarizes the modeling work undertaken prior to 2005.

## **1.2. HISTORICAL BACKGROUND TO WORK**

Modelling in-stream salinity has a history extending to before the development of the Murray-Darling Basin Commission (MDBC) 1988 Salinity and Drainage Strategy, which focused on irrigation induced salinity. The complexity and scope of modelling of dryland salinisation processes has evolved in line with the needs of natural resource management. With the concerns about dryland salinity came additional water quality data to provide evidence of the salinity trends. The increased data led to broad policy and greater demands on models to provide useful results to guide the cost effective selection of salinity management options. The following sections give a brief history of the development of salinity policy and its implications on the development of salinity modelling.

### **1.2.1. 1988 Salinity and Drainage Strategy**

The Murray Darling Basin Ministerial Council (MDBMC) adopted the Salinity and Drainage Strategy (SDS) in 1988. The objectives of the strategy revolved around:

- improving the water quality in the Murray River for the benefit of all users;
- controlling existing land degradation, prevent further degradation and where possible rehabilitate resources to ensure sustainable use; and
- Conserving the natural environment.

The SDS set out specific salinity reduction targets against benchmark conditions. The strategy also defined the rights and responsibilities of the State and Commonwealth Governments. Implementation included applying the strategic direction and allocating salinity credits and construction of various projects (under cost sharing arrangements). The salinity assessment work required a combination of observed salinity data and in stream river modelling. Assessments of salinity impacts were at a local or semi-regional scale, eg. Beecham and Arranz (2001), and the results from these were assessed by the MDBC for salinity impact in the Murray River.

The 1999 SDS review identified major achievements of the SDS as: (i) reducing salt entering the Murray River by constructing salt interception scheme; and (ii) developing land, water and salt management plans to identify and manage the problems.

### **1.2.2. 1997 Salt trends**

Concerns about the increase in the extent of dryland salinisation prompted an assessment of water quality data to look for evidence of a corresponding increase in in-stream salinities. The resultant Salt Trends study (Jolly et al., 1997) reported increasing trends in Electrical Conductivity (EC) over time in major and minor tributaries of the MDB.

The factors controlling salt mobilisation were identified and included a wide range of processes including climatic distribution, groundwater hydrology and chemistry, land use, surface water hydrology and chemistry, geology, topography, soil characteristics and land degradation. The study recommended a broad range of activities be undertaken to better understand the dry land salinisation processes.

### **1.2.3. 1999 Salinity Audit**

The awareness from studies such as Salt Trends highlighted that instream impacts of dryland salinisation were greater than first thought prior to development of the SDS. This prompted further investigations to provide information on the possible future magnitude of increased instream salinity. To this end, the MDBC coordinated a Salinity Audit of the whole MDB (MDBC, 1999). The Salinity Audit was intended to establish trend in salt mobilisation in the landscape, and corresponding changes in in-stream salinities for all major tributaries, made on the basis that there were not going to be any changes in management.

The methods adopted by NSW (Beale et al., 1999) to produce these outputs linked statistical estimates of flow and salt load in tributaries of the MDB, with rates of groundwater rise in their catchments. The results of this study indicated that salinity levels in the NSW tributaries of the MDB would significantly increase over the next 20-100 years, with major associated economic and environmental costs.

The results of the Salinity Audit resulted in the MDBMC and NSW Government developing strategies to manage salinity. These are reported in Sections 1.3.3 and 1.3.6 respectively.

### **1.2.4. 2006 Salinity Audit**

Additional biophysical data has recently been analysed which confirm the actual extent of salinity outbreaks and current status of in-stream salinity. However, these studies have also cast serious doubt on trends predicted using rising groundwater extrapolations (DECC 2006). A concerted effort to improve understanding of the extent of salinity, and its relationship with climatic regime and groundwater behaviour in the hydrological cycle in different contexts, has shown inconsistencies with the general regional rising water tables theory (Summerell et al. 2005).

In particular, the new work indicates that climate regime so dominates that it is difficult to detect the impacts of land-use or management interventions, and that response times between recharge and discharge, especially in the local-scale fractured rock aquifer systems that dominate in the tablelands and slopes of eastern NSW, are much shorter than previously thought. This leads to the conclusion that the impacts of clearing on groundwater levels have already been incurred, so no continuing effect can be attributed to this cause. Many (not all) of the NSW MDB sub catchments are in a state of 'dynamic equilibrium', and their groundwater levels fluctuate about a new average value in response to climate regime (long periods of above or below average rainfall) (DECC, 2007).

### **1.3. CURRENT POLICY FRAMEWORK**

A range of natural resource policies provide reasons for developing the salt transport models. These include basin wide policies developed through the MDBC, and State-wide policies developed through the NSW Government. The interrelationship of the key policies to this work are shown in Figure 1.1.

#### **1.3.1. MDBC Integrated Catchment Management**

Integrated Catchment Management (ICM) is the process by which MDBC seeks to meet its charter to:

“...promote and coordinate effective planning and management for the equitable, efficient and sustainable use of the water, land and other environmental resources of the Murray–Darling Basin.” (MDBC, 2001)

The ICM process requires that stakeholders consider the effect on all people within the catchment of their decisions on how they use land, water and other environmental resources. The process uses management systems and strategies to meet targets for water sharing and water quality. Two strategies that fall under ICM are described in Section 1.3.2 and Section 1.3.3.

#### **1.3.2. Murray-Darling Basin Ministerial Council Cap on water diversions**

In 1997 the MDBMC implemented a cap on water diversions (“The Cap”) in the MDB. The Cap was developed in response to continuing growth of water diversions and declining river health, and was the first step towards striking a balance between consumptive and instream users in the Basin. The Cap limits diversions to that which would have occurred under 1993/4 levels of:

- irrigation and infrastructure development;
- water sharing policy; and
- river operations and management.

#### **1.3.3. Murray-Darling Basin Ministerial Council Basin Salinity Management Strategy**

The MDBMC responded to the salinity problems predicted in the Salinity Audit with the Basin Salinity Management Strategy (BSMS). The objectives of the strategy are:

- maintain the water quality of the shared water resources of the Murray and Darling Rivers;
- control the rise in salt loads in all tributaries of the basin;
- control land degradation; and
- maximise net benefits from salinity control across the Basin.

These BSMS is implementing nine elements of strategic action, including:

- capacity building;
- identify values and assets at risk;
- setting salinity targets;
- managing trade-offs;
- salinity and catchment management plans,
- redesigning farming systems;
- targeting reforestation and vegetation management;
- constructing salt interception works; and
- ensuring Basin-wide accountability by monitoring, evaluating and reporting.

The last of these is particularly relevant to this work. The statutory requirements for the BSMS are specified in Schedule C of the Murray-Darling Basin Agreement, replacing those parts that previously

referred to the 1988 SDS. The key parts of Schedule C that relate to the modelling work are discussed in the following subsection.

#### **1.3.3.1. Schedule C of the Murray-Darling Basin Agreement**

Clauses 5(2), 5(3), 37(1) and 36(1)(a) of Schedule C dictate that the MDBC and the Contracting States must prepare estimates of baseline conditions flow, salt load, and salinity for the benchmark period at the end-of-valley target site for each of the major tributaries by 31 March 2004. These estimates must be approved by a suitably qualified panel appointed by the MDBC.

The baseline conditions refer to the physical and management status of the catchment as of 1 January 2000, specifically:

- land use (level of development in landscape);
- water use (level of diversions from the rivers);
- land and water management policies and practices;
- river operation regimes;
- salt interception schemes;
- run-off generation and salt mobilisation; and
- groundwater status and condition.

The benchmark climatic period refers to the 1 May 1975-30 April 2000 climate sequence; ie., rainfall and potential evapotranspiration.

Part VIII of Schedule C refers specifically to models, and sets out the performance criteria for the models. The models must be able to:

- (i) Simulate under Baseline Conditions, the daily salinity, salt load and flow regime at nominated sites for the Benchmark Climatic period.
- (ii) Predict the effect of all accountable Actions and delayed salinity impacts on salinity, salt load and flow at each of these nominated sites for each of 2015, 2050, and 2100,

These model capabilities must be approved by a suitably qualified panel appointed by the MDBC. There is specific provision that the models are reviewed by the end of 2004, and at seven-yearly intervals thereafter.

#### **1.3.4. Catchment Action Plans**

The NSW Government established the Catchment Management Boards Authorities in 2003, whose key roles include developing Catchment Action Plans (CAPs), and managing incentive programs to implement the plans. These are rolling three-year investment strategies and are updated annually.

The CAPs are based on defining investment priorities for natural resource management, and salinity is one aspect that is considered where appropriate. Models can play an important role in identifying where to target investment to achieve the best environmental benefit value for money which supports prioritisation. Models also have a crucial role in monitoring, evaluation and reporting, if only because they provide a means of separating the effects of the management signal from the dominant climate signal. The models bring consistency and rigour to analysis of alternate management options, and help comply with the Standard for Quality Natural Resource Management (NRC, 2005).

### **1.3.5. NSW Water Sharing Plans**

The Water Management Act 2000 aims to provide better ways to equitably share and manage NSW's water resources. Water Sharing Plans are ten year plans that outline how water is to be shared between the environment and water users. These plans cover both surface water and groundwater and both inland and coastal areas and contain both rules for resource access and use.

### **1.3.6. NSW Salinity Strategy**

In 2000, the NSW Government released the NSW Salinity Strategy. The Strategy brought together previously divided approaches into one strategy revolving around salinity targets. The salinity targets enable:

- Quantification of desirable salinity outcomes;
- Management of cumulative impacts of various actions at various sites
- Comparison of the environmental, economic and social benefits and costs for various actions; and
- Choice of the most cost effective action to treat the problem.

The salinity targets were developed and recommended through the Catchment Management Boards. To monitor the salinity targets and to assess the impacts of management options for land use changes on these salinity targets, numerical modelling tools to estimate salt load wash off and salt load transport became high priority. The modelling framework to meet these salinity strategies is described in Section 1.4.

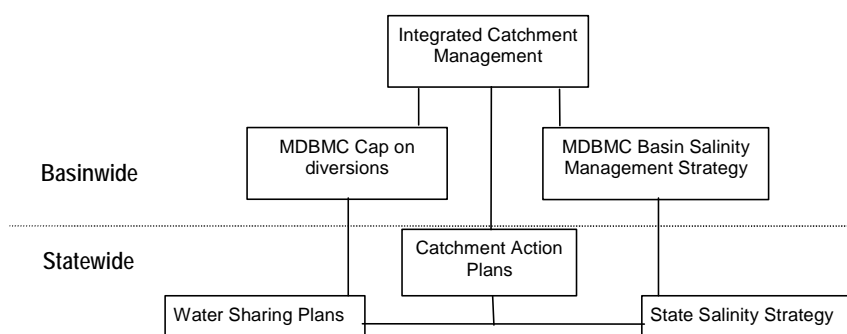
### **1.3.7. NSW Environmental Services Scheme**

In 2002, the NSW Government launched the Environmental Services Scheme (ESS) seeking expressions of interest from landholder groups. The aim was to identify the environmental benefits that could be achieved by changed land use activity and to have them valued by the community. This recognised that good farm management can slow the march of salinity, reduce acid sulfate soil and improve water quality. The scheme provides financial support for some of these activities, and is one of the actions under the NSW Salinity Strategy.

To judge the impacts of the proposed land use changes on end of valley and within valley salinity targets has again put pressure on the need for numerical models that can simulate salt wash off processes and salt transport processes.

### **1.3.8. CMA Incentive schemes**

CMA incentive schemes are used as mechanisms for funding on ground works and measures. As with the ESS, the aim is to buy environmental outcomes rather than output. Models are critical to evaluating the expected outcomes from given outputs. Property Vegetation Plans (PVPs) are evaluated with a Decision Support Tool which uses two salinity models. There is provision for incentive PVPs as well as clearing PVPs and continuing use PVPs.



**Figure 1.1. Relationship of Basinwide and Statewide policies and plans**

## **1.4. DWE MODEL FRAMEWORK**

NSW has developed a framework of models that link the surface water hydrology and salinity processes to support salinity management. A range of processes are represented in models that vary from the property scale to the basin scale. The scale of application of a model, in both spatial sense and temporal sense, influences the model structure and detail. Aspects of natural processes that are important at one scale may not matter at another. Figure 1.2 shows the linkage between the surface water and salinity models, their application at different scales and the desired outcomes of within valley and end of valley salinity targets.

### **1.4.1. Objectives of modelling**

The primary objective of the modelling is to support the implementation of the CAPs. This requires understanding and appropriate representation of the salt movement in and from the landscape to the streams, and in the streams to the end of valley target locations.

Property scale modelling is required to support decisions on land use change and property investments on-farm. This required modelling of the effect of land use on runoff, salt washoff, and recharge. Decisions at this scale can directly impact on the landholder's income.

Moving from the property scale to catchment and then to basin scale requires the dryland salinisation processes to be modelled together with wash off and groundwater interaction to estimate the water and salt flowing into the river system.

The objectives of the basin modelling are to be able to assess the end of valley salinity levels, and evaluating the performance of salinity management scenarios. To achieve this objective salt needs to be transported down the river, amalgamated with other catchment runoff and salt loads. It is also necessary to deal with such issues as dams and major irrigation developments (eg., Murrumbidgee Irrigation).

Model results for salinity need to be available in both concentrations and total salt loads to meet the needs of the policies. Results for impacts of land use changes on streamflow (runoff yields) are also necessary.

### **1.4.2. Modelling requirements**

The modelling had the following requirements:

- Daily predictions

- Applicable across different scales - local (site, property, farm), landscape, sub-catchment, catchment and basin
- Applicable for all NSW catchments
- Model complexity consistent with available data
- Link to tools to evaluate economics, social impacts, environmental services, cumulative impacts
- Represent land use changes and consequent impacts
- must be able to model water management independently

### **1.4.3. Strengths and Limitations**

The following points detail some of the strengths and weakness of this model framework:

- Only technology available consistent with salinity targets – These models are the best available at present to meet the needs of the policy. As time progresses it is expected advancements with these model will improve the model capabilities and output.
- Complements adaptive management approach in NSW
- State of the art modelling appropriate for the temporal and spatial scales required by State and National policy
- Integrates catchment and instream processes
- Model uncertainty
- Data gaps and data uncertainty
- Error propagation
- Spatial generalisation

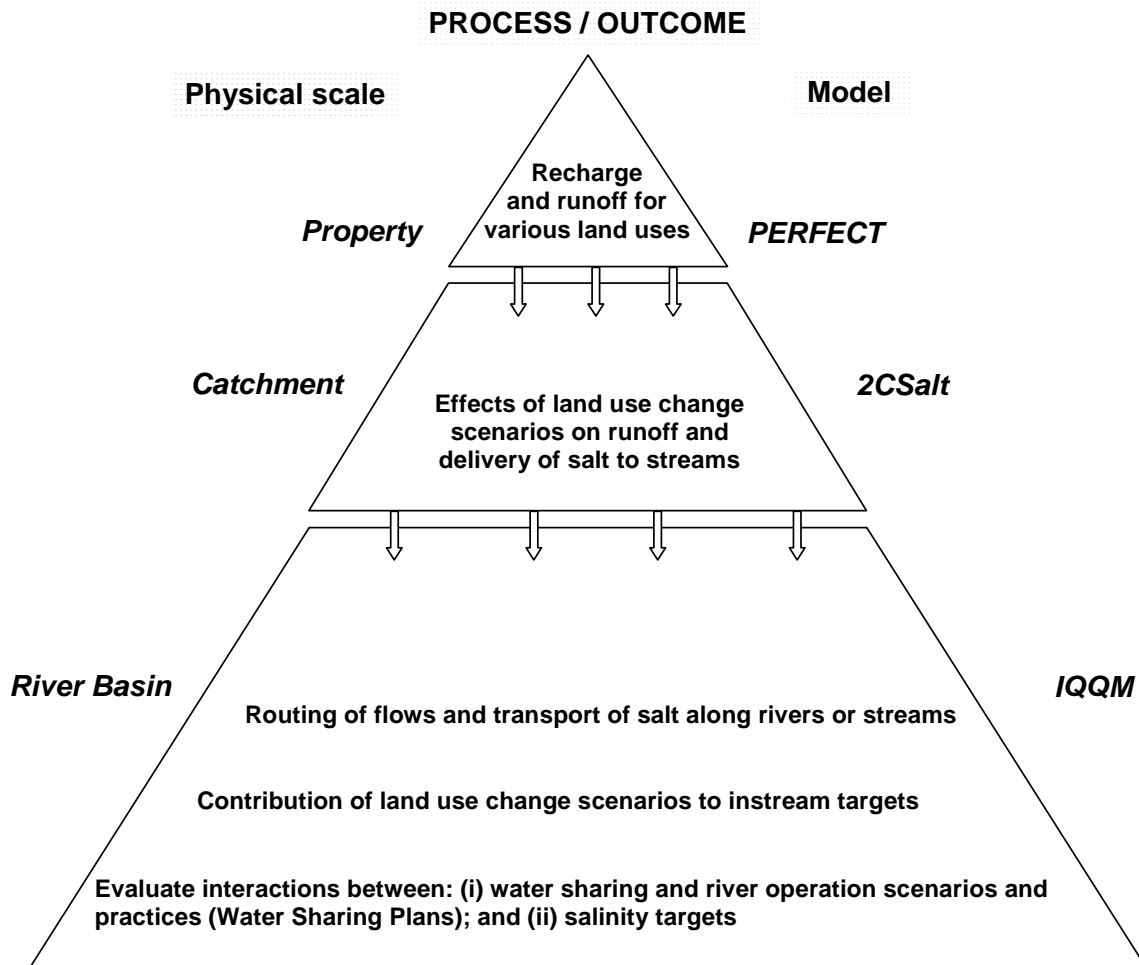
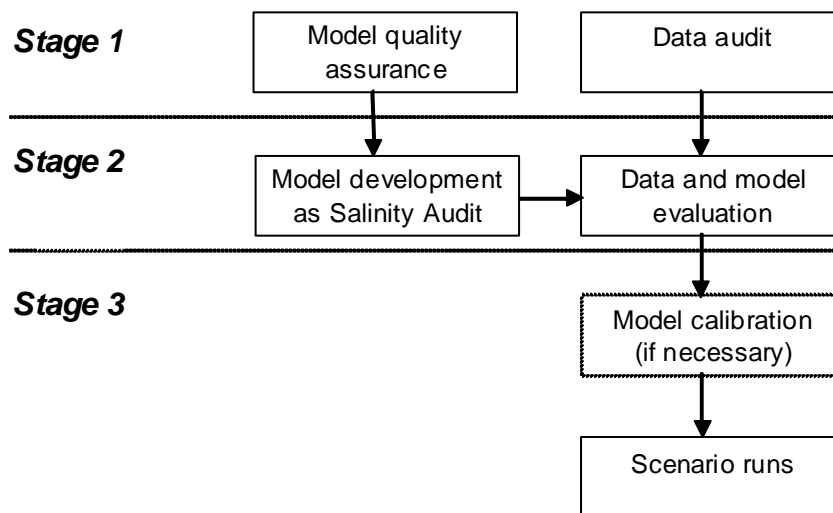


Figure 1.2. Applications and linkages of DECC and DWE models at different scales

## 1.5. STAGED MODEL DEVELOPMENT

The work reported here was developed in logical stages as shown in Figure 1.3. The tasks in Stage 1 were done in parallel. The initial estimate of salinity behaviour in the river system was done in Stage 2 using the work done for the Salinity Audit (Beale et al., 1999) as the starting point. The results from this task were evaluated in the second task of Stage 2. The first task in Stage 3 was done if the results from the model evaluation were not satisfactory. The final task in model development is running the scenarios. The tasks for all three stages are discussed in more detail in the following subsections.



**Figure 1.3. Stages of model development**

### 1.5.1. Stage 1: Model QA and Data Audit

The existent IQQM that had been configured and calibrated for the Macquarie River system was the starting point for the in-stream salinity model. The software Fortran 90 source code that simulates the salt transport is relatively untested, and therefore there is the possibility that it contains errors. A set of Quality Assurance (QA) tests was done on the software and tributary model to eliminate any software related errors that could confound interpretation of the results.

Representative data is needed to develop and calibrate the model. Records of discrete and continuous Electrical Conductivity (EC) data are stored on DWE data bases. This data was extracted, and an audit of the spatial and temporal characteristics of this data was made. This data was also screened, and some important characteristics analysed. The representativeness of the data was assessed further in Stage 2.

### 1.5.2. Stage 2: Initial model development and data and model evaluation

This stage was subject to satisfactorily correcting software errors, and completing processing of salinity data. A 'first cut' estimate of salinity was made based on the work done for the Salinity Audit, and evaluated against the processed data. This stage tested the possibility that the prior work would produce satisfactory results when converted to a different modelling environment, and would have had the advantages of minimising to recalibrate the models, and also resulted in consistent outputs with

those from the Salinity Audit. As these outputs were used to generate salt targets, this is a desirable outcome. For this reason the similarities and differences between the results are analysed in some depth in Appendix B.

The outputs required from the salt transport model are similar to those required for the Salinity Audit 'current' case as reported in Beale et al., 1999. There are two principal differences in the specifications for the output.

- (i) The Baseline Conditions: water sharing policies used to estimate diversions and corresponding river flow were for the 1993/4 levels of development; whereas this work uses 1 January 2000 conditions.
- (ii) Benchmark climatic period: was 1 January 1975-31 December 1995; whereas the current benchmark period is 1 May 1975-30 April 2000.
- (iii) Time step: monthly were needed for the Salinity Audit, whereas daily are needed for the BSMS.

There are also important differences in the methods used:

- (iv) Combining tributary flows and salt loads. The Salinity Audit was done using monthly flows processed in EXCEL spreadsheets, whereas this work uses the IQQM daily simulation model.
- (v) Salt balances: The checks to ensure tributary salt loads were consistent with observed data in the mainstream was done using salt loads in the Salinity Audit, whereas this work will be using resultant concentrations.

The results were evaluated by first evaluating how representative the data was, and also by comparing model results with salinity observations at target locations to assess the model's performance. The model evaluation uses objective statistical methods, supported by interpretation and presentation of time series graphs. The statistical methods express measures of confidence in: (i) the ability of the data to represent the system behaviour; and (ii) with what levels of confidence do the model results reproduce the data. These statistical measures were developed to reflect judgements made from traditional visual interpretations of graphs of time series or exceedance plots of the results from simulations compared against observations. The rationale behind this approach is to have a consistent and rigorous way to assess and report results.

### **1.5.3. Stage 3: Model calibration and scenario modelling**

Pending the results of the model evaluation, the inflows to the river system will be revised to better match distributions of salinities at the evaluation points.

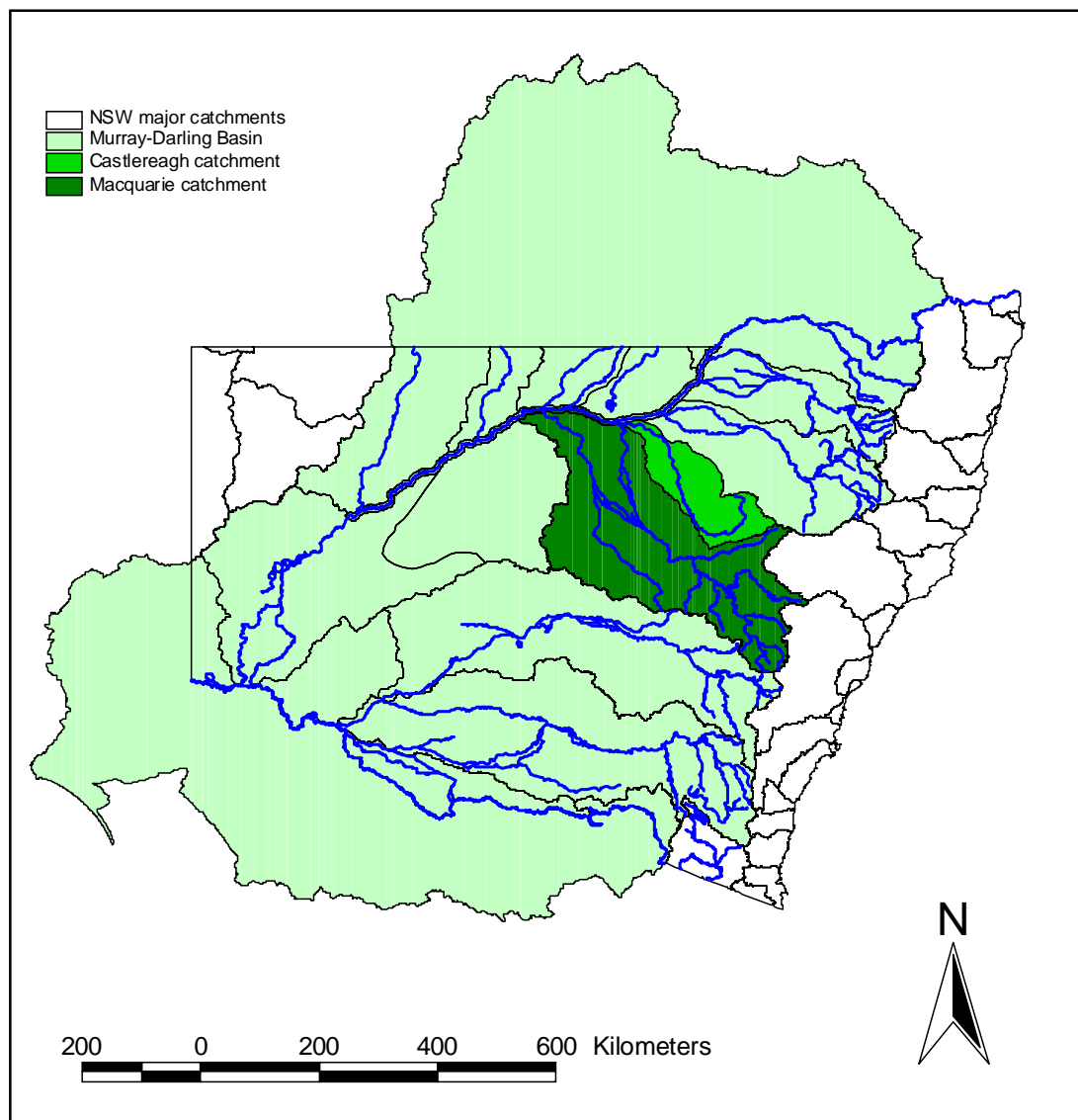
The model will then be adjusted to represent various conditions of the river valley. The adjustments would be made to river management operations such as environmental flow rules, irrigation diversion rules. The first scenario will be the *Baseline Conditions* model to represent the flow and salt loads that represent catchment conditions as at 1 January 2000.

## 2. The Macquarie-Bogan-Castlereagh System

### 2.1. PHYSICAL FEATURES OF THE CATCHMENT

#### 2.1.1. General

The Macquarie-Bogan-Castlereagh system is one of the major NSW sub-catchments of the Murray-Darling Basin (Figure 2.1). It covers a total area of about 92,000 km<sup>2</sup> from the Great Dividing Range near Bathurst to the Barwon River near Brewarrina, 560 km to the north-west.



**Figure 2.1. Relationship of Macquarie and Castlereagh catchments to Murray-Darling Basin**

The Macquarie-Bogan-Castlereagh catchments include a number of small cities, including Dubbo, Orange and Bathurst, all with populations of about 30,000 people (Figure 2.2). There are also a





















































































































































































































































