

Salinity predictions for NSW rivers within the Murray-Darling Basin

G.T.H. Beale
R. Beecham
K. Harris
D. O'Neill
H. Schroo
N.K. Tuteja
R.M. Williams



Acknowledgements

The following have contributed to this report, as authors and/or by providing analytical and mapping inputs: G. Beale, R. Beecham, S. Bish, J. Bradd, R. Cooke, R. Crawford, J. Dwyer, S. Grant, K. Harris, F. Harvey, S. Keane, D. O'Neill, S. Rish, E. Roberts, H. Schroo, G. Summerell, B. Turner, N. Tuteja, M. Williams and D. Woolley.

Published by:

Centre for Natural Resources

NSW Department of Land and Water Conservation

10 Valentine Av, Parramatta NSW 2150

January 2000

© NSW Government

ISBN 0 7347 51117

CNR99.048

TABLE OF CONTENTS

<u>Summary.....</u>	<u>I</u>
<u>1 INTRODUCTION</u>	<u>1</u>
1.1 BACKGROUND	1
1.2 PROJECT OUTLINE	3
<u>2 DATA AVAILABILITY.....</u>	<u>6</u>
2.1 HYDROGEOLOGY DATA	6
2.2 SURFACE HYDROLOGY DATA	7
2.3 GIS SPATIAL DATA.....	8
<u>3 METHODOLOGY.....</u>	<u>9</u>
3.1 GROUNDWATER DERIVED SALT BALANCE	9
3.1.1 Determination of groundwater level trends and salinity.....	10
3.1.2 Predicted areas with groundwater levels at less than 2 m.....	10
3.1.3 Calculation of the potential salt loads delivered from the groundwater system to the soil.....	12
3.1.4 Summary of assumptions made in estimating the groundwater derived potential salt loads.....	13
3.2 ESTIMATION OF ACTUAL DELIVERED IN-STREAM SALT LOADS FROM RUNOFF GENERATION AND SALT WASH OFF MECHANISMS	13
3.2.1 Choice of scale for the ‘current’ salt balance analysis.....	14
3.2.2 Estimation of daily salt loads from third order catchments	14
3.3 ‘CURRENT’ IN-STREAM SALT BALANCES AT END OF SYSTEM FOR EACH SECOND ORDER CATCHMENT.....	19
3.4 ESTIMATION OF SALT EXPORT FROM SECOND ORDER CATCHMENTS UNDER LIKELY FUTURE CONDITIONS.....	20
<u>4 POTENTIAL SALT LOADS DELIVERED FROM THE GROUNDWATER SYSTEM UNDER ‘CURRENT’ AND LIKELY FUTURE CONDITIONS AT 2020, 2050 AND 2100</u>	<u>25</u>
4.1 GROUNDWATER SALINITIES AND GROUNDWATER LEVEL TRENDS	27
4.2 POTENTIALLY SALINISED AREAS AS INDICATED BY WATERTABLE DEPTH LESS THAN 2 M.....	28
4.3 PREDICTED POTENTIAL SALT LOADS	28
4.4 AREAS EXCLUDED FROM THE ANALYSIS.....	35
<u>5 IN-STREAM SALT BALANCES FOR SECOND ORDER CATCHMENTS UNDER ‘CURRENT’ CONDITIONS.....</u>	<u>37</u>
5.1 SALT BALANCE FOR THE BORDER RIVERS	38
5.2 SALT BALANCE FOR GWYDIR.....	50
5.3 SALT BALANCE FOR NAMOI.....	59
5.4 SALT BALANCE FOR CASTLEREAGH.....	70

5.5	SALT BALANCE FOR MACQUARIE—BOGAN.....	70
5.6	SALT BALANCE FOR LACHLAN.....	80
5.7	SALT BALANCE FOR MURRUMBIDGEE.....	87
6	<u>FUTURE PREDICTED IN-STREAM SALT LOADS EXPORTED FROM SECOND ORDER CATCHMENTS.....</u>	95
6.1	SCALING FACTORS.....	96
6.1.1	<i>Determining factors for the Gwydir Catchment.....</i>	<i>97</i>
6.2	BORDER RIVERS (MACINTYRE RIVER)—FUTURE SALT EXPORTS.....	99
6.3	GWYDIR RIVER—FUTURE SALT EXPORTS.....	102
6.4	NAMOI RIVER—FUTURE SALT EXPORTS.....	105
6.5	CASTLEREAGH RIVER—FUTURE SALT EXPORTS.....	108
6.6	MACQUARIE BASIN—FUTURE SALT EXPORTS.....	110
6.6.1	<i>Macquarie River—future salt exports.....</i>	<i>111</i>
6.6.2	<i>Bogan River—future salt exports.....</i>	<i>114</i>
6.7	LACHLAN RIVER—FUTURE SALT EXPORTS.....	116
6.8	MURRUMBIDGEE RIVER—FUTURE SALT EXPORTS.....	118
6.9	MURRAY RIVER—FUTURE SALT EXPORTS.....	121
7	<u>CATCHMENT SCALE SALT BALANCE STUDY (CATSALT).....</u>	124
8	<u>POTENTIAL ENVIRONMENTAL CONSEQUENCES OF INCREASING DRYLAND SALINITY IN STREAMS AND WETLANDS.....</u>	133
8.1	INTRODUCTION.....	133
8.2	SENSITIVITY OF AQUATIC BIOTA.....	135
8.2.1	<i>Fish.....</i>	<i>135</i>
8.2.2	<i>Aquatic plants.....</i>	<i>135</i>
8.2.3	<i>Riparian vegetation.....</i>	<i>136</i>
8.2.4	<i>Waterbirds.....</i>	<i>136</i>
8.2.5	<i>Frogs.....</i>	<i>137</i>
8.2.6	<i>Invertebrates.....</i>	<i>137</i>
8.2.7	<i>Other species.....</i>	<i>138</i>
8.2.8	<i>Implications.....</i>	<i>138</i>
8.3	WATER QUALITY IMPLICATIONS.....	138
8.4	IMPACTS ON END OF SYSTEM WETLANDS.....	139
8.4.1	<i>Wetland impacts of increased salinity levels.....</i>	<i>139</i>
8.4.2	<i>The Great Cumbung Swamp.....</i>	<i>140</i>
8.4.3	<i>The Gwydir Wetland.....</i>	<i>141</i>
8.4.4	<i>The Macquarie Marshes.....</i>	<i>142</i>
8.4.5	<i>Other wetlands (both floodplain and upland areas).....</i>	<i>142</i>

8.5	<u>FURTHER RESEARCH NEEDS</u>	143
9	<u>DISCUSSION</u>	145
9.1	<u>OVERVIEW</u>	145
9.2	<u>STRENGTHS</u>	147
9.3	<u>ADDITIONAL PERSPECTIVE ON USING THE CATSALT MODEL</u>	147
9.4	<u>DATA AVAILABILITY AND RESOLUTION</u>	148
9.5	<u>VARIABILITY OF SALINITY</u>	148
9.6	<u>TOWN WATER SUPPLY IMPACTS</u>	148
9.7	<u>IRRIGATION IMPACTS</u>	150
9.8	<u>WETLAND IMPACTS</u>	151
10	<u>CONCLUSIONS</u>	152
11	<u>RECOMMENDATIONS FOR FURTHER WORK</u>	153
12	<u>REFERENCES</u>	155
	 <u>APPENDICES</u>	 159
	<i>Cumulative distribution functions for catchments</i>	
Appendix 1	<u>Macintyre Catchment</u>	159
Appendix 2	<u>Gwydir Catchment</u>	163
Appendix 3	<u>Namoi Catchment</u>	169
Appendix 4	<u>Macquarie Catchment</u>	174
Appendix 5	<u>Lachlan Catchment</u>	180
Appendix 6	<u>Murrumbidgee Catchment</u>	185
Appendix 7	<u>Town water supplies in relation to source, predicted in-stream salinity and urban salinity hazard</u>	191

TABLE OF FIGURES

<u>Figure I</u>	<u>Average annual stream salt load</u>	III
<u>Figure II</u>	<u>Average annual stream salinity</u>	III
<u>Figure III</u>	<u>Probability of exceeding a monthly average threshold salinity of 800 $\mu S.cm^{-1}$ for streams in the Macintyre River Catchment (Basin 416) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	VII
<u>Figure IV</u>	<u>Probability of exceeding a monthly average threshold salinity of 1600 $\mu S.cm^{-1}$ for streams in the Macintyre River Catchment (Basin 416) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	VII
<u>Figure V</u>	<u>Probability of exceeding a monthly average threshold salinity of 800 $\mu S.cm^{-1}$ for streams in the Gwydir River Catchment (Basin 418) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	VII
<u>Figure VI</u>	<u>Probability of exceeding a monthly average threshold salinity of 1600 $\mu S.cm^{-1}$ for streams in the Gwydir River Catchment (Basin 418) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	VII
<u>Figure VII</u>	<u>Probability of exceeding a monthly average threshold salinity of 800 $\mu S.cm^{-1}$ for streams in the Namoi River Catchment (Basin 419) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	X
<u>Figure VIII</u>	<u>Probability of exceeding a monthly average threshold salinity of 1600 $\mu S.cm^{-1}$ for streams in the Namoi River Catchment (Basin 419) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	X
<u>Figure IX</u>	<u>Probability of exceeding a monthly average threshold salinity of 800 $\mu S.cm^{-1}$ for streams in the Macquarie River Catchment (Basin 421) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	XI
<u>Figure X</u>	<u>Probability of exceeding a monthly average threshold salinity of 1600 $\mu S.cm^{-1}$ for streams in the Macquarie River Catchment (Basin 421) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	XI
<u>Figure XI</u>	<u>Probability of exceeding a monthly average threshold salinity of 800 $\mu S.cm^{-1}$ for streams in the Lachlan River Catchment (Basin 412) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	XIII
<u>Figure XII</u>	<u>Probability of exceeding a monthly average threshold salinity of 1600 $\mu S.cm^{-1}$ for streams in the Lachlan River Catchment (Basin 412) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	XIII
<u>Figure XIII</u>	<u>Probability of exceeding a monthly average threshold salinity of 800 $\mu S.cm^{-1}$ for streams in the Murrumbidgee River Catchment (Basin 410) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	XIV
<u>Figure XIV</u>	<u>Probability of exceeding a monthly average threshold salinity of 1600 $\mu S.cm^{-1}$ for streams in the Murrumbidgee River Catchment (Basin 410) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions</u>	XIV
<u>Figure 2.1</u>	<u>Location of census bore surveys</u>	8
<u>Figure 3.1</u>	<u>Schematic diagram of the NSW Salt Balance Methodology</u>	11
<u>Figure 3.2</u>	<u>Excluded alluvial areas</u>	12

<u>Figure 4.1</u>	<u>Murray-Darling Basin salinity and drainage strategy groundwater derived salt loads. Conductivities in geologies in river basins.</u>	32
<u>Figure 4.2</u>	<u>Murray-Darling Basin salinity and drainage groundwater derived salt loads. Conductivity and rate of water level rise.</u>	33
<u>Figure 4.3</u>	<u>Water level rise (m/yr)</u>	34
<u>Figure 4.4</u>	<u>Estimated salt loads (1998)</u>	34
<u>Figure 4.5</u>	<u>Average salt load ($t.km^{-2}.year^{-1}$) 1998</u>	35
<u>Figure 4.6</u>	<u>Average salt load ($t.km^{-2}.year^{-1}$) 2020</u>	35
<u>Figure 4.7</u>	<u>Average salt load ($t.km^{-2}.year^{-1}$) 2050</u>	35
<u>Figure 4.8</u>	<u>Average salt load ($t.km^{-2}.year^{-1}$) 2100</u>	35
<u>Figure 5.1a</u>	<u>Macintyre River Catchment (Basin 416)</u>	38
<u>Figure 5.1b</u>	<u>Gwydir River Catchment (Basin 418)</u>	39
<u>Figure 5.1c</u>	<u>Namoi River Catchment (Basin 419)</u>	39
<u>Figure 5.1d</u>	<u>Castlereagh River Catchment (Basin 420)</u>	39
<u>Figure 5.1e</u>	<u>Macquarie River Catchment (Basin 421)</u>	39
<u>Figure 5.1f</u>	<u>Lachlan River Catchment (Basin 412)</u>	39
<u>Figure 5.1g</u>	<u>Murrumbidgee River Catchment (Basin 410)</u>	39
<u>Figure 5.1h</u>	<u>Murray River Catchment (Basin 409)</u>	39
<u>Figure 5.2</u>	<u>Schematic diagram of the gauging stations and the residual areas used in Border Rivers Salt Balance Analysis</u>	39
<u>Figure 5.3a</u>	<u>Border Rivers salt balance analysis at 416 019 (Severn R. @ Pindari Dam)</u>	44
<u>Figure 5.3b</u>	<u>Observed and estimated salt loads at 416 019 for 1975–95 (Severn R. @ Pindari)</u>	44
<u>Figure 5.3c</u>	<u>Observed and estimated average monthly salt load at 416 019 for 1975–95 (Severn R. @ Pindari)</u>	44
<u>Figure 5.3d</u>	<u>Border Rivers salt balance analysis at 416 006 (Severn R. @ Ashford)</u>	45
<u>Figure 5.3e</u>	<u>Observed and estimated salt loads at 416 006 for 1975–95 (Severn R. @ Ashford)</u>	45
<u>Figure 5.3f</u>	<u>Observed and estimated average monthly salt load at 416 006 for 1975–95 (Severn R. @ Ashford)</u>	45
<u>Figure 5.3g</u>	<u>Border Rivers salt balance analysis at 416 012 (Macintyre R. @ Holdfast)</u>	46
<u>Figure 5.3h</u>	<u>Observed and estimated salt loads at 416 012 for 1975–95 (Macintyre R. @ Holdfast)</u>	46
<u>Figure 5.3i</u>	<u>Observed and estimated average monthly salt load at 416 012 for 1975–95 (Macintyre R. @ Holdfast)</u>	46
<u>Figure 5.3j</u>	<u>Border Rivers salt balance analysis at 416 007 (Dumaresq R. @ Bonshaw Weir)</u>	47
<u>Figure 5.3k</u>	<u>Observed and estimated salt loads at 416 007 for 1975–95 (Dumaresq R. @ Bonshaw Weir)</u>	47

<u>Figure 5.3l</u>	<u>Observed and estimated average monthly salt load at 416 007 for 1975–95 (Dumaresq R. @ Bonshaw Weir)</u>	47
<u>Figure 5.3m</u>	<u>Border Rivers salt balance analysis at 416 002 (Macintyre R. @ Boggabilla)</u>	48
<u>Figure 5.3n</u>	<u>Observed and estimated salt loads at 416 002 for 1975–95 (Macintyre R. @ Boggabilla)</u>	48
<u>Figure 5.3o</u>	<u>Observed and estimated average monthly salt load at 416 002 for 1975–95 (Macintyre R. @ Boggabilla)</u>	48
<u>Figure 5.3p</u>	<u>Observed average monthly salt load (t/month) and observed EC ($\mu\text{S.cm}^{-1}$) at end of system for Border Rivers—Macintyre (1975–95) 416 001</u>	49
<u>Figure 5.3q</u>	<u>Observed average monthly salt load (t/month) and observed EC ($\mu\text{S.cm}^{-1}$) at end of system for Border Rivers—Gil Gil Creek at Galloway (1975–95) 416 052</u>	49
<u>Figure 5.4</u>	<u>Schematic diagram of the gauging stations and the residual areas used in Gwydir salt balance analysis</u>	50
<u>Figure 5.5a</u>	<u>Gwydir salt balance analysis at 418 008 (Gwydir R. @ Bundarra)</u>	52
<u>Figure 5.5b</u>	<u>Observed and estimated salt loads at 418 008 for 1975–95 (Gwydir R. @ Bundarra)</u>	52
<u>Figure 5.5c</u>	<u>Observed and estimated average monthly salt load at 418 008 for 1975–95 (Gwydir R. @ Bundarra)</u>	52
<u>Figure 5.5d</u>	<u>Gwydir salt balance analysis at 418 026 (Gwydir R. @ d/s Copeton Dam)</u>	53
<u>Figure 5.5e</u>	<u>Observed and estimated salt loads at 418 026 for 1975–95 (Gwydir R. @ d/s Copeton Dam)</u>	53
<u>Figure 5.5f</u>	<u>Observed and estimated average monthly salt load at 418 026 for 1975–95 (Gwydir R. @ d/s Copeton Dam)</u>	53
<u>Figure 5.5g</u>	<u>Gwydir salt balance analysis at 418 012 (Gwydir R. @ Pinegrove)</u>	54
<u>Figure 5.5h</u>	<u>Observed and estimated salt loads at 418 012 for 1975–95 (Gwydir R. @ Pinegrove)</u>	54
<u>Figure 5.5i</u>	<u>Observed and estimated average monthly salt load at 418 012 for 1975–95 (Gwydir R. @ Pinegrove)</u>	54
<u>Figure 5.5j</u>	<u>Gwydir salt balance analysis at 418 013 (Gwydir R. @ Gravesend Road Bridge)</u>	55
<u>Figure 5.5k</u>	<u>Observed and estimated salt loads at 418 013 for 1975–95 (Gwydir R. @ Gravesend Road Bridge)</u>	55
<u>Figure 5.5l</u>	<u>Observed and estimated average monthly salt load at 418 013 for 1975–95 (Gwydir R. @ Gravesend Road Bridge)</u>	55
<u>Figure 5.5m</u>	<u>Gwydir salt balance analysis at 418 001 (Gwydir R. @ Pallamallawa)</u>	56
<u>Figure 5.5n</u>	<u>Observed and estimated salt loads at 418 001 for 1975–95 (Gwydir R. @ Pallamallawa)</u>	56
<u>Figure 5.5o</u>	<u>Observed and estimated average monthly salt load at 418 001 for 1975–95 (Gwydir R. @ Pallamallawa)</u>	56

<u>Figure 5.5p</u>	<u>Observed and estimated average monthly salt load (t/month) and observed EC ($\mu S.cm.^{-1}$) contributions from stations 418 001 and 418 052 for Gwydir (1975–95)</u>	57
<u>Figure 5.6</u>	<u>Schematic diagram of the gauging stations and the residual areas used in Namoi salt balance analysis</u>	60
<u>Figure 5.7a</u>	<u>Namoi salt balance analysis at 419 024 (Peel R. @ Paradise Weir)</u>	64
<u>Figure 5.7b</u>	<u>Observed and estimated salt loads at 419 024 for 1975–95 (Peel R. @ Paradise Weir)</u>	64
<u>Figure 5.7c</u>	<u>Observed and estimated average monthly salt load at 419 024 for 1975–95 (Peel R. @ Paradise Weir)</u>	64
<u>Figure 5.7d</u>	<u>Namoi salt balance analysis at 419 006 (Peel R. @ Carrol Gap)</u>	65
<u>Figure 5.7e</u>	<u>Observed and estimated salt loads at 419 006 for 1975–95 (Peel R. @ Carrol Gap)</u>	65
<u>Figure 5.7f</u>	<u>Observed and estimated average monthly salt load at 419 006 for 1975–95 (Peel R. @ Carrol Gap)</u>	65
<u>Figure 5.7g</u>	<u>Namoi salt balance analysis at 419 007 (Namoi R. @ Keepit)</u>	66
<u>Figure 5.7h</u>	<u>Observed and estimated salt loads at 419 007 for 1975–95 (Namoi R. @ Keepit)</u>	66
<u>Figure 5.7i</u>	<u>Observed and estimated average monthly salt load at 419 007 for 1975–95 (Namoi R. @ Keepit)</u>	66
<u>Figure 5.7j</u>	<u>Namoi salt balance analysis at 419 001 (Namoi R. @ Gunnedah)</u>	67
<u>Figure 5.7k</u>	<u>Observed and estimated salt loads at 419 001 for 1975–95 (Namoi R. @ Gunnedah)</u>	67
<u>Figure 5.7l</u>	<u>Observed and estimated average monthly salt load at 419 001 for 1975–95 (Namoi R. @ Gunnedah)</u>	67
<u>Figure 5.7m</u>	<u>Namoi salt balance analysis at 419 012 (Namoi @ Boggabri)</u>	68
<u>Figure 5.7n</u>	<u>Observed and estimated salt loads at 419 012 for 1975–95 (Namoi R. @ Boggabri)</u>	68
<u>Figure 5.7o</u>	<u>Observed and estimated average monthly salt load at 419 012 for 1975–95 (Namoi R. @ Boggabri)</u>	68
<u>Figure 5.7p</u>	<u>Observed and estimated average monthly salt load (t/month) and observed EC $\mu S.cm.^{-1}$ at end of system for Namoi (1975–1995)</u>	69
<u>Figure 5.8a</u>	<u>Observed average monthly salt load (t/month) for Castlereagh R. at Coonamble 420 005 (1975–95)</u>	71
<u>Figure 5.8b</u>	<u>Average monthly salt load (t/month) for Castlereagh R. at Coonamble 420 005 (1975–95)</u>	71
<u>Figure 5.9</u>	<u>Schematic diagram of the gauging stations and the residual areas used in Macquarie-Bogan salt balance analysis</u>	72
<u>Figure 5.10a</u>	<u>Macquarie salt balance analysis at 421 025 (Macquarie R. @ Bruinbun)</u>	75
<u>Figure 5.10b</u>	<u>Observed and estimated salt loads at 421 025 for 1975–95 (Macquarie R. @ Bruinbun)</u>	75

<u>Figure 5.10c</u>	<u>Observed and estimated average monthly salt load at 421 025 for 1975–95 (Macquarie R. @ Bruinbun)</u>	75
<u>Figure 5.10d</u>	<u>Macquarie salt balance analysis at 421 019 (Cudgegong R. @ Yamble Bridge)</u>	76
<u>Figure 5.10e</u>	<u>Observed and estimated salt loads at 421 019 for 1975–95 (Cudgegong R. @ Yamble Bridge)</u>	76
<u>Figure 5.10f</u>	<u>Observed and estimated average monthly salt load at 421 019 for 1975–95 (Cudgegong R. @ Yamble Bridge)</u>	76
<u>Figure 5.10g</u>	<u>Macquarie salt balance analysis at 421 040 (Macquarie R. @ d/s of Burrendong Dam)</u>	77
<u>Figure 5.10h</u>	<u>Observed and estimated salt loads at 421 040 for 1975–95 (Macquarie R. @ d/s of Burrendong Dam)</u>	77
<u>Figure 5.10i</u>	<u>Observed and estimated average monthly salt load at 421 040 for 1975–95 (Macquarie R. @ d/s of Burrendong Dam)</u>	77
<u>Figure 5.10j</u>	<u>Macquarie salt balance analysis at 421 006 (Macquarie R. @ Narromine)</u>	78
<u>Figure 5.10k</u>	<u>Observed and estimated salt loads at 421 006 for 1975–95 (Macquarie R. @ Narromine)</u>	78
<u>Figure 5.10l</u>	<u>Observed and estimated average monthly salt load at 421 006 for 1975–95 (Macquarie R. @ Narromine)</u>	78
<u>Figure 5.10m</u>	<u>Observed and estimated average monthly salt load (t/month) and observed EC ($\mu S.cm.^{-1}$) at end of system Macquarie (1975–95)</u>	79
<u>Figure 5.10n</u>	<u>Observed and estimated average monthly salt load (t/month) and observed EC ($\mu S.cm.^{-1}$) at end of system Bogan (1975–95)</u>	79
<u>Figure 5.11</u>	<u>Schematic diagram of the gauging stations and the residual areas used in Lachlan salt balance analysis</u>	81
<u>Figure 5.12a</u>	<u>Lachlan River salt balance analysis at 412 067 (Lachlan R. @ d/s of Wyangala)</u>	83
<u>Figure 5.12b</u>	<u>Observed and estimated salt loads at 412 067 for 1975–95 (Lachlan R. @ d/s of Wyangala)</u>	83
<u>Figure 5.12c</u>	<u>Observed and estimated average monthly salt load at 412 067 for 1975–95 (Lachlan R. @ d/s of Wyangala)</u>	83
<u>Figure 5.12d</u>	<u>Lachlan River salt balance analysis at 412 002 (Lachlan R. @ Cowra)</u>	84
<u>Figure 5.12e</u>	<u>Observed and estimated salt loads at 412 002 for 1975–95 (Lachlan R. @ Cowra)</u>	84
<u>Figure 5.12f</u>	<u>Observed and estimated average monthly salt load at 412 002 for 1975–95 (Lachlan R. @ Cowra)</u>	84
<u>Figure 5.12g</u>	<u>Lachlan River salt balance analysis at 412 057 (Lachlan R. @ Nanami)</u>	85
<u>Figure 5.12h</u>	<u>Observed and estimated salt loads at 412 057 for 1975–95 (Lachlan R. @ Nanami)</u>	85
<u>Figure 5.12i</u>	<u>Observed and estimated average monthly salt load at 412 057 for 1975–95 (Lachlan R. @ Nanami)</u>	85

<u>Figure 5.12j</u>	<u>Lachlan River salt balance analysis at 412 004 (Lachlan R. @ Forbes—Cottons Weir)</u>	86
<u>Figure 5.12k</u>	<u>Observed and estimated salt loads at 412 004 for 1975–95 (Lachlan R. @ Forbes—Cottons Weir)</u>	86
<u>Figure 5.12l</u>	<u>Observed and estimated average monthly salt load at 412 004 for 1975–95 (Lachlan R. @ Forbes—Cottons Weir)</u>	86
<u>Figure 5.13</u>	<u>Schematic diagram of the gauging stations and the residual areas used in Murrumbidgee salt balance analysis</u>	88
<u>Figure 5.14a</u>	<u>Murrumbidgee River salt balance analysis at 410 039 (Tumut R. @ Brungle Bridge)</u>	91
<u>Figure 5.14b</u>	<u>Observed and estimated salt loads at 410 039 for 1975–95 (Tumut R. @ Brungle Bridge)</u>	91
<u>Figure 5.14c</u>	<u>Observed and estimated average monthly salt load at 410 039 for 1975–95 (Tumut R. @ Brungle Bridge)</u>	91
<u>Figure 5.14d</u>	<u>Murrumbidgee River salt balance analysis at 410 004 (Murrumbidgee @ Gundagai)</u>	92
<u>Figure 5.14e</u>	<u>Observed and estimated salt loads at 410 004 for 1975–95 (Murrumbidgee @ Gundagai)</u>	92
<u>Figure 5.14f</u>	<u>Observed and estimated average monthly salt load at 410 004 for 1975–95 (Murrumbidgee @ Gundagai)</u>	92
<u>Figure 5.14g</u>	<u>Murrumbidgee River salt balance analysis at 410 001 (Murrumbidgee @ Wagga Wagga)</u>	93
<u>Figure 5.14h</u>	<u>Observed and estimated salt loads at 410 001 for 1975–95 (Murrumbidgee @ Wagga Wagga)</u>	93
<u>Figure 5.14i</u>	<u>Observed and estimated average monthly salt load at 410 001 for 1975–95 (Murrumbidgee @ Wagga Wagga)</u>	93
<u>Figure 5.14j</u>	<u>Observed average monthly salt load (t/month) and observed EC ($\mu\text{S.cm}^{-1}$) at end of system for Murrumbidgee (1975–95)</u>	94
<u>Figure 6.1a</u>	<u>Cumulative distribution function for average monthly salt load (t/month) time series at end of system for Border Rivers (Macintyre)</u>	100
<u>Figure 6.1b</u>	<u>Cumulative distribution function for average monthly EC ($\mu\text{S.cm}^{-1}$) time series at end of system for Border Rivers (Macintyre)</u>	101
<u>Figure 6.1c</u>	<u>Cumulative distribution function for average monthly salt load (t/month) time series at end of system for Border Rivers_2 (Gil Gil Creek @ Galloway)</u>	101
<u>Figure 6.1d</u>	<u>Cumulative distribution function for average monthly EC ($\mu\text{S.cm}^{-1}$) time series at end of system for Border Rivers_2 (Gil Gil Creek @ Galloway)</u>	102
<u>Figure 6.2a</u>	<u>Predicted change in average annual salt load and EC for Gwydir Catchment at EOS under cap scenario conditions</u>	103
<u>Figure 6.2b</u>	<u>Cumulative distribution function for average monthly salt load (1000 t/month) time series at end of system for Gwydir</u>	104
<u>Figure 6.2c</u>	<u>Cumulative distribution function for average monthly EC ($\mu\text{S.cm}^{-1}$) time series at end of system for Gwydir</u>	104

<u>Figure 6.3a</u>	<u>Predicted change in average annual saltload and EC for Namoi Catchment at EOS under cap conditions.</u>	106
<u>Figure 6.3b</u>	<u>Cumulative distribution function for average monthly salt load (1000t/month) time series at end of system for Namoi</u>	107
<u>Figure 6.3c</u>	<u>Cumulative distribution function for average monthly EC ($\mu S.cm^{-1}$) time series at end of system for Namoi</u>	107
<u>Figure 6.4a</u>	<u>Predicted change in average annual salt load and EC for Castlereagh Catchment at EOS under cap conditions.</u>	109
<u>Figure 6.4b</u>	<u>Cumulative distribution function for average monthly salt load (1000 t/month) time series at end of system for Castlereagh</u>	109
<u>Figure 6.4c</u>	<u>Cumulative distribution function for average monthly EC ($\mu S.cm^{-1}$) time series at end of system for Castlereagh</u>	110
<u>Figure 6.5a</u>	<u>Predicted change in average annual saltload and EC for Macquarie Catchment at EOS under cap conditions.</u>	111
<u>Figure 6.5b</u>	<u>Cumulative distribution function for average monthly salt load (1000 t/month) time series at end of system for Macquarie</u>	112
<u>Figure 6.5c</u>	<u>Cumulative distribution function for average monthly EC ($\mu S.cm^{-1}$) time series at end of system for Macquarie</u>	113
<u>Figure 6.5d</u>	<u>Predicted change in average annual saltload and EC for Bogan River Catchment at EOS using observed flows.</u>	114
<u>Figure 6.5e</u>	<u>Cumulative distribution function for average monthly salt load (1000 t/month) time series at end of system for Bogan River</u>	115
<u>Figure 6.5f</u>	<u>Cumulative distribution function for average monthly EC ($\mu S.cm^{-1}$) time series at end of system for Bogan River</u>	115
<u>Figure 6.6a</u>	<u>Predicted change in average annual saltload and EC for Lachlan Catchment at EOS under cap conditions.</u>	117
<u>Figure 6.7a</u>	<u>Predicted change in average annual saltload and EC for Murrumbidgee Catchment at EOS under cap conditions.</u>	118
<u>Figure 6.7b</u>	<u>Cumulative distribution function for average monthly salt load (1000t/month) time series at end of system for Murrumbidgee</u>	119
<u>Figure 6.7c</u>	<u>Cumulative distribution function for average monthly EC ($\mu S.cm^{-1}$) time series at end of system for Murrumbidgee</u>	119
<u>Figure 6.8</u>	<u>Average annual salt contribution by contributing subcatchment, 1998</u>	122
<u>Figure 6.9</u>	<u>Average annual salt contribution by contributing subcatchment, 2020</u>	122
<u>Figure 6.10</u>	<u>Average annual salt contribution by contributing subcatchment, 2050</u>	122
<u>Figure 6.11</u>	<u>Average annual salt contribution by contributing subcatchment, 2100</u>	122
<u>Figure 7.1</u>	<u>Schematic diagram of the CATSALT model</u>	127
<u>Figure 7.2</u>	<u>Schematic diagram of the SMAR model</u>	128
<u>Figure 7.3</u>	<u>Kyeamba salinity hazard map</u>	129
<u>Figure 7.4</u>	<u>Comparison of daily observed and simulated streamflow (SMAR) and error updating model for Kyeamba at Ladysmith</u>	131

<u>Figure 7.5</u>	<u>Comparison of annual precipitation and simulated actual evaporation and streamflow (SMAR) and error updating model for Kyeamba at Ladysmith</u>	131
<u>Figure 7.6</u>	<u>Comparison of simulated annual surface runoff, groundwater runoff and total simulated streamflow from SMAR for Kyeamba at Ladysmith</u>	131
<u>Figure 7.7</u>	<u>Comparison of observed and estimated daily saltload for Kyeamba valley</u>	132
<u>Figure 7.8</u>	<u>Cumulative distribution function of observed and estimated saltloads</u>	132
<u>Figure 7.9</u>	<u>Cumulative distribution function of observed and simulated saltloads for 2020 2050 and 2100 for Kyeamba valley (1975–92)</u>	132

LIST OF TABLES

<u>Table 4.1</u>	<u>Water level change and salinity statistics for Reconnaissance Bore Catchments</u>	27
<u>Table 4.2a</u>	<u>Distribution of estimated groundwater salinity, by catchment and geological unit</u>	28
<u>Table 4.2b</u>	<u>Distribution of estimated water level change, by catchment and geological unit</u>	28
<u>Table 4.3</u>	<u>Estimated factors for increased potential salinised areas, as indicated by watertable less than 2m, by catchment and geological unit</u>	30
<u>Table 4.4</u>	<u>Estimated salt load delivered to the land surface by catchment and geological unit</u>	31
<u>Table 5.1</u>	<u>Average annual salt export rate and model parameter values for the Border Rivers Catchment based on 1975–95 conditions</u>	41
<u>Table 5.2</u>	<u>Results of the salt balance analysis of Border Rivers catchments based on 1975–95 conditions</u>	42
<u>Table 5.3</u>	<u>Average annual salt export rate and model parameters for Gwydir Catchment based on 1975–95 conditions</u>	51
<u>Table 5.4</u>	<u>Results of the salt balance analysis for the Gwydir Catchment based on 1975–95 conditions</u>	58
<u>Table 5.5</u>	<u>Average annual salt export rate and model parameter values for the Namoi Catchment based on 1975–95 conditions</u>	61
<u>Table 5.6</u>	<u>Results of the salt balance analysis for Namoi Catchment based on 1975–95 conditions</u>	62
<u>Table 5.7</u>	<u>Average annual salt export rate and model parameter values for the Macquarie-Bogan Rivers Catchment based on 1975–95 conditions</u>	73
<u>Table 5.8</u>	<u>Results of the salt balance analysis for Macquarie Catchment based on 1975–95 conditions</u>	80
<u>Table 5.9</u>	<u>Average annual salt export rate and model parameter values for the Lachlan Rivers Catchment based on 1975–95 conditions</u>	82
<u>Table 5.10</u>	<u>Results of the salt balance analysis for Lachlan Catchment based on 1975–95 conditions</u>	87

<u>Table 5.11</u>	<u>Average annual salt export rate and model parameters values for the Murrumbidgee Rivers Catchment based on 1975–95 conditions</u>	89
<u>Table 5.12</u>	<u>Results of the salt balance analysis for Murrumbidgee Catchment based on 1975–95 conditions</u>	90
<u>Table 6.1</u>	<u>Scaling factors for second order catchments relative to ‘current’ potential salt loads</u>	96
<u>Table 6.2</u>	<u>Ratio of observed in-stream salt loads to groundwater derived potential salt loads for second order catchments</u>	98
<u>Table 6.3</u>	<u>‘Current’ and predicted average annual salt exports under cap flow conditions for the NSW component of the Border Rivers Sub-basin</u>	99
<u>Table 6.4</u>	<u>‘Current’ and predicted average annual salt concentration (EC) under cap flow conditions for the NSW component of the Border Rivers Sub-basin</u>	99
<u>Table 6.5</u>	<u>‘Current’ salt load for contributing sub-catchments in the Macintyre River system</u>	100
<u>Table 6.6</u>	<u>Gwydir River contributing sub-catchment salt loads for ‘current’ and future conditions using basin wide scaling factors.</u>	105
<u>Table 6.7</u>	<u>Namoi River contributing sub-catchment salt loads for ‘current’ and future conditions using individual scaling factors, area weighted for geology</u>	108
<u>Table 6.8</u>	<u>Macquarie River contributing sub-catchment salt loads for ‘current’ and future conditions using individual scaling factors, area weighted for geology</u>	113
<u>Table 6.9</u>	<u>Lachlan River contributing sub-catchment salt loads for ‘current’ and future conditions using individual scaling factors, area weighted for geology</u>	117
<u>Table 6.10</u>	<u>Murrumbidgee River contributing sub-catchment salt loads for ‘current’ and future conditions using individual scaling factors, area weighted for geology</u>	120
<u>Table 6.11</u>	<u>Redistribution of salt load in the landscape by catchment</u>	123
<u>Table 7.1</u>	<u>Area of each hazard category under ‘current’ conditions and associated soil salinity values in Kyeamba Creek catchment</u>	126
<u>Table 7.2</u>	<u>Saline and non-saline area (km^2) under ‘current’ conditions and at target dates</u>	126
<u>Table 7.3</u>	<u>Comparison of average annual salt load with and without CATSALT model for Kyeamba Creek at Ladysmith for 1975–92 climatic conditions</u>	130

Summary

Across the Murray Darling Basin stream borne salt loads are expected to increase in response to a general rising trend in groundwater levels, induced by both irrigation and dryland landuse.

How much salt will be carried in the Murray and Darling tributary rivers of NSW as a result of dryland salinisation processes and rising groundwater during the coming century is the primary question addressed in this study. Secondary questions regarding the impacts of water salinity changes on river water end uses such as irrigation, urban water supply and wetland ecosystems are also addressed broadly. However, the study does not seek to accurately assess the areal extent or severity of land salinisation.

An assessment of the potential salt load discharging to the land surface from groundwater under 'current' (as estimated for 1998) conditions and at future target dates is calculated using a surrogate area term by catchment and geological unit. On a whole catchment basis, total salt delivery is currently calculated in a range of from 0.3 to 26 $t.km^{-2}.year^{-1}$ with rates within catchments as high as 76 $t.km^{-2}.year^{-1}$ in some geological units. This salt represents the load, which is potentially available from the groundwater store, from which part or all may possibly enter the streams via washoff and base flow. The actual amount calculated is less important than the estimated relative rate of change.

The assessment of groundwater derived potential salt loads has been undertaken with the single expressed purpose of establishing relative rates of change within geological units in each catchment. The change factors obtained are used to scale the patterns of river flow and salt load already observed during the 1975 to 1995 assessment period, to predict future salt load scenarios at the target dates 2020, 2050 and 2100.

The overall rates of change are primarily a function of the rate of groundwater level rise. Assessed on the basis of geological units within secondary basins, these rates of groundwater level rise vary from negative values to greater than 0.4 metres per year. The overall rates of change vary across catchments from a no change scenario in the Macintyre Catchment to a 335% increase by 2100 in the Macquarie and Bogan River Catchments. In most catchments the salt loads are predicted to more than double in the next 100 years, assuming no change in management and a continuation of similar climate variability to that observed in the assessment period. These values are not inconsistent with trends identified within the stream record by Williamson *et al.*, 1997.

Third order catchments of approximately 500–1500 km^2 generally contain only one or two landcare groups. As such they are ideal units in which to frame policy and community collaboration in a total catchment management environment. This strategic level of investigation has enabled:

- Identification of the relative contributions from third order catchments to the end of stream salt load, providing a framework for prioritising catchments for management intervention.
- Identification and quantification of the pattern of contribution across second order catchments, showing clearly that the upland third order catchments are the main sources of salt load accumulating in the second order main streams.
- Identification and quantification of the temporal (time) and spatial (location) pattern of water salinity, by third order catchment and reach along the second order main streams, enabling the assessment of impacts on: urban water supplies, irrigation diversions and wetland ecosystems.

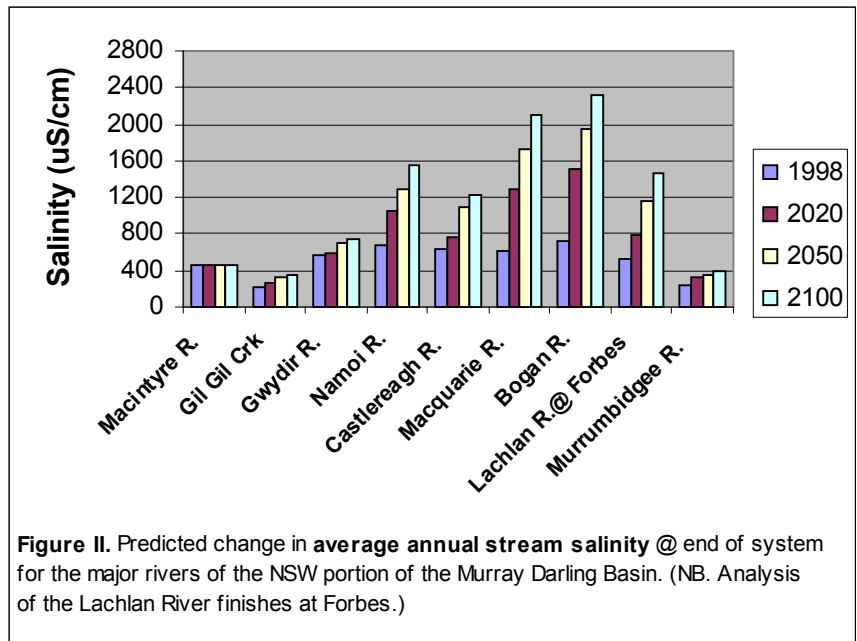
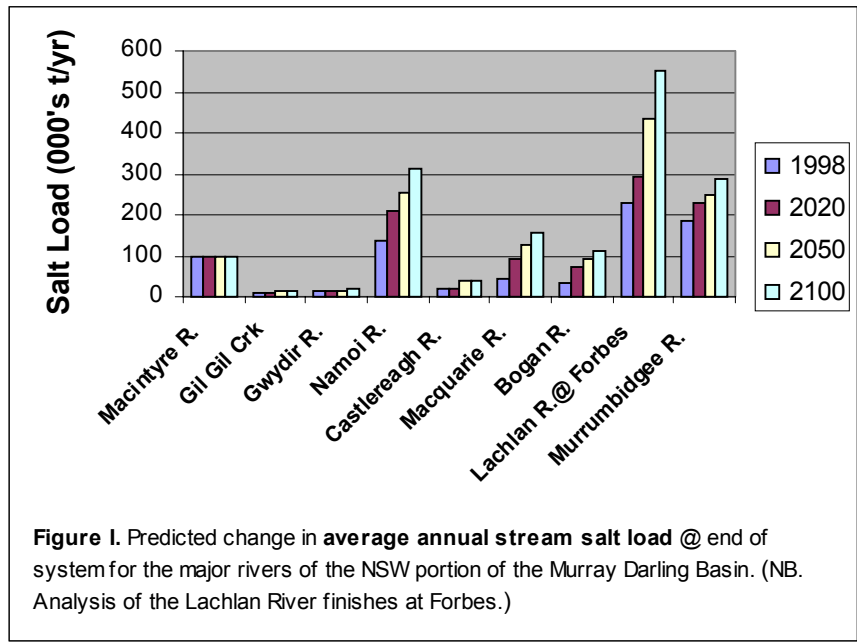
The statistical structure of daily streamflow and salt load over the assessment period 1975–1995 has been established for all contributing third order streams within the second order catchments, as well as at several locations on the main stream. Daily salt loads from the third order catchments are aggregated to monthly values and summed to estimate the cumulative salt mass balance at each of the mainstream locations. The summed estimates are compared to the monthly salt loads observed at the balance points as a check. Losses from the mainstream to wetlands, irrigation areas, stream braiding and other losses are also accounted for. Adjustment of flows to reflect the Murray Darling Basin cap conditions, applicable to each catchment is performed to produce a twenty-one year time series of monthly cap flow, salt load and salinity. Where there is not yet an agreed official cap established for a valley a probable cap scenario has been used.

End of stream average annual salt load and salinity under ‘current’ and predicted conditions are summarised across the basin in Figures I and II.

The Lachlan River analysis was restricted to the catchment above Forbes. The comparatively high salt load apparent in the graph represents the load which is redistributed back into the landscape below Forbes via irrigation diversions and deposition in terminal wetlands. For the remainder of the rivers the end of stream salt load values represent the reduced loads after accounting for diversions for irrigation and losses to wetlands. The translocation of salt, accumulated from the upland contributing third order catchments, back into the landscape, in the lower reaches of the system, sometimes exceeds the salt load exported from the second order catchments. This is an important fact with far reaching implications for land management planning and policy development.

The highest ‘end of stream’ salt loads are found in the Namoi and Murrumbidgee Rivers. However, the salinity impact of the load differs markedly due to the relative dilution from flow volumes in each river. Salinity is conveniently measured as the electrical conductivity of a water or soil sample in $\mu S.cm^{-1}$, where 1 EC unit = 1 $\mu S.cm^{-1}$ at 25° C. River salinities in the Namoi, Castlereagh, Macquarie, Bogan and Lachlan rivers are predicted to exceed the World Health Organisation (WHO) safety limit

for drinking water, of 800 EC, on an average annual basis; and on an average monthly basis with increasing frequency, during the next century.



The rate of addition of cyclic salt deposited in rainfall varies across the basin, generally in the range of 1 to 4 $t.km^{-2}.year^{-1}$. Average salt export rates from third order catchments currently vary from 2 to 48 $t.km^{-2}.year^{-1}$ indicating considerable variation in the degree of salt imbalance currently expressed across the basin. Across the State, the average annual salt export rate for all the third order catchments assessed is currently 14 $t.km^{-2}.year^{-1}$, and is predicted to increase to 20, 25 and

30 $t.km^{-2}.year^{-1}$ respectively at 2020, 2050 and 2100, if the observed rates of groundwater rise continue. The maximum rate for any individual catchment is predicted to increase from the 'current' 48 $t.km^{-2}.year^{-1}$ to 59, 65, and 87 $t.km^{-2}.year^{-1}$ at 2020, 2050 and 2100.

As not all salt brought to the surface through groundwater rise is mobilised to rivers; there is also a change in superficial salt store occurring indicating potentially large increases in land salinisation.

The salt load generated per unit area is in itself not necessarily indicative of the salinity risk associated with a particular catchment. Two catchments that generate a similar load per unit area may exhibit very different salinity profiles due to differences in flow and dilution. Cumulative distribution functions for stream salinity have been calculated for each third order catchment and at all balance points for each second order basin. Streams and reaches have been classified with respect to the probability of average monthly stream salinity exceeding critical threshold values of 800 and 1600 EC under 'current' conditions and at the target dates. Basin wide changes are portrayed in Figures III to XIV where contributing streams and river reaches are colour coded according to the probability of exceedance of these thresholds.

Threshold salinity values of 800 and 1600 EC were chosen to represent risks associated with human consumption, irrigation of sensitive crops and wetland ecosystem health. The World Health Organisation (WHO) recommended limit for safe drinking water is 800 EC while the absolute potable limit for human consumption is 2500 EC (Taylor 1993). For irrigation, salinities of 280 to 800 EC are capable of causing damage to sensitive crops, requiring moderate leaching and restricting the method of application. Soils with poor drainage are generally unsuitable for irrigation with water salinity in the range 800 to 2300 EC, due to a requirement for high levels of leaching. Additional leaching fractions applied will accelerate the formation of groundwater mounds and shallow water tables in irrigation districts and only tolerant species can be grown.

It is suggested that direct adverse biological effects are likely to occur in Australian river stream and wetland ecosystems when salinity levels reach 1560 EC ($1000\text{ mg.L}^{-1} = 0.64\text{ EC in } \mu S.cm^{-1}$). Water with salinity greater than 4700 EC is considered distinctly saline by ecologists as they are typically inhabited by different biota, not found in waters of lower salinity. A number of tributary catchments, particularly in the Macquarie, are likely to exceed this higher figure in 10% to 35% of months over the target dates.

The fate of salt generated in the upland tributary catchments, by redistribution within the landscape and export to the Murray and Darling Rivers, is described in the following valley by valley overview.

Border Rivers

No groundwater driven change to river salt loads has been predicted within the boundary of the Border Rivers Catchment in NSW. Current patterns of salt mobilisation and redistribution in the Macintyre River System are expected to continue for the duration of the coming century. An average annual flow of 760 GL exports 95 400 $t.year^{-1}$ of salt at the end of system, at an average annual salinity of 449 EC. Average annual irrigation diversions of 209 GL (cap scenario) redistribute 12 900 $t.year^{-1}$ back into the agriculturally productive landscape. A further 3600 $t.year^{-1}$ is redeposited in wetlands and other losses between Boggabilla and the Barwon River. Contributing tributary catchments export an average of 9 $t.km^{-2}.year^{-1}$ with maximum export rates of 16 and 14 $t.km^{-2}.year^{-1}$ originating in Frazers Creek and the Severn River below Pindari Dam.

Gil Gil Creek, which has its outlet on the Barwon River, lies within the Border Rivers Catchment, but receives water from the Gwydir via Carole Creek in the Gwydir Catchment. Increasing salt trends in the Gwydir Catchment result in predicted rises in salt load from Gil Gil Creek from the ‘current’ average annual load of 10 900 $t.year^{-1}$ to 11 800, 13 600 and 13 800 $t.year^{-1}$ at 2020, 2050 and 2100 respectively.

Within the valley are seven urban centres, with a total population of 25 300, that use water from rivers and creeks. Water salinity is expected to remain well below the critical threshold level of 800 EC almost constantly except in Ottleys Creek and the Beardy River where it currently exceeds this value in 30% of months.

An overview of the probability of exceeding threshold values of 800 and 1600 EC for streams and reaches is shown in Figures III and IV. The relatively fresh water in the Macintyre indicates few if any salinity problems associated with irrigation in the valley.

Gwydir River

In the Gwydir River Catchment, salt loads observed in the river at Pallamallawa already grossly exceed the estimated discharge of salt to the surface from groundwater in the area of the valley contributing to river salinity. This discrepancy has been taken into account in estimating the rates of change applicable to the whole catchment. However, it also indicates that dryland salinisation processes may be poorly recognised, and that the ‘current’ bore network is not truly representative and is inadequate for appropriate monitoring.

The valley contains wetlands of high environmental significance and considerable areas of irrigation development below Pallamallawa. Salt accumulating to this point, with further additions from Tycannah Creek, is redistributed back into the landscape via irrigation and in wetlands. Overall rates

of change are relatively low, intermediate with no change in the adjacent Border Rivers and moderate rates predicted in the Namoi. On the whole, the majority of salt generated in the upland catchments is redistributed back into the landscape between Tycannah Creek and the end of system in irrigation diversions, over bank flood flows or in the wetlands. The Gwydir and Meehi Rivers deposit salt into the Barwon Darling System in average annual cap scenario flows of 56 GL per year. The average annual salt load exported under 'current' and predicted future conditions is 12 350, 13 300, 16 200 and 17 300 $t.year^{-1}$ at 1998, 2020, 2050 and 2100. Corresponding average annual salinity values are predicted to rise from 560 EC to 600, 700 and 743 EC.

Average annual cap scenario irrigation diversions of 319 GL are predicted to redistribute salt loads increasing from 81 950 $t.year^{-1}$ to 87 450, 104 650 and 111 200 $t.year^{-1}$ back into the landscape. Salt lost to the Gwydir Wetlands and other losses are predicted to rise from 64 800 to 69 100 $t.year^{-1}$, and from 82 700 to 87 900 $t.year^{-1}$ respectively. The distribution of salinity values calculated at Pallamallawa is expected to be representative of the water salinity available in diversions, entering the wetlands and available for stock and domestic use in the lower reaches of the system. A threshold salinity of 800 EC for irrigation and drinking water is currently exceeded in 14% of months and is predicted to be exceeded in 27% of months by 2100. A critical salinity for wetland ecosystem health of 1600 EC is 'currently' only exceeded infrequently but may be exceeded in 12% of months by 2100.

During floods the Gwydir wetlands can be considered a flow through system, and impacts will probably be localised to individual areas within the system as the water evaporates and salinity is concentrated in pools or depressions. Lower flows with higher salinity entering the wetland areas will potentially lead to scalding as evaporation and concentration proceeds. By 2100, given current rates of change, salinity levels capable of adversely affecting the biota, particularly the aquatic plant communities will be exceeded for approximately 1.5 months of the year.

An overview of the probability of exceeding threshold values of 800 and 1600 EC for streams and reaches is shown in Figures V and VI.

Four towns with less than 3000 inhabitants draw water supplies directly from rivers and creeks within the catchment or from bores influenced by them. The average annual salt export from the 17 tributary catchments contributing salt above Pallamallawa is currently 12 $t.km^{-2}.year^{-1}$ rising to 16 $t.km^{-2}.year^{-1}$ in 2100. Rates as high as 29 and 25 $t.km^{-2}.year^{-1}$ are currently observed in Halls Creek and the Horton River. The Warialda Creek Catchment currently exports 9 $t.km^{-2}.year^{-1}$ and exceeds 800 EC in 52% of months and 1600 EC in 33% of months, with the predicted situation deteriorating to 60% and 40% in 2100. Warialda, however, does not take its water from this creek.

Figure (III) Probability of exceeding a monthly average threshold salinity of $800 \mu S.cm^{-1}$ for streams in the Macintyre River Catchment (Basin 416) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Figure (IV) Probability of exceeding a monthly average threshold salinity of $1600 \mu S.cm^{-1}$ for streams in the Macintyre River Catchment (Basin 416) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Figure (V) Probability of exceeding a monthly average threshold salinity of $800 \mu S.cm^{-1}$ for streams in the Gwydir River Catchment (Basin 418) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Figure (VI) Probability of exceeding a monthly average threshold salinity of $1600 \mu S.cm^{-1}$ for streams in the Gwydir River Catchment (Basin 418) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Namoi River

The Namoi River exports large quantities of salt to the Barwon River. ‘Current’ export rates are more than for the Macquarie, Bogan, Castlereagh and Gwydir combined. They are predicted to increase (for cap scenario conditions) from 135 600 $t.year^{-1}$ to 208 200, 255 900 and 312 100 $t.year^{-1}$ at 2020, 2050 and 2100 respectively. Corresponding salinity increases, though alarming, are somewhat mitigated by greater dilution flows.

Average flow at the end of the Namoi System is 503 GL per year with the ‘current’ average salinity of 680 EC predicted to increase to 1050, 1280 and 1550 EC at 2020, 2050 and 2100 respectively. In the Namoi, additional salt inflow from alluvial aquifers in the reach between the last balance point and the end of system has been accounted for. Irrigation diversions of 240 GL per year currently carry an annual average salt load of 55 200 $t.year^{-1}$ climbing to 83 200, 101 500 and 123 100 $t.year^{-1}$ at the target dates. The corresponding average annual salinity of the irrigation water, which reflects the values at the last balance point, is expected to rise from 630 EC to 980, 1190 and 1140 EC.

High quality, floodplain aquifers are subject to groundwater pumping in the Namoi and levels are generally static or falling. These aquifers are recharged during flood flows and are obviously storing a proportion of the increasing salt load present in these events. However, the salinity, rather than the salt load associated with the period of recharge, will determine the impact on groundwater salinity, which is expected to fall within the most favourable segment of the river salinity variability.

Although there are further salt additions coming from flood wash off and base flow from downstream alluvial aquifers, the distribution of average monthly water salinity at Boggabri is applicable for assessing the probable impacts on irrigation diversions, and urban water supplies. Here, a threshold salinity of 800 EC is currently exceeded in 20% of months and is predicted to overstep this value in 39%, 48% and 63% of months in 2020, 2050 and 2100. The critical threshold of 1600 EC is at present exceeded in 6% of months, rising in probability to 11%, 20% and 27% of months. Further upstream at Gunnedah, the picture is much the same; and at gauging station 419 007, below Keepit Dam, 800 EC is now exceeded in only 2% of months. However, this situation is predicted to deteriorate to 28%, 36% and 42% of months in 2020, 2050 and 2100. This is relevant to the five towns, with a total population of 49 900, that draw their water supply from the river and tributaries. A further six towns draw their water from alluvial bores that are potentially influenced by the salinity of recharge from rivers.

Salt exports in tributary streams above Boggabri, vary from 2 to 24 $t.km^{-2}.year^{-1}$ with an average of 10 $t.km^{-2}.year^{-1}$ under 'current' conditions. This average is predicted to increase to 15, 18 and 21 $t.km^{-2}.year^{-1}$ with the maximum individual catchment reaching 45 $t.km^{-2}.year^{-1}$ in the Peel River at Chaffey Dam by 2100. However, the Peel River at this point is not expected to exceed 800 EC during the coming century. By contrast, Goonoo Goonoo Creek at Timbumburi, which 'currently' exports 18 $t.km^{-2}.year^{-1}$ and is predicted to reach 39 $t.km^{-2}.year^{-1}$ by 2100, exceeds 800 EC in 42% of months 'currently' and is predicted to exceed 800 EC in 50%, 55% and 65% of months in 2020, 2050 and 2100.

An overview of the probability of exceeding threshold values of 800 and 1600 EC for streams and reaches is shown in Figures VII and VIII.

Castlereagh

Groundwater trends in the Castlereagh Catchment indicate moderate rates of change. 'Current' in stream salt loads are less than one eighth of the calculated 'current' potential groundwater salt load discharge. While observed surface expression of dryland salinity has not yet become widespread, groundwater rates of rise indicate a 22% increase in potential discharge by 2020 and a 99% increase by 2050.

River salt prediction in the valley has been undertaken only on the basis of observed flow and salt load at Coonamble. Further analysis of upland tributary catchments was not possible due to a lack of stream flow and salinity data. 'Current' annual average salt loads exported from the valley are expected to increase from 19 500 $t.year^{-1}$ to 21 500, 39 000 and 41 000 $t.year^{-1}$ in 2020, 2050, and 2100 respectively. The associated annual average river salinity is predicted to rise from 640 EC to 760, 1100 and 1230 EC, respectively. The threshold of 800 EC is currently exceeded at Coonamble in

30% of months but is predicted to exceed it in 32% of months in 2020 and 45% in 2050 and 2100. The probability of average monthly salinity exceeding 1600 EC is currently 20%, increasing to 21% in 2020 and 30% in 2050 and 2100. The valley contains two towns, with a total population of 4100 people, that take their water supply from the river. A further two towns with more than 3000 people use water from bores in alluvial aquifers. There are no significant diversions of water for irrigation and no significant losses to wetlands in the valley. Redistribution of salt into the landscape is almost always associated with flooding of the lower valley floodplains.

Macquarie River

The Macquarie River valley includes the Bogan River. The average outflow from both rivers to the Barwon-Darling was 150 GL and 234.5 GL respectively over the assessment period. Twenty-one defined sub-catchments contribute to the flow and salt load in the Macquarie River above Narromine. From this point on, substantial diversions for irrigation redistribute a significant proportion of the salt load back into the landscape and a somewhat greater proportion is deposited in the Macquarie Marshes before the remainder is exported from the valley.

Groundwater driven rates of change in salt mobilisation to the surface are high, with valley wide factors expected to increase salt loads in the rivers by 2.07, 2.79 and 3.35 times the ‘current’ base value in 2020, 2050 and 2100 respectively.

The estimated breakdown of the fate of ‘current’ and future average annual salt loads downstream of Narromine is shown in the following table.

Year	Macquarie River @ Narromine	Diversions for Irrigation	Wetlands and other losses	Stock & Domestic Water Supply	End of System
Average tonnes per year					
1998	234 400	77 900	111 600	1 000	43 900
2020	508 400	169 850	243 250	2 200	93 100
2050	677 400	225 350	322 750	2 900	126 400
2100	818 900	271 800	389 300	3 500	154 300

There is no significant development of irrigation in the Bogan Valley. Output of salt from the Bogan River is predicted to increase from the ‘current’ average of 33 800 *t.year*⁻¹ to an average of 70 900, 94 500 and 111 400 *t.year*⁻¹ in 2020, 2050 and 2100.

At the end of system, the average annual salinity in the Macquarie is predicted to rise from 620 to 1280, 1730, and 2110 EC and in the Bogan River, from 730 to 1500, 1950 and 2320 EC in 2020, 2050 and 2100, respectively. At Narromine, the threshold water salinity value of 800 EC for human consumption and irrigation of sensitive crops, is ‘currently’ exceeded on an average monthly basis 10% of the time. However, the 800 EC threshold is predicted to be exceeded 30%, 55%, and 83% of

the time in 2020, 2050 and 2100. There are twelve urban centres, with a combined population of 65 500, that use water from rivers and creeks within the valley. This includes Dubbo with a population of more than 34 000.

Figure VII. Probability of exceeding a monthly average threshold salinity of $800 \mu\text{S.cm}^{-1}$ for streams in the Namoi River Catchment (Basin 419) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Figure VIII. Probability of exceeding a monthly average threshold salinity of $1600 \mu\text{S.cm}^{-1}$ for streams in the Namoi River Catchment (Basin 419) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

The threshold of 1600 EC, critical for wetland ecosystems health, is currently exceeded in less than 5% of months. However, this exceedance probability is predicted to deteriorate to 10%, 15% and 20% of the time in 2020, 2050 and 2100, respectively. The Macquarie Marshes is a predominantly flow through system, as opposed to a terminal basin, and the impacts will be localised to individual areas within the system as the water evaporates and salinity is concentrated into pools or depressions. Based on the monthly exceedance probabilities above, for approximately three months per year, flows would adversely affect the Macquarie Marshes in 2100. This could be assumed to occur in low flow conditions but could still significantly affect instream biota and hence the recruitment of biota into and between wetland areas. This would have a significant impact on the Marshes with expected loss of species diversity and composition (which would begin to be impacted at 1600 EC or lower, beginning in 2020 or later). The high salinity levels would also lead to increasing salinity within wetlands isolated from the main river channel with potential salt scalding occurring in these areas as the saline waters are further concentrated.

One implication of this change in salinity levels in the Macquarie River could be that the 50 GL environmental water allocation for the Marshes, currently nominated to assist bird breeding, may need to be used for water quality control to flush any saline areas that may occur.

Deterioration of tributary catchments in the Macquarie is likely to be more severe and widespread than in most other valleys within the State. The average tributary catchment exports $12 \text{ t.km}^{-2}.\text{year}^{-1}$ under 'current' conditions with the highest 'current' export rates of 22, 19 and $18 \text{ t.km}^{-2}.\text{year}^{-1}$ coming from the Crudine River, Bell River and Buckinbah Creek. The average tributary export rate is predicted to rise to $23 \text{ t.km}^{-2}.\text{year}^{-1}$ in 2020 with individual catchments as high as $42 \text{ t.km}^{-2}.\text{year}^{-1}$.

An overview of the probability of exceeding threshold values of 800 and 1600 EC for streams and reaches is displayed in Figures IX and X.

Lachlan River

The Lachlan is generally considered to be a terminal river system, only flowing out of the Great Cumbung Swamp to the Murrumbidgee River in flood flows of approximately 1 in 20 years ARI or greater. All salt generated in the upland tributary catchments above Forbes is redistributed back into the landscape in irrigation diversions, flood entrapment, or within this significant wetland environment.

The average annual flow at Forbes is 1147 GL for the assessment period and cap conditions. Of this amount, 306 GL is estimated to be diverted for irrigation below Forbes with the remainder predominantly feeding the wetlands (Transmission losses and flows to Willandra Creek are not accounted for in this study). ‘Current’ salt loads associated with these flows are 227 900 $t.year^{-1}$ at Forbes, 60 800 $t.year^{-1}$ in diversions and 167 100 $t.year^{-1}$ deposited into the wetlands and floodplain. Loads are predicted to rise to 293 700, 78 300 and 215 300 $t.year^{-1}$ respectively in 2020 and to 433 000, 115 500, and 317 500 $t.year^{-1}$ in 2050.

Average annual salinity and its monthly distribution at Forbes is indicative of the concentrations experienced downstream. The ‘current’ annual average salinity of 530 EC is predicted to increase to 780, 1150 and 1460 EC in 2020, 2050 and 2100. The probability of exceedance of the 800 EC threshold is currently 5% but is predicted to deteriorate to 8%, 35% and 60% on an average monthly basis at 2020, 2050 and 2100. Further upstream at Nanami, the distribution is very similar. Average monthly salinities at Forbes, which currently do not exceed 1600 EC, are predicted to reach higher levels in 5% and 12% of months in 2050 and 2100.

Figure IX. Probability of exceeding a monthly average threshold salinity of 800 $\mu S.cm^{-1}$ for streams in the Macquarie River Catchment (Basin 421) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Figure X. Probability of exceeding a monthly average threshold salinity of 1600 $\mu S.cm^{-1}$ for streams in the Macquarie River Catchment (Basin 421) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Average monthly salinities in the Boorowa River at Prossers Crossing are ‘currently’ greater than 800 EC in 57% of months, and are predicted to be greater in 66%, 90% and 100% of months in 2020, 2050 and 2100. At Narrawa North on the Crookwell River, the corresponding probabilities are estimated to jump from 18% ‘currently’ to 32%, 55% and 64% in 2020, 2050 and 2100.

One town draws water from the Lachlan above Wyangala Dam, and five towns with a total population of 17 500 draw water from the downstream reach to Forbes. Three towns with a total population of 5800 draw from the reach to Hillston. Three towns draw water separately from the Boorowa River, the Crookwell River and the Burrangong Rivers.

The Great Cumbung Swamp is considered a terminal basin. However, the water salinity within the wetland is ‘currently’ not significantly higher than the receiving waters from the Lachlan River. This is generally explained by the seepage of water into the shallow groundwater table. This results in the subsequent leaching of salt from the root zones. This process appears to have been operational during the period of the swamp’s development and maintenance.

By 2100, 13% of the time (or approximately one and a half months per year) flows would adversely affect the Great Cumbung Swamp. Daily or weekly variations in salinity levels could also be significant depending on flow regime and source of saline inputs.

Given the predicted variability a potential change in species composition (particularly in the aquatic plant communities) and reduction in species diversity would occur. The area’s potential for a habitat for specific waterbird breeding (particularly for colonial species that rely on fresh water for drinking and invertebrates for feeding) could be reduced. This would change significantly if a groundwater mound developed in the area, prevented further seepage into the groundwater, and led to the area becoming a truly terminal system with increasing salinity concentrations due to evapo-transpiration.

The impact of increasing salinity on the groundwater table requires further investigation. The long term potential for groundwater to rise to levels, within parts of the swamp, that effectively reduce or reverse the ‘current’ leaching of salt, should urgently be assessed since this appears to be the greatest threat to conservation of the ‘current’ wetland values. Fourteen tributary sub-catchments contribute salt above Forbes. They ‘currently’ range in salt output per unit area from 6 to $35 t.km^{-2}.year^{-1}$ with an average of $19 t.km^{-2}.year^{-1}$. This average is set to increase to 24, 35, and $46 t.km^{-2}.year^{-1}$, by 2020, 2050 and 2100.

An overview of the probability of exceeding threshold values of 800 and 1600 EC for streams and reaches is displayed in Figures XI and XII.

Murrumbidgee River

Of the 17 tributary sub-catchments above Wagga Wagga in the Murrumbidgee valley, several currently contribute the highest average annual salt loads per unit area found anywhere in the NSW portion of the Murray Darling Basin. Loads currently range from 4 to $48 t.km^{-2}.year^{-1}$ and are predicted to expand to 6 to $74 t.km^{-2}.year^{-1}$ by the end of the 21st century. Salt exports from the whole

Murrumbidgee valley are the highest also, yet water salinity in the Murrumbidgee is currently the best in the State and is expected to remain so.

Four urban centres (total population 341 500), including Canberra, use substantial quantities of river water from the catchment above Burrinjuck Dam. Thirteen centres with a total population of greater than 50 000 obtain water from the Jugiong off-take. From Jugiong to Wagga Wagga a further five centres, including two on the Tumut River system, draw water for more than 63 000 people. Water from the Murrumbidgee at Narrandera services 50 000 people in 14 centres and a further two towns are supplied between Narrandera and Balranald. As can be seen from Figures XIII and XIV, none of these water supplies is expected to be threatened by salinity in the next 100 years.

Substantial irrigation diversions are fed from the Murrumbidgee below Wagga Wagga and significant wetlands also exist in the lower reaches of the system. Of the average annual flow of 4592 GL under cap conditions at Wagga Wagga, 2424 GL is diverted for irrigation, 19 GL is used for stock and domestic water supply, 799 GL is deposited in wetlands and 1350 GL flows out to the Murray River at end of system. The accompanying estimated salt loads are summarised in the table below.

Year	Murrumbidgee River @ Wagga Wagga	Diversions for Irrigation	Wetlands and other losses	Stock & Domestic Water Supply	End of System
Average tonnes per year					
1998	401 800	162 700	53 600	1300	184 200
2020	482 300	189 050	62 300	1500	229 450
2050	529 100	208 100	68 600	1650	250 750
2100	607 400	240 000	79 100	1900	286 400

Water salinity for downstream uses is expected to reflect the same concentration and variability as at Wagga Wagga where threshold values of 800 EC and 1600 EC will remain well above the range of average monthly EC predicted for the coming century. Tributary catchments such as Muttama Creek and Jugiong Creek already exceed 800 EC in 35% and 77% of months and 1600 EC in 20% and 33% of months respectively. An overview of the probability of exceeding threshold values of 800 and 1600 EC for streams and reaches is displayed in Figures XIII and XIV.

Figure XI. Probability of exceeding a monthly average threshold salinity of 800 $\mu\text{S.cm}^{-1}$ for streams in the Lachlan River Catchment (Basin 412) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Figure XII. Probability of exceeding a monthly average threshold salinity of 1600 $\mu\text{S.cm}^{-1}$ for streams in the Lachlan River Catchment (Basin 412) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Figure XIII. Probability of exceeding a monthly average threshold salinity of $800 \mu\text{S.cm}^{-1}$ for streams in the Murrumbidgee River Catchment (Basin 410) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Figure XIV. Probability of exceeding a monthly average threshold salinity of $1600 \mu\text{S.cm}^{-1}$ for streams in the Murrumbidgee River Catchment (Basin 410) for (a) 1998 (b) 2020 (c) 2050 (d) 2100 conditions

Murray River

The contribution of salt to the River Murray from the Upper Murray River tributaries in NSW has not been fully assessed as complex diversion and regulation effects occur en route to the Murray. Salt exports from the Tooma River, Jingellic Creek and Billabong Creek above Walbundrie have been calculated. Only one town high in the headwaters has been identified as using water from the river in this part of the valley, where water salinity is not expected to pose any threat.

The Jingellic Creek Catchment has an area of 378 km^2 and an average annual salt load of $12.2 \text{ t.km}^{-2}.\text{year}^{-1}$ under 'current' conditions. This is predicted to rise to 17, 19 and $29 \text{ t.km}^{-2}.\text{year}^{-1}$ in 2020, 2050 and 2100 respectively. The Tooma River Catchment is 1890 km^2 in area and currently carries an average annual salt load of $8.5 \text{ t.km}^{-2}.\text{year}^{-1}$. The predicted average salt loads from the Tooma River are 12, 13 and $20 \text{ t.km}^{-2}.\text{year}^{-1}$ in 2020, 2050 and 2100 respectively. The Upper Billabong Catchment above Walbundrie has an area of 3065 km^2 and an average annual salt load of $10.2 \text{ t.km}^{-2}.\text{year}^{-1}$, predicted to increase to 14, 15 and $19 \text{ t.km}^{-2}.\text{year}^{-1}$, in 2020, 2050 and 2100 respectively.

Billabong Creek flows into the Edward River before entering the Murray River. Coleambally and Berriquin drains and Yanco Creek also influence the flows and salinity in the lower reaches of the Billabong Creek. The Edward River flow and salinity are determined by diversions coming from the Murray River and Mulwala Canal and diversions into the irrigation districts. Worsening conditions in Upper Billabong Creek may have adverse effects on irrigation diversions in its lower reaches but quantifying that impact was not attempted in this study.

Further Issues

It is evident that irrigation areas, floodplains and wetlands act as sinks in which salt is currently accumulating. With rising salt loads and higher salinities, the longevity of this process before these sinks themselves become further sources of salt is not known. It will depend on the rate of addition, the status of the watertable, and the management of the rivers by regulation as well as land management intervention and water-use access rules.

In both irrigation and wetland ecosystems, the seasonal average salinity and the risk of extremes (spikes) during the season are important as the former determines longer-term accumulation and the latter can cause instant crop or biota damage response. Predicted changes in the Macquarie Valley, in particular, will place the Macquarie Marshes under extreme stress.

Accelerated groundwater rise beneath irrigation areas, exacerbated by additional leaching requirements for practical crop agronomy, has in the past resulted in stored salt being mobilised to the surface in adjacent non-irrigated and low lying sections of the landscape. The irrigation community has in the past, in such circumstances, called for the introduction of drainage and disposal back into the river.

Irrigators will seek to avoid high salinity spikes (which means these will be passed on downstream) and there will be a tendency to build more and larger on-farm storages to intercept freshes. If that was allowed to happen in the more up stream sections of the valley, there could be very serious environmental consequences in the regulated stressed and semi stressed river sections.

In trying to preserve the reliability of their water entitlement, transfers to fresher within valley or inter-valley river sections would be sought. This, of course, would accelerate degradation of salinity and volume in those rivers and their downstream dependants.

For many towns, water supplies are likely to be affected, both in terms of suitability for human consumption and maintenance of infrastructure. Only towns with greater than 500 inhabitants have been assessed in this study. Many towns already obtain water from bores, some of which are augmented with surface water from the river, and can switch between the two to optimise water quality. Ultimately surface water and groundwater are just one resource. Deteriorating surface waters interact with groundwater via recharge processes and groundwater pumping.

As salinity increases, costs will also increase because of corrosion of infrastructure, and industrial and domestic appliances; as well as the added cost of adaptation to appropriate technology, construction of bore fields or storages and purchase of fresh water for sensitive purposes. Salinisation of urban land is also increasing, and in the light of the rising groundwater levels identified in this study is likely to worsen unless proactively addressed.

The areal extent and severity of land salinisation has not been addressed in this study as topography could not be incorporated due to a lack, at the time, of an appropriate digital elevation model. Other data problems were also experienced. A review of the State's surface water and groundwater monitoring networks, including issues of archiving and quality checking, should take into account both the spatial and temporal detail required to effectively assess land and water salinity impacts across the basin.

1 Introduction

1.1 Background

The Murray and Darling Rivers combined form the largest single, surface water drainage basin in Australia. Flows travel through the basin from the eastern States of Queensland, New South Wales, Victoria, South Australia and the Australian Capital Territory. The basin covers one seventh of the landmass of Australia. The largest proportion of the basin is located within NSW.

Prior to European settlement forest and woodland probably covered 520 000 square kilometres or two thirds of the State of NSW. Of this approximately only 210 000 square kilometres remain. The rest of the State was covered by, open-woodland and native grass and shrub-lands. Clearing has continued in recent times. There has been an increase of 86% in the area cleared for cropping in the Western Division, over the twenty years to 1991. Between 1972 and 1980 an average of 430 km^2 were cleared annually and clearing continues today at an estimated 150 km^2 per year (NSW Vegetation Forum 1996).

Much of the basin consists naturally of semi arid rangelands. A large and variable store of salt in the driest parts of the basin is indicated by large tracts of halophytic shrub-understorey in the extensive Mulga woodlands and Belah bluebush woodlands, smaller areas of mallee, Bimble-box pine woodlands, saltbush bluebush downs and saltbush plains. Irrigation areas have been developed on flat ground in the low rainfall zones of the major sub basins, where these semi arid shrub-woodlands once grew. In the higher rainfall zones on the slopes and tablelands of the Great Dividing Range, clearing of the native woodland and forest communities for dryland agriculture and pastoralism has entirely altered the surface and groundwater hydrology. The extent of this clearing is most prevalent in the south east of the basin where dryland salinity has been recognised for the longest time.

There are nine major sub basins in the basin:

- The Condamine-Culgoa Basin
- The Darling River Basin
- The Northern Border Rivers Basin
- The Castlereagh-Macquarie Basin
- The Lachlan River Basin
- The Murrumbidgee-Riverina Basin
- The Goulburn-Upper Murray Basin
- The Loddon-Campaspe Basin and

- The Lower Murray Basin.

Seven of these are located primarily within New South Wales and each may contain several river systems that are dealt with individually in this report. For the remainder of this report, the primary rivers, the Murray and the Darling, are referred to as first order streams or catchments. River basins such as the Murrumbidgee, Macquarie or Namoi rivers are called second order streams or catchments. The smaller tertiary sub-catchment creeks and rivers such as the Kyeamba Creek, the Boorowa River or the Mooki River are referred to as third order streams or catchments.

Water in the basin is utilised by consumers for end uses including irrigation, stock and domestic water supply, industrial water supply, major wetlands of environmental significance, and urban water supply. Deteriorating water quality due to salinity is of concern for all end users. Not only does increasing salinity limit the usefulness of water for these various purposes, but salt also accumulates at the point of use to the detriment of that environment and/or activity. This is particularly important for South Australians at the end of the system where the cumulative impact of upstream salt contribution and management is felt. Water supply pipelines for Adelaide and the Adelaide Hills are supplied from the Murray River at Mannum and Tailem Bend respectively. Measurement of water salinity for the whole system is benchmarked on the Murray River at Morgan in S.A. where the Whyalla, Port Pirie and Port Augusta water supply pipeline begins.

The Murray-Darling Basin Ministerial Council (MDBMC) was established in 1985. The Council's charter is to promote and coordinate effective planning and management for the equitable, efficient and sustainable use of the land, water and environmental resources of the Murray-Darling Basin.

The Salinity and Drainage Strategy of the Murray Darling Basin Commission (MDBC) was adopted by the MDBMC in April 1989. The strategy provided a framework for action, for addressing the problems of river salinity waterlogging and land salinisation. These actions combine engineering works and land management changes in irrigation districts embodied in community based Land and Water Management Plans. The strategy provides for joint action by NSW, Victoria, S.A. and the Commonwealth Governments.

Initially it was thought that salinity and waterlogging associated with irrigation were the dominant problem. Hence the strategy concentrated first on the irrigated areas. However, it has become evident from increased monitoring and data analysis that the salt contribution of the dryland catchments has been grossly under-estimated.

Salinity is conveniently measured as the electrical conductivity of a water or soil sample in $\mu S.cm.^{-1}$ where 1 EC unit = 1 $\mu S.cm.^{-1}$. The strategy was based on an initial estimate that the impact of clearing in the dryland catchments would result in higher salt loads and an eventual increase of 30 to 50 EC units measured at Morgan by the year 2006. However, as early as 1989 Allison and Schonfeldt

predicted impacts of 140 EC units attributable to clearing for both dryland and irrigated agriculture in the Victorian riverine plain alone.

Estimates of current and future areas affected by dryland salinisation have been quoted in the media and other forums including Williamson *et al.*, 1997, and the Prime Minister's Science, Engineering and Innovation Council, 1998. The reported estimate of present dryland area affected by salinisation in the basin is approximately 2000 square kilometres. It has been predicted that this area will increase to 10 000 square kilometres by 2010 and that up to 7500 square kilometres could be affected in NSW by the year 2050. The Basin Sustainability Committee of the MDBC instigated a two-stage review of the Salinity and Drainage Strategy in February 1997. Stage one, the collation of the information base for the review, led to the commissioning of this present Salt Load Study. For NSW the study has been conducted by the NSW Department of Land and Water Conservation's (DLWC), Centre for Natural Resources (CNR). A parallel study with identical objectives and broadly comparable methodology was undertaken by Sinclair Knight Merz on behalf of the Victorian State Government.

1.2 Project Outline

Where salt input into a basin is equal to salt output, within the natural variation, the salt balance is considered to be in equilibrium. If there is an inexhaustible salt store within a basin, given a relevant time frame, salt output may exceed salt input at a steady rate; yet the salt balance can still be considered to be in equilibrium. Following the clearing of the native vegetation in the Murray Darling Basin and subsequent changes to the catchment water balance, the salt balance is understood to be undergoing widespread change. A new equilibrium condition is expected to become established in the future. This report attempts to quantify, in stages, the progressive salt load impacts during the next 100 years for the major second order streams in New South Wales. The years 2020, 2050 and 2100 are nominated as the 'target dates' for prediction of salt loads during this period.

Salt and water balances for third order catchments are integrated to provide end of stream, salt load time series estimates, from which the resulting implications for water salinity at Morgan S.A. can be calculated. Estimates of salt load under 'current' conditions and at the target dates are calculated based on the variability in stream flow and salt load observed within the assessment period 1975 to 1995.

Previous studies (Williamson *et al.*, 1997 and Jolly *et al.*, 1997) confirm the incidence and extent of rising trends in salinity and salt load for streams across the basin, particularly in the mid to upper catchments where dryland salinity processes dominate. These studies have concentrated on finding an historic trend within the stream flow and salinity data without relating it specifically to groundwater movements or any causal factor. The trends reflect the climatic and river diversion regime of their recorded history.

Other studies have tried to locate the areas most threatened by dryland salinity by mapping areas of potential hazard (Bradd, 1995). The salinity hazard map is derived from an analysis of the probability that salinisation will occur for a given set or combination of static variables such as geology, soil type, landform, aquifer yield and salinity, rainfall zone, vegetation and land management. This approach does not attempt to define the areal extent of potential salinisation. Rather, it reflects the areal extent of the combined static factors used in the analysis, ranking combinations, according to the weight of evidence that salinity already exists. It has no dynamic component, and its detail depends on mapped areas of 'current' salinity expression, which may or may not be comprehensive, and the mapping scale used. Previous studies have not quantified the areal extent of high watertables and potential land salinisation in the dryland catchments of NSW, or how areas affected may change over time.

At a series of meetings during early 1998 between CNR staff and representatives of Sinclair Knight Merz, the Victorian Government and MDBC, an agreed core methodology was adopted for both States. It was agreed that projections of future stream salinity and salt load should be based on trends in groundwater movement extrapolated to the target dates.

Calculations of groundwater derived salt loads for all geologies within each second order catchment are presented as a first approximation of the potential salt load that is able to enter the river system. This analysis is constrained in its usefulness by the limitations of data availability and scale and the technical assumptions that are forced upon the methodology in the absence of key data. In general, these initial potential salt loads may not accurately reflect the stream and land salinisation potential. However, the ratios of 'current' and future potential salt loads derived from the groundwater assessment provide the only useable dynamic factors for calculating rates of change for future dates and linking land salinisation to river salt loads.

Not all of the potential salt load can be expected to actually enter the river system. The estimate of an additional 140 EC units at Morgan given by Allison and Schonfeldt (1989) cited above, is conditional on all the salt load accumulating at the surface reaching the river and an unlimited salt store. This is plainly unrealistic.

The approach in our study is to consider the river system itself as the integrator of all relevant processes. Hence, in this study, a thorough statistical analysis of recorded stream flows and salt loads for the assessment period 1975 to 1995 is used to establish the base conditions from which future loads are calculated, using the change rate factors obtained from the groundwater assessment.

The climatic pattern of the assessment period is unique and is not representative of the variability inherent in the full historical record available for the basin. Analysis of rainfall patterns in south eastern Australia indicate a period of below average rainfall for the first half of the 'current' century,

followed by predominantly above average rainfall in the second. The assessment period falls during this protracted time of above average rainfall and presumably above average groundwater recharge. River flows reflect the climate of the assessment period as well as the impact of river regulation.

Diversions from the rivers for irrigation supply varied as further development of irrigation occurred during the assessment period. The average annual salt loads for the assessment period for each second order stream reflect the development of the water resource during that period. In 1995 the NSW Government announced the introduction of a cap on total water use in the basin, following the recommendation of the MDBMC, in addition to an already existing embargo on the issuing of new licences. The actual cap in a valley varies from year to year depending on climatic conditions. It is based on maintaining diversions at levels equivalent to those occurring if 1993/1994 development conditions and rules are maintained. To make future projections valid the salt loads are adjusted to the MDBMC cap conditions using the ratio of observed to cap flow.

Preliminary results of this work were presented to the MDBMC in November 1998. The results presented in this report have been subjected to substantial re-working and rigorous checks since that time to ensure consistency and accuracy. The validity of the resultant projections is heavily dependent on the quality and scope of the data available, including the assumption that the climatic variability of the calibration period is representative of future flows.

2 Data Availability

Data used in the study fall into three functional categories:

1. Hydrogeology data used to determine the groundwater derived potential salt loads by catchment and geology,
2. Surface hydrology data used to determine the statistical structure of river flow and salt loads by second order catchment and third order sub-catchment, and
3. GIS spatial data used in regionalising parameters, area weighting geology and sub-catchment contributions to scaling factors for future salt loads from third order catchments and preparation of attribute statistics for salinity hazard mapping and general presentation of results.

2.1 Hydrogeology Data

The most important data sources available to determine the groundwater derived potential salt loads are the bore records of the DLWC groundwater database. The data include a record of both groundwater levels and salinity measured in terms of electrical conductivity (EC) where 1 EC unit = $1 \mu S.cm^{-1}$ (at 25° C). A conversion factor of 0.65 is used to convert EC to $mg.L^{-1}$. Additional sources of data include ‘local’ data held by DLWC regional personnel, groundwater model outputs and data from the Australian Geological Survey Organisation (AGSO).

Dryland salinity is a phenomenon generally associated with aquifers in the fractured rock zones within a catchment. The current NSW groundwater observation network is primarily based on the highly productive alluvial aquifers associated with the main river valleys. Most of the bores in this network are now impacted by groundwater abstraction, as discussed below in Section 4.4. While there are time series water level and water salinity data extending back as far as the early 1970s for these alluvial aquifers, the information from them is not generally suitable for the present analysis.

Groundwater and salinity data from a series of reconnaissance studies undertaken in the late 1980s and early 1990s are used to predict the depth to watertable, and consequent potential salt loads, for 1998, 2020, 2050 and 2100. These surveys are reported in Bish (1993), Bish and Gates (1991), Gates and Williams (1988), Hamilton (1992), Lytton *et al.* (1993), Salas (1990), Williams (1990), Williams and Saunders (1990), Woolley (1991). The areas covered by these surveys are shown in Figure 2.1.

The reconnaissance studies establish baseline groundwater level trends in hard rock (fractured) aquifers. The areas were selected because of the presence of dryland salinisation, a potential for impacts due to specific local hydrogeological conditions, and/or because of local community concern. Each survey involves the measurement of water levels and water salinity from a sample of bores that

provide a reasonably even distribution on each 1:25 000 or 1:50 000 map sheet across the study area. The information is compared with records supplied to DLWC at the time of bore construction, to provide a gross estimate of the historic variations in salinity and depth to water. An assessment of the area in the vicinity of the bore is provided by the landholder. The data are used to predict, in general terms, which areas are likely to be impacted by dryland salinisation and which geological units are most likely to be vulnerable.

There are 1560 bores across all catchments and geologies used in the analysis for this study. One hundred and ten bores, at key sites, are also analysed where a more frequent record exists for recent water level trends. These shorter more recent trends are used to indicate whether the overall trends are generally valid.

For the present study, no attempt is made to ‘massage’ the data from either the reconnaissance surveys or the ‘key sites study’. All data are used without adjustment (e.g. no allowance is made for the possible impact of pumping on measured water levels). The data are separated into catchments and then further subdivided into geological units within each catchment using GIS techniques.

2.2 Surface Hydrology Data

Records from the DLWC hydrometric network are the primary source of data for determining the statistical structure of flow and salt load relationships across the basin. Most of the streamflow record is held in the DLWC HYDSYS database. All continuous EC records are held in HYDSYS and discrete records are held in the DLWC TRITON water quality database. Additional records are also obtainable from regional databases. The discrete EC records for the Murrumbidgee Region in TRITON are known to be corrupt, and so were sourced from the region for this valley. Data used to adjust flow and salt loads to the 1993 and 1994 development conditions and management rules (MDBMC cap) are sourced from Integrated Quantity and Quality Model (IQQM) simulations, with daily output for most second order catchments and monthly output for the Murrumbidgee. Cap scenario IQQMs have been used to produce preliminary cap flows for the Gwydir, Border Rivers, Barwon/Darling, Namoi, and Lachlan.

Not all third order tributaries are gauged. Sub-catchments fall into three categories: those with flow and EC data, those with flow data only and those with neither flow nor EC data. Those in the last category are referred to as residual catchments. Twenty-one year, time series data sets are used from the period 1975 to 1995. Continuous daily volumetric flow data is available at most stations for the full period. Where there is an incomplete record, missing data is supplemented with output from Sacramento modelling or by correlation with a nearby station. Stations are further categorised according to whether they are used to calculate salt inflows to the mainstream or whether they are used to check mainstream water and salt balances.

Figure 2.1 Location of census bore surveys

EC data is available generally as discrete samples recorded at varying intervals. In some cases continuous EC data is available from HYDSYS. EC data is not generally available for the whole twenty-one year period. Therefore, the statistical structure is determined from the subset of years with consistent data. Where a short record of continuous EC data is available together with a longer period of discrete record, the continuous data is discarded from the analysis to avoid bias. In many cases the available continuous data are more recent and fall outside the assessment period. Continuous flow and EC records in the Murrumbidgee are used to determine the most appropriate stochastic model.

Catchments across the State vary in the completeness of flow and EC records for the assessment period. On average there are 20 years of continuous observed flow data for inflow catchments across the State with an average of 122 corresponding discrete EC data points. Ranges in average monthly EC vary between catchments within a total range of 50 EC to 1500 EC. For the mainstream balance points the average observed flow data covers 20.5 years with an average of 152 corresponding EC values. The ranges of mainstream EC values vary and are generally less than for inflow catchments, lying within a total range of 50 EC to 900 EC.

2.3 GIS Spatial Data

This study does not encompass the entire NSW portion of the Murray-Darling Basin. It concentrates on those catchments for which there is both sufficient hydrogeology data and a reasonable concern regarding the probability of increased future salt inflow to the Murray and Darling Rivers. The river basins examined are the Macintyre (Border Rivers), Gwydir, Namoi, Castlereagh, Macquarie, Bogan, Lachlan, Murrumbidgee and Upper Murray. Digitised catchment boundaries for second and third order catchments are held in ArcView by DLWC at Parramatta. Contributing areas of geology for each set of catchment and sub-catchments are determined from the 1:4 000 000 scale geology map of NSW.

A Digital Terrain Model (DTM) of sufficient detail and statewide coverage is not currently available within DLWC for analysis of topographic effects.

3 Methodology

Two linked methodologies are combined to determine the salt loads delivered from third and second order streams to the Murray and Darling Rivers for ‘current’ and future dates. The first establishes the ‘potential’ salt load delivered to the land surface from groundwater rise and is essentially a stand-alone methodology. The second methodology establishes actual in-stream salt loads for the second order rivers and utilises rates of change established in the previous method to extrapolate from existing ‘current’ salt loads to future salt loads. The relationship between the components of the complete methodology is illustrated in Figure 3.1.

3.1 Groundwater Derived Salt Balance

The methodology adopted for estimation of salt loads delivered to catchment land surfaces by groundwater is constrained by the type and amount of data available. This data is essentially limited to groundwater levels at two points in time and associated water salinity measurements. The groundwater level trend and salinity information, together with values for aquifer specific yield assumed for each of the various geological units, are combined with a conceptual model of catchment hydrogeology to estimate salt loads delivered to the catchment surfaces. The data sources and methods used are described in Woolley *et al.* (1999).

For the purpose of this study, the groundwater delivered potential salt load is assumed to be the rate of delivery of salt to the ground surface (in tonnes per year) from the groundwater store, driven by a rising groundwater level. The adopted conceptual model for prediction is based on the following assumptions:

- Salt will be delivered to the land surface when the water table is less than 2 m below ground level. At this point, the salt carried by the groundwater is transferred directly to the land surface. No estimation of concentration times or rates of mobilisation of salt occurring in the top 2 m of the land surface after the date when groundwater is deemed to have reached 2 m is accounted for.
- In areas where the water table has reached this limiting depth, the factors causing the regional rise of groundwater levels will continue. Groundwater will continue to flow upward into these areas.
- For a given area affected, the rate of delivery of salt to this position in the landscape is governed by the rate of regional groundwater level rise and by the salinity of the groundwater.
- There will be no delivery of salt to the land surface when the water table is deeper than 2 m.

- The land surface is treated as if it were flat. That is, in the absence of terrain analysis, the calculation of the areal extent of watertable within 2 m of the ground surface does not account for the influence of topography.
- Extensive low-lying alluvial areas in the western low rainfall areas, where runoff is negligible, do not contribute salt load to streams except during rare flood events, and are excluded from the groundwater-delivered salt load calculation (see Figure 3.2).

Two important factors influencing the rate of delivery of salt to the 2 m zone of the land surface are the micro and macro topography, and the geology of the catchment. The catchment geology is accounted for by classifying the entire catchment area into five broad groups, namely the plutonic rocks, volcanic rocks, metasediments, sedimentary rocks and the alluvium (strictly young unconsolidated near-surface deposits of sedimentary character). It is not possible, however, within the scope of this study, to adjust for the impact of topographic variations due to a lack of an appropriate Digital Terrain Model (DTM).

3.1.1 Determination of groundwater level trends and salinity

Groundwater level trends are determined by comparing the reconnaissance bore survey data from the late 1980s and early 1990s with water levels recorded at the time of bore construction. This gives a two point linear estimate of change. Any fluctuations during the period can not be accounted for and the rate of change is assumed constant. This assumption is tested using the data from bores in the key sites study and is generally found to be reasonable. Improving this estimate is not possible given the available data.

Future water level behaviour is predicted by extrapolating the estimated linear annual rate of change described above. Bores with a predicted water level within 2 m of the ground surface at the nominated target dates are identified by this means. Groundwater salinity is assessed on the basis of measurements made during the bore surveys, and is also assumed to remain constant with time.

3.1.2 Predicted areas with groundwater levels at less than 2 m

The percentage of all bores in each of the broad geological units in each second order catchment with water levels predicted to be less than 2 m below ground surface are determined for each target date. This percentage is assumed to be the same as the percentage of 'potentially' salinised land within the area occupied by that geological unit. Using the total area of the geological unit in the catchment, the predicted area of potential salinisation within each geological unit is calculated for each of the target dates.

Figure 3.2 Excluded Alluvial Areas

3.1.3 Calculation of the potential salt loads delivered from the groundwater system to the soil

The prediction of salt loads delivered to the zone within 2 m of the land surface in the respective catchments is based on the average rate of water level change derived from the reconnaissance bores in each geological unit. The hydrogeological system delivers groundwater of constant salinity to the surface at a constant rate. The standard deviation of the rate of water level change for bores within a geological unit is used to provide some indication of confidence limits to the analysis. The reliability of the data is a function of the number of reconnaissance bore data points measured. Some geological units within a catchment have a reasonable number, but in others there are few data points that can be used for a statistical assessment of the data reliability.

The salt load potentially delivered to the surface in each geological unit in each catchment is estimated by considering the potentially salinised area of each, the rate of water table rise, an assigned value for the specific yield of the geological unit, and the salinity of the groundwater. Specific yield is essentially the drainable porosity, and determines the volume of water available in a unit volume of geological material at saturation. Values for specific yield were assigned from published estimates for each geological unit

Using values determined as described above, the salt loads delivered to the surface in each geological unit are calculated as follows:

$$Q_s^{pot} = A_{sal} C_g^s S_y \frac{dz_g}{dt} \quad (3.1)$$

where, Q_s^{pot} is the potential salt load, A_{sal} is the area potentially salinised, C_g^s is the salinity of the groundwater, S_y is the specific yield and dz_g / dt is the rate of groundwater level rise. Using an appropriate conversion factor Q_s^{pot} can be expressed in $t.year^{-1}$.

The potential salt load from Eq. (3.1), expressed as tonnes per year for the assessment period, provides an estimate of salt delivered from the groundwater system to the surface in each geological unit. The salt can potentially be transported to the stream through catchment scale runoff generation and salt wash off mechanisms including direct seepage into watercourses.

Potential salt load values are set to zero where the data indicate declining or steady water levels, ie a negative or zero rate of rise.

3.1.4 Summary of assumptions made in estimating the groundwater derived potential salt loads

The analysis used here, and the predictions for groundwater-delivered salt loads made from it, are based on a number of assumptions. Most are referred to specifically in the preceding Sections 3.1.1 to 3.1.3. Some are open to debate but they are adopted because they provide the best approximation available on the basis of existing data. These assumptions are summarised below:

1. Salt load delivered to the land surface by groundwater can be estimated from the relationship described by Eq. (3.1).
2. Long term groundwater level trends may be considered linear with time, and used to extrapolate into the future.
3. The data sample available, and used for the study, is representative; and of adequate size, to enable reasonable assessment of the groundwater level trends.
4. The values adopted for specific yield (from published material) are representative.
5. Groundwater salinity does not vary with time. (An unlimited salt store is implied.)
6. Salt is delivered to the unsaturated zone when the water table is within 2 m of the land surface, where it is available for mobilisation by surface processes.
7. There is a mechanism for transporting salt concentrated in the 2 m surface zone from the catchment. No salt transport mechanism or the efficiency associated with this process is proposed.

3.2 Estimation of Actual Delivered In-stream Salt Loads from Runoff Generation and Salt Wash off Mechanisms

The potential salt load estimate [Eq. (3.1)] obtained from groundwater level trends for each geological unit in each second order catchment provides an upper limit of the salt load. In theory, this salt load can be transported to the stream from runoff generation and salt wash off mechanisms. However, not all salts delivered from the groundwater system under current and likely future conditions would be transported, mainly due to limited desorption of salts with overland flow and lateral throughflow, from all parts of the catchment. Not all parts of the catchment will contribute to the streamflow due to the nature of the physical processes generating catchment scale runoff. The areas contributing to surface runoff grow with the intensity and duration of the rainfall and the soil moisture status i.e. the partial area view (Kirkby, 1978; Beven and Kirkby, 1979).

The methodology assumes that the impacts of all the relevant processes are already integrated into salt loads in-stream. Therefore, it is considered necessary to first establish the in-stream salt balance under current conditions for all second order catchments in the NSW component of the Murray Darling Basin as a baseline. Future in-stream salt loads are calculated from this baseline using factors for the rate of change estimated for the intervening period. The rates of change are obtained from the ratio of groundwater derived potential salt loads for target dates with respect to those obtained for current conditions.

3.2.1 Choice of scale for the ‘current’ salt balance analysis

The area of the NSW component of the Murray Darling Basin is $599\,873\text{ km}^2$ or about 57% of the total area of the basin (Crabb, 1997). The areas of second order catchments in NSW vary in the order of $1\times 10^4\text{ km}^2$ to $1\times 10^5\text{ km}^2$. The catchment area of the third order streams, contributing to the second order streams, generally vary in the range $500\text{--}2000\text{ km}^2$. The integration of salt balances to a second order catchment scale (i.e. Murrumbidgee, Namoi etc.), using a macroscopic approach, is possible only at the third order catchment scale. Therefore, the third order catchment scale has been adopted as the basic unit on which the salt balance methodology has been developed. The time scale adopted for the salt load simulations is one day. The daily salt loads from the third order catchments are integrated over a month for 1975–95 and used in the salt balance analysis.

3.2.2 Estimation of daily salt loads from third order catchments

The estimation of daily salt load from the third order catchment requires information on two State variables (together with the variation in time), namely, flow and salinity at the catchment outlet. The third order catchments can be classified under three categories depending on the type of data available for analysis:

- (a) catchments with continuous flow and continuous/ discrete salinity data (electrical conductivity EC in $\mu S.cm^{-1}$),
- (b) catchments with continuous flow data and no EC data, and
- (c) catchments with no flow or EC data (hereafter referred to as the residual catchments).

In the residual third order catchments, estimates of daily streamflow are modelled using IQQM. Therefore, for the purpose of salt balance analysis, categories ‘(b)’ and ‘(c)’ are pooled together to represent the third order catchments with continuous observed or simulated flow data and no EC data.

3.2.2.1 Estimation of daily salt load from third order catchments with flow and EC data

Salinity (EC) data are available at 567 stations in the NSW component of the Murray-Darling Basin, of which 43 stations have continuous data and 37 stations have both continuous and discrete sample data of varying lengths of record. The remaining 487 stations have discrete sample data only (generally one value per 15 to 30 days with varying lengths of record). Therefore, a tool is required to estimate continuous daily salt load time series data for each third order catchment where both flow and EC data are available.

The stochastic component of the CATSALT model (Tuteja and Beale, 1999; in press) has been used to estimate the daily salt load time series by modelling the statistical structure of the relationship embodied in the continuous streamflow and discrete salt concentration/load data. The CATSALT model is designed to address three basic questions:

1. How much salt is annually (along with its temporal distribution) exported from third order catchments under ‘current’ conditions (stochastic component)?
2. How can the knowledge of physical processes relating to salt delivery from the groundwater system to the soil and consequent salt washoff mechanisms be used to explain the salt exported from the third order catchments at a daily time step (semi distributed quasi physical component)?
3. How much salt will be exported from the third order catchment under likely future conditions at 2020, 2050 and 2100 given that ‘current’ trends in groundwater table rise continue (predictive component)?

The stochastic component of the CATSALT model is described here. For a more detailed discussion on the model and its implementation in the Kyeamba Creek Catchment, located in the Murrumbidgee Catchment refer to Chapter 7 or Tuteja and Beale (1999, in press). In the stochastic component, four alternative hypotheses are postulated (Models I–IV) and regression equations are formulated to obtain a continuous time series of salt concentration/load, for each hypothesis. The concept is similar to that of the Linear Perturbation Model (LPM) popularly used in rainfall runoff modelling for catchments substantially influenced by seasonality (Nash and Barsi, 1983; Kachroo, 1992). Fourier Transforms are used to preserve seasonality (average smoothed conditions on a daily basis) in the streamflow and salt concentration/load. The daily salt loads thus obtained from the third order catchments can be used to establish the ‘current’ salt balances. The four developed alternative hypotheses of the stochastic model and the associated model formulations are described below.

Model I: The expected value (or the smoothened average) of the daily flow (Q_μ in $m^3.s^{-1}$) results in the expected value (or the smoothened average) of the salt concentration (C_μ^s in $\mu S.cm^{-1}$) obtained from Fourier Transforms (described later by Eq. (3.12)) and the departures of the daily flow and the daily salt concentration time series from their respective expected values can be related using a non-linear form of the regression equation as in Eq. (3.2).

$$\text{Model I: } C_T^s(t) = C_\mu^s + \eta |Q_T(t) - Q_\mu|^\lambda \left(\frac{Q_\mu - Q_T(t)}{|Q_T(t) - Q_\mu|} \right) \quad (3.2)$$

Where: $Q_T(t)$ = observed streamflow ($m^3.s^{-1}$), $C_T^s(t)$ = in-stream salt concentration ($\mu S.cm^{-1}$), η and λ are the parameters of the regression equation, t = time since beginning of the simulation period (d), T = assessment period for the climatic conditions i.e. 1975–95.

The expression inside the brackets on the right hand side of Eq. (3.2) ensures addition (when $Q_T(t) < Q_\mu$) or subtraction (when $Q_T(t) > Q_\mu$) of the incremental salt concentration from the average periodic salt concentration in the river, depending on the nature of the dilution of salts (that is, more dilution in case of high streamflows and vice-versa). The total in-stream daily salt load ($Q_T^s(t)$ in $t.d^{-1}$) can be obtained using Eq. (3.3).

$$Q_T^s(t) = 0.0864 \times 0.64 \times C_T^s(t) Q_T(t) \quad (3.3)$$

where the factor 0.64 converts the EC denoted by C_T^s from $\mu S.cm^{-1}$ to $g.m^{-3}$.

Model IIA–D: The expected value of the average daily periodic flow (Q_μ in $m^3.s^{-1}$) results in the expected value of the salt load (Q_μ^s in $t.d^{-1}$) and the departures of the daily flow and the daily salt load time series from their respective expected values are related using linear [Model IIA; Eq. (3.4)] or non-linear [Model IIB; Eq. (3.5)] forms of regression equation. Alternatively, the daily in-stream salt load time series can be related directly to the observed daily streamflow using linear [Model IIC; Eq. (3.6)] or non-linear [Model IID; Eq. (3.7)] forms of regression equation.

$$\text{Model IIA: } Q_T^s(t) = 0.0864 \times 0.64 \times Q_\mu C_\mu^s + [\eta + \lambda(Q_T(t) - Q_\mu)] \quad (3.4)$$

$$\text{Model IIB: } Q_T^s(t) = 0.0864 \times 0.64 \times Q_\mu C_\mu^s + e^\eta |Q_T(t) - Q_\mu|^\lambda \left(\frac{Q_T(t) - Q_\mu}{|Q_T(t) - Q_\mu|} \right) \quad (3.5)$$

$$\text{Model IIC: } Q_T^s(t) = \eta + \lambda Q_T(t) \quad (3.6)$$

$$\text{Model IID: } Q_T^s(t) = e^\eta (Q_T(t))^\lambda \quad (3.7)$$

Model III: The relationship between daily in-stream salt concentration ($C_T^s(t)$ in $\mu S.cm^{-1}$) and daily streamflow ($Q_T(t)$ in $m^3.s^{-1}$) is described by the convolution summation of a linear time invariant system which takes into account the memory of the statistical relationship between these two variables. The ordinary least square solution (OLS) of the linear time invariant single input single output system described by Eq. (3.8) is given by Eq. (3.9).

$$Model\ III: C_T^s(t) = \sum_{j=1}^{m'} Q_T(t-j+1)h_j + \varepsilon_t \quad (3.8)$$

$$\{h\} = [Q_T]^T [Q_T]^{-1} [Q_T]^T \{C_T^s\} \quad (3.9)$$

where $\{h\} = [h_1 \ h_2 \ \dots \ h_{m'}]^T$ is the pulse response function vector ($\mu S.cm^{-1}.m^{-3}.s$), m' = memory of the pulse response function, Q_T = observed streamflow ($m^3.s^{-1}$), and ε_t = residual error.

Model IV: The relationship between daily in-stream salt load [$Q_T^s(t)$ in $t.d^{-1}$] and daily streamflow [$Q_T(t)$ in $m^3.s^{-1}$] is described by the convolution summation of a linear time invariant system which takes into account the memory of the statistical relationship between these two variables. The ordinary least square solution (OLS) of the linear time invariant single input single output system described by Eq. (3.10) is given by Eq. (3.11).

$$Model\ IV: Q_T^s(t) = \sum_{j=1}^{m'} Q_T(t-j+1)h_j + \varepsilon_t \quad (3.10)$$

$$\{h\} = [Q_T]^T [Q_T]^{-1} [Q_T]^T \{Q_T^s\} \quad (3.11)$$

where $\{h\} = [h_1 \ h_2 \ \dots \ h_{m'}]^T$ is the pulse response function vector ($t.d^{-1}.m^{-3}.s$).

The estimate of the expected value of daily flow (Q_μ), and salt concentration (C_μ^s) in Equations (3.2) to (3.11) can be obtained using Fourier Transforms. A Fourier series can be fitted exactly by a smooth function to a set of ω points on the (μ, u_μ) plane as in Eq. (3.12).

$$u_\mu = u_0 + \sum_{j=1}^h \left[A_j \cos\left(\frac{2\pi j \mu}{\omega}\right) + B_j \sin\left(\frac{2\pi j \mu}{\omega}\right) \right] \quad (3.12)$$

where: ω is the degrees of freedom (e.g. 365 for daily time series), h is the maximum number of harmonics (182 for daily time series), j is the rank of harmonic with frequency j / ω and fundamental frequency $1 / \omega$, A_j and B_j are the Fourier coefficients, u_0 is a parameter and u_μ is the periodic statistic of the variable (e.g. streamflow or salt concentration). In the case of an average

daily streamflow and salt concentration time series, u_μ represents the expected value of the time series Q_μ ($m^3.s^{-1}$) and C_μ^s ($\mu S.cm^{-1}$) respectively and μ equals 1 to 365.

The parameters u_0 , A_j and B_j can be estimated using Equations (3.13) to (3.15) respectively.

$$u_0 = \frac{1}{\omega} \sum_{t=1}^{\omega} u_\mu \quad (3.13)$$

$$A_j = \frac{2}{\omega} \sum_{t=1}^{\omega} \left[\hat{u}_\mu \cos\left(\frac{2\pi j \mu}{\omega}\right) \right] \quad \text{where } j = 1, 2, \dots, h \quad (3.14)$$

$$B_j = \frac{2}{\omega} \sum_{t=1}^{\omega} \left[\hat{u}_\mu \sin\left(\frac{2\pi j \mu}{\omega}\right) \right] \quad \text{where } j = 1, 2, \dots, h \quad (3.15)$$

In order to make the model parsimonious (reasonably acceptable explained variance with minimum number of parameters), the choice of the number of harmonics to be used in the Fourier Series are obtained using cumulative periodogram analysis i.e. the variance explained by each harmonic and the choice of degree of smoothing. The variance explained by each j th harmonic (σ_j^2), total variance ($\sigma_{u_\mu}^2$) and proportion of variance explained by the j th harmonic (P_j) are obtained using Eqs (3.16), (3.17) and (3.18) respectively. For a detailed description and derivation of these equations refer to Sallas *et al.* (1980) and Tuteja (1992).

$$\sigma_j^2 = \frac{A_j^2 + B_j^2}{2} \quad (3.16)$$

$$\sigma_{u_\mu}^2 = \frac{1}{\omega} \sum_{t=1}^{\omega} (u_\mu - u_0)^2 = \frac{1}{2} \sum_{j=1}^h (A_j^2 + B_j^2) \quad (3.17)$$

$$P_j = \frac{\sigma_j^2}{\sigma_{u_\mu}^2} \quad \text{where } j = 1, 2, \dots, h \quad (3.18)$$

The average periodic value (or the expected value) of the streamflow (daily) and salt concentration/load are thus obtained and used for establishing salt balance under ‘current’ conditions.

It is pointed out that the expected value of the flow (Q_μ) is estimated strictly in accordance with Eqs (3.12–3.15). However, the expected value of EC (i.e. C_μ^s) is estimated by pooling the values over respective months and allocating the average monthly value to middle of the month. Thereafter a linear variation of EC is obtained and used further for Fourier Series analysis as in Eqs (3.12–3.15).

The choice of best model is based on the following criteria: (a) R^2 between observed ($Q_T^s \text{ t.d}^{-1}$) and estimated salt load ($\hat{Q}_T^s \text{ t.d}^{-1}$), (b) ability of the model to reproduce the seasonality in salt load, and (c) ability of the model to reproduce the probability distribution function (*pdf*) of the daily salt load time series. The R^2 criterion is given greater emphasis amongst all the criteria.

3.2.2.2 Estimation of daily salt load from third order catchments with no EC data

In the case of third order catchments with no EC data, Model IIC [Eq. (3.6)] is imposed (with the exception of Murrumbidgee where Model IIA is used), circumventing the problem of estimating expected values of EC from the Fourier Series analysis. The parameters η and λ , obtained either from regionalisation or from another similar third order catchment in close proximity where flow and EC data are available, are substituted into Eq. (3.6). For each second order catchment, regionalisation of η and λ is done by regression with either the catchment area or mean annual runoff (third order catchments), or by using parameter values obtained from third order catchments in close proximity with observed flow and EC data.

3.3 'Current' In-stream Salt Balances at End of System for Each Second Order Catchment

The monthly salt load time series [q_T^s in t.month^{-1} ; Eq. (3.19)] is obtained from the daily salt load estimates for all third order catchments for the assessment period 1975–95 (21 years) as described in Section 3.2. The monthly salt load time series (q_T^s), hereafter referred to as the observed salt load time series, is then used to establish the salt balances under 'current' conditions. This provides an independent check of the predicted daily salt load from the third order catchments and, therefore, a check on the parameter estimation process discussed in Section 3.2. The salt balances are computed on a monthly basis rather than on a daily basis in order to reduce the impact of error in routing parameters on the salt balance. Some interaction between the water balance and the salt balance is unavoidable because the streamflows from residual catchments, used in the salt balance analysis are generated from model calibrations. Therefore the uncertainties associated with model parameters are likely to influence the salt balance.

$$q_T^s(i, j) = \sum_{k=1}^{k_{\max}} Q_T^s(i, j, k) \quad (3.19)$$

where Q_T^s = daily salt load (t.d^{-1}), q_T^s = monthly salt load (t.month^{-1}), i, j, k refers to the year, month and day respectively, and k_{\max} refers to number of days in a month.

In most instances there are three to five suitable salt balance locations within each second order catchment. The salt balance analysis is derived by comparing the observed salt load (q_T^s) at the balance point [from Eqs (3.2) to (3.12)] with the estimated salt load (\hat{q}_T^s) obtained by adding all inputs contributing salt load to the balance point. Note that although modelled using at site flow and EC data, q_T^s is referred to as the observed salt load to distinguish it from the estimated salt load \hat{q}_T^s obtained by adding all inputs. Balance points are chosen to give a reasonable representation of salt contributions from uplands in the east to low lying western areas of the basin where diversions just begin to have an impact on the water balance and consequently the salt balance. Flow and salt load tend to accumulate downstream to a point where diversions and losses begin to reduce the mainstream flow and salt load. The most downstream balance location is chosen to coincide with this point as nearly as possible. The ratio of the observed monthly salt loads at the most downstream balance point (i.e. the last balance point) and at the end of stream, is used to scale the estimated salt load at the last balance point to the catchment outlet.

3.4 Estimation of Salt Export from Second Order Catchments Under Likely Future Conditions

The salt balance under likely future conditions at the target dates (i.e. 2020, 2050 and 2100) can change as a result of: (a) rising groundwater table and an increase in the area influenced by salinity, and (b) climate variability and climate change. Investigation of the effects of climate change on the salt balance is outside the scope of this study. The base period for climate variability is taken as 1975–95. The effect of rising groundwater table and the area influenced by salinity is accounted for by interfacing the groundwater derived potential salt loads (Section 3.1.3) with the ‘current’ salt balance to estimate the future salt exports from each third order catchment. A detailed description of coupling of the groundwater derived potential salt loads and the in-stream salt loads to predict salt export rates from the third order catchments at the target dates is given below.

The total in-stream salt load ($q^s \text{ t.month}^{-1}$) at the outlet of each third order catchment can be expressed as sum of the salt load from surface runoff ($q^{sr} \text{ t.month}^{-1}$) and the salt load associated with the baseflow from the groundwater system ($q^{sg} \text{ t.month}^{-1}$). The variation of in-stream salt load can therefore be written as in Eq. (3.20):

$$dq^s = dq^{sr} + dq^{sg} \quad (3.20)$$

where, dq^s , dq^{sr} and dq^{sg} denote the variation of in-stream salt load, salt load in surface runoff and salt load in baseflow respectively (t.month^{-1}).

The in-stream salt load from surface runoff can be expressed in terms of soil salinity (C_{soil}^s), surface runoff (q^r), saline area (A^{sal}) and non-saline area (A^{nsal}) [Eq. (3.21)]. The in-stream salt load associated with the baseflow from the groundwater system can be expressed in terms of groundwater salinity (C_g^s) and the baseflow (q^g) [Eq. (3.22)].

$$q^{sr} = q^{sr}(C_{soil}^s, q^r, A^{sal}, A^{nsal}) \quad (3.21)$$

$$q^{sg} = q^{sg}(C_g^s, q^g) \quad (3.22)$$

The variation of in-stream salt load directly from groundwater flow and interflow (dq^{sg}) can be expressed as in Eq. (3.23).

$$dq^{sg} = \frac{\partial q^{sg}}{\partial C_g^s} dC_g^s + \frac{\partial q^{sg}}{\partial q^g} dq^g \quad (3.23)$$

where dC_g^s = total variation of the groundwater salinity, and dq^g = total variation of the groundwater flow into the stream.

Assuming no shift in water balance ($dq^g = 0$) and no change in groundwater salinity ($dC_g^s = 0$), the right hand side (RHS) of Eq. (3.23) reduces to zero.

Using Eq. (3.21), the variation of salt load in surface runoff can be expressed as in Eq. (3.24):

$$dq^{sr} = \frac{\partial q^{sr}}{\partial C_{soil}^s} dC_{soil}^s + \frac{\partial q^{sr}}{\partial q^r} dq^r + \frac{\partial q^{sr}}{\partial A^{sal}} dA^{sal} + \frac{\partial q^{sr}}{\partial A^{nsal}} dA^{nsal} \quad (3.24)$$

where dC_{soil}^s , dq^r , dA^{sal} and dA^{nsal} represent the total variation in soil salinity, surface runoff, saline and non-saline area respectively.

Letting A denote the total area and substituting $A^{nsal} = A - A^{sal}$ in Eq. (3.24), assuming no shift in water balance ($dq^r = 0$), and integrating on both sides, Eq. (3.25) is obtained.

$$q^{sr} = \int \frac{\partial q^{sr}}{\partial C_{soil}^s} dC_{soil}^s + \int \left(\frac{\partial q^{sr}}{\partial A^{sal}} - \frac{\partial q^{sr}}{\partial A^{nsal}} \right) dA^{sal} \quad (3.25)$$

The first term on the RHS of Eq. (3.25) represents the in-stream salt load with surface runoff resulting from the soil salinisation process alone. The second term on the RHS represents the total salts entering the stream with surface runoff from the composite area term alone (i.e. both saline and non-saline areas). Although, a major proportion of the area under 'current' conditions is non-saline (soil salinity less than $2000 \mu S.cm^{-1}$), the salts from desorption processes from the non-saline area

can potentially still dominate the in-stream salt load. Assuming that the change in soil salinity as a result of rising groundwater table would be somewhat slower than the rate of increase in saline area, the major term influencing the in-stream salt load from surface runoff would be the composite area term (i.e. second term on RHS of Eq. (3.25)). It is pointed out that this is a simplifying assumption and is not entirely justified, bearing in mind the processes related to the expression of salinity and the salt transport mechanisms. Incorporating the above hypothesis into Eq. (3.25) and combining with Eq. (3.22) and Eq. (3.23), the total in-stream salt load is proportional to the composite area term as in Eq. (3.26).

$$q^s \propto \int \left(\frac{\partial q^{sr}}{\partial A^{sal}} - \frac{\partial q^{sr}}{\partial A^{nsal}} \right) dA^{sal} \quad (3.26)$$

The term on the RHS of Eq. (3.26) is analogous to the groundwater derived potential salt load ($q_T^{ps} \text{ t.year}^{-1}$) from the groundwater trends analysis for each third order catchment [Eq. (3.27)].

$$q_T^s \propto q_T^{ps} \quad (3.27)$$

where T refers to ‘current’ conditions (i.e. 1998).

Using Eq. (3.27) and the groundwater derived potential salt loads, the in-stream salt load for likely future conditions $T1$ (i.e. 2020, 2050 or 2100) for the assessment period can be estimated by Eq. (3.28):

$$\hat{q}_{T1}^s(t) = \left(\frac{q_{T1}^{ps}}{q_T^{ps}} \right) \hat{q}_T^s(t) \quad (3.28)$$

where $\hat{q}_T^s(t)$ = estimate of the monthly salt load exported from the third order catchment for the assessment period (1975–95) under ‘current’ conditions (i.e. 1998) T ($t.month^{-1}$), $\hat{q}_{T1}^s(t)$ = estimate of the monthly salt load exported from the third order catchment for the assessment period under future conditions (i.e. 2020, 2050 or 2100) $T1$ ($t.month^{-1}$), q_T^{ps} and q_{T1}^{ps} are the groundwater derived potential salt loads for ‘current’ conditions (1998) and for target dates (2020, 2050 and 2100) respectively for each third order catchment ($t.month^{-1}$).

Estimates of the potential salt loads for each geological unit and for each second order catchment, under ‘current’ conditions ($Q_{s,T}^{pot}$ in $t.km^{-2}.year^{-1}$) and at target dates ($Q_{s,T1}^{pot}$ in $t.km^{-2}.year^{-1}$), are available from the groundwater trends analysis [Eq. (3.1)] and are presented in Table 4.4. The summation of the product of area of each geological unit under each third order catchment with the

respective potential salt loads (Q_T^{ps} or Q_{T1}^{ps}) provides estimates of the potential salt load delivered to the surface (q_T^{ps} and q_{T1}^{ps} in $t.km^{-2}$) for ‘current’ conditions and at the respective target dates.

It is emphasised that implementation of Eq. (3.28) does NOT mean that all additional groundwater derived potential salt load will enter the stream. Instead this implies that the functionality representing the salt transport and washoff processes is scaled up in proportion to the increase in groundwater derived potential salt load. In the absence of explicit accounting of salt transport mechanisms, this is a reasonable assumption.

The predicted monthly in-stream salt loads [Eq. (3.28)] from all third order catchments at the required target dates are then added together on a monthly basis to give the monthly salt exports from the first salt balance location to the last salt balance location (in each second order catchment). Downstream of the last salt balance location, diversions begin to have an impact on the water balance and therefore redistribution of the salt loads. At the target dates (i.e. 2020, 2050 and 2100), this is accounted for by, adjusting the monthly salt load time series at the last balance location with respect to the ratio of ‘current’ salt loads at downstream and upstream locations. Letting ‘u/s’ and ‘d/s’ denote the last salt balance location and the next downstream gauging station respectively, the predicted salt export at the d/s location for the target dates are obtained using Eq. (3.29).

$$[\hat{q}_{T1}^s(t)]_{d/s} = \frac{[q_T^s(t)]_{d/s}}{[q_T^s(t)]_{u/s}} [\hat{q}_{T1}^s(t)]_{u/s} \quad (3.29)$$

where: $[q_T^s(t)]_{u/s}$ and $[\hat{q}_{T1}^s(t)]_{u/s}$ represent the salts exported at the upstream location under ‘current’ conditions and at the required target dates respectively ($t.month^{-1}$), $[q_T^s(t)]_{d/s}$ and $[\hat{q}_{T1}^s(t)]_{d/s}$ represent the salts exported at the downstream location under ‘current’ conditions and at the required target dates respectively ($t.month^{-1}$).

Estimates of salt export at the outlet of each second order catchment are obtained using Eq. (3.29) and moving progressively from upstream to downstream from the last salt balance location on the main river. In most cases, the downstream gauging station represents end of system of the second order catchment. The estimated salt load at the end of second order catchment includes the increase in salt load from dryland areas due to rising groundwater level. However, the accumulated mass balance error at the last balance location will introduce bias in the future salt load predictions. This bias is corrected with respect to the observed salt load at the second order catchment outlet using Eq. (3.30):

$$[\hat{q}_k^s(t)]_{d/s}^{cor} = [q_T^s(t)]_{d/s} + \{[\hat{q}_k^s(t)]_{d/s} - [\hat{q}_T^s(t)]_{d/s}\} \quad (3.30)$$

where $\left[\hat{q}_k^s(t)\right]_{d/s}^{cor}$ = estimated salt load corrected for bias at the second order catchment outlet for conditions, k ('current', 2020, 2050 or 2100) ($t.month^{-1}$), $\left[q_T^s(t)\right]_{d/s}$ = observed monthly salt load at the second order catchment outlet for 'current' conditions ($t.month^{-1}$), $\left[\hat{q}_k^s(t)\right]_{d/s}$ and $\left[\hat{q}_T^s(t)\right]_{d/s}$ represent the estimated monthly salt load at the second order catchment outlet for conditions, k ('current', 2020, 2050 and 2100), and 'current' conditions, T (1998), respectively ($t.month^{-1}$). Notice when k equals T (i.e. 1998), Eq. (3.30) collapses to the observed salt load as the last term on RHS of Eq. (3.30) becomes zero.

Finally, the estimates of salt exported at the outlets of the second order catchments for conditions representing the MDBMC cap on diversions (MDBC, 1998) are based on the hypothesis that the salt concentration at each location is not changed by diversions. Therefore, the salt loads under 'current' conditions (1998) and at target dates (2020, 2050 and 2100) are adjusted with respect to the ratio of each monthly flow with and without the cap conditions.

4 Potential Salt Loads Delivered from the Groundwater System under ‘Current’ and Likely Future Conditions at 2020, 2050 and 2100

The reliability of the analysis of the groundwater salinity and level data is dependent on the data set available. The areal coverage of the data samples available is generally sparse and the variability is generally high. Statistics of the reconnaissance bore data set are summarised in Table 4.1, showing the mean, standard deviation, mean plus and minus one standard deviation and number of samples, for salinity and groundwater level change in each geological unit (and catchment total) for each second order catchment.

4.1 Groundwater Salinities and Groundwater Level Trends

Table 4.2(a) and Figure 4.1 show the distribution of average groundwater salinity across both the second order catchments and geological units. Highest salinities and the highest range of values occur within the metasediments and alluvium. The smallest range occurs within the volcanics. The greatest variation within a catchment is found in the Castlereagh Catchment and the smallest apparent range is in the Gwydir Catchment.

Figure 4.2 shows a graphical summary of the groundwater salinity data for each catchment. The ‘bar-type’ representation shows the average and average \pm standard deviation values. (Note that most of the standard deviations are so large that the ‘average - standard deviation’ values are reduced to negative values, which are shown as zero values in the diagram). The highest average conductivity values occur in the Lachlan, Macquarie and Murrumbidgee catchments.

The summarised data, for water level changes predicted by this study, by catchment and by geological unit, are listed in Table 4.2(b). Similar, but more extensive information is shown in Table 4.1. The calculated rates of change in water level for each catchment are also summarised in Figure 4.2 in the same way as shown for the salinity data. A significantly higher than average rate of rise of water levels is apparent for the Murray Catchment and, to a lesser extent, the Murrumbidgee. Across all catchments, there is an overall average rate of rise of about 0.1 m/yr.

A further breakdown into geological units is shown in Figure 4.3, which emphasises the higher average rates of rise in the Murray and Murrumbidgee catchments.

Predicted depths to water table for the bores used in this study have been calculated for the target dates (‘current’, 2020, 2050, 2100) using the average rate of water level change from each reconnaissance bore, in each geological unit, in each catchment. The proportion of bores within a

geological unit, with a depth to water of less than 2 m, was used as a surrogate estimate of the proportion by area, of each geological unit in a catchment potentially salinised at each target date.

4.2 Potentially Salinised Areas as Indicated by Watertable Depth Less than 2 m

The estimated area of potentially salinised land within each geological unit, in each catchment, has been calculated for ‘current’ and future conditions. The factor by which the ‘current’ area is estimated to be increasing is shown in Table 4.3 as the ratio of future potential area to ‘current’ potential area. Large areas of low-lying alluvium considered to be providing a negligible salt load to streams (see Figure 3.1) are eliminated. Table 4.3 further indicates the total area occupied by each geological unit in the catchment, including the area of non-contributing alluvium. The potential areas of salinisation estimated for ‘current’ conditions are very much in excess of the areas in which salinised land has been recorded to date and are not shown. However, actual salinised areas in dryland catchments are poorly represented in GIS. In the DLWC Central Western Region a recent survey has revealed a 700% increase in the area previously mapped within the last decade in the Lachlan Catchment (A. Nicholson pers. comm).

There are several possible reasons for the discrepancy. The observed salinised areas do not include any allowance for surrounding areas where the watertable may be within 2 m of the surface and the observed area is prone to underestimation because potentially at the time they were surveyed the indicators of salinisation were poorly recognised. Alternatively, the projected areas under ‘current’ conditions and for the required target dates might be grossly overestimated by extrapolation from unreliably small data sets. Further, much of the land where the water level rises to within 2 m of the land surface might not become salinised within the time frame of this study due to variable groundwater salinity, climatic variability or the area simply being in salt balance.

In addition, the area extrapolated from the bore analysis represents the expansion in the piezometric surface rather than the water table. Discharge is unlikely to occur over the whole area due to various confining geological structures. However, as the piezometric surface expands in area and height, the overall discharge from existing and new areas of salinisation and waterlogging will continue to increase. Due to the compensating effect of pressure, the overall discharge of water with its attached salinity is expected to be broadly similar to the discharge calculated using Equation 3.1. It is difficult to assess the accuracy of this estimate of potential salinised area in the absence of any previous studies. Intuitively it would seem prone to overestimation since there is no topographic analysis.

	Castlereagh			Gwydir		Lachlan		Macintyre		Macquarie		Murray		Murrumbidgee		Namoi	
	Statistics	Salinity (uS/cm)	Rate of Rise (m/year)	Salinity (uS/cm)	Rate of Rise (m/year)	Salinity (uS/cm)	Rate of Rise (m/year)	Salinity (uS/cm)	Rate of Rise (m/year)	Salinity (uS/cm)	Rate of Rise (m/year)	Salinity (uS/cm)	Rate of Rise (m/year)	Salinity (uS/cm)	Rate of Rise (m/year)	Salinity (uS/cm)	Rate of Rise (m/year)
Total Catchment	Average	1569.009	0.144	1106.923	0.016	4489.832	0.117	775	-0.005	3078	0.074	2335	0.556	3231	0.304	1983	0.058
	Std Dev.	1561.742	0.386	1567.399	0.305	5953.902	0.301	426	0.588	3731	0.339	1495	0.398	3297	0.558	1917	0.311
	Ave+Std Dev	3130.751	0.530	2674.322	0.320	10443.735	0.419	1200	0.583	6809	0.413	3830	0.954	6527	0.863	3900	0.370
	Ave-Std Dev	7.267	-0.242	-460.476	-0.289	n/a	-0.184	349	-0.593	-654	-0.265	840	0.158	-66	-0.254	67	-0.253
	n	110	78	13	40	173	209	57	50	55	299	50	58	235	317	164	129
Volcanics	Average	1421.136	0.134	440.000	-0.029	np**	np	886	-0.188	1320	-0.025	np	np	np	np	1351	0.203
	Std Dev.	906.473	0.307	573.585	0.360			512	0.368	557	0.320					854	0.366
	Ave+Std Dev	2327.610	0.441	1013.585	0.330			1398	0.181	1877	0.295					2205	0.569
	Ave-Std Dev	514.663	-0.172	-133.585	-0.389			375	-0.556	763	-0.345					497	-0.164
	n	22	21	4	15			23	23	10	3					26	20
Plutonics	Average	np	np	1693.333	0.078	1951.459	0.094	319	1.137	2520	0.089			2396	0.239		-0.112
	Std Dev.			2129.194	0.136	1686.043	0.171	144	1.667	1319	0.428			1948	0.378		n/a
	Ave+Std Dev			3822.527	0.213	3637.502	0.266	463	2.803	3839	0.517			4344	0.617		n/a
	Ave-Std Dev			-435.861	-0.058	265.417	-0.077	175	-0.530	1200	-0.339			448	-0.139		n/a
	n			6	7	37	47	2	3	6	34	0	0	107	131	0	1
Sedimentary	Average	1519.213	0.149	823.333	0.059	np	np	658	0.273	1935	0.105	np	np	np	np	2041	-0.011
	Std Dev.	1608.776	0.425	933.506	0.189			318	0.579	1642	0.321					1917	0.340
	Ave+Std Dev	3127.989	0.574	1756.839	0.248			975	0.852	3577	0.427					3958	0.329
	Ave-Std Dev	-89.564	-0.276	-110.173	-0.130			340	-0.306	294	-0.216					124	-0.351
	n	80	54	3	7			16	8	15	67					60	44
Metasediments	Average	7760.000	0.022		-0.039	3265.698	0.159	np	np	4256	0.060	2410	0.551	3398	0.432		
	Std Dev.	n/a	n/a		0.515	2611.419	0.374			3994	0.339	1375	0.340	3259	0.810		
	Ave+Std Dev	n/a	n/a		0.476	5877.117	0.533			8250	0.399	3785	0.891	6657	1.242		
	Ave-Std Dev	n/a	n/a		-0.554	654.280	-0.216			262	-0.279	1035	0.212	140	-0.377		
	n	1	1	0*	6	53	69			11	134	39	48	64	97	0	0
Alluvium	Average	1841.500	0.175		0.057	6403.072	0.098	788	-0.096	5008	0.068	2069	0.580	4459	0.261	2150	0.063
	Std Dev.	931.082	0.111		0.036	7823.216	0.292	358	0.206	5966	0.311	1915	0.632	4541	0.409	2136	0.259
	Ave+Std Dev	2772.582	0.286		0.093	14226.288	0.390	1146	0.110	10974	0.379	3983	1.212	8999	0.670	4286	0.323
	Ave-Std Dev	910.418	0.064		0.020	-1420.144	-0.194	430	-0.302	-958	-0.243	154	-0.051	-82	-0.147	14	-0.196
	n	6	2	0	2	83	93	16	16	13	61	11	10	64	89	78	64

* If n = 0, then there are no bores in the indicated unit and hence no data

** np: The indicated geological unit is not present in catchment

Table 4. 1 Water level change and salinity statistics for Reconnaissance Bore Catchments

Although the relationship between the percentage of bores with groundwater levels less than 2 m and area potentially salinised is tenuous it does provide a first approximation of the relative level of change possible over the time period in question.

	TOTAL CATCHMENT				BY GEOLOGICAL GROUP (AVG.)				
	Min:	Max:	Avg:	SD:	Volcanics	Plutonics	Sedimentary	Metased.	Alluvium
Castlereagh	30	7760	1569	1562	1421	np	1519	7760	1842
Gwydir	130	5800	1107	1567	440	1693	823	nd	nd
Lachlan	31	38000	4490	5954	np	1951	np	3266	6403
Macintyre	80	2200	775	426	886	319	658	np	788
Macquarie	180	21600	3078	3731	1320	2520	1935	4256	5008
Murray	308	7330	2335	1495	np	nd	np	2410	2069
Murrumbidgee	42	20400	3231	3297	np	2396	np	3398	4459
Namoi	0	9260	1983	1917	1351	nd	2041	nd	2150
Average:			1959		677	1110	872	2636	2840

np - not present nd - no data

(a) Electrical Conductivity (uS/cm)

Table 4. 2a Distribution of estimated groundwater salinity, by catchment and geological unit

	TOTAL CATCHMENT				BY GEOLOGICAL GROUP (AVG.)				
	Min:	Max:	Avg:	SD:	Volcanics	Plutonics	Sedimentary	Metased.	Alluvium
Castlereagh	-0.753	2.194	0.144	0.386	0.134	np	0.149	0.022	0.175
Gwydir	-1.163	0.600	0.016	0.305	-0.029	0	0.059	-0.039	0.057
Lachlan	-1.450	1.618	0.117	0.301	np	0.078	np	0.159	0.098
Macintyre	-1.128	3.050	-0.005	0.588	-0.188	1.137	0.273	np	-0.096
Macquarie	-1.267	1.928	0.074	0.339	-0.025	0.089	0.105	0.06	0.068
Murray	0.008	2.193	0.556	0.398	np	nd	np	0.551	0.58
Murrumbidgee	-1.755	4.920	0.304	0.558	np	0.239	np	0.432	0.261
Namoi	-1.223	1.395	0.058	0.311	0.203	-0.112	-0.011	nd	0.063
Median:			0.088			np - not present		nd - no data	

(b) Rate of Change (m/year, negative indicates falling level)

Table 4.2b Distribution of estimated water level change, by catchment and geological unit

4.3 Predicted Potential Salt Loads

An appreciation for the overall variability within the potential salt load estimates for each catchment can be gained from Figure 4.4. Predicted potential salt loads calculated for ‘current’ conditions and for the required target years are depicted in the maps in Figures 4.5 to 4.8, showing loads per square kilometre for each of the geological units within each catchment. The corresponding numerical results are listed in Table 4.4

Comparing predictions for ‘current’ conditions with observed in-stream salt loads (Section 5) at the last balance point prior to the influence of diversions, the potential salt loads range from extreme

underestimates to substantial over estimates (see also Table 6.2). The potential salt loads calculated here estimate the salt delivery to the ground surface without proposing any appropriate transport mechanism between potential salinised areas and the river system.

The hydrogeology estimates of potential salt load are primarily used in this study as a means of establishing factors for scaling the in-stream salt loads for the required target dates. Where these potential salt load estimates are greater than or closer to the observed in-stream salt loads the scaling factors are not affected. However, where these estimates are much less than the observed, unreasonably high scaling factors (Section 6.1) are obtained. For example the Gwydir Valley salt load estimates are cause for some concern. The estimates are very low, and the ratio of observed salt load in the Gwydir River to the estimated groundwater-delivered salt load for ‘current’ conditions is about 20:1.

The same ratio for the other valleys is generally close to unity or substantially less, suggesting that estimated salt loads from groundwater for the Gwydir, from this analysis, is substantially underestimated.

Salt loads from the Murray Catchment are difficult to calculate as the basin extends across two States and the data used for this study pertain only to the New South Wales portion of the catchment. There are no reconnaissance bore data for some of the geological units in the Murray, Gwydir and Murrumbidgee catchments. Using the present technique, higher potential salt loads for these areas, could be expected, given such data.

The predicted salt loads for the target dates, given in Table 4.4, provide a working estimate of the potential salt loading within the landscape, given the data available for the analysis. The close match in some catchments between them and ‘current’ in-stream salt load is perhaps fortuitous. Wherever overestimated, the relationship between them and in-stream salt loads is considered analogous to potential and actual evapotranspiration, where processes, unquantified in the methodology adopted here, restrict the transfer of water and salt from the landscape to the river system.

The predicted loads delivered to the ground surface must be regarded only as a general guide to the potential salt load that is available to contribute to the river system. Discrepancies arise from the limited data set used, the simplified conceptual model and the lack of any means to account for the effect of topography. However, they provide an estimate of the relative level of change that can be expected over the next century. This provides the best estimate obtainable from the data available in NSW for factoring in-stream salt loads under ‘current’ conditions to the target dates.

		Total area of geology in catchment, km2	Increase factors for estimated potential salinised area within geologies		
			2020	2050	2100
Castlereagh	Volcanics	1485	1.50	1.67	1.83
	Sedimentary	5418	1.86	2.15	2.58
	Plutonics				
	Metasediments	18	>10	>10	>10
	Alluvium	5158	1.00	2.00	2.00
	Excluded Alluv.	5202			
	Total	17169	1.22	1.99	2.09
Gwydir	Volcanics	2653			
	Sedimentary	5066	>10	>>10	>>>10
	Plutonics	3483	1.50	2.50	3.00
	Metasediments	1701	1.52	2.52	2.52
	Alluvium	2481	1.00	>10	>>10
	Excluded Alluv.	10802			
	Total	25844	2.22	5.43	6.58
Lachlan	Volcanics				
	Sedimentary				
	Plutonics	12267	1.67	2.33	2.78
	Metasediments	24391	1.31	1.92	2.38
	Alluvium	35375	1.10	1.70	2.60
	Excluded Alluv.	18369			
	Total	90517	1.31	1.93	2.55
MacIntyre	Volcanics	6441	1.50	1.67	1.67
	Sedimentary	4316	1.00	1.00	1.00
	Plutonics	2884	1.00	1.00	1.00
	Metasediments				
	Alluvium	2390	1.00	>10	>>10
	Excluded Alluv.	7777			
	Total	23352	1.11	1.17	1.22
Macquarie	Volcanics	592	1.00	>10	>10
	Sedimentary	6638	1.54	1.92	2.23
	Plutonics	6219	1.17	1.33	2.00
	Metasediments	21264	2.20	3.00	3.60
	Alluvium	18793	2.20	3.00	3.60
	Excluded Alluv.	21099			
	Total	74309	1.91	2.59	3.15
Murray	Volcanics				
	Sedimentary				
	Plutonics	128			
	Metasediments	644	4.00	6.20	8.20
	Alluvium	2248	1.25	1.25	2.00
	Excluded Alluv.	13232			
	Total	16268	1.44	1.60	2.44
Murrumbidgee	Volcanics	647			
	Sedimentary				
	Plutonics	20259	1.27	1.44	1.61
	Metasediments	16788	1.23	1.33	1.51
	Alluvium	17336	1.57	1.81	2.43
	Excluded Alluv.	29030			
	Total	84060	1.32	1.48	1.74
Namoi	Volcanics	4202	1.29	1.57	1.86
	Sedimentary	13197	2.00	3.67	5.33
	Plutonics	2012	1.00	1.00	1.00
	Metasediments	2471			
	Alluvium	9792	1.90	2.30	2.90
	Excluded Alluv.	10014			
	Total	41231	1.69	2.34	3.07

NB. Where the starting point (current 1998 estimated area) is zero extreme factors are obtained for future conditions. In this case a factor >10 is indicated. If the factor continues to increase additional >> signs are used. A factor of 1.0 equals no change

Table 4.3 Estimated factors for increased potential salinised areas, as indicated by watertable less than 2 m, by catchment and geological unit

				Total load (T/yr)				Load/Area (T/yr/km2)			
		km2	catchment	1998	2020	2050	2100	1998	2020	2050	2100
Castlereagh	Volcanics	1485	9	5270	7905	8784	9662	3.55	5.32	5.91	6.51
	Sedimentary	5418	32	20257	37620	43408	52090	3.74	6.94	8.01	9.61
	Plutonics		0	n.p.							
	Metasediments	18	0	0	400	400	400	0.00	22.09	22.09	22.09
	Alluvium	5158	30	135180	135180	270359	270359	26.21	26.21	52.41	52.41
	Excl. alluvium	5202	30								
	Total **	17169	100	160707	181105	322951	332511	9.36	10.55	18.81	19.37
Gwydir	Volcanics	2653	10	0	0	0	0	0	0	0	0
	Sedimentary	5066	20	0	6414	22450	25657	0.00	1.27	4.43	5.06
	Plutonics	3483	13	4246	6369	10615	10615	1.22	1.83	3.05	3.05
	Metasediments	1701	7	3248	4937	8185	8185	1.91	2.90	4.81	4.81
	Alluvium	2481	10	0	0	8240	16480	0.00	0.00	3.32	6.64
	Excl. alluvium	10802	42								
	Total	25844	100	7494	17721	49491	60938	0.29	0.69	1.92	2.36
Lachlan	Volcanics		0	n.p.							
	Sedimentary		0	n.p.							
	Plutonics	12267	14	13761	22934	32108	38224	1.12	1.87	2.62	3.12
	Metasediments	24391	27	305460	399448	587423	728404	12.52	16.38	24.08	29.86
	Alluvium	35375	39	387983	426781	659571	1008755	10.97	12.06	18.65	28.52
	Excl. alluvium	18369	20								
	Total	90517	100	707203	849163	1279101	1775383	7.81	9.38	14.13	19.61
MacIntyre	Volcanics	6441	28	0	0	0	0	0	0	0	0
	Sedimentary	4316	18	50379	50379	50379	50379	11.67	11.67	11.67	11.67
	Plutonics	2884	12	33978	33978	33978	33978	11.78	11.78	11.78	11.78
	Metasediments		0	n.p.							
	Alluvium	2390	10	0	0	0	0	0	0	0	0
	Excl. alluvium	7777	33								
	Total	23352	100	84358	84358	84358	84358	3.61	3.61	3.61	3.61
Macquarie	Volcanics	592	1	0	0	0	0	0	0	0	0
	Sedimentary	6638	9	34065	52407	65509	75990	5.13	7.90	9.87	11.45
	Plutonics	6219	8	8005	9339	10673	16009	1.29	1.50	1.72	2.57
	Metasediments	21264	29	78984	173765	236952	284343	3.71	8.17	11.14	13.37
	Alluvium	18793	25	116293	255845	348879	418655	6.19	13.61	18.56	22.28
	Excl. alluvium	21099	28								
	Total	74309	100	237347	491356	662014	794998	3.19	6.61	8.91	10.70
Murray	Volcanics		0	n.p.							
	Sedimentary		0	n.p.							
	Plutonics	128	1	n.d.							
	Metasediments	644	4	11844	47376	73433	97122	18.39	73.57	114.03	150.81
	Alluvium	2248	14	175385	219231	219231	350770	78.03	97.54	97.54	156.07
	Excl. alluvium	13232	81								
	Total	16268	100	187229	266608	292665	447892	11.51	16.39	17.99	27.53
Murrumbidgee	Volcanics	647	1	n.d.							
	Sedimentary		0	n.p.							
	Plutonics	20259	24	166864	212372	240183	267993	8.24	10.48	11.86	13.23
	Metasediments	16788	20	1275720	1570117	1700961	1929936	75.99	93.53	101.32	114.96
	Alluvium	17336	21	725849	1140620	1313441	1762776	41.87	65.80	75.77	101.69
	Excl. alluvium	29030	35								
	Total	84060	100	2168433	2923109	3254584	3960706	25.80	34.77	38.72	47.12
Namoi	Volcanics	4202	10	26199	33685	41170	48655	6.23	8.02	9.80	11.58
	Sedimentary	13197	32	0	0	0	0	0	0	0	0
	Plutonics	2012	5	n.d.							
	Metasediments	2471	6	n.d.							
	Alluvium	9792	24	33938	64482	78057	98420	3.47	6.59	7.97	10.05
	Excl. alluvium	10014	24								
	Total	41231	100	60137	98166	119227	147075	1.46	2.38	2.89	3.57

n.p. -geological unit not present

n.d. - no data

** NOTE:

Total load (t/yr) is total salt load from contributing parts of catchment

Load/area (t/y/km2) for total catchment is total salt load divided by entire catchment area

Gwydir values based on use of data collected in March 1999 for metasediment and alluvial areas

Table 4.4 Estimated salt load delivered to the land surface by catchment and geological unit

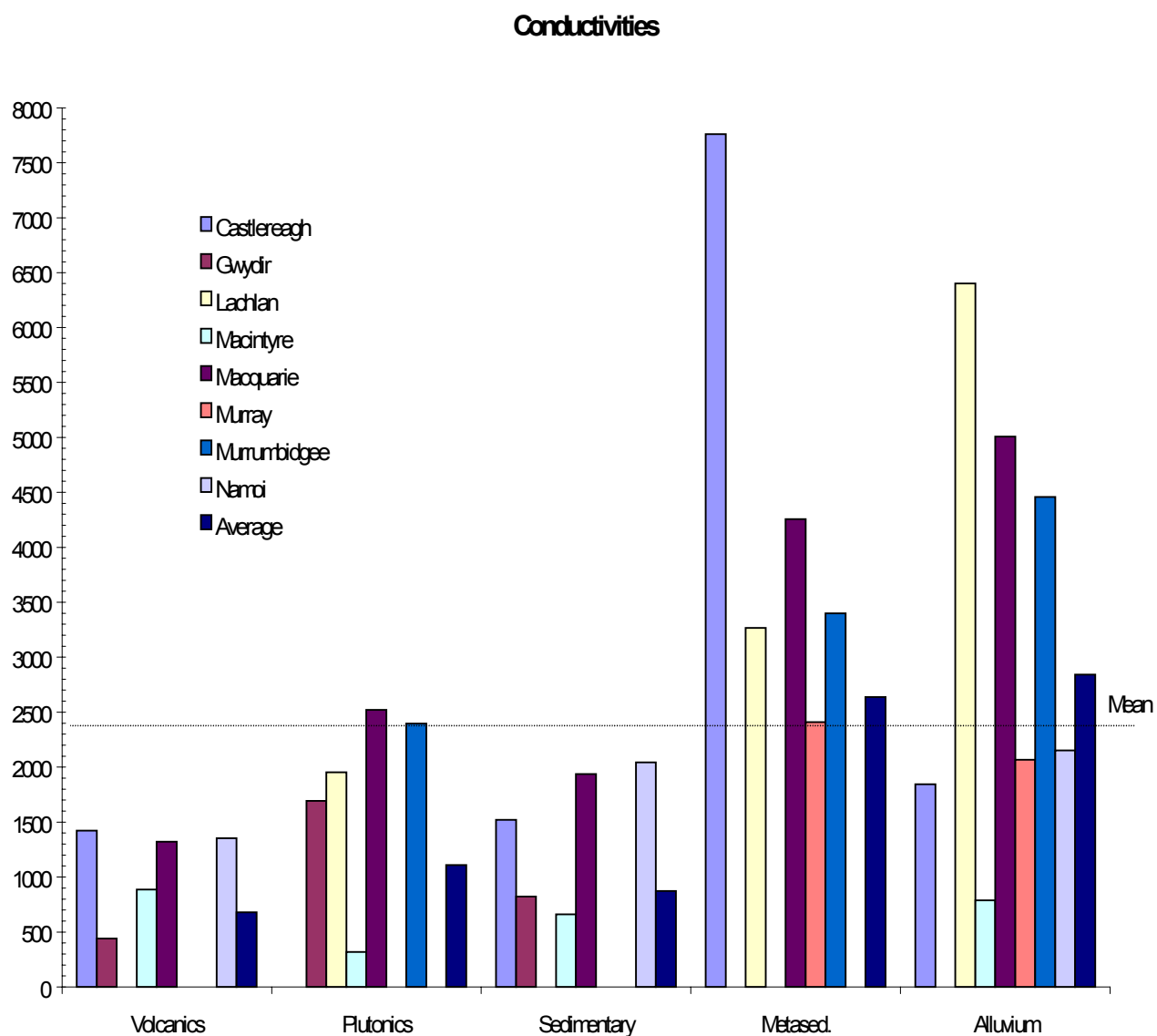


Figure 4.1 Murray-Darling Basin salinity and drainage strategy groundwater derived salt loads

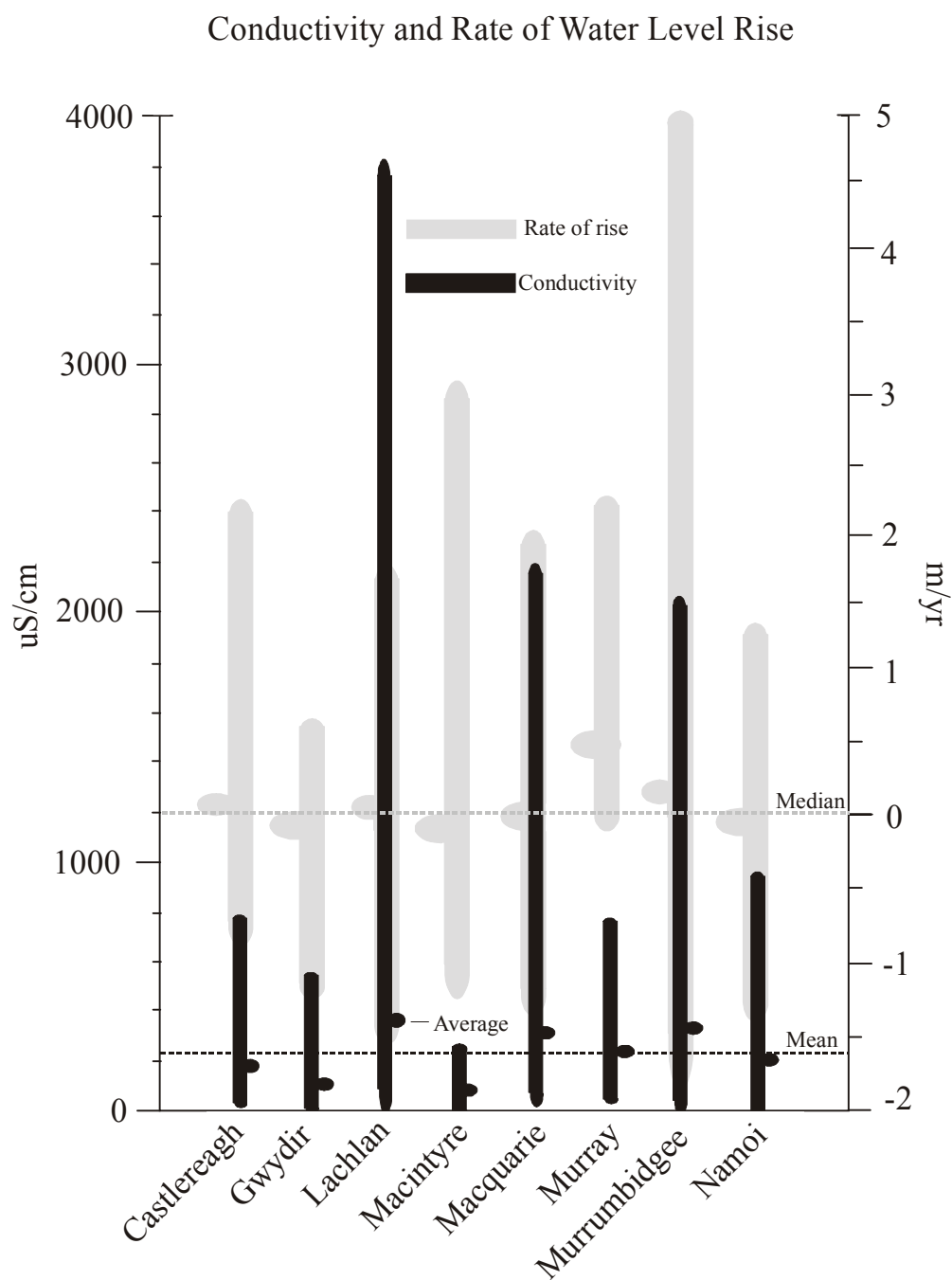


Figure 4.2 Murray-Darling Basin Salinity and Drainage Groundwater Derived Salt Loads

Figure 4.3. Water level rise (m/yr)

Figure 4.4. Estimated salt loads, 1998

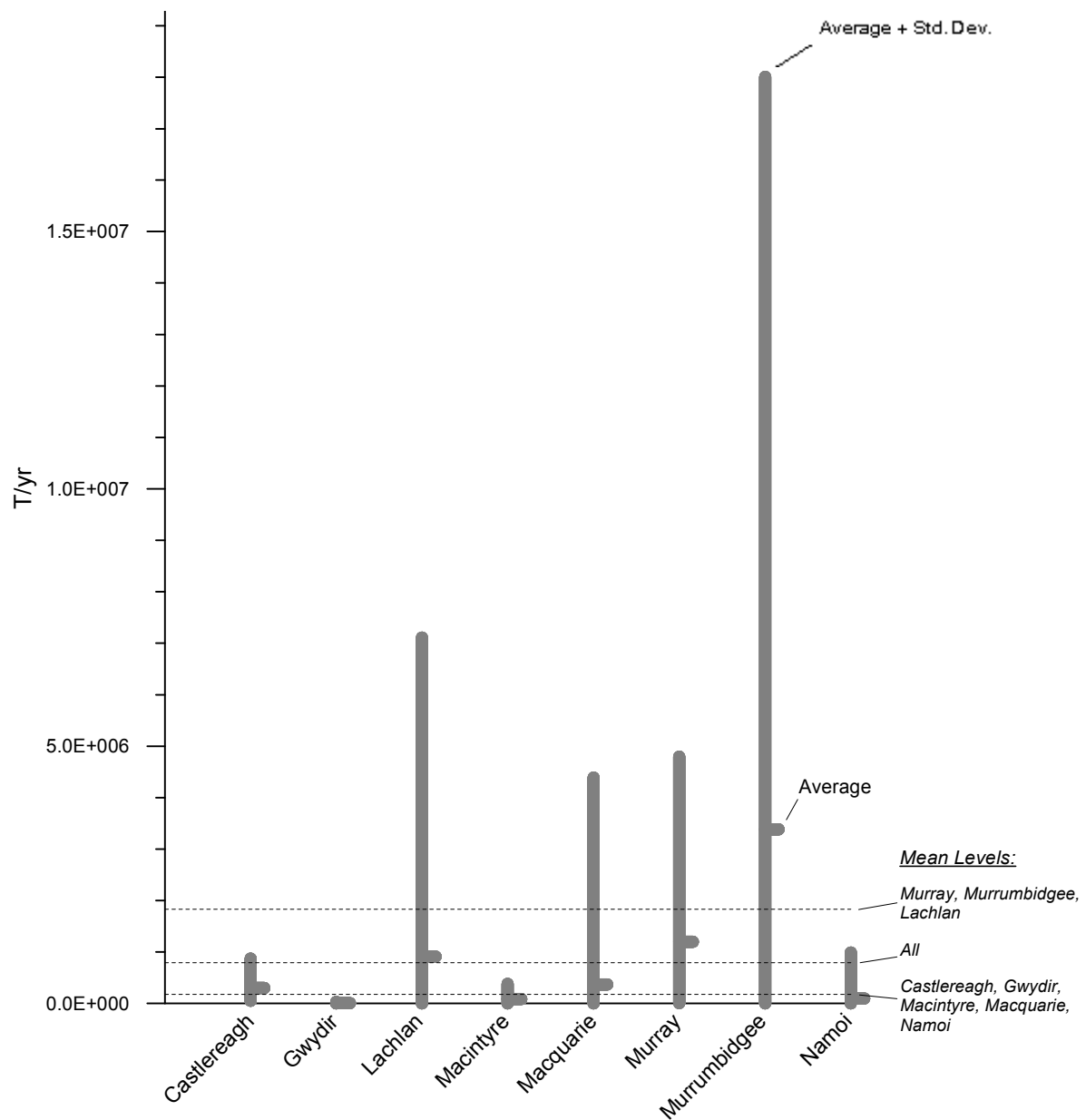


Figure 4.5. Average salt load ($\text{t.km}^{-2}.\text{year}^{-1}$) 1998

Figure 4.6. Average salt load ($\text{t.km}^{-2}.\text{year}^{-1}$) 2020

Figure 4.7. Average salt load ($\text{t.km}^{-2}.\text{year}^{-1}$) 2050

Figure 4.8. Average salt load ($\text{t.km}^{-2}.\text{year}^{-1}$) 2100

4.4 Areas Excluded From the Analysis

In addition to the areas of excluded alluvium shown in Figure 3.1, large areas of New South Wales are not included in the analysis of salt load increases from dryland areas. In the main they are not expected to be major contributors of salt within the timeframe of the required target dates.

- **Alluvial Aquifers.** These are the groups of unconsolidated sediments primarily associated with the present day rivers.

Darling Basin. This area is generally north and west from Dubbo to Moree and east of the Bogan River. Regional groundwater levels under ‘current’ conditions are rising at rates estimated to be less than 0.1 m per year. However, due to the large groundwater abstractions from the high yielding aquifers along the eastern margins of the area, water levels are actually generally static or falling. The exception is the area immediately east of Narromine where irrigation by surface water has seen rapid water table rises.

Murray Geological Basin. The area considered here is generally west from Hillston, Narrandera and Albury; north of the Murray River; south of the Broken Hill – Parkes railway line and east of Balranald and Ivanhoe. Outside the irrigation districts in the eastern areas of high groundwater yield, water tables are not rising due to increasing groundwater abstractions. The western fringe areas have water tables that are rising, but scenarios from Punthakey *et al.* (1996) indicate there will not be significant areas with water tables at depths of less than 2 m within the study timeframe.

Darling River Trunk. The water tables along the river from Mungindi to Wentworth have risen due to river regulation but this does not appear to have increased the salt inflow to the river. Exceptions may be the localised effects of irrigation in the upstream areas such as Bourke and the operation of the Menindee Lakes storages. Both these areas are currently being assessed.

NSW Mallee. Prathapar *et al.* (1994) showed that there was negligible impact on the groundwater system under all but cropped areas in this region. They further indicated

that the time for significant impact from the cropped areas was several hundred years, which is outside the timeframe of this study. The vast majority of the native vegetation in the region remains uncleared.

Murray River Trunk. Recent modelling work (SKM, 1998) indicates that increased salt load due to dryland processes west of Euston is unlikely. Upstream as far as Albury there is a considerable body of work which indicates that dryland processes will not add salt in the project timeframe.

- **Hard Rock Areas.** These are generally metasediments or granites.

Cobar Block. This covers the area generally north of the Broken Hill - Parkes railway line, west of the Bogan River and east of the Darling River. Groundwater levels in this area tend to remain static or show a slight variation due to changing climatic conditions. They are not expected to contribute to salt load increases.

West of the Darling River. The rocks in this area are generally either those of the Great Artesian Basin or associated with the Broken Hill Block. There is no data to suggest groundwater levels will rise to cause salinisation, although local problems in urban areas due to poor water management practices have been reported.

5 In-Stream Salt balances for Second Order Catchments Under ‘Current’ Conditions

The in-stream salt balance for each second order catchment, namely, the Border Rivers, Gwydir, Namoi, Castlereagh, Macquarie-Bogan, Lachlan and the Murrumbidgee, is discussed in this section. The stochastic component of the CATSALT model [Eqs (3.2) to (3.11); Section 3.2] is used to assess the daily salt load exported from the third order catchments under ‘current’ conditions (1998) with observed flow and EC data. The model parameters of these third order catchments are regionalised to obtain the daily salt export rates for catchments with no EC data. The basis for obtaining flow data at all stations used in this study is described in Section 2.2.

The salt balance is done according to the methodology described in Section 3.3. The accuracy of salt balance is assessed on the basis of following criteria: (a) R^2 between observed ($q_T^s \text{ t.month}^{-1}$) and the estimated salt load ($\hat{q}_T^s \text{ t.month}^{-1}$), (b) mass (salt) balance error, and (c) the slope α of the regression line $q_T^s = \alpha \hat{q}_T^s$. The historical 1975–95 climatic conditions are referred to as either the ‘current’ conditions or 1975–95 conditions and these are used for the salt balance analysis. However all references to the cap flow scenario wherever used are specifically mentioned throughout the report.

Before implementing the various alternative hypotheses described in Section 3.2 [Models I, IIA–D, III and IV; Eqs (3.2) to (3.18)] on a statewide basis, these were extensively tested in the Murrumbidgee Catchment on the continuous flow and EC data for the Murrumbidgee River at Wagga Wagga and Gundagai and on discrete data for Kyeamba and for Tarcutta Creeks (Tuteja and Beale, 1999 ; in press). The model formulations that are based on flow and EC relationships were found to perform poorly in all cases [Eqs (3.2) and (3.8)]. This is because the rising and falling limbs of the hydrograph should be related to EC by separate relationships as against a single composite relation used in this study. These are therefore not used on a statewide basis.

In contrast, the model formulations based on flow and salt load relationships produced good results [Models IIA–D: Eqs(3.4) to (3.7); Model IV: Eqs(3.10) to (3.11)]. To investigate the dependence of salt load on the history of the streamflow process, the salt load on a particular day was related to the flow on that day together with the flow observed on a number of previous days, representing the memory of the system (Model IV). The memory was varied from 1 to 10 days, and in all cases there was little or no improvement in R^2 over and above the case when salt load was related to the flow on that day itself, i.e. when memory equals 1. The first parameter associated with flow on a given day remains the most significant and the other parameters converge alternatively to low positive and

negative values around zero. This indicates that Model IV collapses to Model IIC i.e. a linear model for salt load on a given day as a function of flow on the same day. All four stations showed similar responses. Therefore, for the statewide study, only Models IIA–D are implemented at stations with daily observed flow and EC data. In case of Model IIA or IIB, two harmonics provide an optimum combination for explaining the cumulative explained variance [Cumulative Periodogram Analysis, Eqs (3.13) to (3.18)] while satisfying the principle of parsimony (i.e. minimum number of parameters required to reproduce the autocovariance structure).

5.1 Salt Balance for the Border Rivers

The gauging stations and the residual areas (with no observed streamflow data) that are used in the salt balance analysis for the Border Rivers Catchment (Macintyre) are shown in Figures 5.1a and 5.2. The salt balance in the Border Rivers Catchment is computed at 5 gauging stations (shown as dark nodes in Figure 5.2), namely: the Severn R. at Pindari Dam (416 019), Severn R. at Ashford (416 006), Macintyre R. at Holdfast (416 012), Dumaresq R. at Bonshaw Weir (416 007) and Macintyre R. at Boggabilla (416 002). No salt balance analysis is undertaken for the Gil Gil Creek Catchment, which receives flow and salt inputs from Carole Creek in the Gwydir Catchment. Salt export from Gil Gil Creek is estimated using the appropriate model form with the calibrated model parameters for Gil Gil Creek at Galloway (416 052) for ‘current’ conditions only.

The gauging stations with observed flow and EC data (shown in *italics* in Figure 5.2) are used for identifying the appropriate model form to obtain the daily salt load time series [Eqs (3.2) to (3.8)]. The parameter values for the most suitable model form obtained from calibration and the associated statistics are shown in Table 5.1. In most cases, Models IIC and IID are found to be the appropriate candidate models according to the R^2 criterion. In some cases (residual areas R1–R4), the parameters are taken from stations in close proximity with similar size and flow characteristics (see Table 5.1 for parameter values and the associated statistics).

The results of the salt balance analysis for the Severn R. at Pindari Dam (416 019), Severn R. at Ashford (416 006), Macintyre R. at Holdfast (416 012), Dumaresq R. at Bonshaw Weir (416 007) and Macintyre at Boggabilla (416 002) are shown in Figures 5.3a–o. The summary statistics indicating accuracy of the salt balance at five salt balance locations are shown in Table 5.2. The salt balance at all locations is reasonably good with the goodness of fit varying in the range 0.86 to 0.99. Unlike the influence of dams in other third order catchments (e.g. Namoi at Keepit Dam and Gwydir at Copeton Dam), the effect of salt mixing from various inputs into the reservoir at Pindari Dam (416 019) does not seem to have any substantial influence on the salt balance.

Figure 5.1a. Macintyre River Catchment (Basin 416)

Figure 5.1b. Gwydir River Catchment (Basin 418)

Figure 5.1c. Namoi River Catchment (Basin 419)

Figure 5.1d. Castlereagh River Catchment (Basin 420)

Figure 5.1e. Macquarie–River Catchment (Basin 421)

Figure 5.1f. Lachlan River Catchment (Basin 412)

Figure 5.1g. Murrumbidgee River Catchment (Basin 410)

Figure 5.1h. Murray River Catchment (Basin 409)

Figure 5.2. Schematic diagram of the gauging stations and the residual areas used in the Border Rivers Salt Balance Analysis

Station	Catchment Area km^2	\bar{Q} $mm.y^{-1}$	n	Range	Model	Parameter estimation	η	λ	R^2	\bar{Q}_s^{year} $10^3 t.y^{-1}$	$\bar{Q}_s^{year} / Area$ $t.y^{-1}.km^{-2}$
416 039	1790	83	113	200–400	IID	At site	2.67	0.932	0.80	19800	11.1
R1	340	188			IID	Other	2.67	0.90		4200	12.4
416 019	2130	85	975	150–250	IIC	At site	3.70	8.53	0.90	19100	9.0
416 021	804	81	104	250–500	IID	At site	2.96	0.954	0.89	12700	15.8
R2	76	3822			IID	Other	2.67	0.90		1100	14.5
416 006	3010	89	116	150–250	IID	At site	2.48	0.925	0.92	28000	9.3
416 010	2020	27	72	350–600	IIC	At site	27.0	8.76	0.83	21300	10.5
R3	1710	120			IID	Other	2.95	0.887		11800	6.9
416 012	6740	67	139	250–400	IID	At site	2.95	0.887	0.95	61500	9.1
416 020	402	32	91	600–850	IIA	At site	-6.11	23.00		4000	10.0
R4	1228	56			IID	Other	2.95	0.887		1900	1.6
416 011	5550		188	200–250	IIC	At site	18.2	6.78	0.87	36100	6.5
416 008	866	77	112	200–650	IIC	At site	7.510	4.08	0.74	5300	6.1
416 007	7280	60	129	200–250	IIC	At site	16.1	8.03	0.93	46300	6.4
416 002	22600	45	120	200–350	IIC	At site	59.3	10.2	0.85	142100	6.3

\bar{Q} : Mean annual runoff; n : Number of days with common flow and EC data; \bar{Q}_s^{year} : Mean annual salt load

Salt balance locations: 416 019 (Severn R. at Pindari), 416 006 (Severn R. at Ashford), 416 012 (Macintyre R. at Holdfast), 416 007 (Dumaresq R. at Bonshaw Weir), and Macintyre at Boggabilla (416 002).

Table 5.1 Average annual salt export rate and model parameter values for the Border Rivers Catchment based on 1975–95 conditions

Station	Catchment Area km^2	\bar{Q} $GL.y^{-1}$	\bar{Q}_s^{year} $1 \times 10^3 t.y^{-1}$	R^2	Slope α in $Q_s = \alpha \hat{Q}_s$	Mass balance error $\frac{\sum(\hat{Q}_s - Q_s)}{\sum(Q_s)} \times 100$
416 019	2130	181	19100	0.93	0.78	25.6
416 006	3010	268	28000	0.98	0.83	17.6
416 012	6740	452	61500	0.96	0.94	7.0
416 007	7280	437	46300	0.99	1.02	0.0
416 002	22600	1017	142100	0.86	0.78	22.6

\bar{Q} : Mean annual runoff, \bar{Q}_s^{year} : Mean annual salt load, Q_s : Observed monthly salt load, \hat{Q}_s : Estimated monthly salt load

Salt balance locations: Severn R. at Pindari (416 019), Severn R. at Ashford (416 006), Macintyre R. at Holdfast (416 012), Dumaresq R. at Bonshaw Weir (416 007) and Macintyre at Boggabilla (416 002).

Table 5.2 Results of the salt balance analysis of Border Rivers catchments based on 1975–95 conditions

At Pindari Dam (416 019), the observed salt loads are underestimated during July to October and are marginally overestimated for the remaining period (Figure 5.3a–c). Although marginally influenced by the dam and the error in quantifying flow contributions from the residual area R1, the 7% inaccuracy in salt balance is mainly due to inaccuracy in the estimated model parameter values. This results in overestimation of the salt loads in the high range and also an overall mass balance error of about 25%. However, with the exception of peak salt loads at Pindari Dam that are somewhat overestimated, the salt loads for a major part of the year are reproduced reasonably well.

The results of salt balance analysis for the Severn R. at Ashford (416 006) and Macintyre R. at Holdfast (416 012) are quite good and progressively improve from upstream to downstream indicating that the salt balance is reliable (Figures 5.3d–e, 5.3g–h and 5.3j–k). The temporal distribution of the salt loads at these stations is also reasonably good (Figures 5.3f, 5.3i and 5.3l). Estimates of the salt contribution from residual areas in NSW (R5_NSW and R6_NSW, Figure 5.2) and Queensland (R5_Qld and R6_Qld, Figure 5.2) are obtained in proportion to the contributing areas. The factors used for salt load estimation, given by Eqs (5.1) to (5.4), represent ratios of the corresponding contributing areas.

$$[\hat{q}_T^s]_{R5_NSW} = 1.7 [q_T^s]_{008} \quad (5.1)$$

$$[\hat{q}_T^s]_{R5_Qld} = 0.154 [q_T^s]_{R5_NSW} \quad (5.2)$$

$$\left[\hat{q}_T^s\right]_{R6_NSW} = 0.129\left\{\left[q_T^s\right]_{012} + \left[q_T^s\right]_{020} + \left[\hat{q}_T^s\right]_{R4}\right\} \quad (5.3)$$

$$\left[\hat{q}_T^s\right]_{R6_Qld} = 0.65\left\{\left[q_T^s\right]_{012} + \left[q_T^s\right]_{020} + \left[\hat{q}_T^s\right]_{R4}\right\} \quad (5.4)$$

where $\left[\hat{q}_T^s\right]_i$ and $\left[q_T^s\right]_i$ are the estimated and observed monthly salt load contributions from the area i under ‘current’ conditions, T (i.e. 1998 conditions).

The salt balance analysis for the Macintyre River at Boggabilla (416 002) is undertaken by using estimates of monthly salt loads from residual areas in NSW and Queensland (R5_NSW, R6_NSW, R5_Qld and R6_Qld) according to Eqs (5.1) to (5.4) (see Figures 5.3m–o). The results show reasonable reproduction of the observed salt loads although high values are generally overestimated. In view of the rather crude assessment of the salt loads from residual areas from Eqs (5.1) to (5.4), the salt balance accuracy of about 86% is considered reasonably acceptable. This error, however, does not create any problems for future salt load estimation at target dates because the groundwater trends do not indicate any increase in potential salt loads.

The average monthly observed salt load and EC at the end of system for the Macintyre system (Barwon at Mungindi—416 001) and Gil Gil Creek at Galloway (416 052) are shown in Figures 5.3p and 5.3q respectively. It is pointed out that a significant proportion of the salt loads in Gil Gil Creek at Galloway (416 052) comes from Carole Creek in the Gwydir Catchment. This has implications for estimation the salt exports under likely future conditions at target dates. While there is no increase in future salt export rate from the Border Rivers Catchment, there is expected to be an increase in salt exports from Gil Gil Creek under likely future conditions as a result of the increase in groundwater trends based potential salt loads in the Gwydir Catchment.

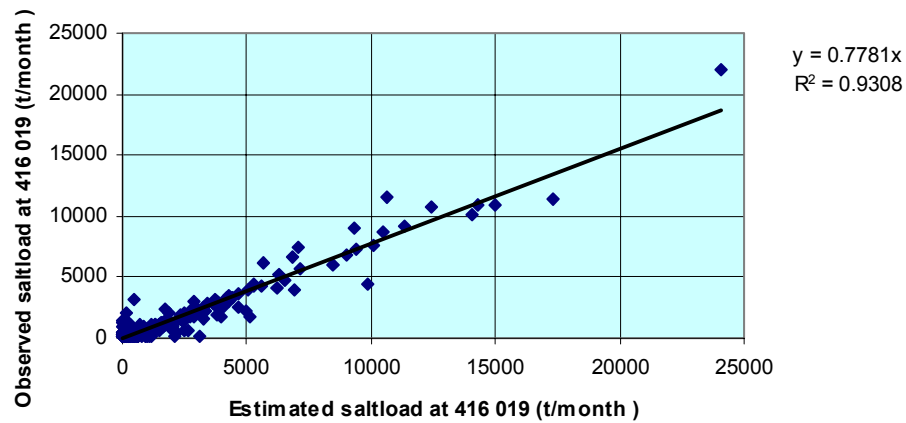


Figure 5.3a Border Rivers salt balance analysis at 416 019 (Severn R. @ Pindari Dam)

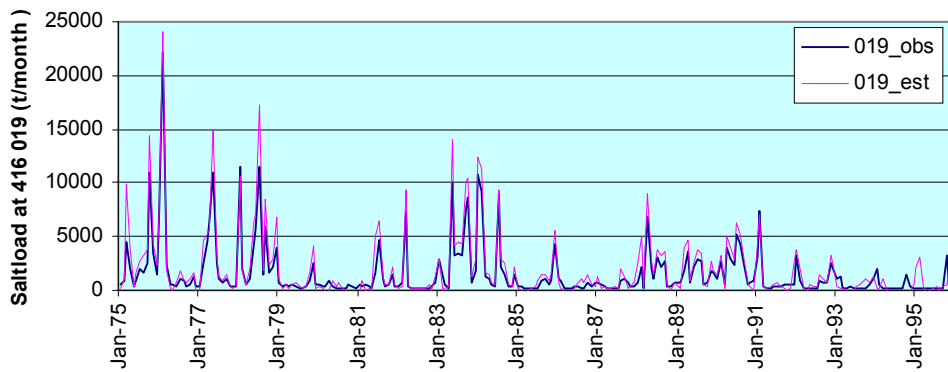


Figure 5.3b Observed and estimated monthly salt loads at 416 019 for 1975-95 (Severn R. @ Pindari Dam)

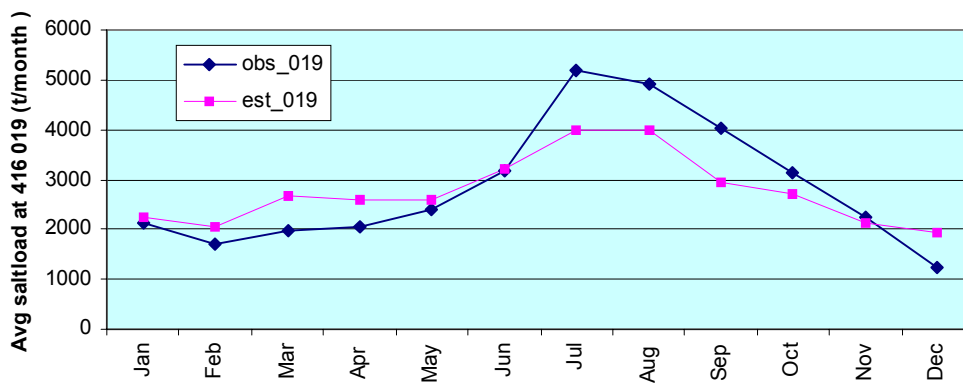


Figure 5.3c Observed and estimated average monthly salt load at 416 019 for 1975-95 (Severn R. @ Pindari Dam)

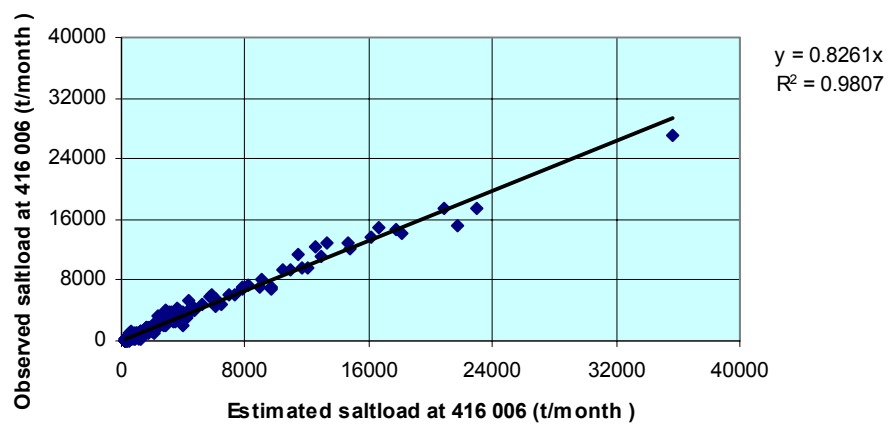


Figure 5.3d Border Rivers salt balance analysis at 416 006 (Severn R. @ Ashford)

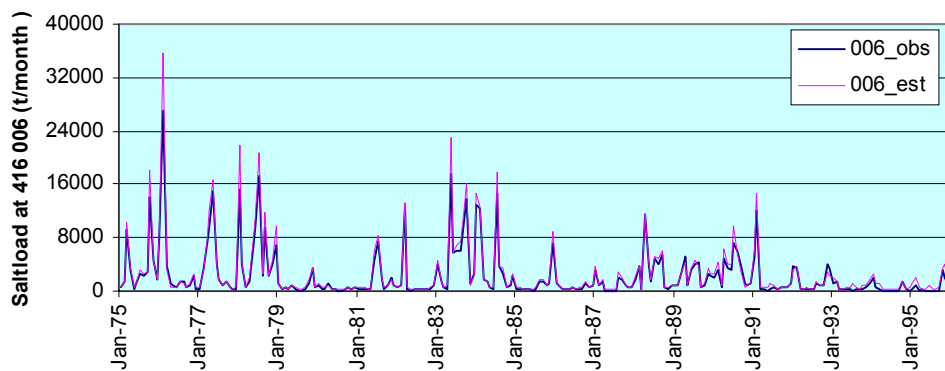


Figure 5.3e Observed and estimated monthly salt loads at 416 006 for 1975-95 (Severn R. @ Ashford)

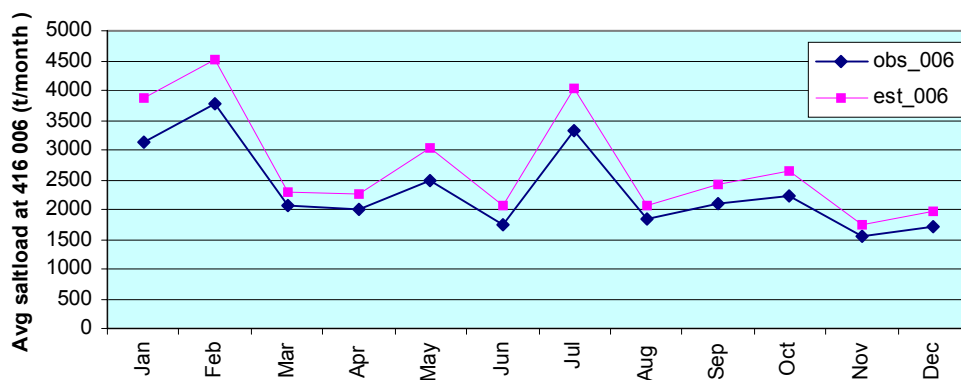


Figure 5.3f Observed and estimated average monthly salt load at 416 006 for 1975-95 (Severn R. @ Ashford)

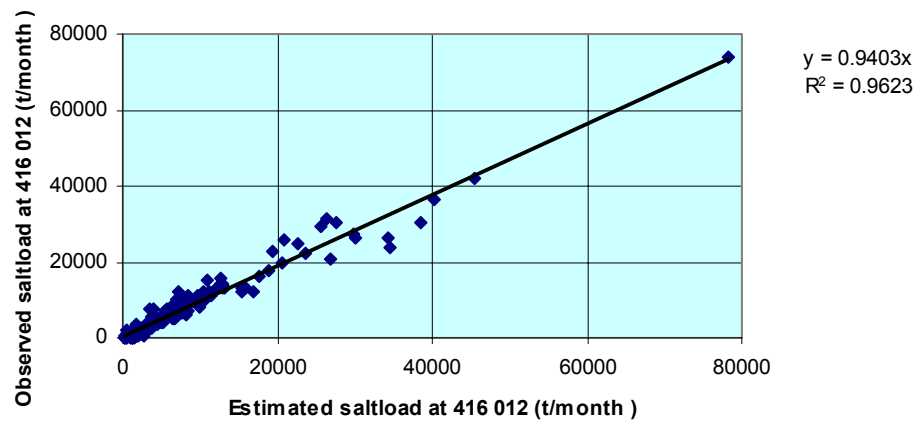


Figure 5.3g Border Rivers salt balance analysis at 416 012 (Macintyre R. @ Holdfast)

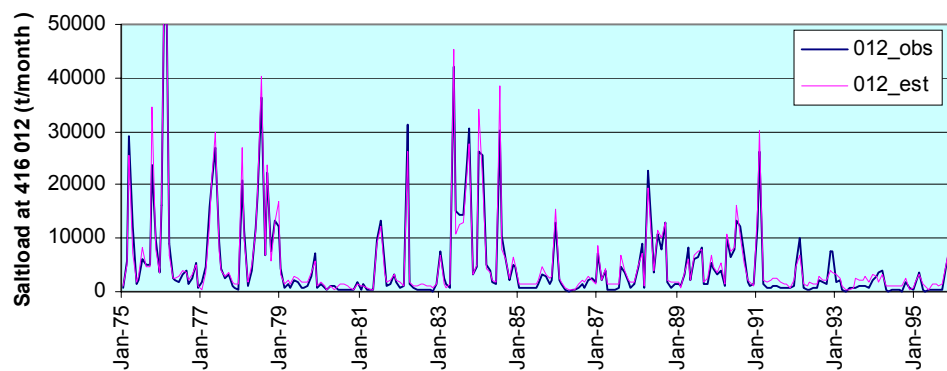


Figure 5.3h Observed and estimated monthly salt loads at 416 012 for 1975-95 (Macintyre R. @ Holdfast)

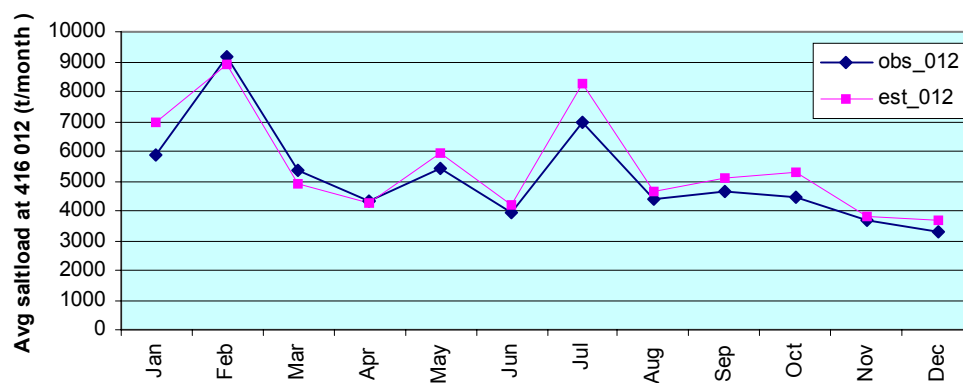


Figure 5.3i Observed and estimated average monthly salt load at 416 012 for 1975-95 (Macintyre R. @ Holdfast)

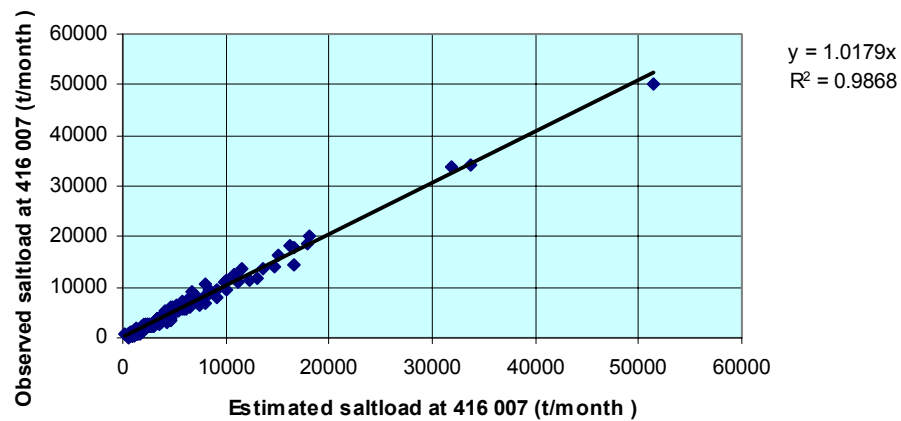


Figure 5.3j Border Rivers salt balance analysis at 416 007 (Dumaresq R. @ Bonshaw Weir)

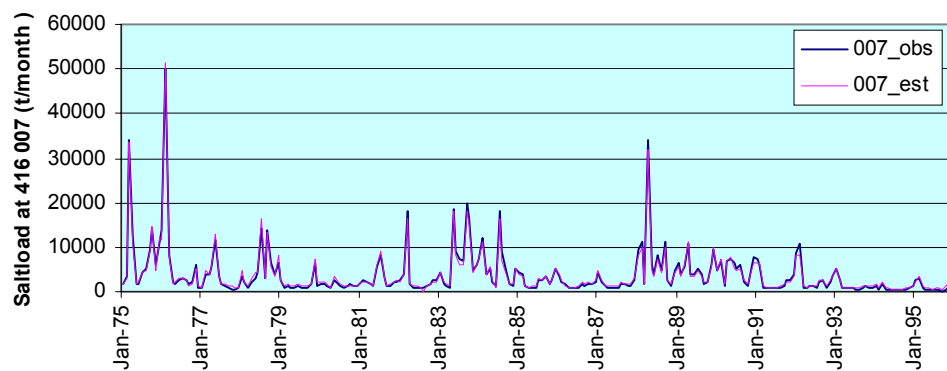


Figure 5.3k Observed and estimated monthly salt loads at 416 007 for 1975-95 (Dumaresq R. @ Bonshaw Weir)

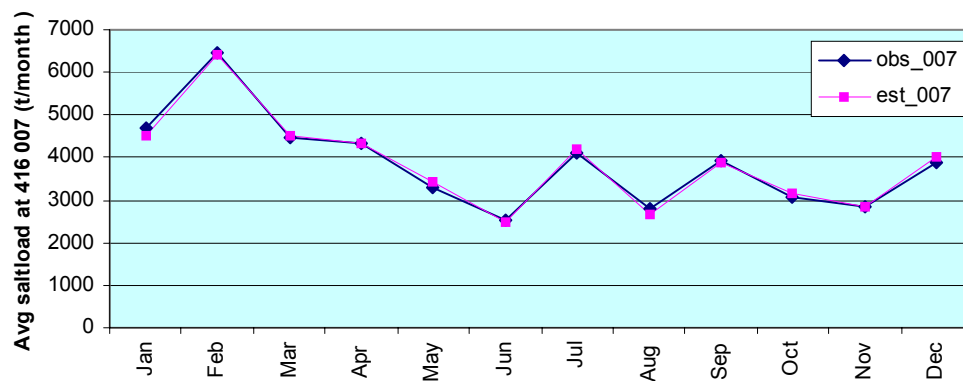
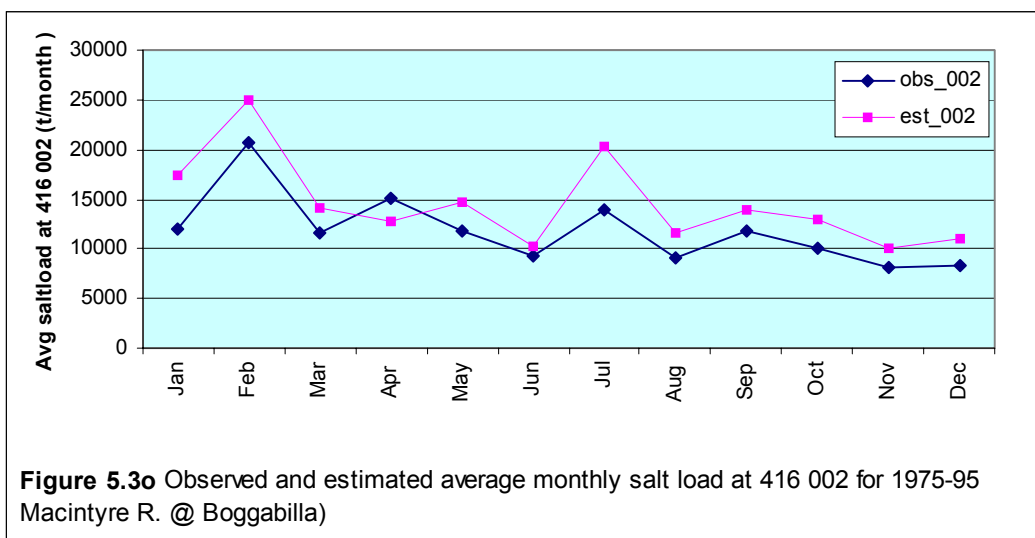
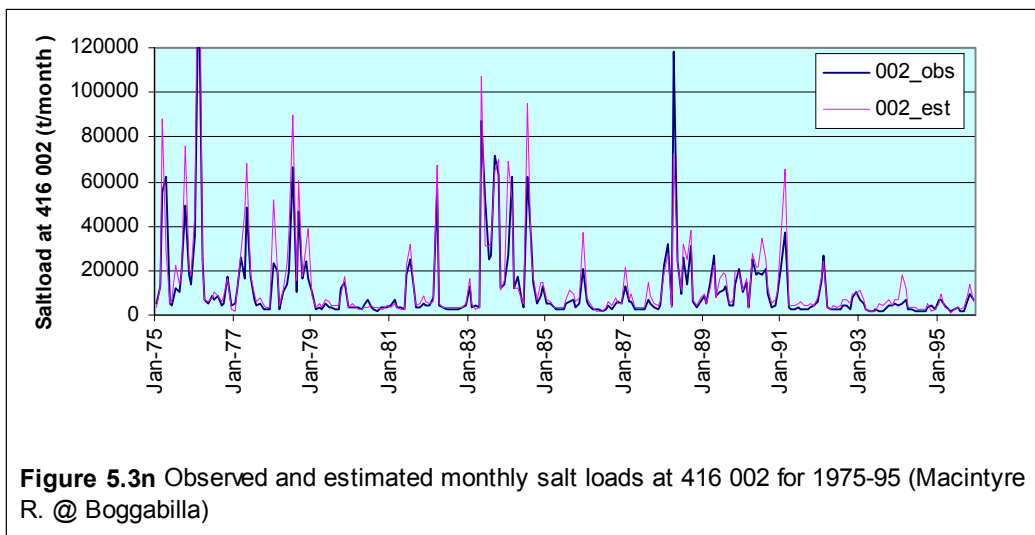
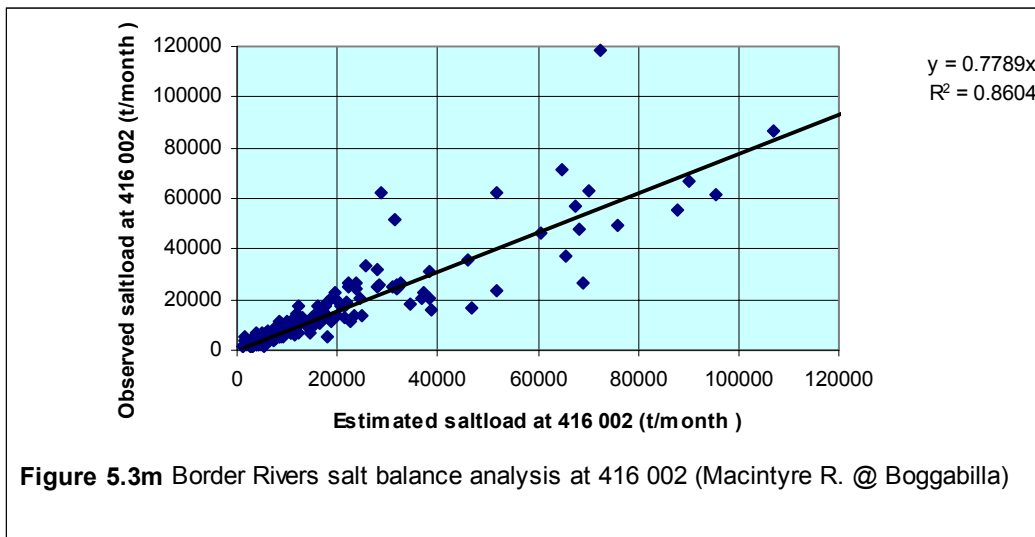
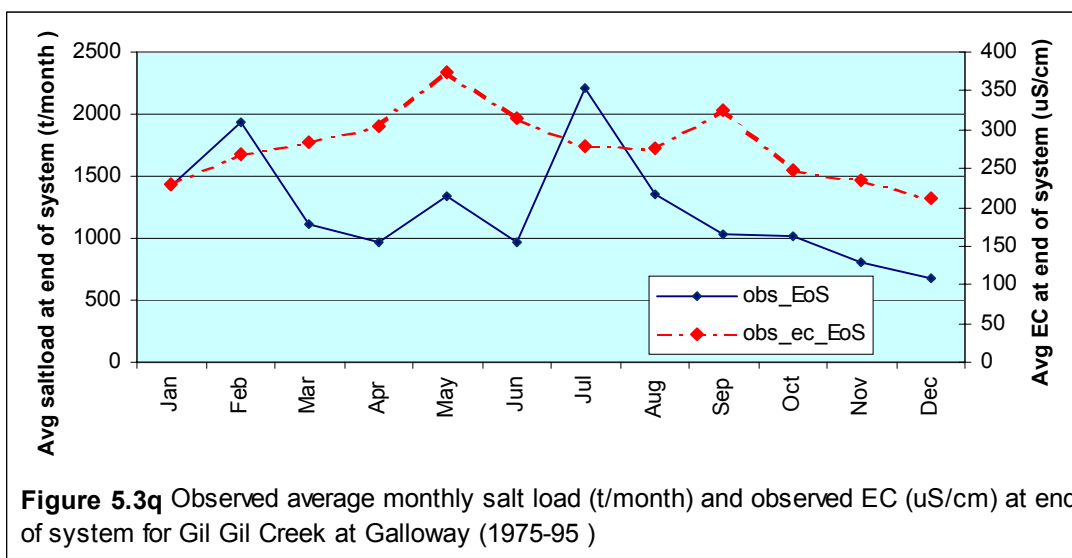
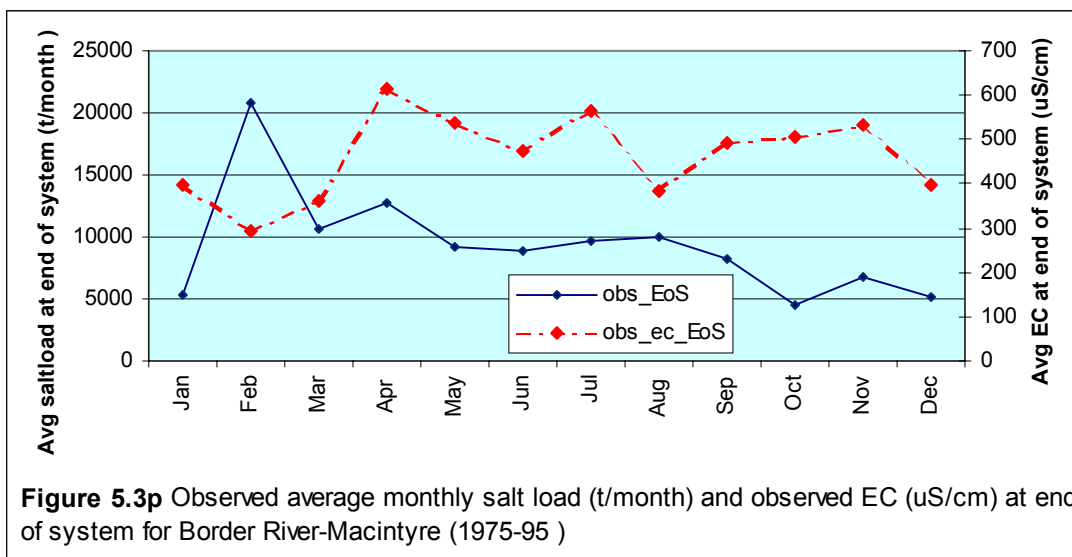


Figure 5.3l Observed and estimated average monthly salt load at 416 007 for 1975-95 (Dumaresq R. @ Bonshaw Weir)





5.2 Salt Balance for Gwydir

A schematic diagram of the gauging stations and the residual areas (with no observed streamflow data) used in the salt balance analysis is shown in Figure 5.4. The third order catchments associated with these locations are shown in Figure 5.1b. The salt balance in the Gwydir Catchment is computed at 5 stations (shown as dark nodes in Figure 5.4), namely, Gwydir R. at Bundarra (418 008), Gwydir R. d/s of Copeton Dam (418 026), Gwydir R. at Pinegrove (418 012), Gwydir R. at Gravesend Rd Bridge (418 013), and Gwydir R. at Pallamallawa (418 001).

The gauging stations with observed flow and EC data (shown in *italics* in Figure 5.4) are used for identifying the appropriate model form to obtain the daily salt load time series [Eqs (3.2) to (3.8)]. The parameter values for the most suitable model form obtained from calibration and the associated statistics are shown in Table 5.3. As found in the Namoi Catchment (Section 5.3), in most cases Model IIC [Eq. (3.6)] is the best candidate model for estimating daily salt loads. This is because Model IIC is likely to perform better in catchments not significantly influenced by seasonality. Furthermore, unlike Models IIA and IIB, Model IIC circumvents the need for obtaining expected values of flow and EC. Model IIC is also used for the remaining stations with no EC data. Implementation of Model IIC requires the knowledge of the parameters η and λ in addition to the daily flow values. The parameters η and λ are obtained from stations in close proximity with similar catchment size and flow characteristics (see Table 5.3 for parameter values and the associated statistics). Some adjustments are made to the parameters for 418 018, 418 015, R3 and R4 because the estimated salt loads at these locations were either consistently overestimating or consistently underestimating the observed salt load time series.

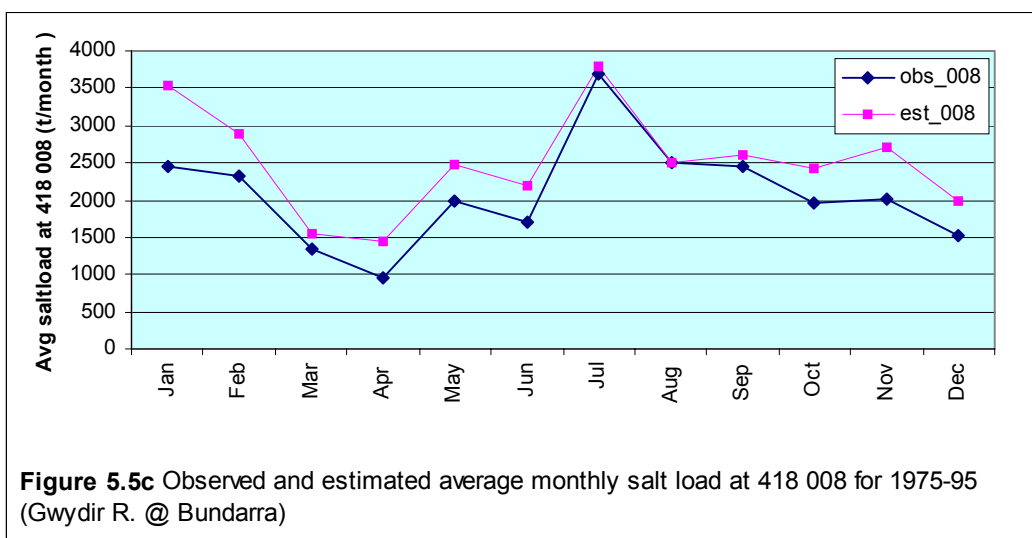
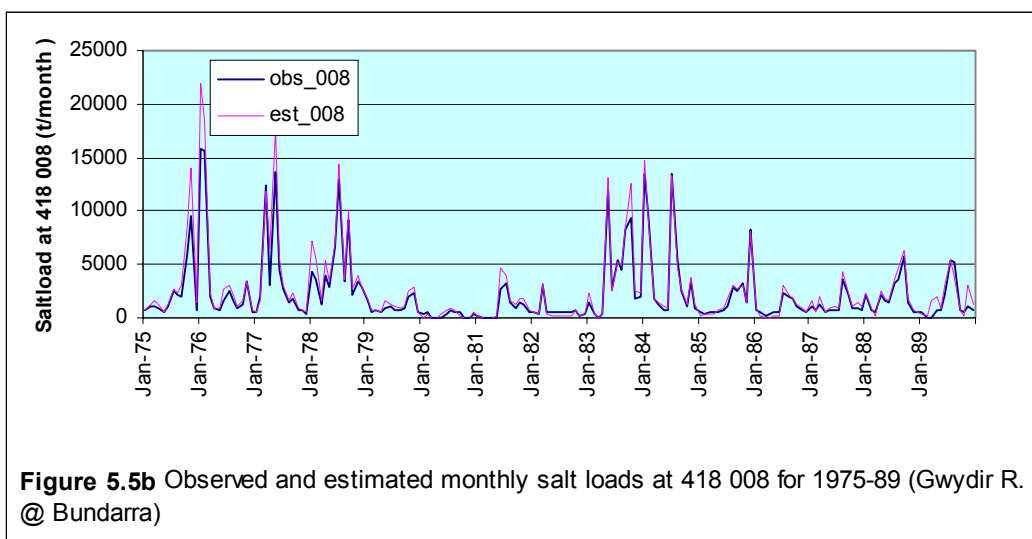
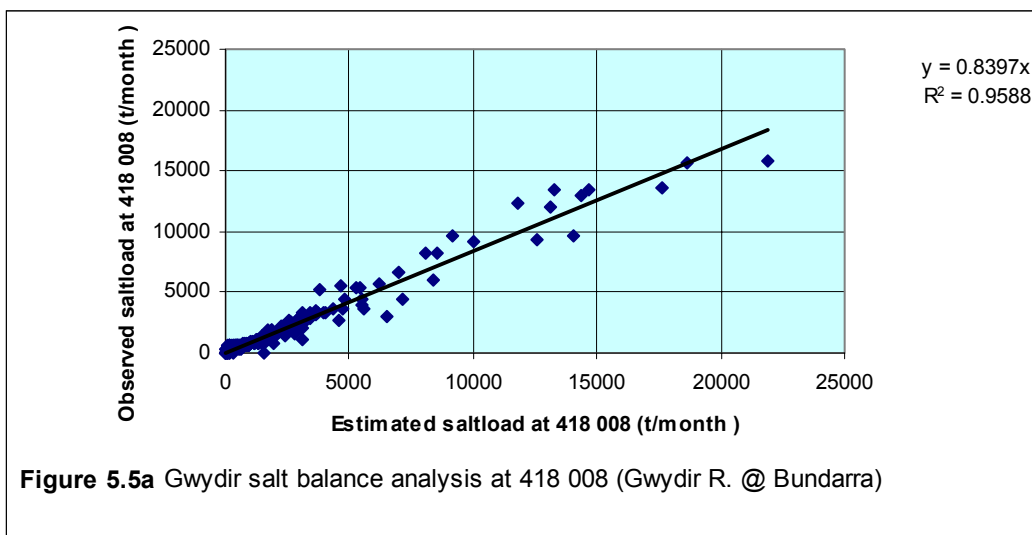
Figure 5.4. Schematic diagram of the gauging stations and the residual areas used in Gwydir salt balance analysis

Station	Catchment Area km^2	\bar{Q} $mm.y^{-1}$	n	Range	Model	Parameter estimation	η	λ	R^2	\bar{Q}_s^{year} $10^3 t.y^{-1}$	$\bar{Q}_s^{year} / Area$ $t.y^{-1}.km^{-2}$
418 029	1940	63			IIC	Other	18.1	6.08		13.7	7
418 021	353	85	86	150–350	IIC	At site	1.95	6.0	0.90	2.5	7
418 022	516	81	76	150–350	IIC	At site	1.62	6.73	0.79	3.7	7
418 023	656	110			IIC	Other	1.62	6.73		6.2	9
R1	525	91			IIC	Other	6	1.6		4.0	8
418 008	3990	68	196	200–400	IIC	At site	18.1	6.08	0.81	27.0	7
418 033	173	64	68	100–250	IIC	At site	0.62	3.17	0.95	0.6	3
418 005	246	89	85	150–250	IIC	At site	0.72	5.58	0.82	1.7	7
R2	831	44			IIC	Other	6	6		5.0	6
418 026	5240	71	159	150–200	IIC	At site	5.36	7.1	0.92	32.4	6
418 018	551	49	48	400–800	IIC	Other	5.6	26.0		9.9	18
R3	600	44			IIC	Other	5.6	26.0		9.8	16
418 012	6389	66	154	200–350	IIC	At site	37.9	8.17	0.70	53.5	8
418 025	175	40	47	1000–1200	IIC	At site	-0.4	61.3	0.79	5.1	29
418 017	864	38	58	950–1500	IIC	At site	11.8	23.7	0.94	13.0	15
418 015	1756	108	179	500–700	IIC	Other	19.2	17.0	0.72	44.1	25
418 016	537	41	73	550–950	IIC	At site	5.9	12.7	0.99	4.7	9
R4	1300	105			IIC	Other	10.0	10.0		19.5	15
418 013	11020	64	270	300–550	IIC	At site	84.2	10.9	0.83	119.7	11
R5	1280	34			IIC	Other	5.9	12.7		7.9	6
418 001	12300	59	119	250–650	IIC	At site	111.0	12.9		149.4	12
418 032	866	44			IIC	Other	9.7	16.3		9.9	11

\bar{Q} : Mean annual runoff; n : Number of days with common flow and EC data; \bar{Q}_s^{year} : Mean annual salt load

Salt balance locations: 418 008 (Gwydir at Bundarra), 418 026 (Gwydir R. d/s of Copeton dam), 418 012 (Gwydir R. at Pinegrove), 418 013 (Gwydir R. at Gravesend Rd Bridge) and 418 001 (Gwydir R. at Pallamallawa).

Table 5.3 Average annual salt export rate and model parameters for Gwydir Catchment based on 1975–95 conditions



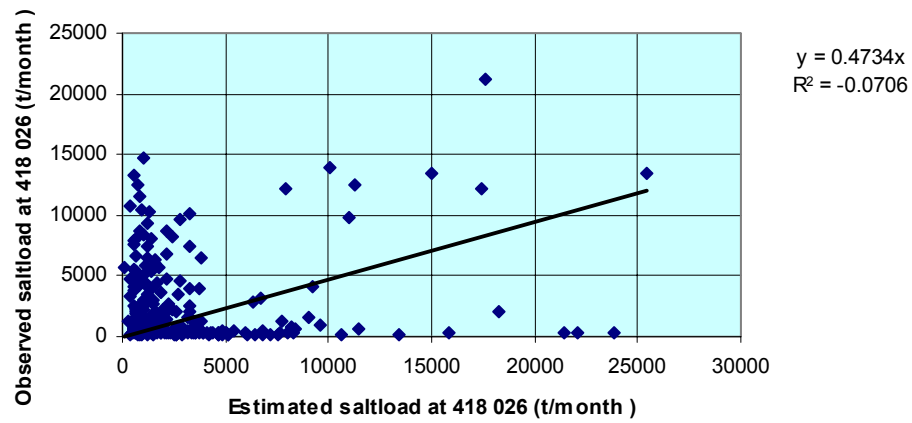


Figure 5.5d Gwydir salt balance analysis at 418 026 (Gwydir R. @ d/s Copeton dam)

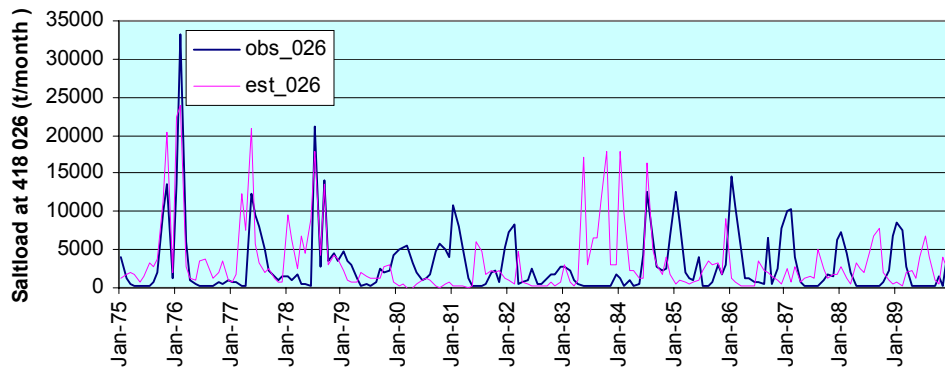


Figure 5.5e Observed and estimated monthly salt loads at 418 026 for 1975-95 (Gwydir R. @ Copeton dam)

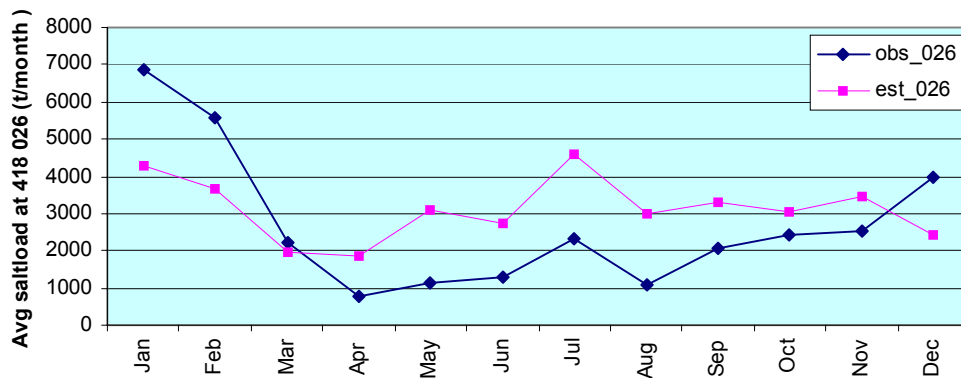


Figure 5.5f Observed and estimated average monthly salt load at 418 026 for 1975-95 (Gwydir R. @ Copeton dam)

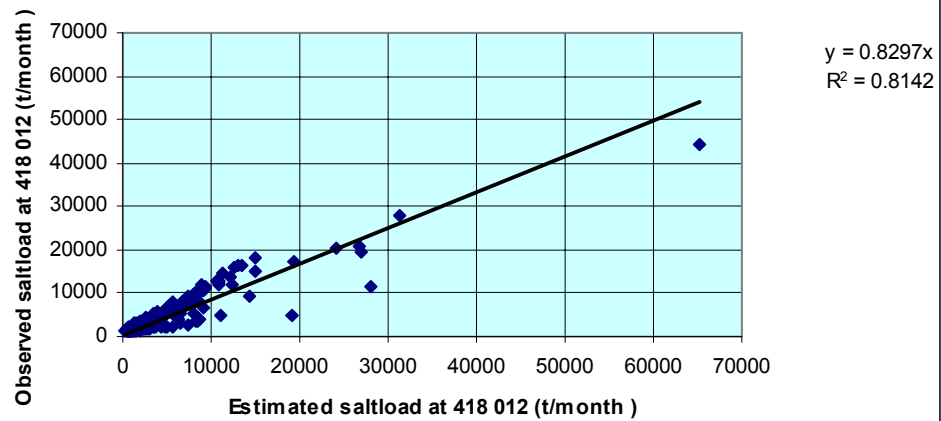


Figure 5.5g Gwydir salt balance analysis at 418 012 (Gwydir R. @ Pinegrove)

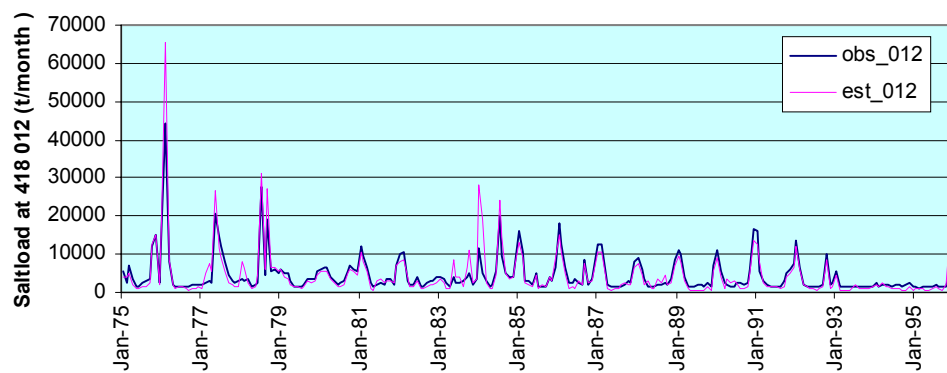


Figure 5.5h Observed and estimated monthly salt loads at 418 012 for 1975-95 (Gwydir R. @ Pinegrove)

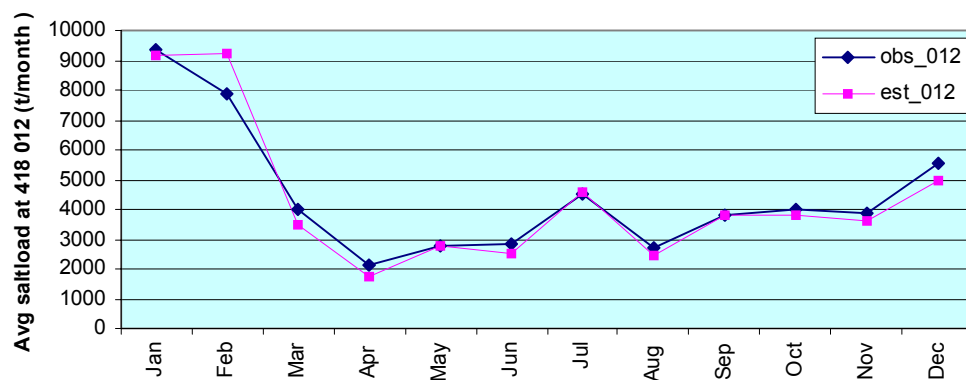


Figure 5.5i Observed and estimated average monthly salt load at 418 012 for 1975-95 (Gwydir R. @ Pinegrove)

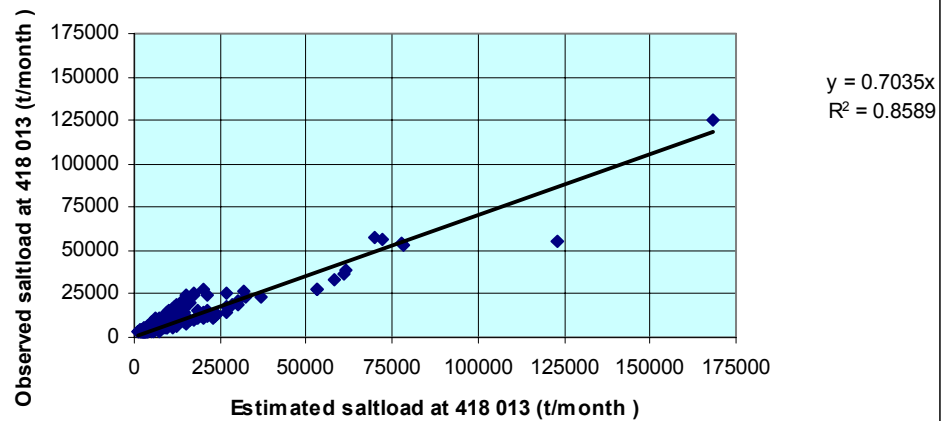


Figure 5.5j Gwydir salt balance analysis at 418 013 (Gwydir R. @ Gravesend Road Bridge)

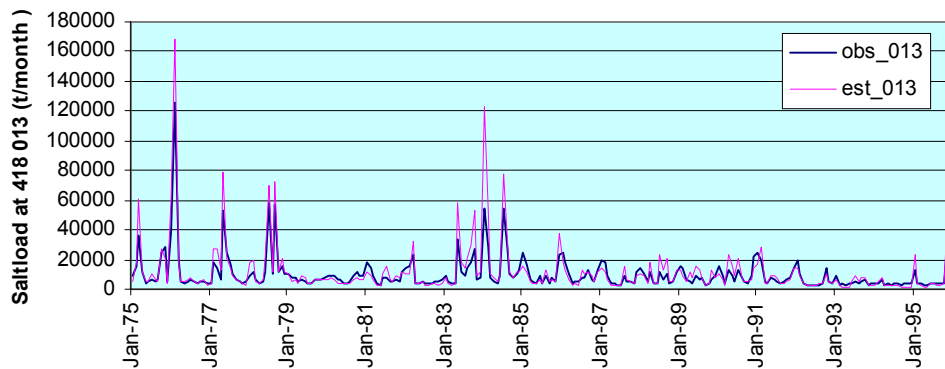


Figure 5.5k Observed and estimated monthly salt loads at 418 013 for 1975-95 (Gwydir R. @ Gravesend Road Bridge)

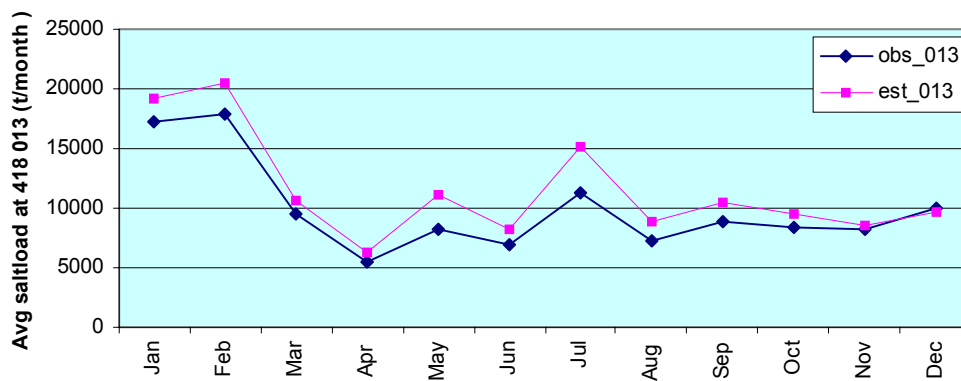
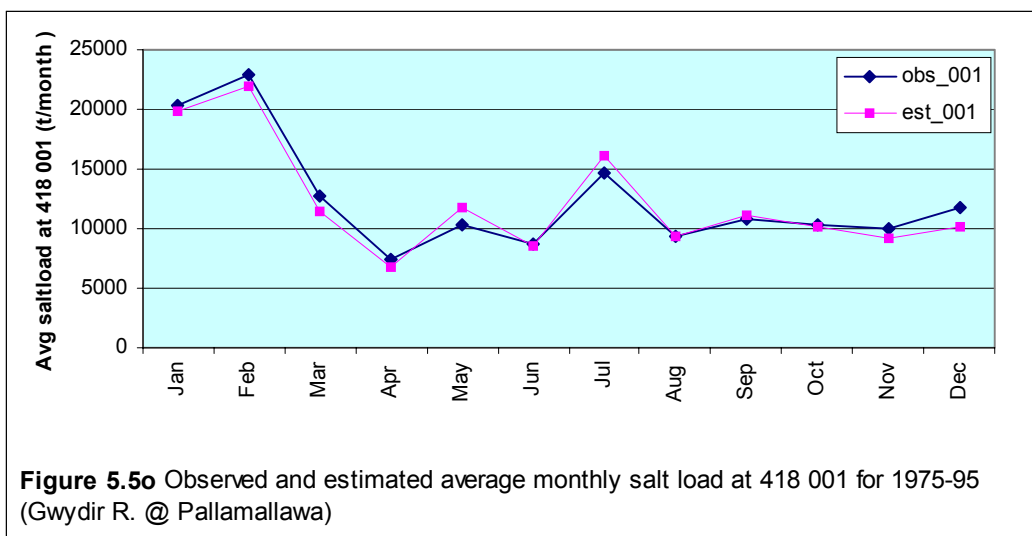
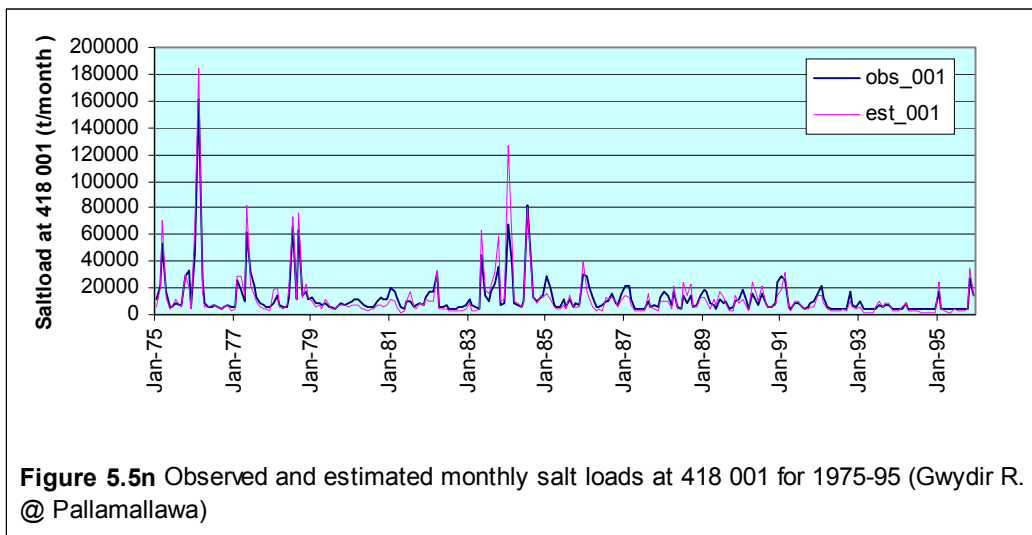
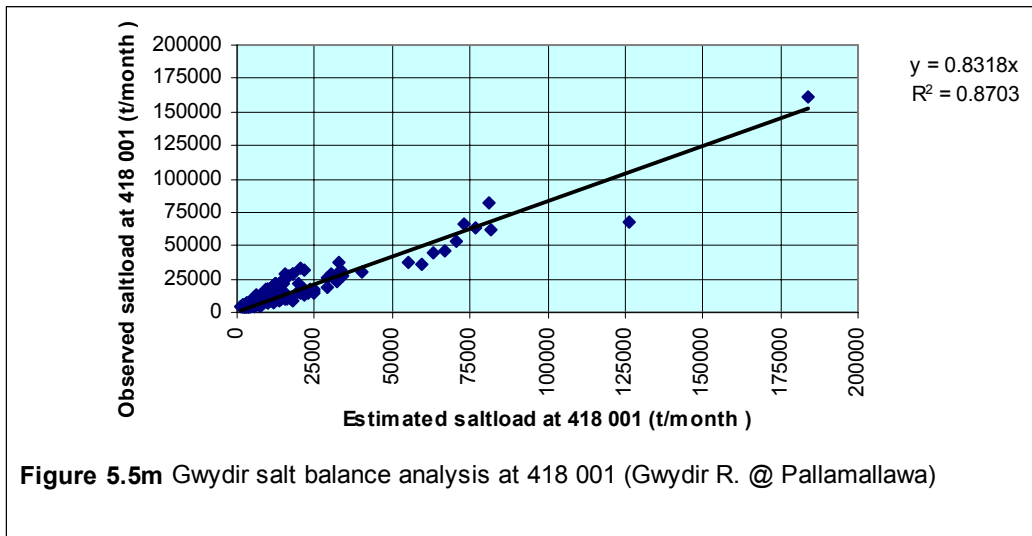
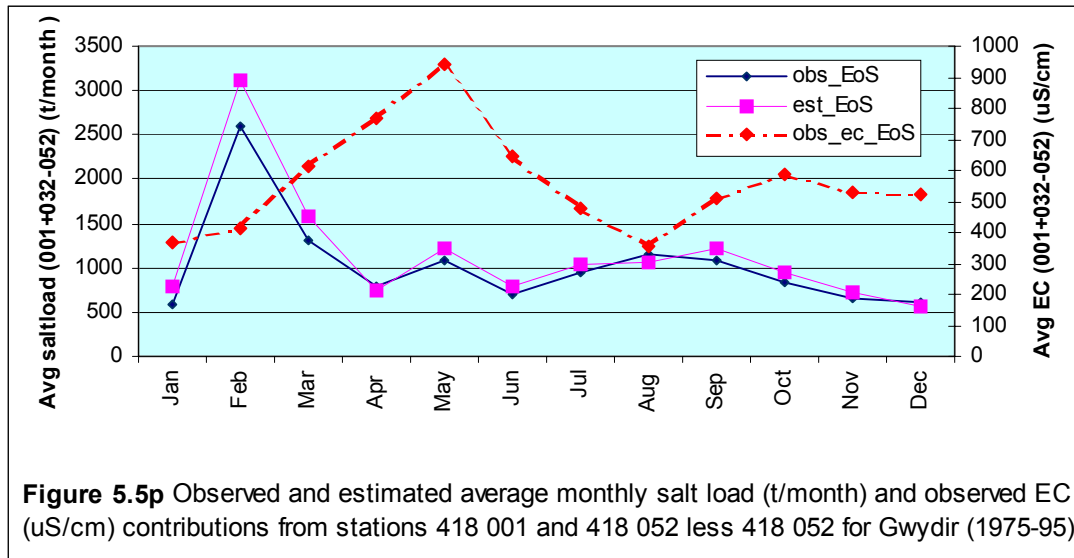


Figure 5.5l Observed and estimated average monthly salt load at 418 013 for 1975-95 (Gwydir R. @ Gravesend Road Bridge)





The results of the salt balance analysis for Gwydir R. at Bundarra (418 008), Gwydir R. downstream of Copeton Dam (418 026), Gwydir R. at Pinegrove (418 012), Gwydir R. at Gravesend Rd Bridge (418 013), and Gwydir R. at Pallamallawa (418 001) are shown in Figures 5.5a–p. The summary statistics indicating the accuracy of the salt balance at all three salt balance locations are shown in Table 5.4. With the exception of the Gwydir at Copeton Dam (418 026), the goodness of fit (R^2) at all salt balance locations varies from 0.81 to 0.96 indicating good agreement between the observed and the estimated monthly salt loads. The problem with the salt balance at Copeton Dam (418 026) occurs because the influence of mixing of salts from various inputs into the reservoir and the reservoir operation schedule in real time are not accounted for in this study. Similarly to the case of Namoi downstream of Keepit Dam, the observed salt loads downstream of Copeton Dam are used for the salt balance analysis at 418 012 (Gwydir River at Pinegrove) in order to avoid dynamic salt routing through the reservoir. The observed salt loads are for downstream of the dam and the estimated salt loads account for all inputs from third order catchments upstream of the dam.

Reproduction of the temporal distribution of average monthly salt load at all salt balance locations except 418 026 is reasonably good. The average monthly salt loads at 418 008, 418 012, 418 013 and 418 001 (Figures 5.5c, i, l, and o) show a bimodal plot. This is a composite effect of the summer dominant rainfall and the reservoir regulation at Copeton Dam. The major problem encountered in the salt balance analysis in Gwydir is the mass balance error. The overestimation of the salt loads at 418 008, 418 026 and 418 013 is about 17%, 15% and 16%, respectively. A close look at the time series plots of observed and estimated monthly salt loads at 418 008 (Figure 5.5b) and 418 013 (Figure 5.5k) show that salt loads associated with high flow events (generally in January to February for 1976–78, 1983–84) are significantly overestimated. Although influenced by inaccuracy in the

water balance, this error in salt mass balance is mainly due to limitations in parameter estimates of Model IIC and lack of a regionalised regression relationship. The bias in $\hat{\lambda}$ is the main reason for this discrepancy, which could not be corrected in spite of adjustments in parameters for the stations 418 018, 418 015, R3 and R4. However, for most of the period (1975–95), the estimated monthly salt loads are reproduced reasonably well. The error in mass balance decreases from 16% overestimation at 418 013 to 2% underestimation at 418 001. This does not mean a good salt balance at 418 013 but that overestimation of the salt loads from upstream of 418 013 are somewhat compensated by underestimation of the salt loads from Residual 5 (see Figure 5.4).

Station	Catchment Area km^2	\bar{Q} $GL.y^{-1}$	\bar{Q}_s^{year} $10^3 t.y^{-1}$	R^2	Slope α in $Q_s = \alpha \hat{Q}_s$	Mass balance error $\frac{\sum(\hat{Q}_s - Q_s)}{\sum(Q_s)} \times 100$
418 008	3990	271	27.0	0.96	0.84	17.0
418 026	5240	372	32.4	-0.07	0.47	15.0
418 012	6389	422	53.5	0.81	0.83	-3.0
418 013	11020	705	119.7	0.86	0.70	16.0
418 001	12300	726	149.4	0.87	0.83	-2.0

\bar{Q} : Mean annual runoff, \bar{Q}_s^{year} : Mean annual salt load, Q_s : Observed monthly salt load, \hat{Q}_s : Estimated monthly salt load

Salt balance locations: 418 008 (Gwydir River at Bundarra), 418 026 (Gwydir River d/s of Copeton Dam), 418 012 (Gwydir River at Pinegrove), 418 013 (Gwydir R. at Gravesend Rd. Bridge), 418 001 (Gwydir R. at Pallamallawa).

Table 5.4. Results of the salt balance analysis for the Gwydir Catchment based on 1975–95 conditions

Carole Creek (418 052) is an effluent of the Gwydir River that feeds into Gil Gil Creek in the Border Rivers Catchment. The braided nature of the Gwydir River downstream of 418 001 (Gwydir R. at Pallamallawa) creates difficulty in quantifying observed and estimated end of system monthly salt loads. The salt loads at end of system are therefore derived as the contributions of salt loads from 418 001 and 418 032 less the salt export from 418 052 (see Figure 5.4). A comparison of the observed and the estimated salt loads shows a reasonably good representation of the monthly salt balance at the end of system (see Figure 5.5p) has been obtained.

On the basis of the above discussion it is concluded that the computed salt balance for the Gwydir is influenced by a mass balance error and that the extent of the mass balance error decreases progressively from upstream to downstream. This is likely to induce bias in salt export estimation, particularly in the months of January and February, from different third order catchments at target

dates. However, the influence of this bias would be somewhat reduced by correction with respect to the observed salt load as described by Eq. (3.30).

5.3 Salt Balance for Namoi

A schematic diagram of the gauging stations and the residual areas (with no observed streamflow data) used in the salt balance analysis is shown in Figure 5.6. The third order catchments associated with these locations are shown in Figure 5.1c. The salt balance analysis in the Namoi Catchment is carried out at 5 gauging stations (shown as dark nodes in Figure 5.6), namely: the Peel R. at Paradise Weir (419 024), Peel R. at Carrol Gap (419 006), Namoi R. at Keepit Dam (419 007), Namoi R. at Gunnedah (419 001), and Namoi R. at Boggabri (410 012).

The gauging stations with observed flow and EC data (shown in *italics* in Figure 5.6) are used for identifying the appropriate model form to obtain the daily salt load time series [Eqs (3.2) to (3.8)]. The parameter values for the most suitable model form obtained from calibration and the associated statistics are shown in Table 5.5. In most cases Model IIC [Eq. (3.6)] is found to be the best candidate model for estimating daily salt loads. This is because Model IIA is likely to perform better in catchments with a marked influence of seasonality. Therefore, Model IIC is used for the remaining stations with no EC data. Implementation of Model IIC requires knowledge of the parameters η and λ in addition to the daily flow values. The parameters η and λ are obtained from regionalisation using a linear form of the regression relationship (intercept forced to zero) with the corresponding area (km^2) for all stations having observed flow and EC data in the Namoi and Gwydir with catchment areas less than $600 km^2$. The regionalised regression relationships found for η and λ are $\hat{\eta} = Area / 79.81$ ($R^2 = 0.75$) and $\hat{\lambda} = Area / 51.68$ ($R^2 = 0.45$) respectively. In the case of stations with area greater than $600 km^2$, the parameters are taken from stations in close proximity with similar size and flow characteristics (see Table 5.5 for parameter values and the associated statistics).

The results of the salt balance analysis for Peel River at Paradise Weir (419 024), Peel River at Carrol Gap (419 006), Namoi River at Keepit Dam (419 007), Namoi River at Gunnedah (419 001), and Namoi River at Boggabri (419 012) are shown in Figures 5.7a–o. The summary statistics indicating the accuracy of the salt balance at all five salt balance locations are shown in Table 5.6.

The scatter plot and the time series plot of observed and estimated monthly salt loads for the Peel River at Paradise Weir (419 024) show good agreement (Figures 5.7a–b). The mass balance error is 2% and the slope (α) of the regression line ($Q_s = \alpha \hat{Q}_s$) between the estimated (\hat{Q}_s) and observed

(Q_s) monthly salt load is 1.15 indicating that salt loads are somewhat underestimated for large events. The R^2 of the observed and the estimated monthly salt load is 93%.

The salt balance at 419 006 (Peel River at Carrol Gap) is rather poor (see Figures 5.7d–e) with a mass balance error of about 25% due to consistent underestimation of the salt load. This is due to high sampling variance and lack of seasonal persistence in both streamflow and EC. There is also a definite interaction of the water balance and the salt balance.

Figure. 5.6. Schematic diagram of the gauging stations and the residual areas used in Namoi salt balance analysis

Station	Catchment Area km^2	\bar{Q} $mm.y^{-1}$	n	Av. Monthly EC Range	Model	Parameter estimation	η	λ	R^2	\bar{Q}_s^{year} $1 \times 10^3 t.y^{-1}$	$\bar{Q}_s^{year} / Area$ $t.y^{-1}.km^{-2}$
419 045	407	113	276	300–400	IIC	At site	1.24	18.1	0.98	9.7	24
R6	733	65			IIC	Regional	9.2	14.2		13.2	18
419 016	898	89	123	350–500	IIC	At site	14.4	9.86	0.91	13.7	15
R7	372	13			IIC	Regional	4.7	7.2		2.0	5
419 024	2410	79	246	400–550	IIC	At site	15.9	14.6	0.81	37.9	16
419 035	503	55	107	900–1100	IIA	At site	-23.9	15.8	0.96	9.1	18
R8	1757	23			IIC	Other	15.9	14.6		12.0	7
419 006	4670	58	159	600–950	IIC	At site	39.9	20.6	0.83	79.7	17
419 043	1650	36	111	400–600	IIC	At site	-0.25	31.3	0.89	19.7	12
R1	370	89			IIC	Regional	4.6	7.2		3.2	9
R2					IIC	Other	4.57	14.5			
419 029	650	57	115	500–800	IIC	At site	4.57	14.5	0.92	6.3	10
419 005	2510	90	69	200–700	IIC	At site	8.59	8.59	0.89	25.7	10
R3	520	23			IIC	Regional	6.5	10.1		4.1	8
419 007	5700	53	172	300–450	IIA	At site	-20.4	18.9	0.91	66.4	12
419 027	3700	29	114	700–1150	IIA	At site	-77.4	16.2	0.99	33.8	9
R4	3030	65			IIC	Other	19.6	7.5		8.3	3
419 001	17100	43	311	400–650	IIC	At site	66.2	16.4	0.97	161.5	9
R5	1460				IIC	Other	19.6	7.5		3.0	2
032	3800	28	52	400–700	IIC	At site	19.6	7.54	0.76	9.8	3
419 012	22600	34	136	400–600	IIC	At site	91	16.3	0.93	178.6	8
419051	454	48	82	300–400	IIC	At site	3.29	8.82	0.96	3.1	7

\bar{Q} : Mean annual runoff, n : Number of days with common flow and EC data, \bar{Q}_s^{year} : Mean annual salt load

Salt balance locations: 419 024 (Peel R. @ Paradise Weir), 419 006 (Peer R. @ Carrol Gap), 419 007 (Namoi R. @ Keepit Dam), 419 001 (Namoi @ Gunnedah), 419 012 (Namoi @ Boggabri).

Table 5.5 Average annual salt export rate and model parameter values for the Namoi Catchment based on 1975–95 conditions

The average annual runoff from the third order catchments contributing flow and salt load to 419 006 varies in the range 13 to 113 $mm.y^{-1}$. Due to high sampling variance and uncertainties in estimating residual flow, uncertainties in estimation of the residual flow, errors in salt balance resulting from water balance errors are inescapable.

Station	Catchment Area km^2	\bar{Q} $GL.y^{-1}$	\bar{Q}_s^{year} $10^3 t.y^{-1}$	R^2	Slope α in $Q_s = \alpha \hat{Q}_s$	Mass balance error $\frac{\sum(\hat{Q}_s - Q_s)}{\sum(Q_s)} \times 100$
419 024	2410	190	37.9	0.93	1.15	-2.0
419 006	4670	271	79.7	0.92	1.46	-25.0
419 007	5700	302	66.4	0.48	0.99	-11.0
419 001	17100	735	161.5	0.84	1.08	-0.4
419 012	22600	768	178.6	0.80	1.03	-3.0

\bar{Q} : Mean annual runoff, \bar{Q}_s^{year} : Mean annual salt load, Q_s : Observed monthly salt load, \hat{Q}_s : Estimated monthly salt load
Salt balance locations: 419 024 (Peel R. @ Paradise Weir), 419 006 (Peel R. @ Carrol Gap), 419 007 (Namoi @ Keepit Dam), 419 001 (Namoi @ Gunnedah), 419 012 (Namoi @ Boggabri).

Table 5.6 Results of the salt balance analysis for the Namoi Catchment based on 1975–95 conditions

In theory, a mass conservative objective function can be imposed in the salt balance calibration methodology. However, such an attempt to mask the water balance error to improve the salt balance statistics has been avoided in this study.

The salt balance analysis results for the Namoi River at Keepit Dam (419 007) are poor, but not because of the error in salt load estimation. Instead, this is due to mixing of salts from input of upstream third order catchments to the reservoir and not conducting any dynamic salt routing through the reservoir incorporating the reservoir operating policy (Figures 5.7g–i and Table 5.6). The observed salt loads are for downstream of the dam and the estimated salt loads are unrouted inputs from third order catchments upstream of the dam.

The salt balance analysis results for the Namoi River at Gunnedah (419 001) and the Namoi River at Boggabri (419 012) are reasonably good (Figures 5.7j–o and Table 5.6). The mass balance errors at 419 001 and 419 012 indicate salt load underestimation of about 0.4% and 3% respectively. The R^2 's of the observed and the estimated monthly salt loads at 419 001 and 419 012 are 0.84 and 0.8, respectively and the slope (α) of the regression line ($Q_s = \alpha \hat{Q}_s$) between the estimated (\hat{Q}_s) and observed (Q_s) monthly salt load is 1.08 and 1.03, respectively. The temporal distribution of the monthly salt loads at the two stations is also reasonably good (Figures 5.7l and 5.7o). The salt load at

end of system is calculated using Eq. (3.20). The term $\left[q_T^{salt}(t) \right]_{d/s}$ is taken as sum of the observed salt loads from 419 049 and 419 026 and $\left[q_T^{salt}(t) \right]_{u/s}$ is taken as the sum of the observed salt loads at 419 012 and 419 051. A comparison of the observed and the estimated salt loads shows a reasonably good representation of the monthly salt balance at the end of system (see Figure 5.7p).

On the basis of the above discussion it is concluded that with the exception of 419 006 (Peel River at Carrol Gap), the Namoi salt balance under ‘current’ conditions is reasonably accurate. The results of the salt balance improve substantially downstream of Keepit Dam (419 007) due mainly to the effect of the dam (by using observed salt load downstream of the dam for salt balance analysis) in masking the water balance error in quantifying flow and salt load contributions from residual areas. The groundwater derived potential salt loads can therefore be coupled with the ‘current’ in-stream salt balance, to estimate likely salt export rates from the Namoi under future conditions at the required target dates.

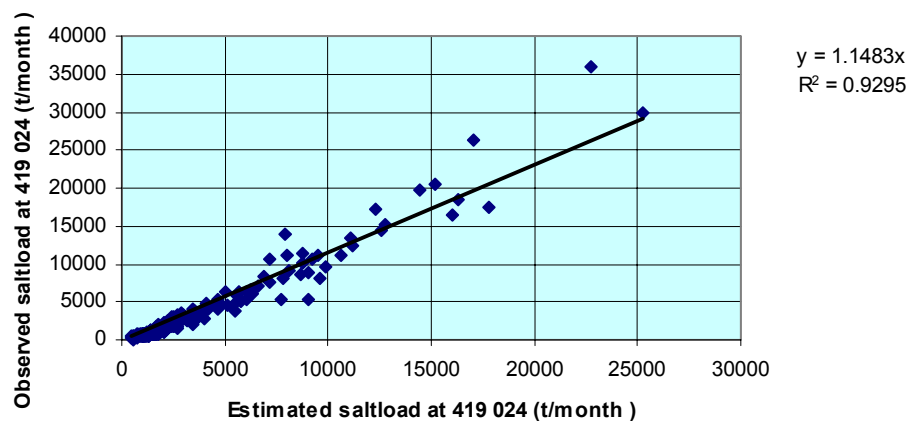


Figure 5.7a Namoi salt balance analysis at 419 024 (Peel R. @ Paradise Weir)

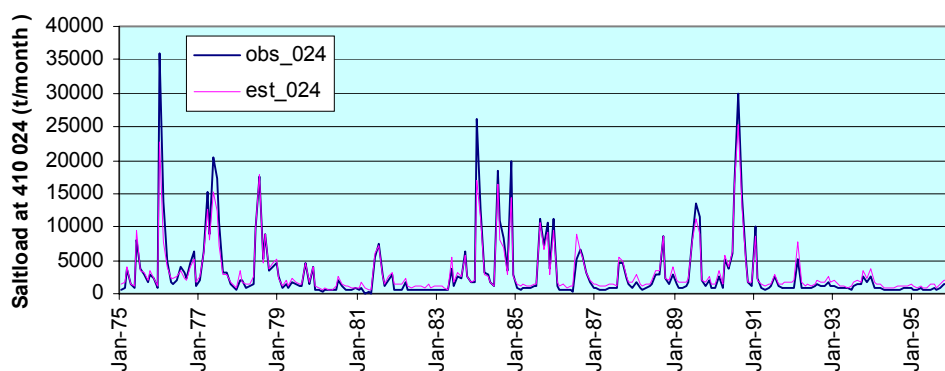


Figure 5.7b Observed and estimated monthly salt loads at 410 024 for 1975-95 (Peel R. @ Paradise Weir; Namoi)

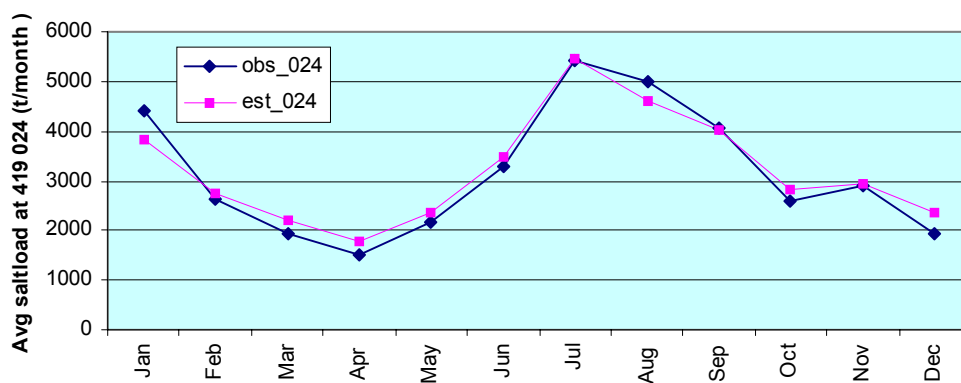


Figure 5.7c Observed and estimated average monthly salt load at 419 024 for 1975-95 (Peel R. @ Paradise Weir; Namoi)

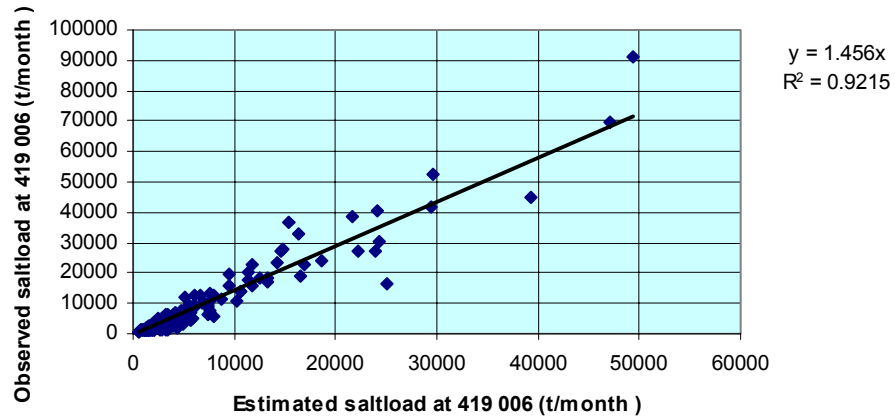


Figure 5.7d Namoi salt balance analysis at 419 006 (Peel R. @ Carrol Gap)

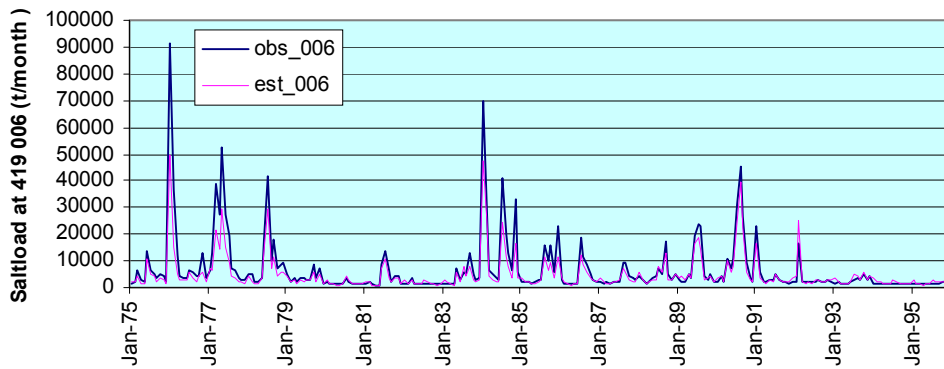


Figure 5.7e Observed and estimated monthly salt loads at 419 006 for 1975-95 (Peel R. @ Carrol Gap; Namoi)

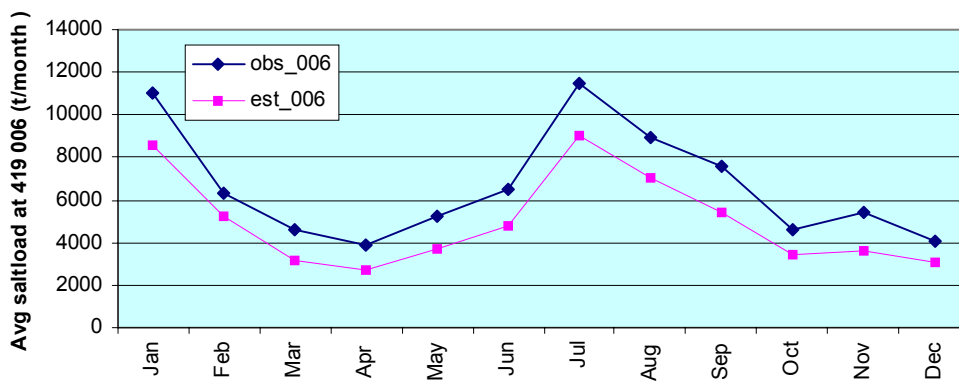


Figure 5.7f Observed and estimated average monthly salt load at 419 006 for 1975-95 (Peel R. @ Carrol Gap; Namoi)

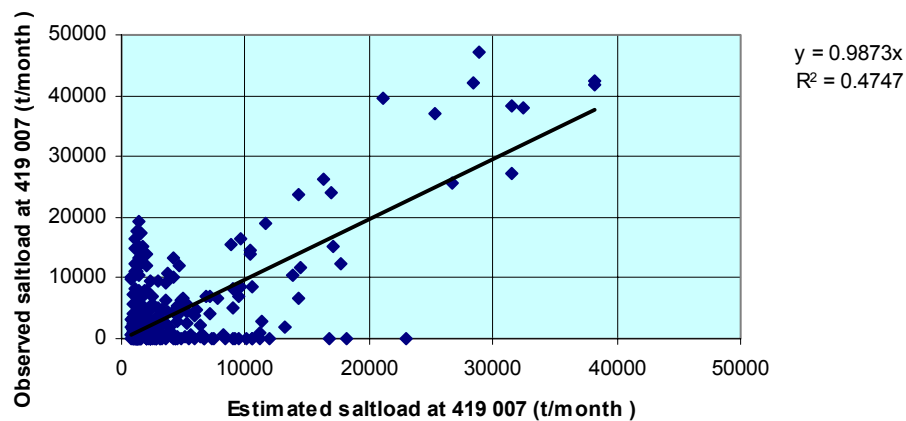


Figure 5.7g Namoi salt balance analysis at 419 007 (Namoi @ Keepit Dam)

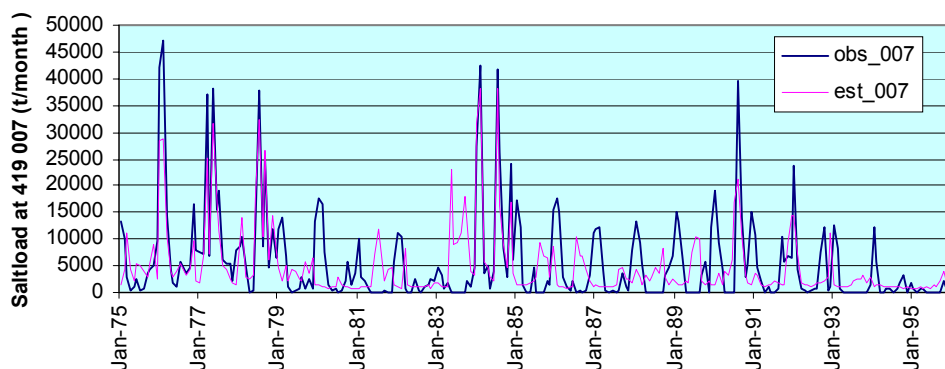


Figure 5.7h Observed and estimated monthly salt loads at 419 007 for 1975-95 (Namoi R. @ Keepit Dam)

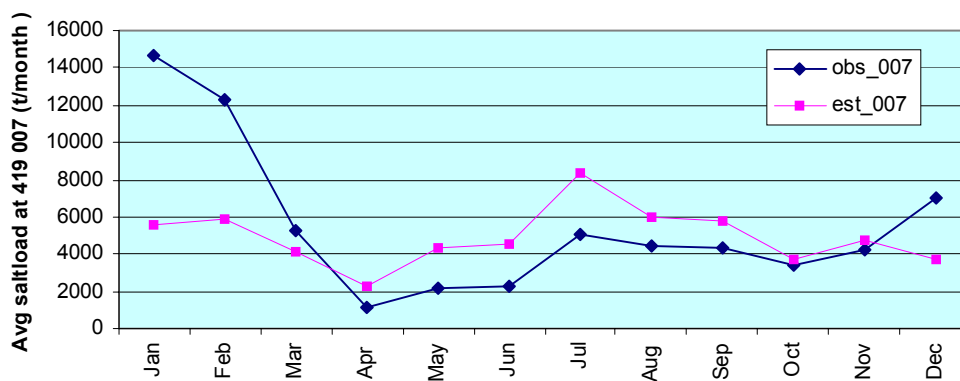


Figure 5.7i Observed and estimated average monthly salt load at 419 007 for 1975-95 (Namoi R. @ Keepit Dam)

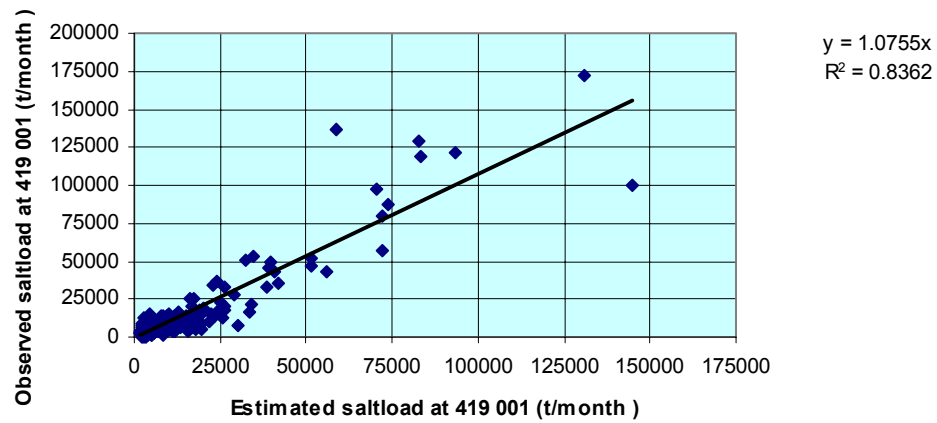


Figure 5.7j Namoi salt balance analysis at 419 001 (Namoi @ Gunnedah)

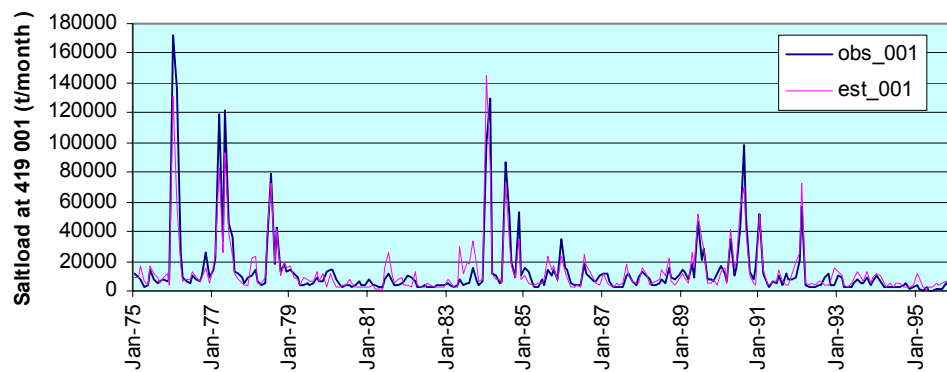


Figure 5.7k Observed and estimated monthly salt loads at 419 001 for 1975-95 (Namoi R. @ Gunnedah)

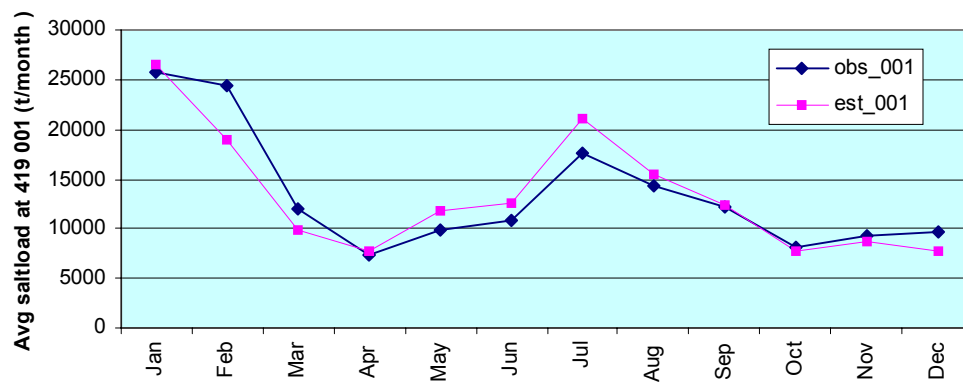


Figure 5.7l Observed and estimated average monthly salt load at 419 001 for 1975-95 (Namoi R. @ Gunnedah)

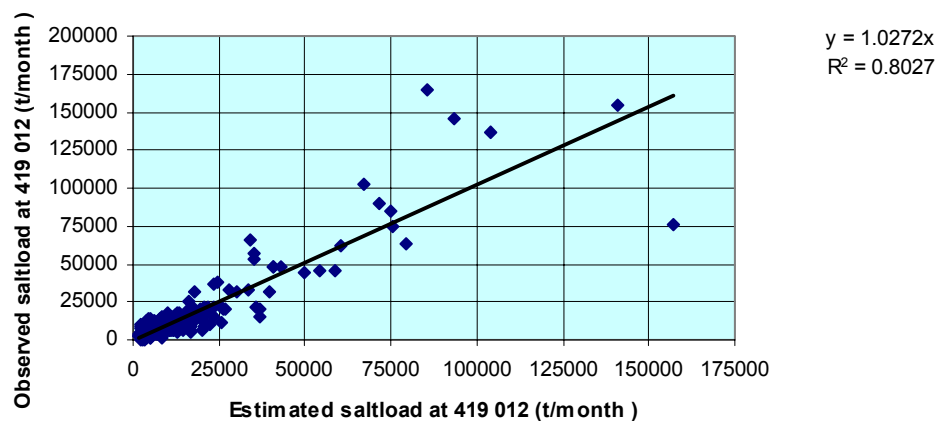


Figure 5.7m Namoi salt balance analysis at 419 012 (Namoi @ Boggabri)

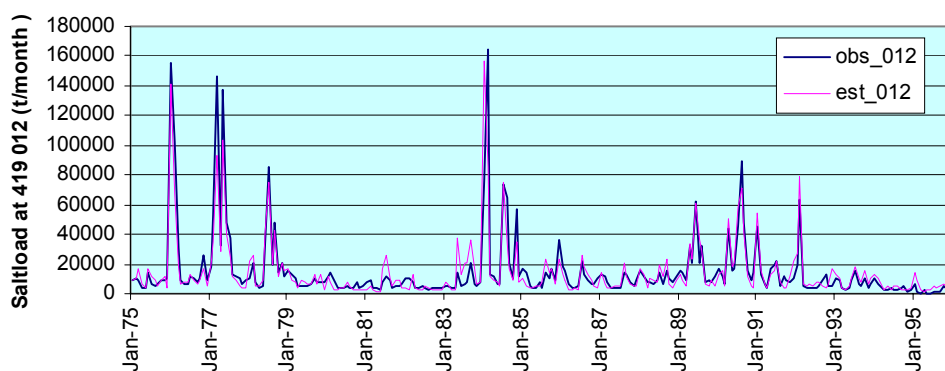


Figure 5.7n Observed and estimated monthly salt loads at 419 012 for 1975-95 (Namoi R. @ Boggabri)

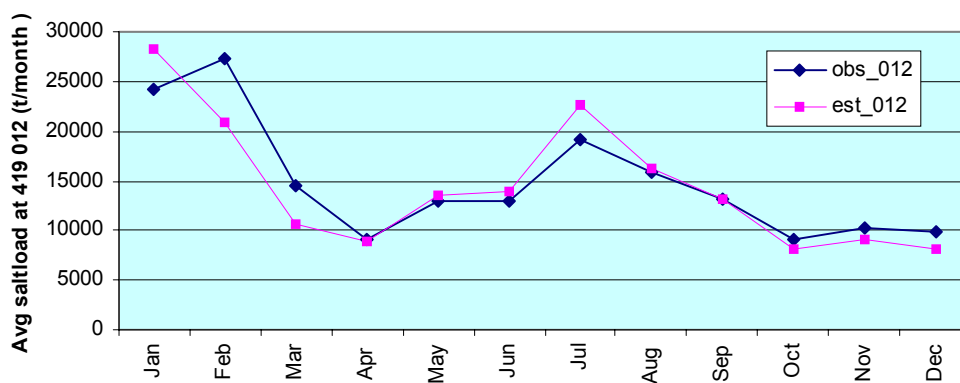
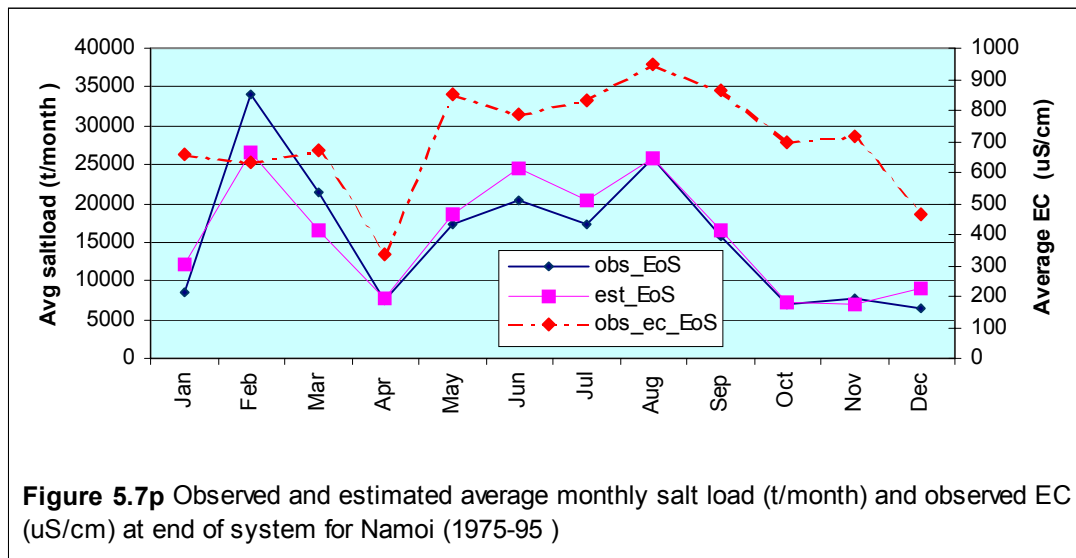


Figure 5.7o Observed and estimated average monthly salt load at 419 012 for 1975-95 (Namoi R. @ Boggabri)



5.4 Salt Balance for Castlereagh

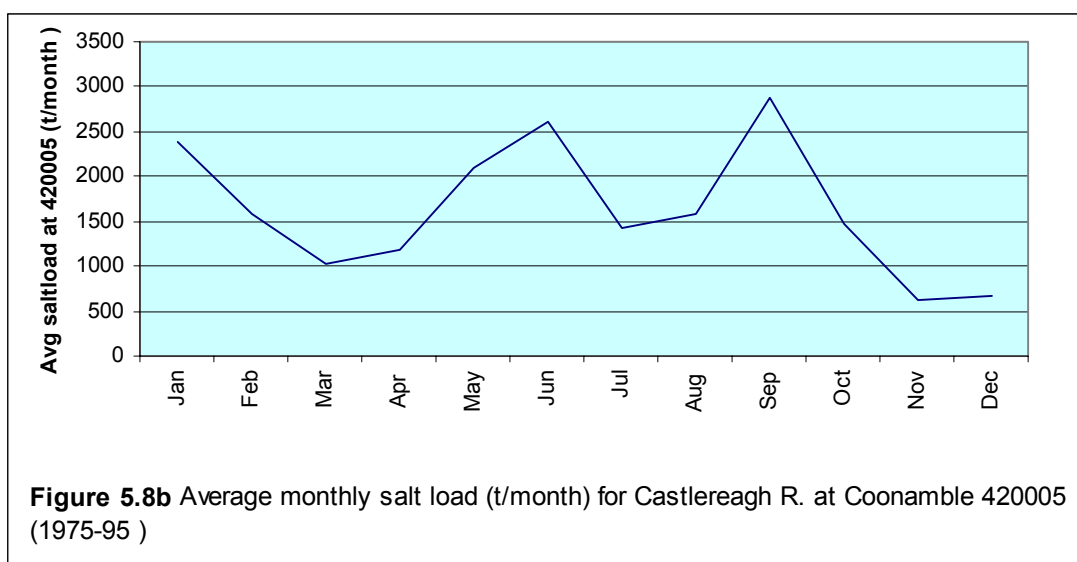
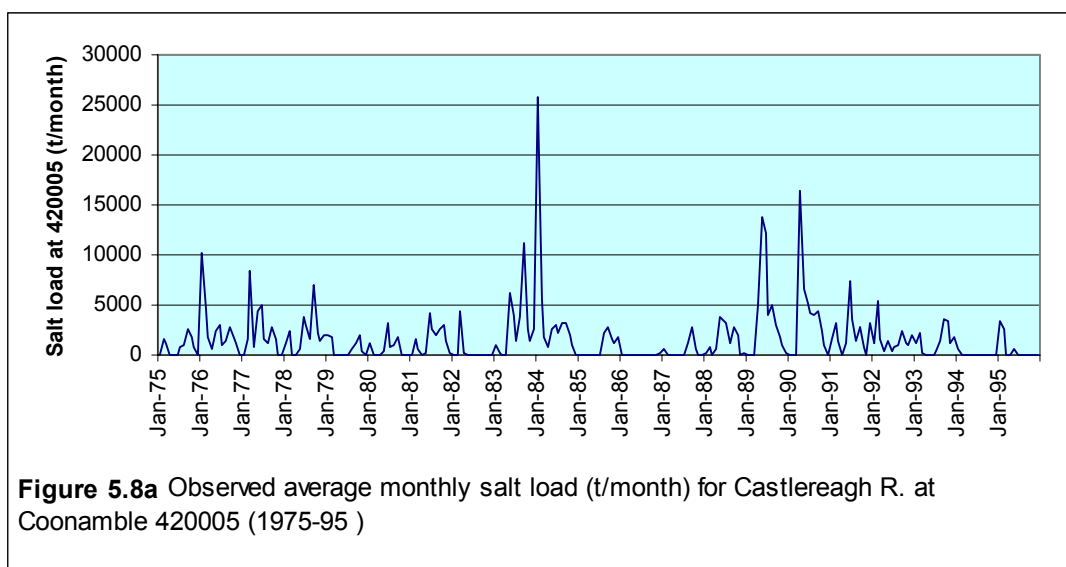
The flow and EC data available for Castlereagh is not enough to conduct a salt balance analysis as for the other second order catchments. The available flow and EC data at 420 005 (Castlereagh at Coonamble) are used to estimate the salt export from the Castlereagh Catchment (see Figure 5.1d). Model IIC is found as the best candidate model. The model parameters and the associated statistics are: η (52), λ (8.3), and R^2 (98.5). The observed salt load time series at 420 005 is shown in Figure 5.8a and the monthly averages are shown in Figure 5.8b. The monthly salt loads thus estimated are coupled with the groundwater derived potential salt loads to estimate the salt exports from the Castlereagh Catchment at the required target dates.

5.5 Salt Balance for Macquarie–Bogan

A schematic diagram of the gauging stations and the residual areas (with no observed streamflow data) used in the salt balance analysis is shown in Figure 5.9. The third order catchments associated with these locations are shown in Figure 5.1e. The salt balance in the Macquarie Catchment is computed at 4 stations (shown as dark nodes in Figure 5.9), namely, Macquarie at Bruinbun (421 025), Cudgegong R. at Yamble Bridge (421 019), Macquarie d/s of Burrendong Dam (421 040), and Macquarie at Narromine (421 006). No salt balance analysis is undertaken for the Bogan Catchment. Salt export from the Bogan is estimated using the appropriate model form with calibrated model parameter for the Bogan River at Gongolgon (421 023).

The gauging stations with observed flow and EC data (shown in *italics* in Figure 5.9) are used for identifying the appropriate model form to obtain the daily salt load time series [Eqs (3.2) to (3.8)]. The parameter values for the most suitable model form obtained from calibration and the associated statistics are shown in Table 5.7. In most cases the competing Models IIA–D performed at a broadly similar level according to the R^2 criterion. However, Model IIC is used in most cases to circumvent the need for obtaining expected values of flow and EC for catchments without EC data.

Implementation of Model IIC requires the knowledge of the parameters η and λ in addition to the daily flow values. The parameters η and λ are regionalised using a linear form of the regression relationship with the mean annual runoff expressed in mm per year. The parameter η is regionalised for all stations using the equation $\hat{\eta} = 32.65 - 0.185 Q_T$. The parameter λ is regionalised using the equation $\hat{\lambda} = 14.6 - 0.068 Q_T$ for stations R1, R2, and 072 and equation $\hat{\lambda} = 21.2 - 0.12 Q_T$ for stations 052, 041, R8–9 and 055. In some cases, the parameters are taken from stations in close proximity with similar size and flow characteristics (see Table 5.7 for parameter values and the associated statistics).



The results of the salt balance analyses for Macquarie at Bruinbun (421 025), Cudgong R. at Yamble Bridge (421 019), Macquarie downstream of Burrendong Dam (421 040), and Macquarie at Narromine (421 006) are shown in Figures 5.10a–l. The summary statistics indicating the accuracy of the salt balances at all four salt balance locations are shown in Table 5.8. With the exception of the Macquarie downstream of Burrendong Dam (421 040), the goodness of fit (R^2) at all salt balance locations varies from 0.75 to 0.93 indicating reasonable agreement between the observed and the estimated monthly salt loads. The problem with the salt balance at Burrendong Dam (421 040) is because of the influence of mixing of salts from various inputs into the reservoir and the reservoir operation schedule in real time is not accounted for. The observed salt loads are downstream of the

dam and the estimated salt loads account for all inputs from third order catchments upstream of the dam. Similarly to the case of the Namoi downstream of Keepit Dam and the Gwydir downstream of Copeton Dam, the observed monthly salt loads downstream of Burrendong Dam are used for the salt balance analysis at 421 006 (Macquarie at Narromine) in order to avoid dynamic salt routing through the reservoir.

The salt balances at 421 025, 421 019 and 421 006 show salt load underestimation of about 22%, 13% and 10.2%, respectively. The time series plot and average monthly plot at these stations show that with the exception of July and August, the salt loads are overestimated, in general (Figures 5.10b–c, 5.5e–f, 5.5k–l). This is because model parameter values for a number of stations and the residual areas used in salt balance analyses are obtained by regionalisation. Although Models IIA and IIC perform at a broadly similar level, Model IIC has been used for regionalisation because it circumvents the need for smoothed flow and EC values. However, since Model IIC is a linear model, it lacks the flexibility of adjusting adequately to appropriately represent the seasonality in flow and salt load. The only way in which the R^2 of a linear model can be maximised in the least square sense is by adjusting the parameters to overestimate salt loads in the low range and underestimate salt loads in the high range. In the model identification process greater emphasis was put on the R^2 objective function criterion, amongst many criteria, along with an attempt to simplify the regionalisation process for parameter estimation. Consistent underestimation (or overestimation) of the salt loads in the low range (or the high range) can possibly be avoided by using Model IIA or IID. This, however, has not been possible in this case owing to time constraints and the extent of the work involved. Similarly to the case of other third order catchments, the salt balance improves progressively from upstream to downstream owing mainly to masking of the error in water balance and salt load model form and the parameter estimation process due to compensation of errors from lumping of inputs. The end of system (for Macquarie only) salt loads are estimated by scaling up the salt loads at 421 012 (Macquarie at Carinda) by a factor of 1.97 obtained on the basis of flow proportions. A comparison of the observed and the estimated salt loads at the end of the system indicates good agreement (see Figure 5.10m).

On the basis of the above discussion, it is concluded that the salt balance for the Macquarie Catchment is reasonably good and can be used for estimating future salt loads at the required target dates by coupling the ‘current’ salt balance with the ratio of groundwater derived potential salt loads at ‘current’ and target dates.

Figure 5.9. Schematic diagram of the gauging stations and the residual areas used in Macquarie-Bogan salt balance analysis

Station	Catchment Area km^2	\bar{Q} $mm.y^{-1}$	n	Range	Model	Parameter estimation	η	λ	R^2	\bar{Q}_s^{year} $1 \times 10^3 t.y^{-1}$	$\bar{Q}_s^{year} / Area$ $t.y^{-1}.km^{-2}$
421 079	1088	42			IIC	Other	13.6	9.14		9.5	8.7
421 058	855	25			IIC	Other	23.2	18.3		10.0	11.7
R4	1547	35			IIC	Other	23.2	18.3		13.6	8.8
421 019	3490	29	108	600–750	IIB	At site	3.87	0.788	0.91	34.0	9.7
421 035	570	160	91	100–150	IIA	At site	-4.41	3.86	0.70	5.1	8.9
421 101	950	89	53	300–600	IIC	At site	16.0	7.09	0.94	12.4	13.1
R1	1310	67			IIC	Regional	20.3	10.0		14.2	10.8
421 072	720	93			IIC	Regional	15.3	8.3		11.5	16.0
R2	1030	38			IIC	Regional	25.9	11.7		12.0	11.7
421 025	4580	85	77	200–350	IIC	At site	17.6	8.96	0.98	45.3	9.9
421 052	621	118			IIC	Regional	10.5	6.7		9.3	15.0
421 041	231	120			IIC	Regional	10.5	6.7		5.1	23.1
421 026	883	102	105	300–450	IIC	At site	13.6	9.14	0.91	14.1	16.0
421 073	740	107			IIC	Other	13.6	9.14		12.1	16.4
R3	3435	82			IIC	Other	17.6	8.96		38.7	11.3
421 040	13980	75	103	200–300	IIA	At site	-46.4	10.1	0.96	147.8	10.6
421 018	1620	67	86	450–800	IIA	At site	-52.4	14.2	0.90	30.4	18.8
421 059	694	32	62	950–1600	IIC	At site	9.12	37.3	0.82	12.6	18.2
R5–6	1226				IIC	Other	34.4	14.6		14.2	11.6
R7	1806				IIC	Other	9.12	37.3		7.8	4.3
421 001	19600									212.9	10.9
421 042	3050	27			IIC	At site	23.2	18.3		15.5	5.1
R8–9	2894	17.7			IIC	Regional	29.4	19.2		24.3	8.4
421 055	626	29			IIC	Regional	27.4	17.8		6.50	10.4
421 006	26160	48.9	90		IIA	At site	-142	10.4	0.971	234.0	9.0

Station	Catchment Area km^2	\bar{Q} $mm.y^{-1}$	n	Range	Model	Parameter estimation	η	λ	R^2	\bar{Q}_s^{year} $1 \times 10^3 t.y^{-1}$	$\bar{Q}_s^{year} / Area$ $t.y^{-1}.km^{-2}$
421 023	27970	8	123	200–400	IIB	At site	3.25	0.715	0.908	34.0	1.2

\bar{Q} : Mean annual runoff; n : Number of days with common flow and EC data; \bar{Q}_s^{year} : Mean annual salt load

Salt balance locations: 421 019 (Cudgegong R. at Yamble Bridge), 421 025 (Macquarie at Bruinbun), 421 040 (Macquarie d/s of Burrendong Dam), 421 006 (Macquarie at Narromine).

Table 5.7 Average annual salt export rate and model parameter values for the Macquarie-Bogan Rivers Catchment based on 1975–95 conditions

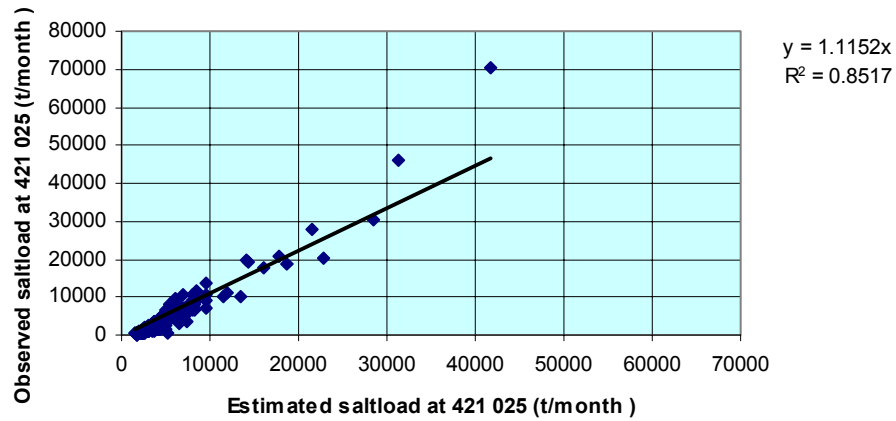


Figure 5.10a Macquarie salt balance analysis at 421 025 (Macquarie R. @ Bruinbun)

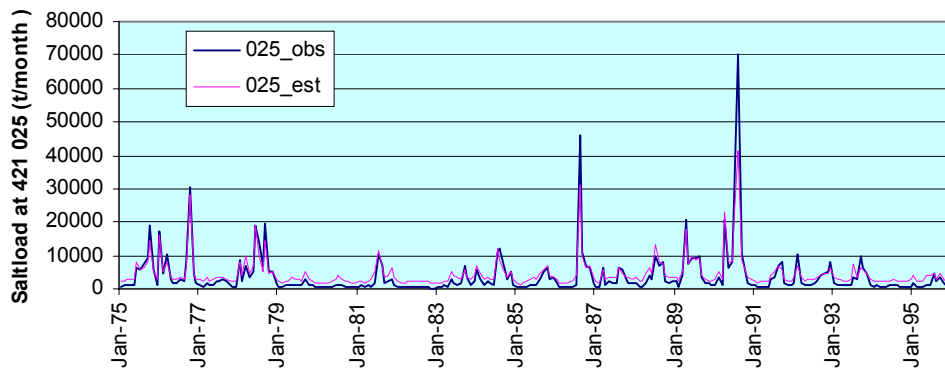


Figure 5.10b Observed and estimated monthly salt loads at 421 025 for 1975-95 (Macquarie R. @ Bruinbun)

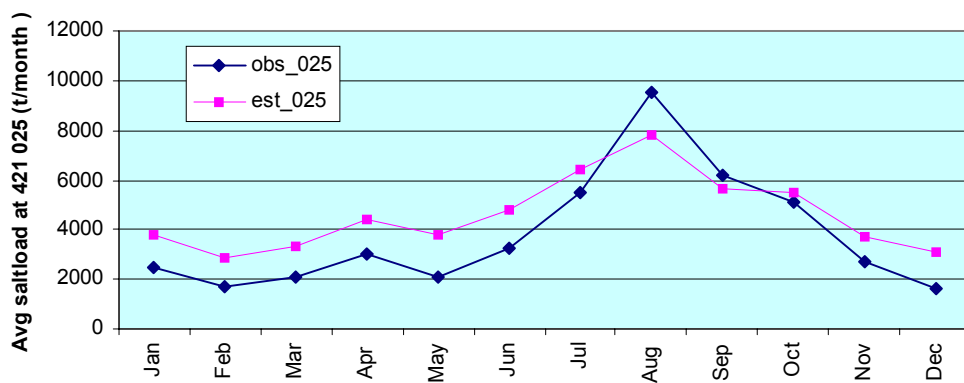


Figure 5.10c Observed and estimated average monthly salt load at 421 025 for 1975-95 (Macquarie R. @ Bruinbun)

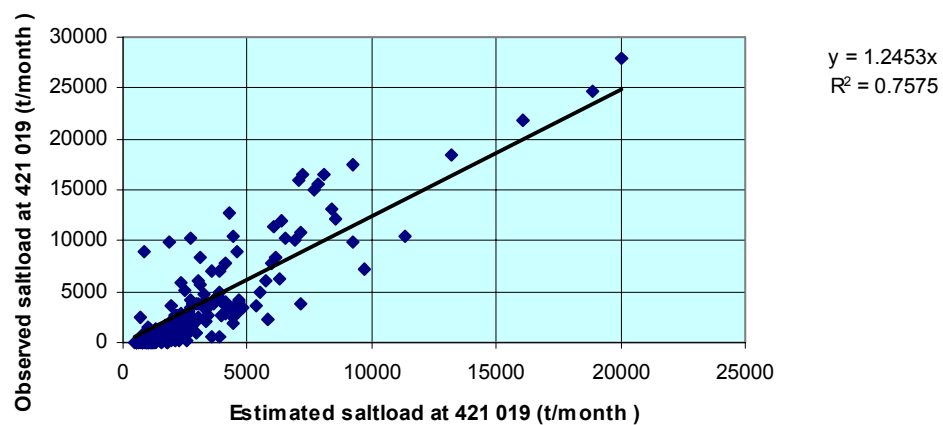


Figure 5.10d Macquarie salt balance analysis at 421 019 (Cudgegong R. @ Yamble Bridge)

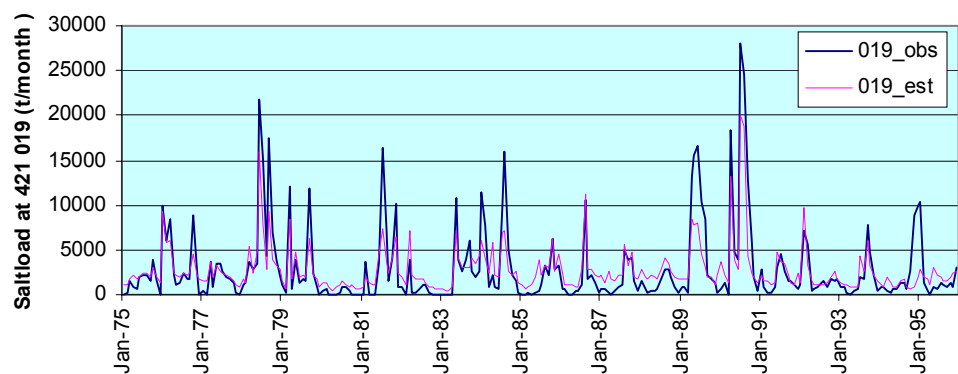


Figure 5.10e Observed and estimated monthly salt loads at 421 019 for 1975-95 (Cudgegong R. @ Yamble Bridge)

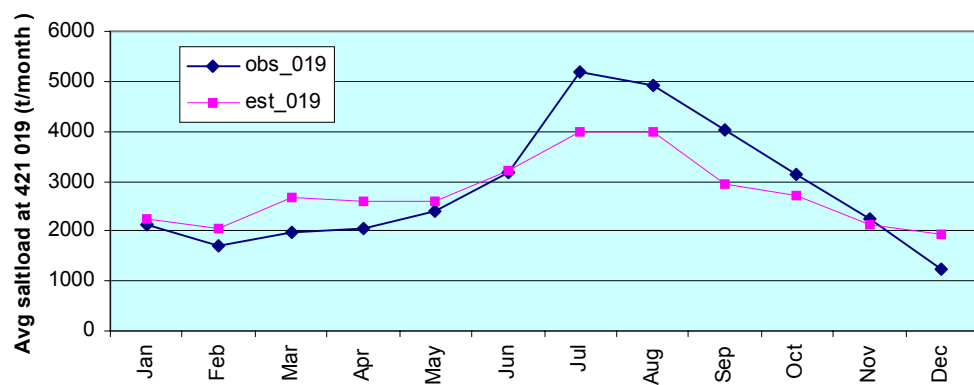


Figure 5.10f Observed and estimated average monthly salt load at 421 019 for 1975-95 (Cudgegong R. @ Yamble Bridge)

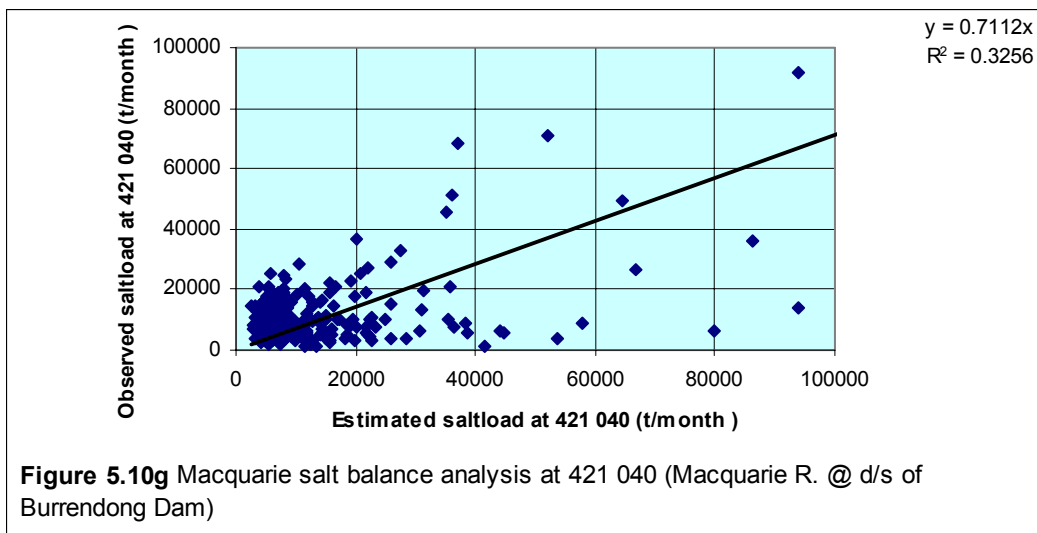


Figure 5.10g Macquarie salt balance analysis at 421 040 (Macquarie R. @ d/s of Burrendong Dam)

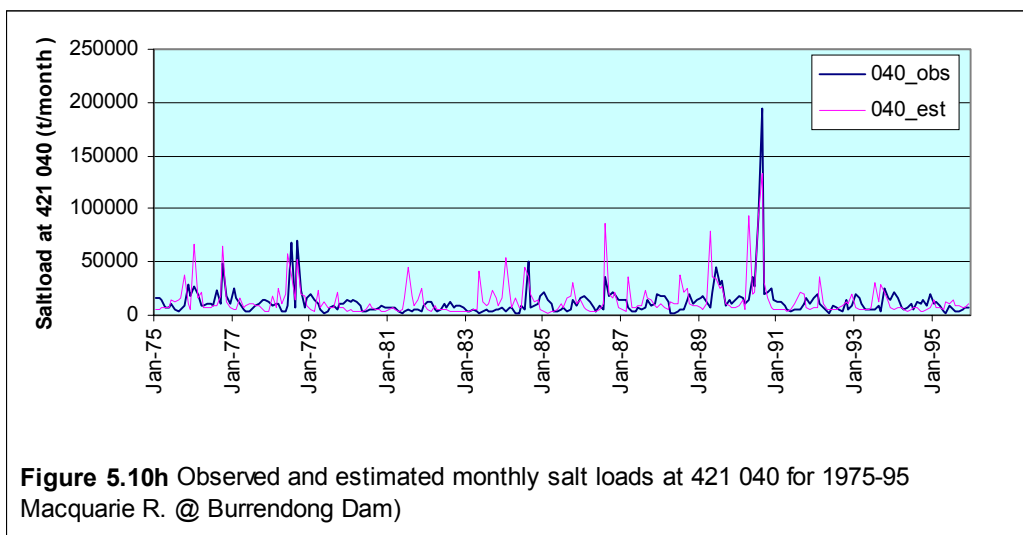


Figure 5.10h Observed and estimated monthly salt loads at 421 040 for 1975-95 (Macquarie R. @ Burrendong Dam)

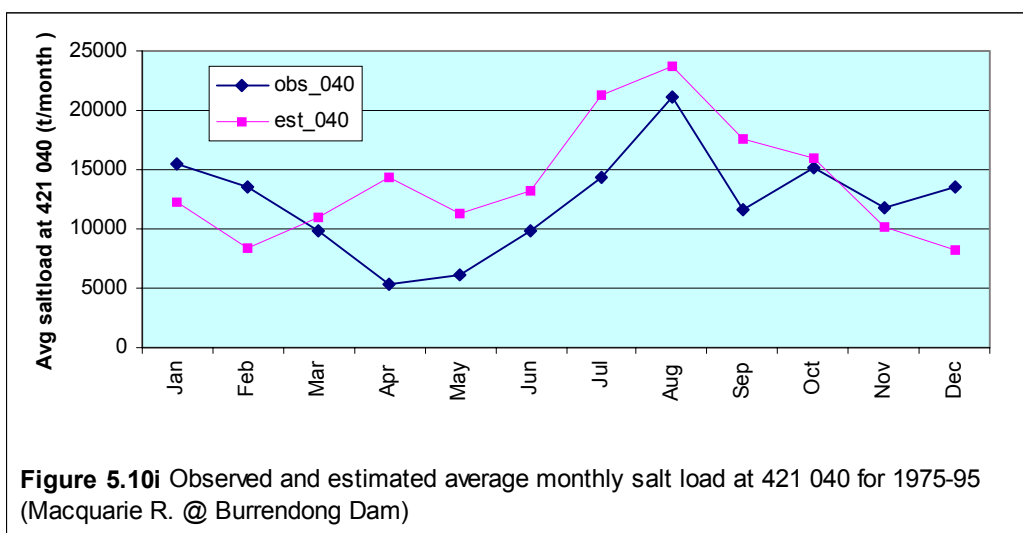
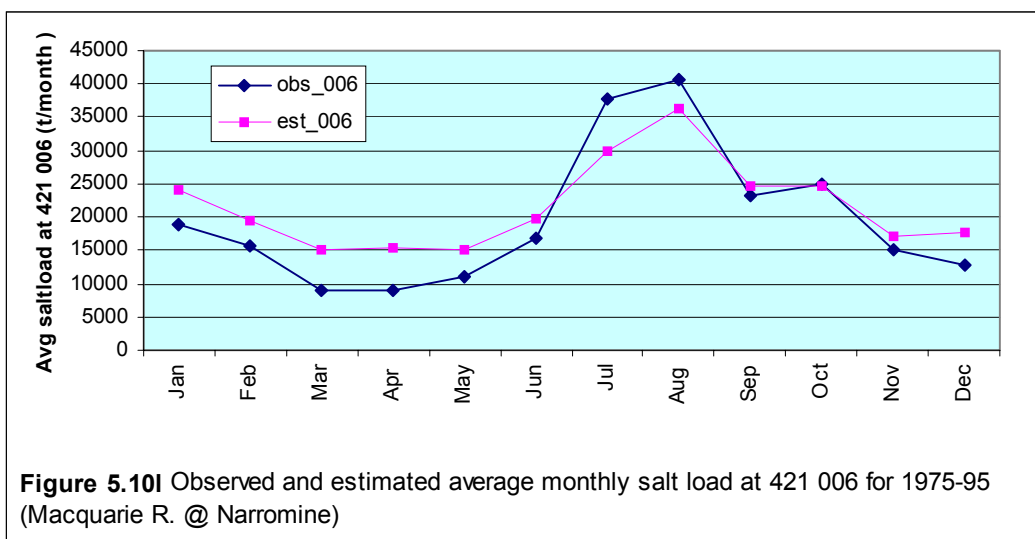
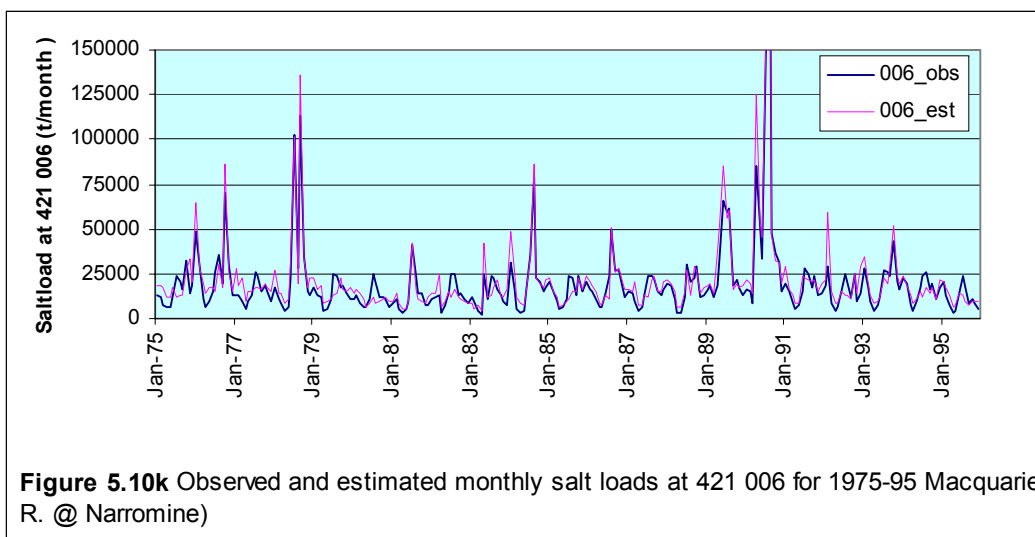
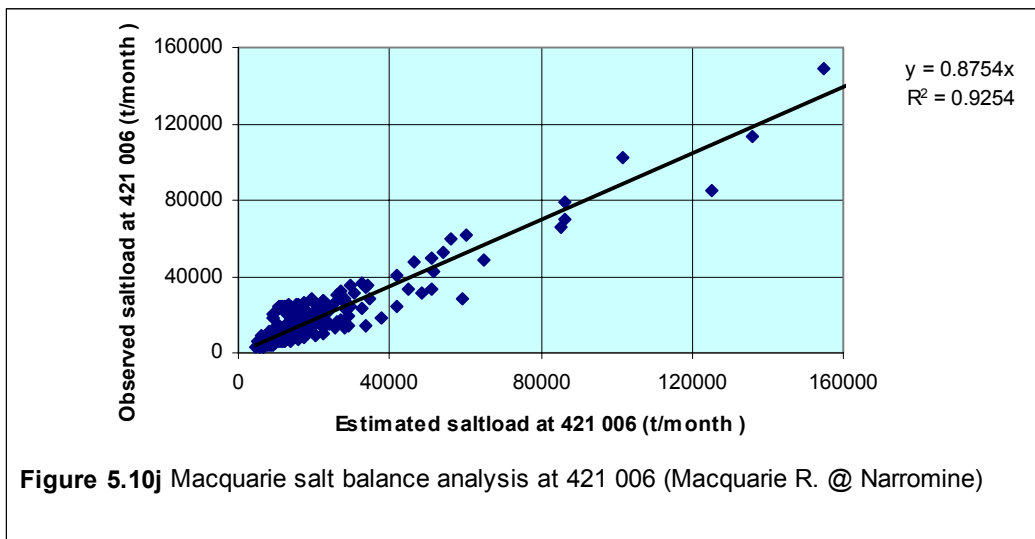
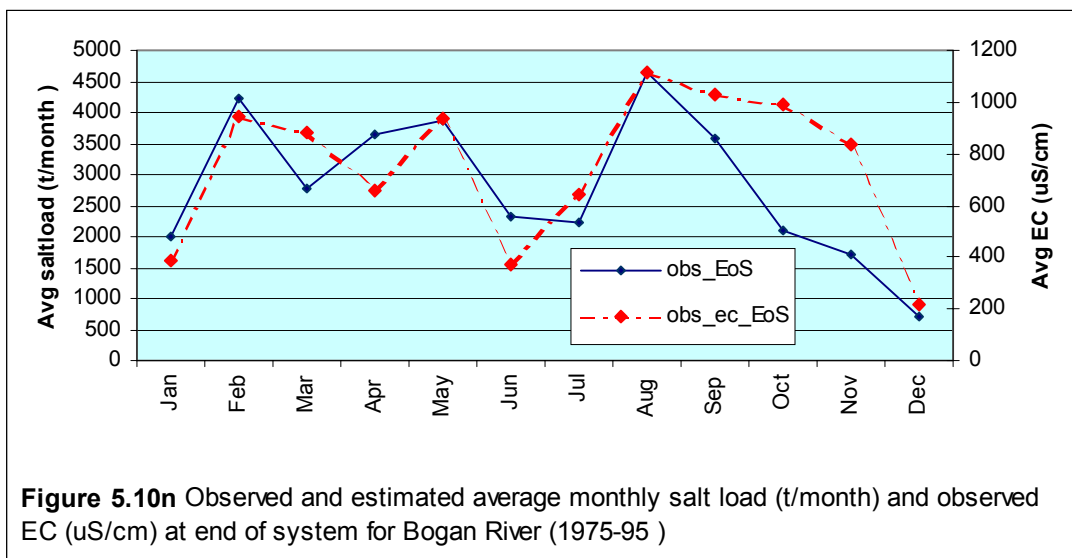
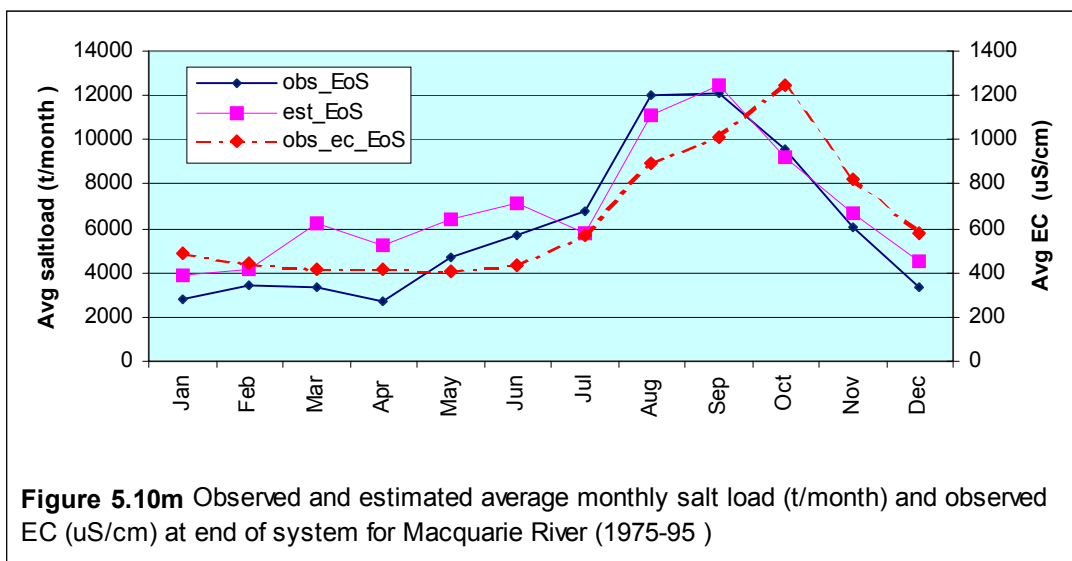


Figure 5.10i Observed and estimated average monthly salt load at 421 040 for 1975-95 (Macquarie R. @ Burrendong Dam)





No salt balance analysis for the Bogan River has been carried out. The salt loads at 421 023 (Bogan River at Gongolgon) are estimated using observed flow and EC data and the appropriate model form with calibrated parameter values (see Table 5.7). The average monthly observed salt loads and the ECs are shown in Figure 5.10n. The monthly salt loads at 421 023 are used for estimating future salt loads from the Bogan Catchment at the target dates by coupling with the groundwater based potential salt loads.

Station	Catchment Area km^2	\bar{Q} $GL.y^{-1}$	\bar{Q}_s^{year} $10^3 t.y^{-1}$	R^2	Slope α in $Q_s = \alpha \hat{Q}_s$	Mass balance error $\frac{\sum(\hat{Q}_s - Q_s)}{\sum(Q_s)} \times 100$
421 025	4580	389	45.3	0.85	1.12	22.0
421 019	3490	101	34.0	0.76	1.25	-3.0
421 040	13980	1049	147.8	0.33	0.71	13.0
421 006	26160	1280	234.0	0.93	0.88	10.6

\bar{Q} : Mean annual runoff, \bar{Q}_s^{year} : Mean annual salt load, Q_s : Observed monthly salt load, \hat{Q}_s : Estimated monthly salt load

Salt balance locations: 421 025 (Macquarie at Bruinbun), 421 019 (Cudgegong R. at Yamble Bridge), 421 040 (Macquarie d/s of Burrendong Dam), 421 006 (Macquarie at Narromine).

Table 5.8 Results of the salt balance analysis for Macquarie Catchment based on 1975–95 conditions

5.6 Salt Balance for Lachlan

A schematic diagram of the gauging stations and the residual areas (with no observed streamflow data) used in the salt balance analysis is shown in Figure 5.11. The third order catchments associated with these locations are shown in Figure 5.1f. The salt balance in the Lachlan Catchment is computed at four stations (shown as dark nodes in Figure 5.11), namely, Lachlan R. downstream of Wyangala Dam (412 067), Lachlan R. at Cowra (412 002), Lachlan R. at Nanami (421 057), and Lachlan R. at Forbes (412 006). The primary difference between the salt balance analysis for the Lachlan and other second order catchments is that diversions begin to influence the water balance substantially along the main stream just downstream of Wyangala Dam. Due to lack of information on flow diversions, flow values adjusted for a cap flow scenario on the main stream and accounting for diversions and system losses (available from IQQM simulations), are used for establishing the salt balance at all balance locations downstream of Wyangala Dam. The salt balance analysis is performed only as far as Forbes, mainly due to the braided nature of the Lachlan River further downstream and the associated difficulties in estimating flows and salt loads. Furthermore, the Lachlan River is treated as a terminal system with no input (water or salt) to the Murrumbidgee River system.

The gauging stations with observed flow and EC data (shown in *italics* in Figure 5.11) are used for identifying the appropriate model form to obtain the daily salt load time series [Eqs (3.2) to (3.8)].

The parameter values for the most suitable model form obtained from the calibration and the associated statistics are shown in Table 5.9. In most cases, Model IIC performs better than other

competing models according to the R^2 criterion. However, in some instances Model IIB performs better than other alternative models. For stations with no flow and/or EC data (e.g. residual areas R1–6, Table 5.9), Model IIC is used and the parameter values are obtained on the basis of stations in close proximity and the mean annual runoff. The salt export rate at all locations varies in the range 6 to $26 \text{ t.year}^{-1}.\text{km}^{-2}$, generally with higher export rates from third order catchments in upland areas.

The results of the salt balance analysis for the Lachlan R. downstream of Wyangala Dam (412 067), Lachlan R. at Cowra (412 002), Lachlan R. at Nanami (421 057), and Lachlan R. at Forbes (421 006) are shown in Figures 5.12a–l. The summary statistics indicating the accuracy of the salt balance at all three salt balance locations are shown in Table 5.12. The average annual salt load increases from $127\,300 \text{ t.year}^{-1}$ at Wyangala Dam to $205\,000 \text{ t.year}^{-1}$ at Cowra and about $247\,500 \text{ t.year}^{-1}$ at Nanami. Thereafter, the average annual salt load decreases to $237\,800 \text{ t.year}^{-1}$ at Forbes because more water is withdrawn from the system through diversions and losses than is added from the Mandagery Creek upstream of Eugowra and the residual area R5 (see Figure 5.11 and Table 5.10).

The goodness of fit (ie R^2) at all the salt balance locations i.e. Wyangala, Cowra, Nanami and Forbes is 0.62, 0.96, 0.96 and 0.74 respectively (Table 5.10). Water mass balance errors results in salt load overestimation of about 2% and 11% at Wyangala Dam and Nanami respectively, and underestimation of about 4% and 4.2% at Cowra and Forbes respectively. The problem with salt balance at Wyangala Dam (412 067) occurs because the influence of mixing of salts from various inputs into the reservoir and the reservoir regulation schedule in real time are not accounted for in this study. This is similar to the case of Gwydir at Copeton Dam and Namoi at Keepit Dam. The observed salt loads are obtained from observations downstream of the dam and the estimated salt loads account for all inputs from third order catchments upstream of the dam. The routing effect from Wyangala Dam is clearly seen in Figure 5.12c. Higher outflows from the dam in comparison to the inflow during January to April and October to December account for higher salt loads downstream of the dam. However, storage of water into the reservoir at other times of the year, results in lesser salt loads downstream of the dam in comparison to salt input into the reservoir.

Figure 5.11. Schematic diagram of the gauging stations and the residual areas used in Lachlan salt balance analysis

Station	Catchment Area km^2	\bar{Q} $mm.y^{-1}$	n	Range	Model	Parameter	η	λ	R^2	\bar{Q}_s^{year} $10^3 t.y^{-1}$	$\bar{Q}_s^{year} / Area$ $t.y^{-1}.km^{-2}$
412 065	2240	74	91	750–1150	IIC	At site	54.10	13.00	0.78	41.9	19.0
412 050	740	119	88	400–600	IIC	At site	10.10	11.40	0.83	15.2	21.0
412 083	321	114	70	350–700	IIC	At site	6.85	10.50	0.86	6.4	20.0
412 028	2770	105	91	200–350	IIC	At site	25.00	6.92	0.85	32.1	12.0
R1	2219	130			IIC	Other	24.00	11.00		34.7	16.0
412 067	8290	99	165	250–350	IIC	At site	26.60	13.00	0.96	127.3	15.0
412 029	1530	59	84	600–1350	IIC	At site	26.40	11.70	0.99	32.2	21.0
R2	1280	171			IIC	Other	26.10	13.00		32.3	25.0
412 002	11100	89	133	250–550	IIC	At site	-48.1	19.5	0.90	205.0	18.0
412 072	840	29	60	900–1850	IIA	At site	21.60	18.10	0.79	9.0	11.0
412 009	2180	89	133	500–750	IIB	At site	3.84	0.66	0.84		26.0
412 055	2550	78			IIC	Other	57.3	14.0		57.3	26.0
R3	1610	166			IIC	Other	20.00	9.00		12.8	8.0
412 057	16100	75	103	300–500	IIC	At site	121.00	14.50	0.92	247.5	15.0
412 030	1630	49	52	350–1500	IIC	At site	16.30	26.60	0.69	29.4	18.0
R5	1270	134			IIC	Other	20.00	13.00		32.8	26.0
412 004	19000	60	136	350–550	IIC	At site	135.00	14.20	0.98	237.8	13.0
R6	400	79			IIC	Other	21.60	18.10		13.8	35.0
412 043	4200	16			IIC	Other	57.30	14.00		25.7	6.0
034/006	25200	32	143	350–500	IIC	At site	111.00	13.80	0.94	170.5	7.0

\bar{Q} : Mean annual runoff; n : Number of days with common flow and EC data; \bar{Q}_s^{year} : Mean annual salt load

Salt balance locations: 412 067 (Lachlan R. d/s of Wyangala Dam), 412 002 (Lachlan R. at Cowra), 412 057 (Lachlan R. at Nanami), and 412 004 (Lachlan R. at Forbes).

Table 5.9 Average annual salt export rate and model parameter values for the Lachlan Rivers Catchment based on 1975–95 conditions

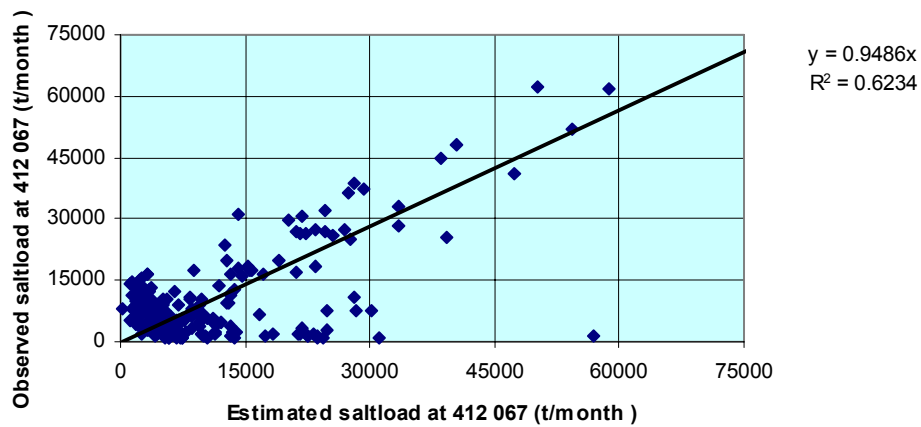


Figure 5.12a Lachlan River salt balance analysis at 412 067 (Lachlan R. @ d/s of Wyangala Dam)

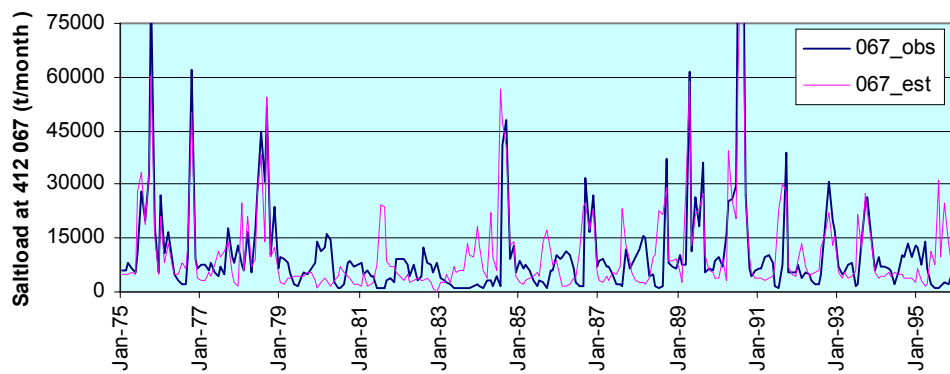


Figure 5.12b Observed and estimated monthly salt loads at 412 067 for 1975-95 (Lachlan R. @ d/s of Wyangala Dam)

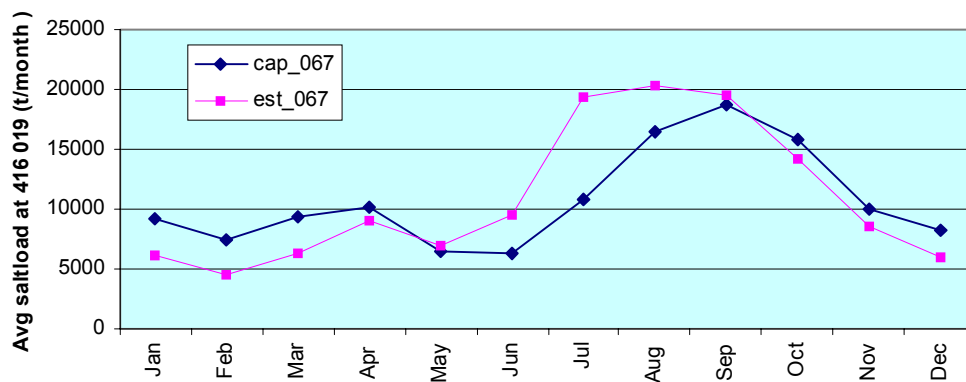


Figure 5.12c Observed and estimated average monthly salt load at 412 067 for 1975-95 (Lachlan R. @ Wyangala Dam)

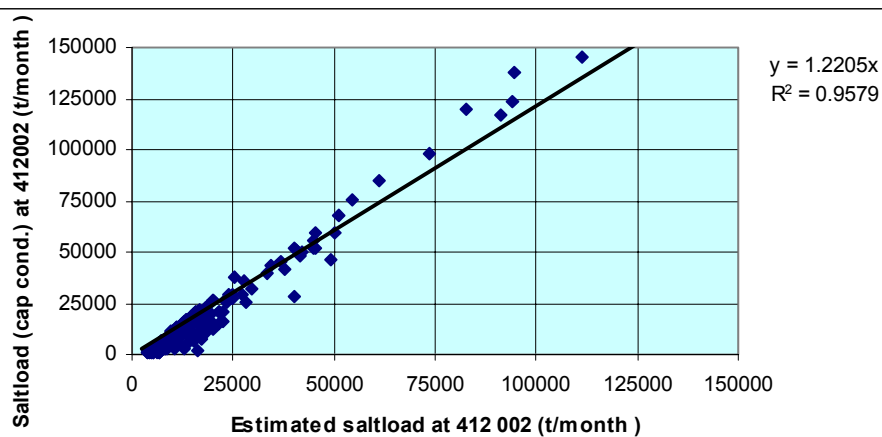


Figure 5.12d Lachlan River salt balance analysis at 412 002 (Lachlan R. @ Cowra)

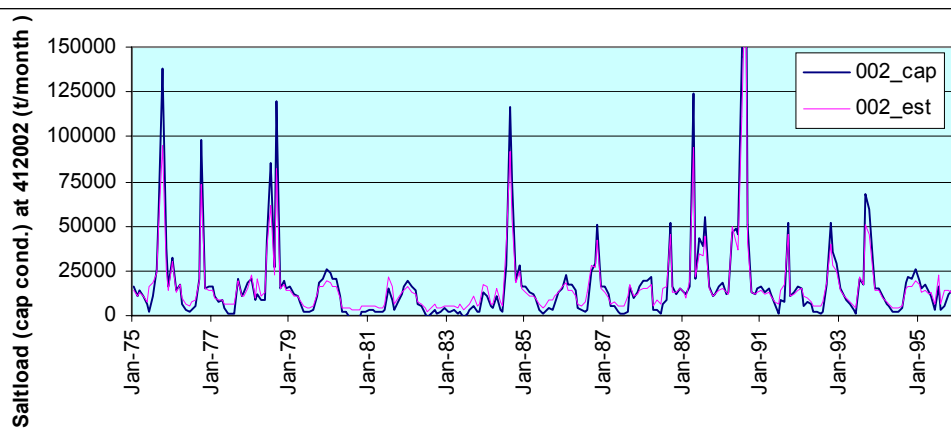


Figure 5.12e Observed and estimated monthly salt loads at 412 002 for 1975-95 (Lachlan R. @ Cowra)

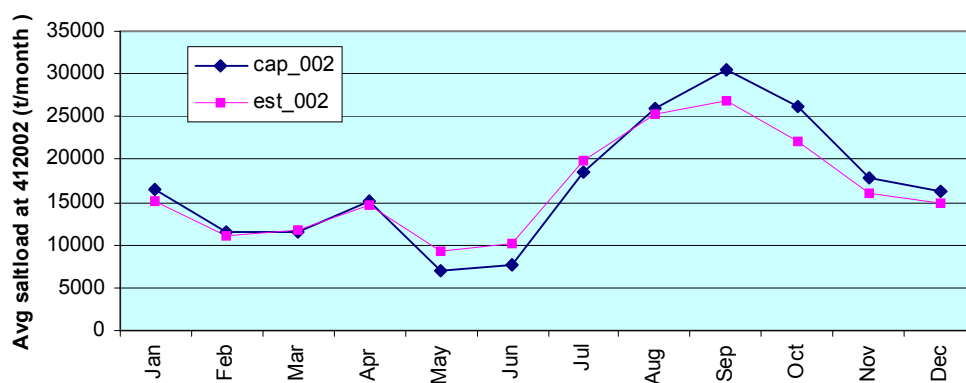


Figure 5.12f Observed and estimated average monthly salt load at 412 067 for 1975-95 (Lachlan R. @ Cowra)

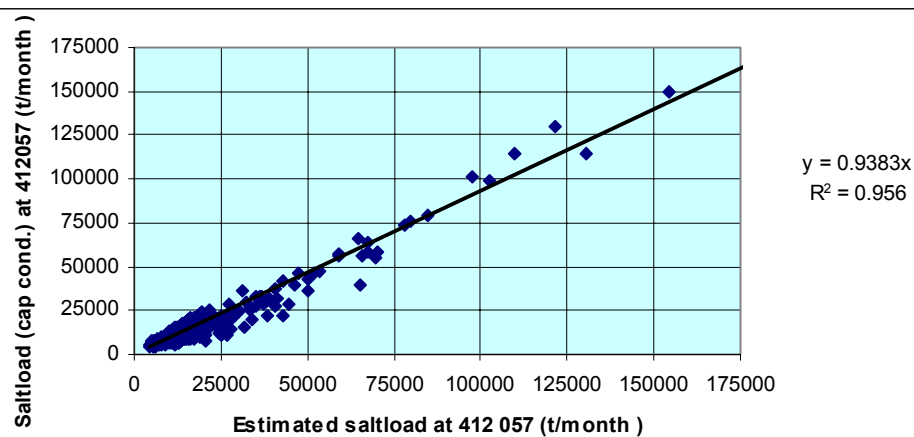


Figure 5.12g Lachlan River salt balance analysis at 412 057 (Lachlan R. @ Nanami)

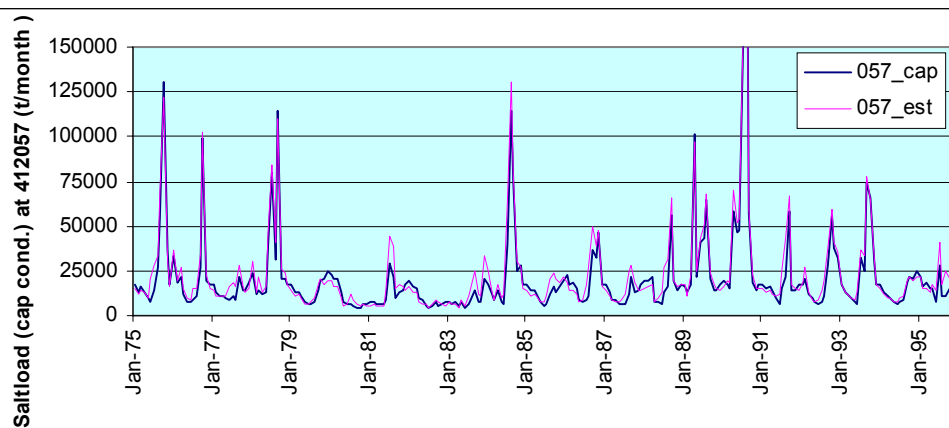


Figure 5.12h Observed and estimated monthly salt loads at 412 057 for 1975-95 (Lachlan R. @ Nanami)

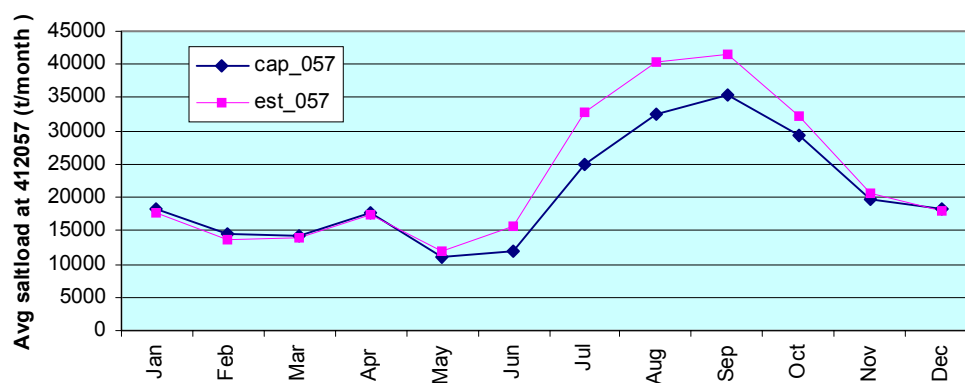
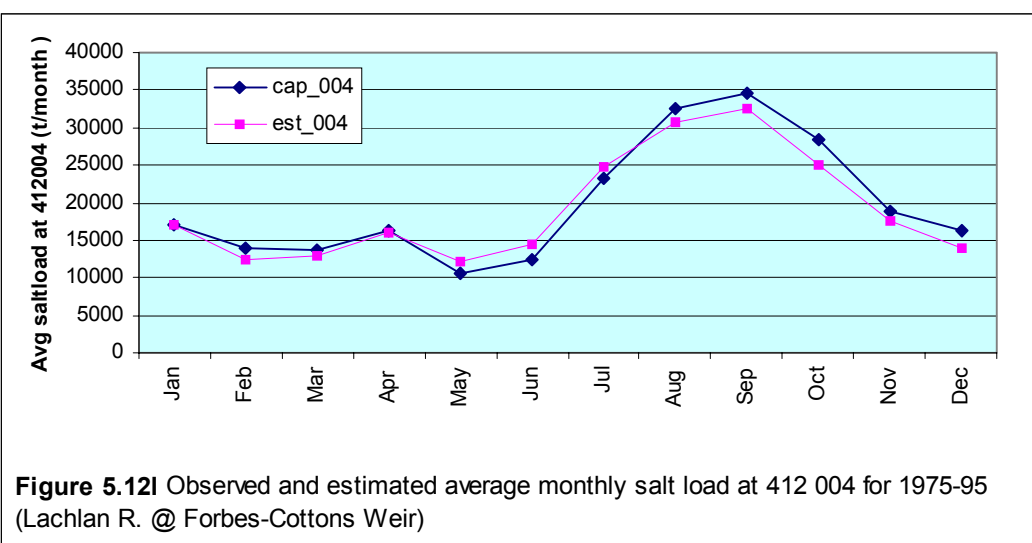
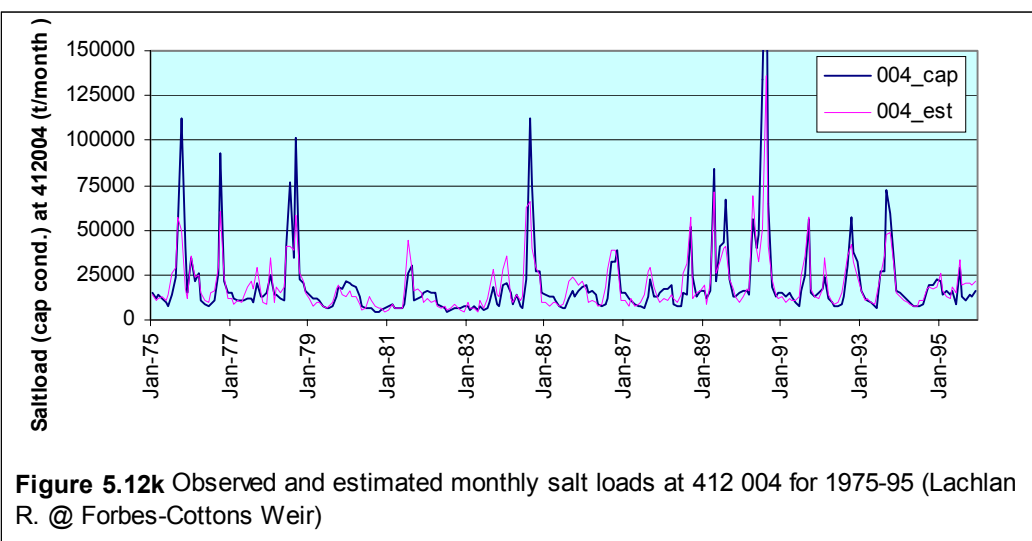
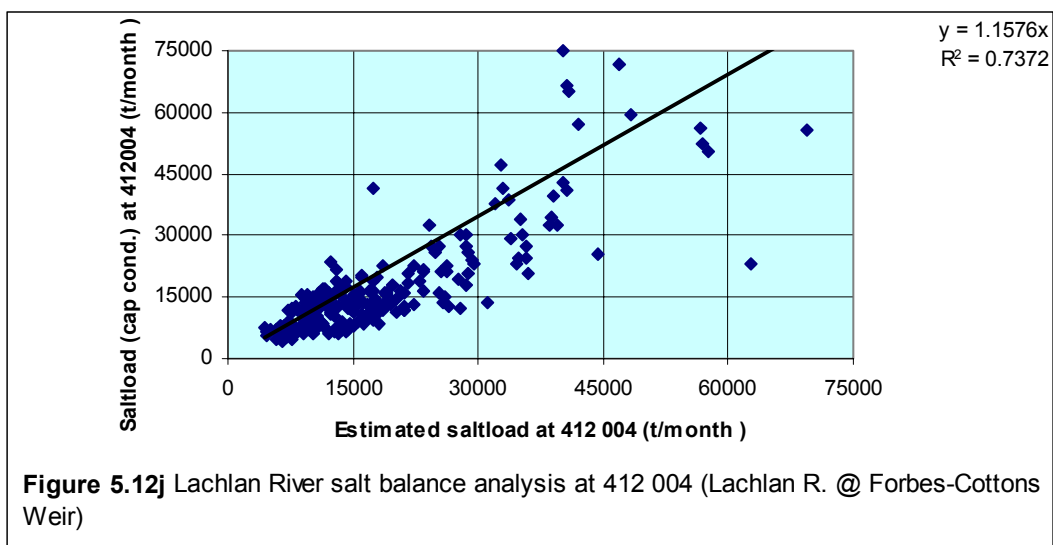


Figure 5.12i Observed and estimated average monthly salt load at 412 057 for 1975-95 (Lachlan R. @ Nanami)



The salt balance for the Lachlan River at Cowra (412 002) and at Nanami (412 057) is accurate to a level of 96% although salt loads are overestimated by about 11% at Nanami mainly during high flow conditions from July to September (Figure 5.12i). The salt balance for the Lachlan River at Forbes, while very good on an average basis (Figure 5.12l), is accurate to a level of only 74% due mainly to a very wide scatter for salt loads in excess of $30\,000\text{ t.month}^{-1}$ (Figure 5.12j). By coincidence, the unsystematic overestimation and underestimation of the salt load provide a compensating effect on an average basis, which does not necessarily indicate a good salt balance at Forbes. Between Nanami and Forbes there are two inputs (Mandagery Creek at 412 030 and residual area R5) and two extractions (Diversion D2 and channel losses L5) (see Figure 5.11). The loss of about 22% accuracy in the salt balance between Nanami and Forbes is due to the following reasons:

- (a) calibration of the stochastic model parameters is done using the observed data; however, the salt load time series is obtained using these parameters for the cap flow condition; the underlying assumption that salt contribution from Nanami to Forbes relative to 412 030, R5, D2 and L5 will remain same for observed as well as cap conditions is not entirely correct;
- (b) inaccuracy in quantifying flow contribution from residual area R5 and channel losses L5, and;
- (c) a relatively less accurate calibration (69%) for Mandagery Creek (412 030) (Table 5.9).

An attempt was made to establish the salt balance for the Lachlan at Condobolin Weir (412 034). However, the difficulty in quantifying flows and salt loads due to the braided nature of the Lachlan River between Forbes and Condobolin did not justify its inclusion in the report. Therefore, on an overall basis the salt balance for the Lachlan is very good down to Nanami and is somewhat less accurate at Forbes. This, however, does not pose any serious implications for this study because the Lachlan River is treated as a terminal system with no water and salt export to the Murrumbidgee River system.

Station	Catchment Area km^2	\bar{Q} $GL.y^{-1}$	\bar{Q}_s^{year} 10^3 t.y^{-1}	R^2	Slope α in $Q_s = \alpha \hat{Q}_s$	Mass balance error $\frac{\sum(\hat{Q}_s - Q_s)}{\sum(Q_s)} \times 100$
412 067	8290	823	127.3	0.62	0.95	2.0
412 002	11100	986	205.0	0.96	1.22	-4.0
412 057	16100	1211	247.5	0.96	0.94	11.0
412 004	19000	1147	237.8	0.74	1.16	-4.2

\bar{Q} : Mean annual runoff, \bar{Q}_s^{year} : Mean annual salt load, Q_s : Observed monthly salt load, \hat{Q}_s : Estimated monthly salt load

Salt balance locations: 412 067 (Lachlan R. d/s of Wyangala Dam), 412 002 (Lachlan R. at Cowra), 412 057 (Lachlan R. at Nanami), 412 004 (Lachlan R. at Forbes).

Table 5.10 Results of the salt balance analysis for Lachlan Catchment based on 1975–95 conditions

5.7 Salt Balance for Murrumbidgee

A schematic diagram of the gauging stations and the residual areas (with no observed streamflow data) used in the salt balance analysis is shown in Figure 5.13. The third order catchments associated with these locations are shown in Figure 5.1g. The salt balance analysis in the Murrumbidgee Catchment is carried out at 3 stations (shown as dark nodes in Figure 5.13), namely, Tumut River at Brungle Bridge (410 039), Murrumbidgee at Gundagai (410 004), and Murrumbidgee at Wagga Wagga (410 001).

The gauging stations with observed flow and EC data (shown in italics in Figure 5.13) are used for identifying the appropriate model form to obtain the daily salt load time series [Eqs (3.2) to (3.8)]. The parameter values for the most suitable model form obtained from calibration and the associated statistics are shown in Table 5.11. In most cases Model IIA [Eq. (3.4)] is found to be the best candidate model for estimating daily salt loads. Therefore, for the remaining stations with no EC data, Model IIA [Eq. (3.4)] is used. Implementation of Model IIA requires knowledge of the parameters η and λ in addition to the average smoothed EC and flow [Eq. (3.12)]. The parameter λ is obtained from regionalisation using a non-linear form of the regression relationship between the corresponding mean annual runoff ($Mm^3.km^{-2}$) and λ for stations with observed flow and EC data. The parameter η and the average smoothed EC are obtained from nearby stations with similar catchment size and flow characteristics (see Table 5.11 for parameter values and the associated statistics). The observed flow and average smoothed flow values are taken from at site information. In the case of the residual catchments, the average flow contributions of R1 to 410 039, R2 to 410 004, and R3 to 410 001 are about 4.75%, 7% and 1.5%, respectively, of the observed flow at 410 039, 410 004 and 410 001 respectively. Therefore, the proportion of daily salt load from R1, R2 and R3 to the salt balance locations at 410 039, 410 004 and 410 001, respectively, are also assumed to be the same as the proportion of observed flow. The salt load contributions from residual catchments relative to the salt loads from other third order catchments are not very significant and, therefore, the effects of this rather crude assumption on the accuracy of salt balance are not substantial.

Figure 5.13. Schematic diagram of the gauging stations and the residual areas used in Murrumbidgee salt balance analysis

Station	Catchment Area km^2	\bar{Q} $mm.y^{-1}$	n	Range	Model	Parameter estimation	η	λ	R^2	\bar{Q}_s^{year} $10^3 t.y^{-1}$	$\bar{Q}_s^{year} / Area$ $t.y^{-1}.km^{-2}$
410 073	1630	1043	1727	50–50	IIA	At site	-6.7	1.56	0.71	35.2	21.6
410 059	233	85.4			IIA	Regional	-6.7	5.2		1.80	7.7
410 057	673	421			IIA	Regional	-6.7	4.9		6.6	9.8
410 071	114	166			IIA	Regional	-11.5	6.2		0.40	3.5
R1	650	113			IIA	Other	-6.7	6.5		2.0	3.5
410 039	3300	652			IIA	R	-6.7	3.6		48.6	14.7
410 008	13100	115	132	150–200	IIA	At site	-11.5	8.39	0.97	147	11.3
410 025	2120	46	215	850–1600	IIB	At site	4.19	0.69	0.75	53.8	25.4
410 044	1025	52			IIA	Regional	-45.6	22.0		23.5	22.9
410 038	411	206			IIA	Regional	-11.5	6.0		5.2	12.7
R2	1144	196			IIA	Other	-45.6	6.0		21.6	18.9
410 004	21100	193	1553	50–370	IIA	At site	-31.1	8.61	0.80	307.9	14.6
410 061	155	257			IIA	Regional	3.31	5.7		7.5	48.4
410 043	568	196			IIA	Regional	3.31	6.0		18.2	32
410 045	758	19			IIA	Regional	4.19	80		6.6	8.7
410 047	1660	115	267	200–300	IIB	At site	2.79	0.783		26.2	15.8
410 048	530	95			IIA	At site	-34.9	33.2		20.4	38.5
R3	1629	70			IIA	Other				6.0	7.9
410 001	26400	174	1580	100–460	IIA	At site	-31.6	9.57	0.92	401.8	15.2

\bar{Q} : Mean annual runoff, n : Number of days with common flow and EC data, \bar{Q}_s^{year} : Mean annual salt load

Salt balance locations: 410 039 (Tumut @ Brungle Bridge), 410 004 (Gundagai), and 410 001 (Wagga Wagga)

Table 5.11 Average annual salt export rate and model parameter values for the Murrumbidgee Rivers Catchment based on 1975–95 conditions

The results of the salt balance analysis for Tumut River at Brungle bridge (410 039), Murrumbidgee River at Gundagai (410 004), and Murrumbidgee River at Wagga (410 001) are shown in Figures 5.14a–i. The summary statistics indicating the accuracy of the salt balances at all three locations are shown in Table 5.12. The scatter plot and the time series plot of observed and estimated monthly salt loads at all three locations show good agreement (Figures 5.14a–b, 5.14d–e, 5.14g–h). The slope (α) of the regression line ($Q_s = \alpha \hat{Q}_s$) between estimated (\hat{Q}_s) and observed (Q_s) monthly salt loads varies between 1.09 at 410 039 to 1.04 at 410 004 and 410 001 indicating that salt load, in general, is marginally underestimated. The mass balance errors at 410 039, 410 004 and 410 001 indicate salt load underestimation of about 5%, 3.2% and 4.7%, respectively. The R^2 of the observed and the estimated monthly salt load increases from 80% at Brungle Bridge (410 039) to about 93% at Wagga Wagga. The progressive increase in accuracy of the salt balance from upstream to downstream salt balance locations is a result of: (a) compensation of inaccuracies in water balance and streamflow estimates of third order residual catchments due to aggregation of flow at downstream locations i.e. interaction of water balance with the salt balance, (b) inaccuracy in the model parameter estimates from the population values due to high sampling variance associated with the EC observations for the third order catchments, and (c) a single functional form between flow and salt load is used in this study; due to marked influence of non-linearity in flow and salt transport mechanisms for the third order catchments, it is desirable to use a separate function for each flow range i.e. low, medium and high flows; this approach, although not used, can substantially improve salt balance at the upstream locations. Disaggregation of errors in salt balance to each of these components is beyond the scope of this study.

Station	Catchment Area km^2	\bar{Q} $GL.y^{-1}$	\bar{Q}_s^{year} $10^3 t.y^{-1}$	R^2	Slope α in $Q_s = \alpha \hat{Q}_s$	Mass balance error $\frac{\sum(\hat{Q}_s - Q_s)}{\sum(Q_s)} \times 100$
410 039	3300	2150	48.6	0.80	1.09	-5.0
410 004	21100	2996	307.9	0.94	1.04	-3.2
410 001	26400	4594	401.8	0.93	1.04	-4.7

\bar{Q} : Mean annual runoff, \bar{Q}_s^{year} : Mean annual salt load, Q_s : Observed monthly salt load, \hat{Q}_s : Estimated monthly salt load

Salt balance locations: 410 039 (Tumut @ Brungle Bridge), 410 004 (Gundagai), and 410 001 (Wagga Wagga)

Table 5.12 Results of the salt balance analysis for Murrumbidgee Catchment based on 1975–95 conditions

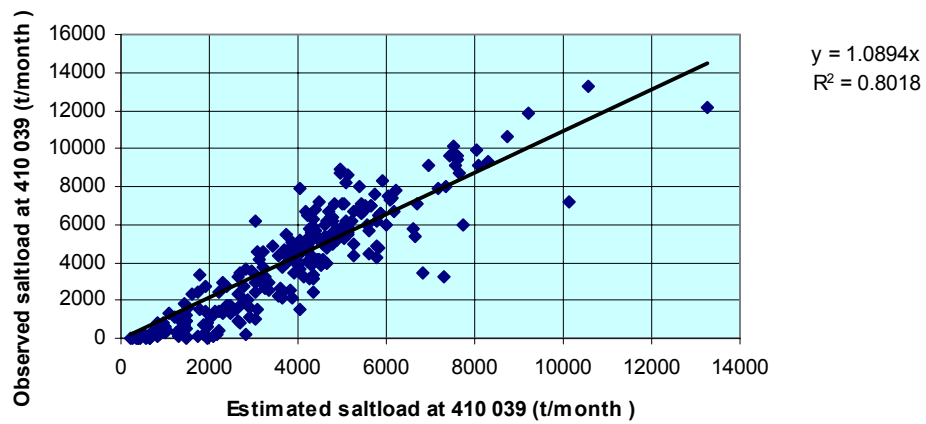


Figure 5.14a Murrumbidgee salt balance analysis at 410 039 (Tumut River @ Brungle Bridge)

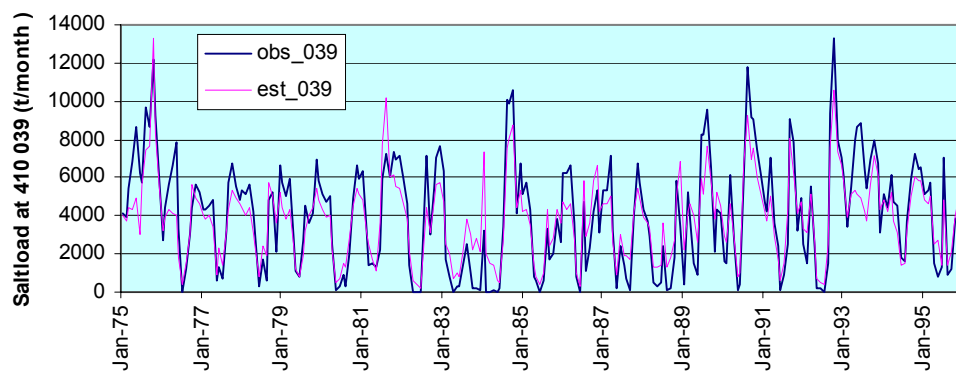


Figure 5.14b Observed and estimated monthly salt loads at 410 039 for 1975-95 (Tumut @ Brungle Bridge)

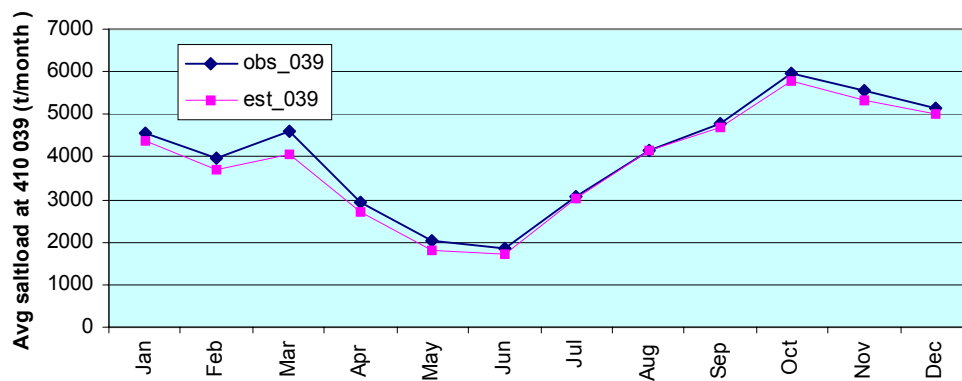
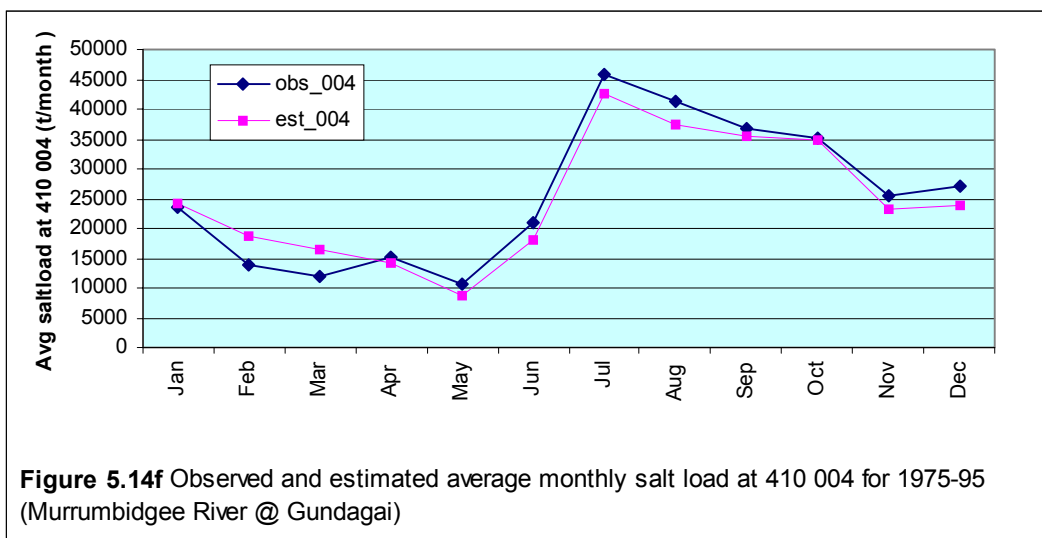
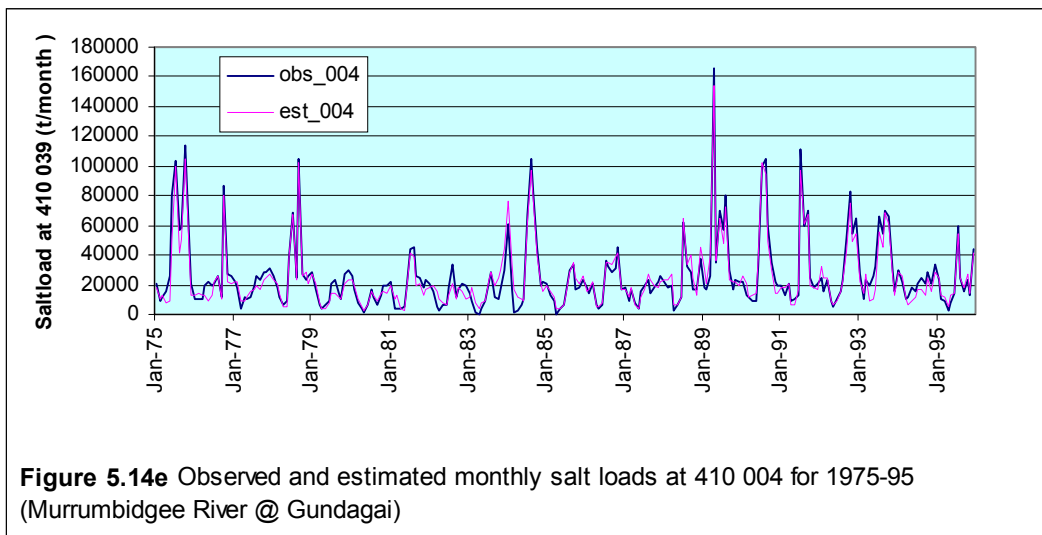
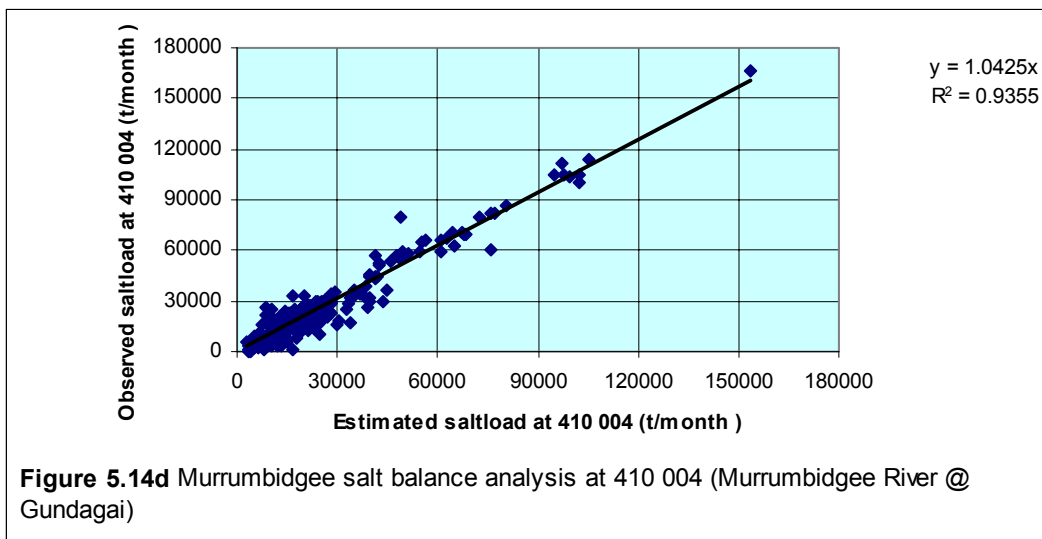
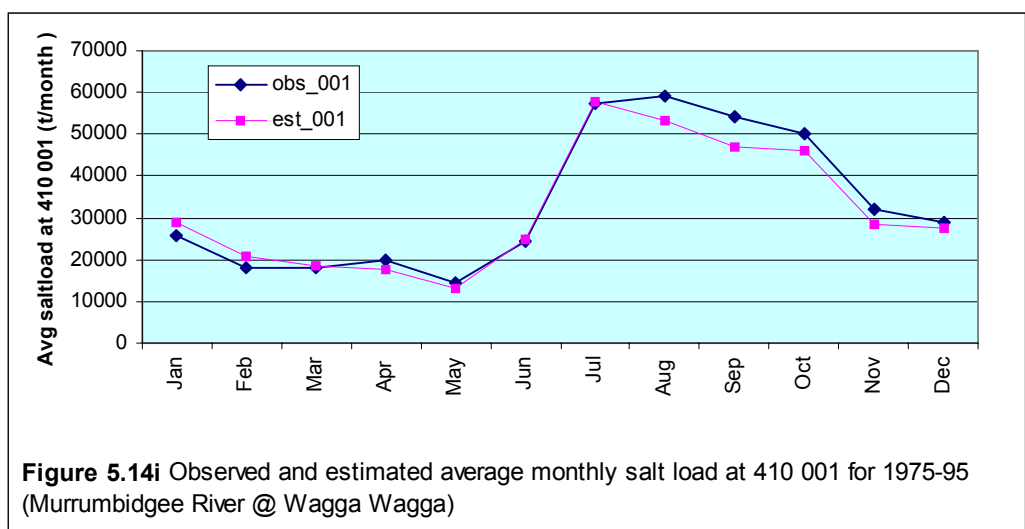
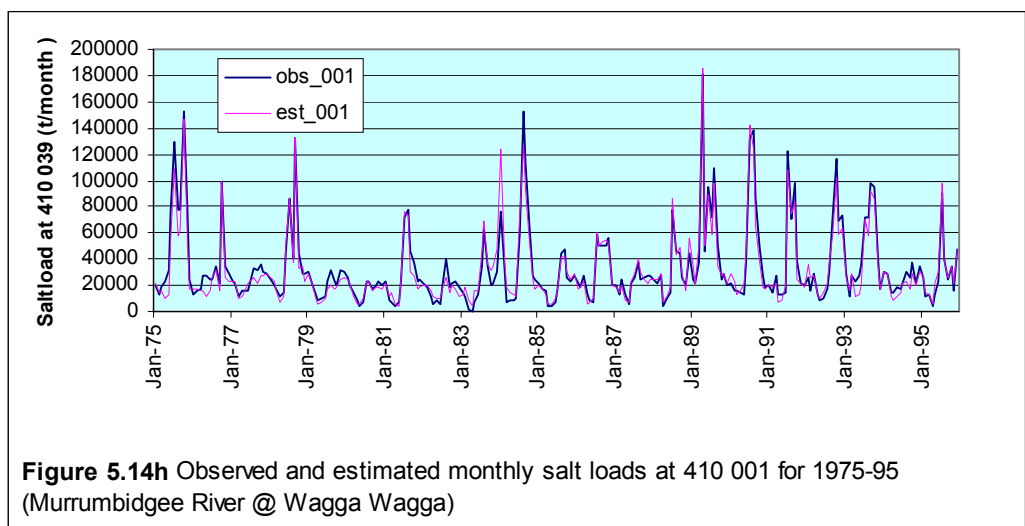
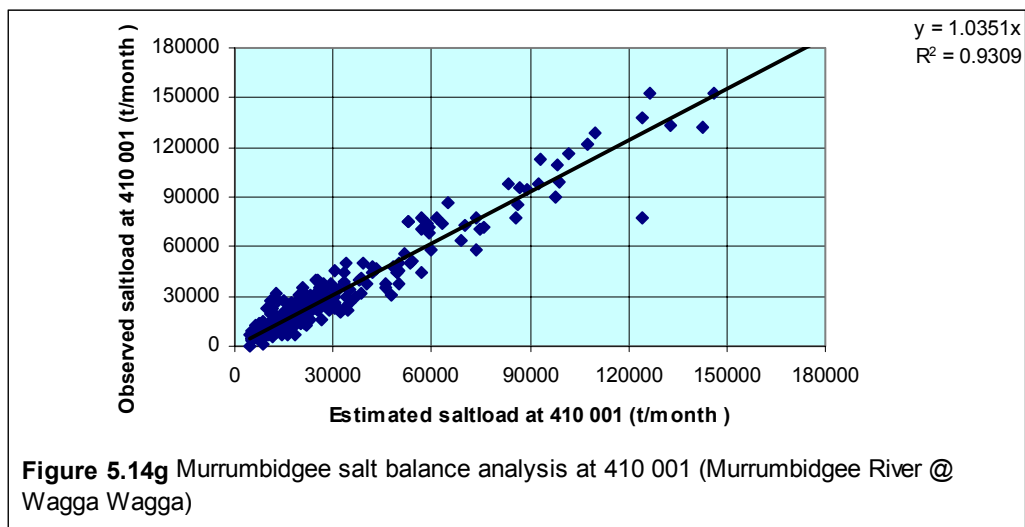
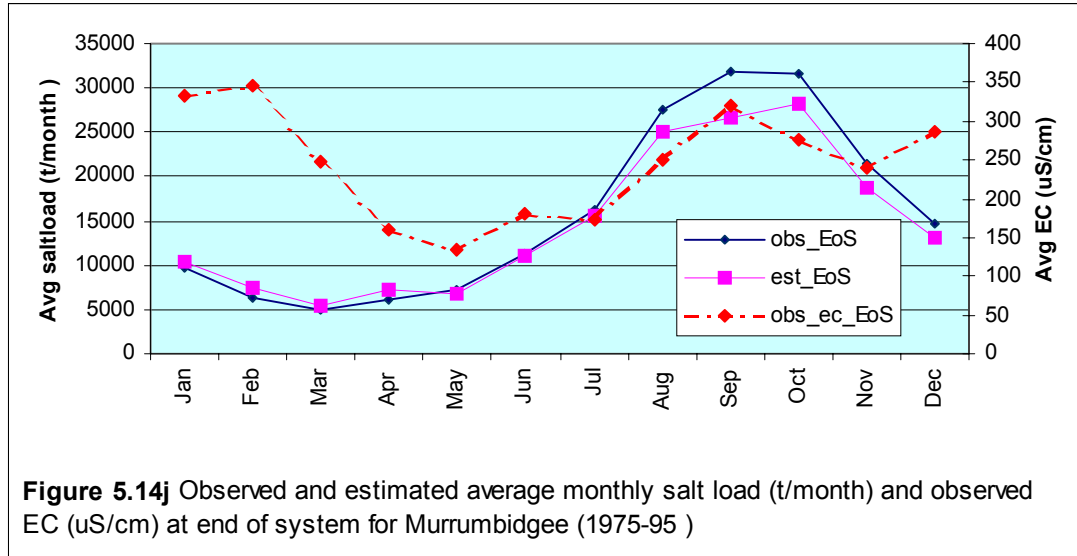


Figure 5.14c Observed and estimated average monthly salt loads at 410 039 for 1975-95 (Tumut River @ Brungle Bridge)







The observed (q_T^s) and estimated (\hat{q}_T^s) average monthly salt loads for 1975–95 conditions at 410 039, 410 004 and 410 001 are shown in Figures 5.14c, 5.14f, and 5.14g respectively. These figures show that the salt balance is reasonably accurate not only on an annual basis at all three locations, but is also accurate in reproducing the temporal distribution of the monthly salt loads. Downstream of Wagga Wagga (410 001), diversions become significant. Therefore, monthly salt load estimates for Murrumbidgee River at Narrandera (410 005), Darlington Point (410 021), Hay (410 002), and Balranald (410 003) are obtained using Eq. (3.30). The observed and estimated average monthly salt loads at the end of system, ie. Murrumbidgee at Balranald (410 003), along with the observed monthly average ECs are shown in Figure 5.3j. While the agreement between observed and the estimated monthly average salt loads is generally good, salt loads for August to December are generally underestimated to varying degrees. This is mainly due to the inability of Eq. (3.29) to explicitly account for salt loads diverted to irrigation areas downstream of Wagga Wagga. It is pointed out that the objective of this study is to account for salt loads from dryland areas and therefore explicit accounting for salt contributions from irrigation areas has not been undertaken in this study.

On the basis of the above discussion, it is concluded that the Murrumbidgee salt balance under ‘current’ conditions is reasonably accurate and that the results can be coupled with groundwater based rates of change, to estimate salt export rates from the Murrumbidgee under likely future conditions at the target dates.

6 Future Predicted In-stream Salt Loads Exported from Second Order Catchments

Across the second order catchments under study in the NSW portion of the Murray-Darling Basin, the input of cyclic salt carried in rainfall varies with distance from the ocean and inland sources. Recorded values are generally in the range from 1.5 to 4 $t.km^{-2}.year^{-1}$ with values as high as 6.7 $t.km^{-2}$ reported for Hay in 1974–75 (Blackburn and McLeod, 1983). In-stream salt export rates from third order catchments, determined in this study, currently range from approximately 3 to 50 $t.km^{-2}.year^{-1}$. Salts delivered to the ground surface, at a second order catchment scale, are estimated to vary from approximately 0.3 to 26 $t.km^{-2}.year^{-1}$. Rates of up to 76 $t.km^{-2}.year^{-1}$ are estimated in some catchment geologies (Table 4.4). These components of the salt balance are dwarfed by the size of the soil salt store.

The soil salt store varies with soil type. Non saline soils, regarded as having an electrical conductivity of less than 2000 $\mu S.cm^{-1}$, generally occupy the vast majority of the surface area of the dryland catchments. For a non-saline soil, with an average EC_e profile of 2000 $\mu S.cm^{-1}$ and an average bulk density of 1.5 $kg.litre^{-1}$, the salt store in the top 0.5 m is equivalent to 480 $t.km^{-2}$. Assuming a higher bulk density of 1.65 $kg.litre^{-1}$ in the lower profile, the salt store in the top 2 m would be approximately 2064 $t.km^{-2}$. For certain soil types, sodosols in particular (soils with sodic subsoils), the soil salt store could be 2 to 3 times more than this amount. Sodosols tend to predominate in the drainage lines of upland catchments. In general, this indicates higher salt stores in the lower parts of the landscape.

The area within a catchment contributing surface runoff to streamflow grows with intensity and duration of rainfall and the soil moisture status, expanding out from the drainage lines, initially in the lower parts of the landscape. Salt from rising groundwater is also generally delivered to the surface in the lower parts of the landscape and, as the area of high water tables expands, it does so in the same manner, progressively affecting the drainage lines, break of slope areas and lower slopes. There is, therefore, a high degree of overlap between the areas of highest initial soil salt store, the area impacted by groundwater delivered salt, and the areas contributing most to runoff generation and streamflow.

It is not possible from the data available to assess what proportion of salt in streamflow comes from saline groundwater discharge and what is coming from the ‘non saline’ soil salt store under ‘current’ conditions. However, as groundwater tables rise it is the streamflow generating areas that will be affected first. This is largely a topographic effect. Given the extent of change indicated in Table 4.3, and allowing for topography, it is reasonable to assume that washoff of salt delivered to the soil surface by groundwater discharge will eventually dominate as the source of in-stream salt load, if it is

not already. Where the ratio of ‘current’ in-stream salt load to groundwater delivered salt load is less than one (Table 6.2) there can be greater confidence in the factors obtained. Where this ratio is much greater than one, as in the Gwydir Catchment, some allowance must be made to adjust the factors.

In the absence of data on the current split between the salt sources, it is reasonable to estimate future in-stream salt loads from their current base level using relative rates of change obtained from the groundwater derived potential salt loads as outlined in Section 3.4. The progressive changes in the salt source split have been examined for the Kyeamba Valley using the full CATSALT model (see Section 7). Although it was found that the initial rates of change were somewhat less than those obtained in the present study, the final salt load predictions for both methods at 2100 were essentially the same. Therefore, although these factors may overestimate the change in the short term, they are deemed to be reasonable overall.

6.1 Scaling Factors

Scaling factors for whole second order catchments are obtained from the ratio of the total estimated ‘current’ groundwater based potential salt loads (ie. the sum of salt load from all contributing geologies) to the estimates of future potential salt loads in Table 4.4. These initial estimates (Table 6.1) provide an overview of the rates of change across the basin. To obtain scaling factors, for the contributing third order catchments, values of salt load per square kilometre per year (Table 4.4) for each individual geology are used. The area of each geology in the third order catchments is used to calculate the salt load per geology in each catchment. The sum of the salt loads for all geologies within each contributing third order catchment at ‘current’ conditions and the target dates is used to derive area weighted scaling factors for each catchment. It should be noted that although the scaling factors are determined for each third order catchment, the delivery rate of salt load from the groundwater is constant across each geology in each second order catchment for any given scenario (‘current’ or target date conditions).

Catchment / Year	2020	2050	2100
Border Rivers (Macintyre)	1.0	1.0	1.0
Gwydir	2.36	6.6	8.13
Namoi	1.63	1.98	2.45
Castlereagh	1.13	2.01	2.07
Macquarie / Bogan	2.07	2.79	3.35
Lachlan	1.20	1.81	2.51
Murrumbidgee	1.35	1.5	1.83
Murray	1.42	1.56	2.39

Table 6.1 Scaling factors for second order catchments relative to ‘current’ potential salt loads

Base level in-stream salt loads under ‘current’ conditions for each third order catchment, obtained from the stochastic analysis discussed in Section 5, are multiplied by the area weighted scaling factors to obtain predicted in stream salt loads at the target dates. The estimation of likely future salt exports in this manner represents a composite effect of salt delivery from the groundwater system to the land surface and the salt carrying capacity, from wash off, of the third order streams.

Scaled in-stream salt loads for each contributing third order catchment are summed to the last balance point on the (second order) main stream for each of the target dates. End of system salt loads are then estimated accounting for diversions and system losses such as flows terminating in the Macquarie Marshes and adjusted to a cap scenario of flows appropriate to each catchment.

6.1.1 Determining factors for the Gwydir Catchment

The Gwydir Catchment presents a special case, requiring an informed adjustment of the scaling factors. The factors obtained from the hydrogeology analysis are inconsistent with the general trends obtained for the rest of the basin, appearing to be excessively high.

The inconsistency in the scaling factors for the Gwydir Catchment also influences the level of predicted salt export from the Border Rivers as flow diversions from the Gwydir are channelled via Carole Creek to Gil Gil Creek. The groundwater analysis for the Macintyre Catchment which forms the main area in NSW contributing to the Border Rivers, indicates no change in potential groundwater based salt load over the next century. Future salt loads in Gil Gil Creek will be determined by what happens in the Gwydir Catchment.

The groundwater based potential salt load estimates for the Gwydir grossly underestimate the ‘current’ in-stream, annual average salt load at the last balance point. For all catchments except the Gwydir and, to a much lesser extent, the Namoi, the groundwater based potential salt loads, overestimate or closely match the ‘current’ in-stream salt load. These are shown in Table 6.2. Where this is the case, using the factors described in the previous section (Section 6.1) to scale up the in-stream salt loads obtained in Section 5 is considered valid. However, the potential groundwater based salt loads under ‘current’ conditions underestimate the in-stream value for the Gwydir by a factor of twenty and for the Namoi by about three.

Further difficulties arise in the Gwydir, in sub-catchments where sedimentary geology dominates, simply as a consequence of the mathematics employed to calculate the area weighted scaling factors. There is a zero potential salt load estimated for ‘current’ conditions in the sedimentary geology. The jump, however, from 0 to $1.27 \text{ t.km}^{-2}.\text{year}^{-1}$ at 2020 (see Table 4.4) on an area weighted basis leads to astronomical scaling factors for some sub-catchments, influencing the salt balance downstream. For the catchment of gauging station 418 032, this factor at 2100 is approximately 66 on an area-weighted

basis; while it is approximately 21 and 31 for residual catchments R1 and R5, respectively. Although this may highlight sub-catchments of potentially high future hazard, the calculated rates of salt load increase are unlikely to occur. This situation is unique to the Gwydir analysis.

Alternative composite scaling factors for the whole of the Gwydir Catchment are obtained by using the 'current' in-stream average annual salt load at the last balance location (ie. at Pallamallawa, station 418 001), as the base from which to calculate the factors. The additional increase in potential salt load at 2020, 2050 and 2100 from Table 4.4 is added to this base figure to obtain the ratios of 'current' and future potential salt load. Composite scaling factors of 1.068, 1.28 and 1.36 for 2020, 2050 and 2100 respectively are obtained for the whole of the Gwydir Catchment. These factors reflect a scenario where wash off from non-saline areas, already expressed in 'current' in-stream salt loads, is expected to continue to dominate the in-stream salt balance. However, this assumes that all additional groundwater based potential salt loads will enter the stream in contrast to all other catchments where this assumption is avoided.

Although these composite factors appear more consistent with those calculated for other catchments, particularly the nearest neighbouring catchments, the Namoi and Macintyre, they are not readily useable for balancing the salt loads from contributing third order catchments in the usual way. There is no means of apportioning the base figure across the geologies within the Gwydir Catchment.

Catchment	Observed in-stream salt load (10^3 t.year⁻¹) @ last balance point	Potential groundwater derived salt load (10^3 t.year⁻¹)	Ratio
Border Rivers	112	84.4	1.33
Gwydir	149.4	7.5	19.94
Namoi	178.6	60.1	2.97
Castlereagh	19.5	160.7	0.12
Macquarie	234.4	237.3	0.99
Lachlan	237.8	707.2	0.34
Murrumbidgee	401.8	2 168.4	0.19
Murray	NA	NA	NA

Table 6.2 Ratio of observed in-stream salt loads to groundwater derived potential salt loads for second order catchments

To estimate the monthly time series of salt exports under the cap scenario adopted for the purpose of this report, the alternative composite factors for the Gwydir, given above, are applied at end of system (minus diversions to Carole Creek) to calculate the future target date time series. The same factors are applied to the salt loads for Gil Gil Creek in the Border Rivers, at the end of system to

account for exports from the Gwydir via Carole Creek. These factors are again used to scale loads from third order catchments without area weighting the geologies.

6.2 Border Rivers (Macintyre River)—Future Salt Exports

Approximately 57% of the flows in the Border Rivers are deemed to come from the NSW side of the basin as per the NSW and Qld water sharing agreement. These include flows from the Macintyre River and Severn River system as well as Gil Gil Creek. Only the contributions from NSW are addressed in this report.

Salt loads under ‘current’ conditions have been balanced down the Macintyre-Severn sub-system and adjusted for a possible cap flow scenario adopted for the purpose of this report (Section 5.1). The average annual salt export of 95 400 $t.year^{-1}$ is expected to remain constant into the future, as there is no estimated increase in potential salt load discernible from the groundwater trend analysis. ‘Current’ and future average annual salt loads and corresponding EC values for the Macintyre and Gil Gil Creek are listed in Tables 6.3 and 6.4. The general patterns of average monthly salt exports and ECs throughout the year at the end of system are shown in Figure 5.3p.

In-stream salt loads per square kilometre per year under ‘current’ conditions assessed on a contributing third order sub-catchment basis are presented in Table 6.5. Residual and gauged catchments are labelled sequentially or according to the gauging station at the outlet, respectively. The location of each is identified in Figure 5.1f and their relationship to one another is shown in the schematic diagram, Figure 5.11. Sub-catchment contributions to the Border Rivers are shown relative to the inputs from contributing third order catchments in all other second order catchments across the State with the exception of the Murray in Figures 6.8 to 6.11.

	Av Annual Cap Flow $GL.year^{-1}$	Salt load $t.year^{-1}$ 1998	Salt load $t.year^{-1}$ 2020	Salt load $t.year^{-1}$ 2050	Salt load $t.year^{-1}$ 2100
Macintyre	760	95 400	95 400	95 400	95 400
Gil Gil Creek	109	10 900	11 800	13 600	13 800
Total	869	106 300	107 200	109 000	109 200

Table 6.3. ‘Current’ and predicted average annual salt exports under cap flow conditions for the NSW component of the Border Rivers Sub-basin

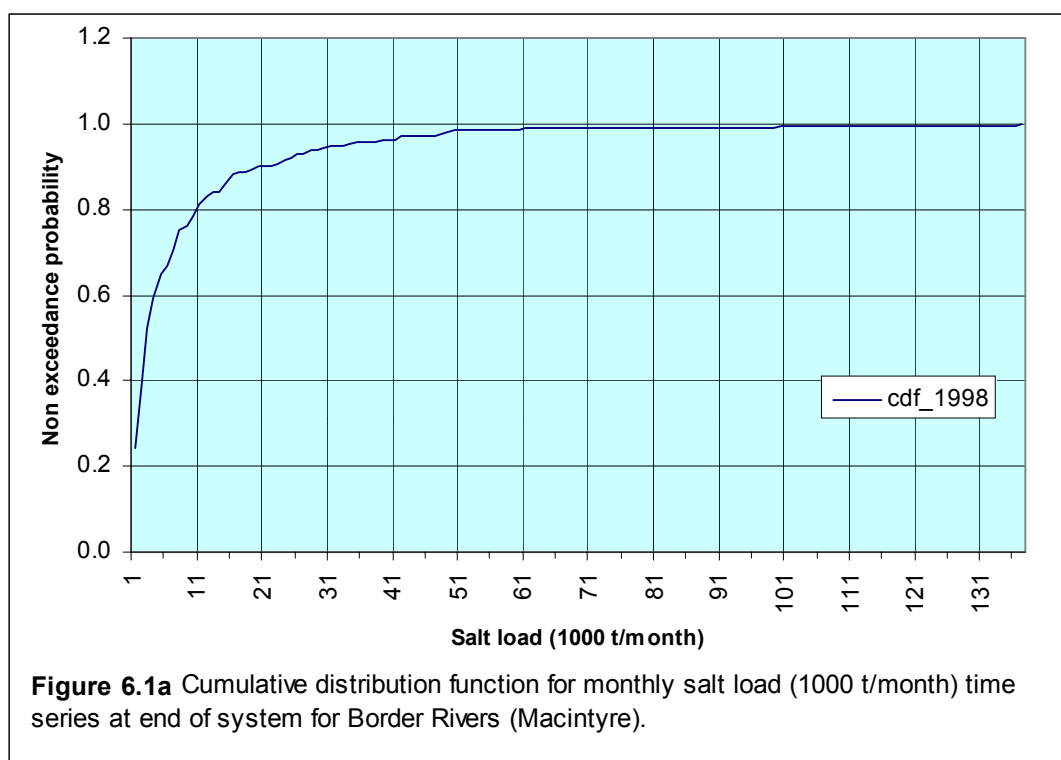
	Av Annual Cap Flow $GL.year^{-1}$	Av Annual EC $\mu S.cm^{-1}$ 1998	Av Annual EC $\mu S.cm^{-1}$ 2020	Av Annual EC $\mu S.cm^{-1}$ 2050	Av Annual EC $\mu S.cm^{-1}$ 2100
Macintyre	760	449	449	449	449
Gil Gil Creek	109	228	262	331	342

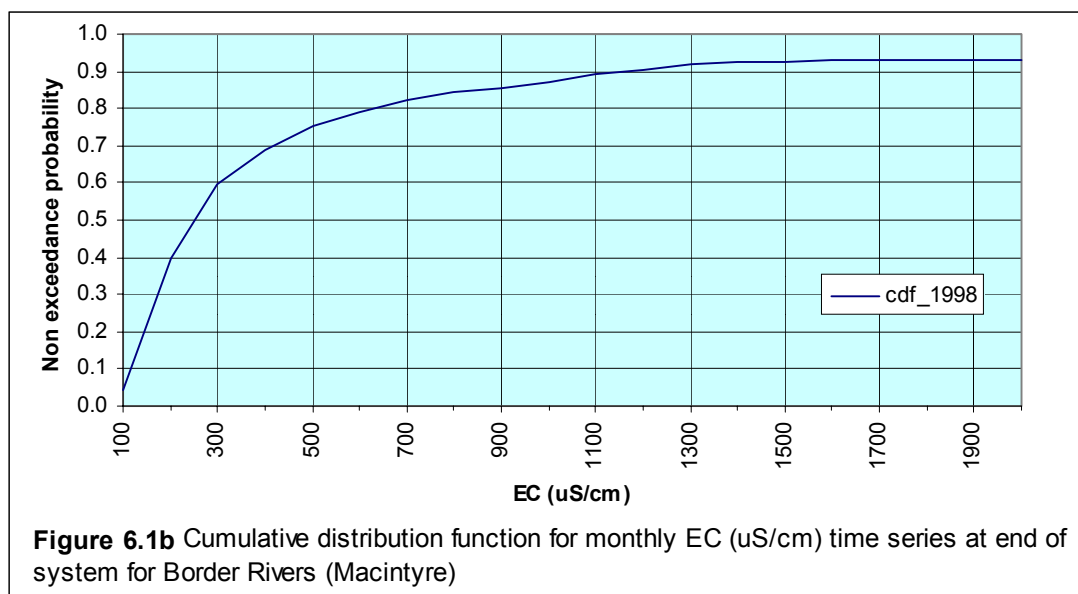
Table 6.4. ‘Current’ and predicted average annual salt concentration (EC) under cap flow conditions for the NSW component of the Border Rivers Sub-basin

Sub catchment	Salt load ($t.km^{-2}.year^{-1}$)
416 039	11
R1	12
416 021	16
R2	14
416 010	11
R3	7
416 020	10
416 008	6
R4	2

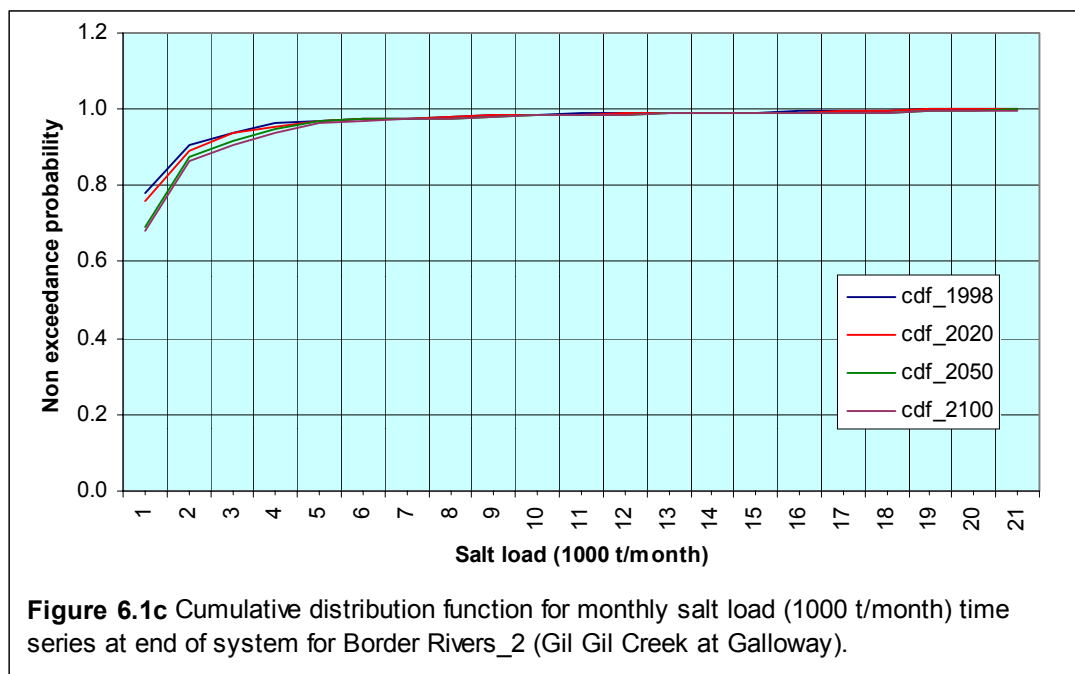
Table 6.5 ‘current’ salt load for contributing sub-catchments in the Macintyre River System

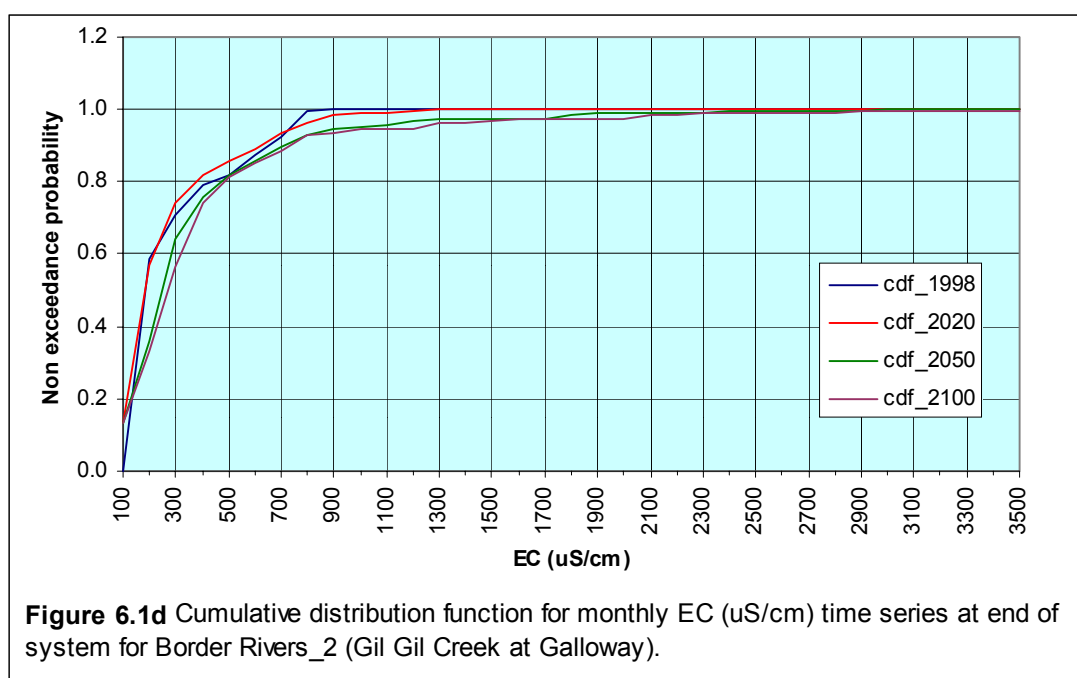
The contributions of the sub-catchments presented in Table 6.5 indicate the range in severity of the salinity problems already present in the system. Relative differences in flow explain most of the differences in salt load contributions, although some influences of geology and groundwater not evident in the hydrogeology analysis could also be present, with implications for remediation.





The cumulative distributions of monthly salt loads and ECs for the Macintyre (1975 to 1995 assessment period) at the end of system are shown in Figures 6.1a and 6.1b respectively, indicating that, given the no change outcome, salt loads will remain less than $16\,000\text{ t}\cdot\text{month}^{-1}$ and ECs will be less than $800\text{ }\mu\text{S}\cdot\text{cm}^{-1}$ in 85% of all months. Cumulative distribution functions calculated at all balance points and gauging stations analysed within the catchment are included in Appendix 1.



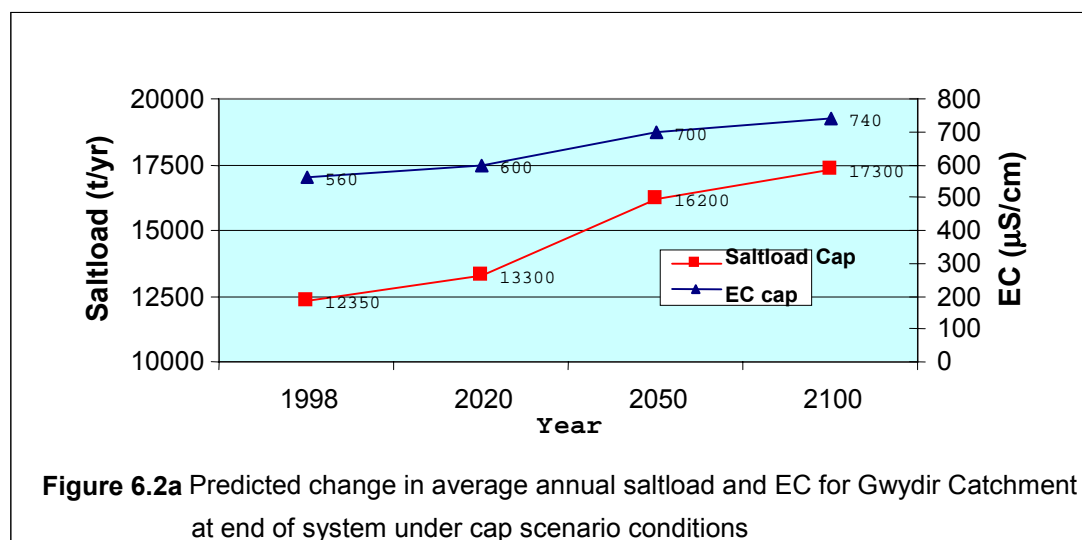


For the Gil Gil Creek system the cumulative distribution of the average monthly salt loads and EC time series for ‘current’ and target date conditions based on the defined calibration period are shown in Figures 6.1c and 6.1d, respectively. Water quality with respect to salinity is high under ‘current’ conditions remaining less than $800 \mu\text{S}\cdot\text{cm}^{-1}$ continuously, and is predicted to remain less than this level in 93% of months in 2100. Salt loads will remain less than $3000 \text{ t}\cdot\text{month}^{-1}$ in 90% of all months over the target period.

6.3 Gwydir River—Future Salt Exports

The Gwydir River analysis aggregates the contributions of 16 gauged and residual sub-catchments prior to the last balance point at gauging station 418 001 (Gwydir R. at Pallamallawa). Following the addition of contributions from Tycannah Creek (418 032), salt loads are substantially affected by diversions as shown in Figure 5.6. Diversions via Carole Creek (418 052) feed Gil Gil Creek, exporting salt via the Border Rivers System. End of system salt loads are derived from the sum of the loads at Pallamallawa and Tycannah Creek, less the amount diverted to Gil Gil Creek and allowing for further diversions and system losses. The historical salt loads at the end of the system are calculated using ratios of observed flows at the last inflow location to those at the catchment outlet. That is, the proportion of the salt load observed at the last inflow location reaching the end of stream, is equal to the ratio of the observed flow at both locations. The resultant salt loads are then adjusted to reflect the adopted cap scenario. In the Gwydir, the braided nature of the lower reaches and insufficient monitoring of high flows has resulted in a situation where the observed flow record for 1975 to 1995 is substantially incomplete. Therefore, translating salt loads to the end of system is

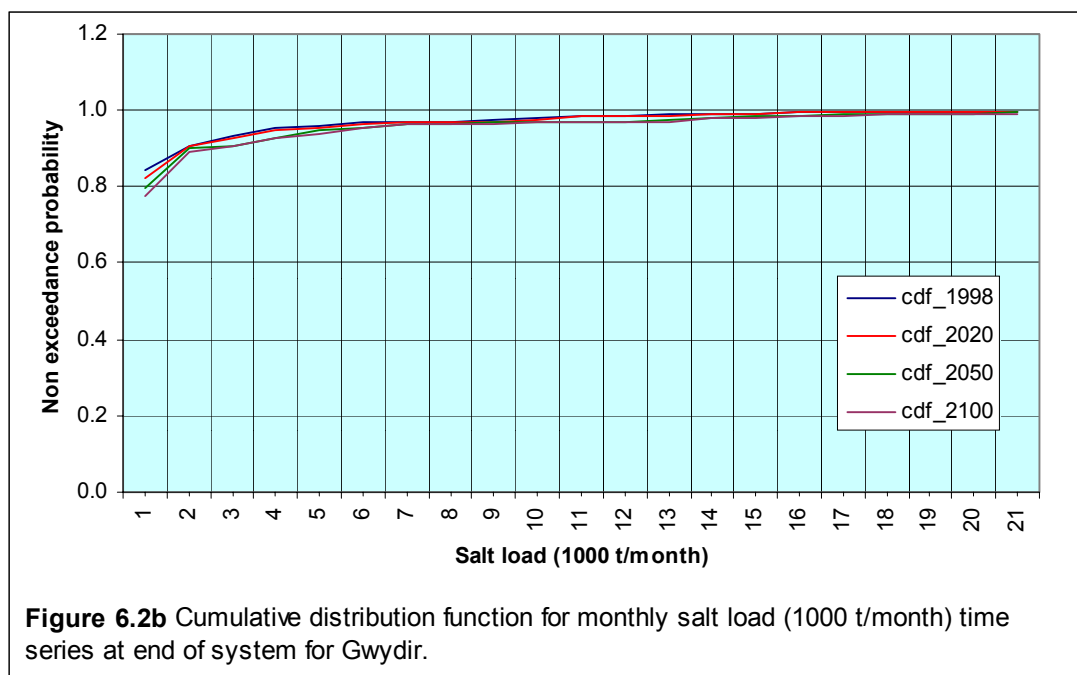
performed using the ratio of modelled flows at Pallamallawa plus observed inflows from Tycannah Creek to modelled flows at the basin outlet under cap conditions.



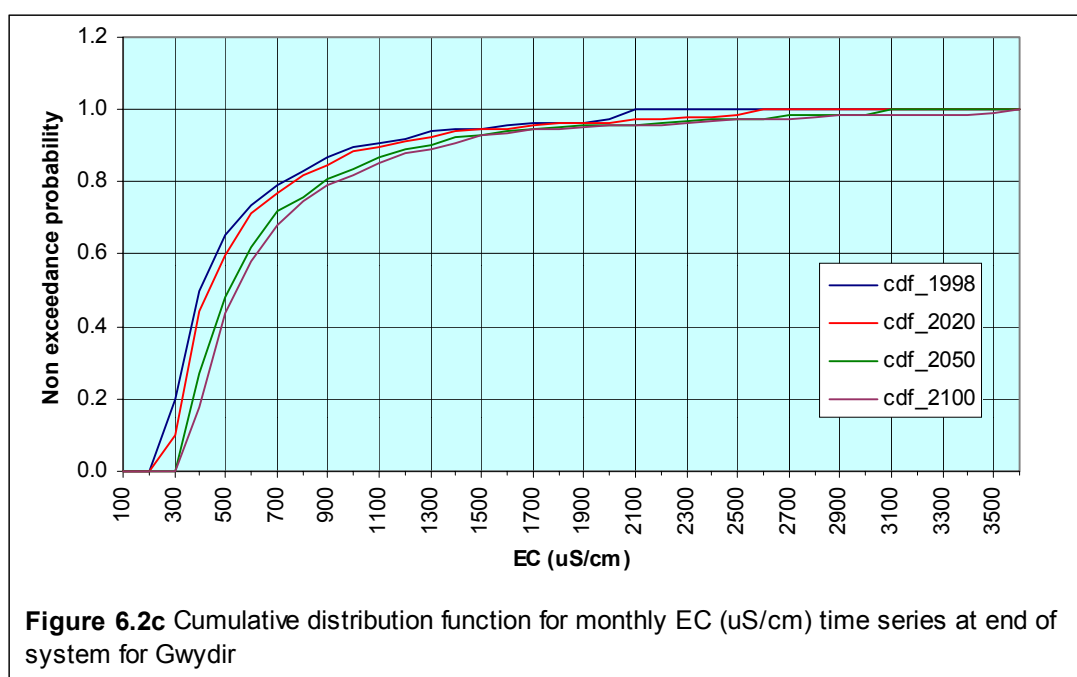
Factoring of salt loads for each of the individual sub-catchments prior to balancing down to Pallamallawa is not possible due to the constraints outlined above in Section 6.1.1. The adjusted factors are used to predict the future salt loads and are applied from 418 001 and 418 032 before translation to the end of system. The change in average annual salt load and EC cap flow conditions for the period 1975 to 1995, the target dates is depicted in Figure 6.1. Salt loads are expected to increase from 12 350 $t.year^{-1}$ under ‘current’ conditions to 17 300 $t.year^{-1}$ at 2100. Although this is a small overall contribution compared to the other systems across the State the deterioration with average annual EC approaching World Health Organisation (WHO) limits for drinking water of 800 $\mu S.cm^{-1}$, is of some concern. The patterns of average monthly salt exports and ECs throughout the year for the end of system are presented in Figure 5.5p. The cumulative distributions of salt loads and ECs at the end of system for ‘current’ and target dates are presented in Figures 6.2b and 6.2c, respectively. The average annual flow at the end of system under cap scenario conditions for the period 1975 to 1995 is 56 $GL.year^{-1}$.

Monthly average salt loads are predicted to remain less than 3000 $t.month^{-1}$ in 90% of all months. However, ECs that are currently less than 800 $\mu S.cm^{-1}$ in 83% of months, are predicted to remain within this limit for only 75% of months in 2100. Cumulative distribution functions calculated at all balance points and gauging stations analysed within the catchment are included in Appendix 2.

Likely impacts on the Gwydir Wetlands are discussed in Section 8.4.3 of this report.



Basin wide factors are applied to the contributing sub-catchments to calculate the loads in $t.km^{-2}.year^{-1}$ shown in Table 6.6. Relative differences in salt load per square kilometre per year for each sub-catchment reflect the combined effects of the rainfall and runoff characteristics on the range of flows, as well as the 'current' expression of salt wash off from the soil store and groundwater contributions.



Sub-catchment contributions to Gwydir are shown relative to the inputs from contributing third order catchments in all other second order catchments across the State with the exception of the Murray in Figures 6.8 to 6.11.

Station/ catchment	1998 <i>t.km⁻².year⁻¹</i>	2020 <i>t.km⁻².year⁻¹</i>	2050 <i>t.km⁻².year⁻¹</i>	2100 <i>t.km⁻².year⁻¹</i>
418 029	7	7.5	9	9.5
418 021	7	7.5	9	9.5
418 022	7	7.5	9	9.5
418 023	9	9.5	11.5	12
R1	8	8.5	10	11
418 033	3	3	4	4
418 005	7	7.5	9	9.5
R2	6	6.5	7.5	8
418 018	18	19	23	24.5
R3	16	17	20.5	22
418 025	29	31	37	39.5
418 017	15	16	19	20.5
R4	15	16	19	20.5
418 015	25	26.5	32	34
418 016	9	9.6	11.5	12
R5	6	6.5	7.5	8
418 032	11	11.5	14	15

Table 6.6 Gwydir River contributing sub-catchment salt loads for ‘current’ and future conditions using basin wide scaling factors

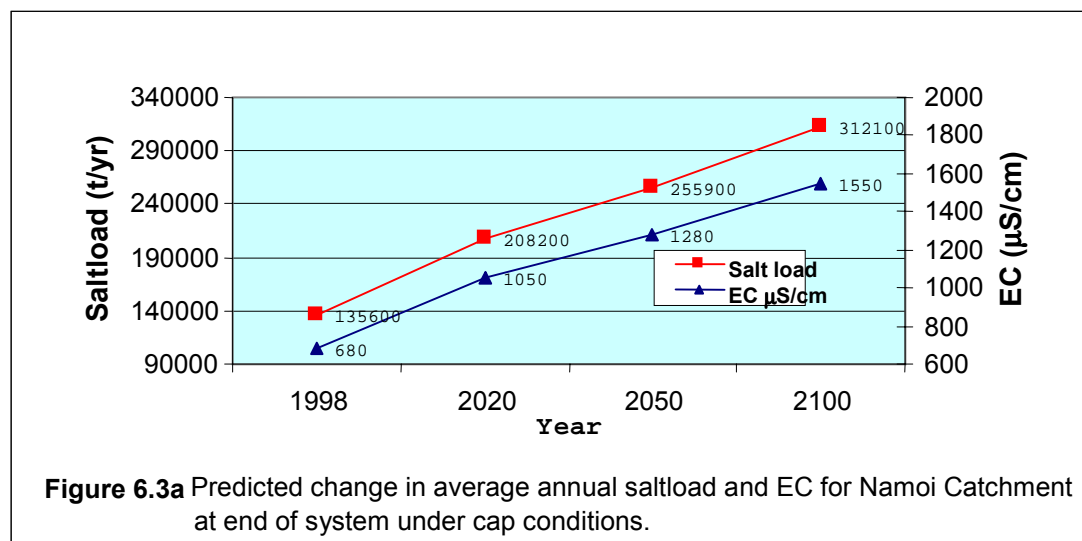
(NB. All values rounded to nearest half tonne)

6.4 Namoi River—Future Salt Exports

Sixteen gauged and residual sub-catchments contribute to salt loads in the Namoi River above the final balance point at gauging station 419 012 (Namoi R. at Boggabri). Additional inputs from Maules Creek (gauging station 419 051) are accounted for prior to translation of the salt loads to the end of system.

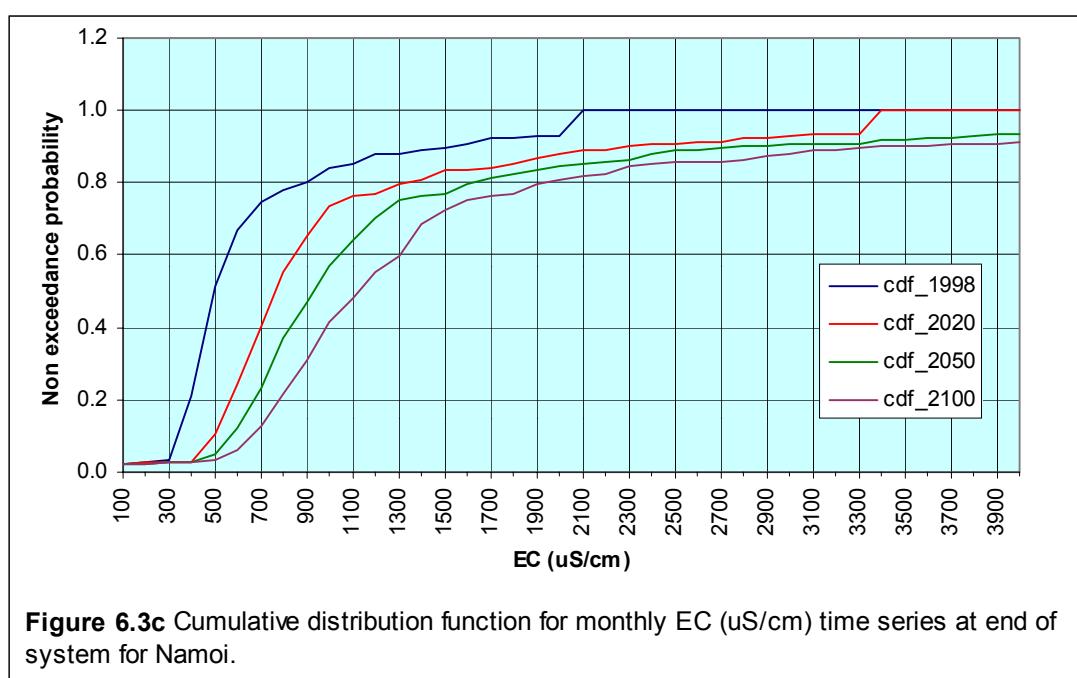
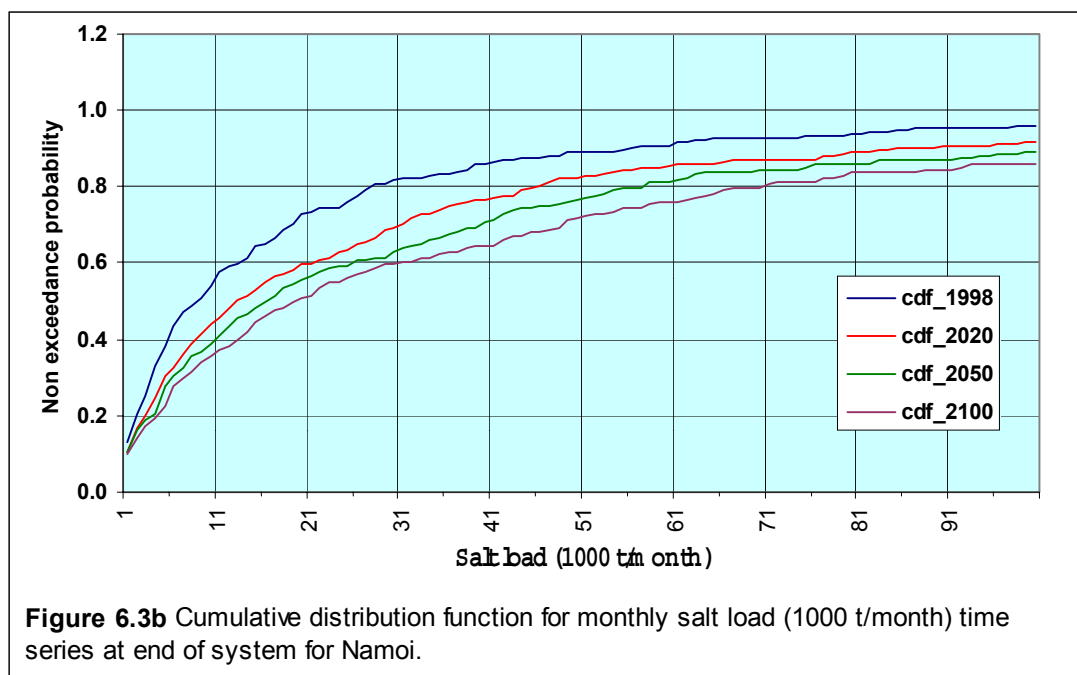
Individual scaling factors derived from an area weighting for each geological unit are applied to the contributing sub-catchments for each of the target dates and balanced downstream to Boggabri before translation to the end of system and adjustment to cap flow conditions. Additional salt entering the main stream between Boggabri and the Barwon River from flood washoff and base-flow from alluvial aquifers is accounted for as well as the impact of diversions. The changes in average annual salt load and EC using cap flow scenario conditions for the assessment period 1975 to 1995, projected to the target dates, are depicted in Figure 6.3a. Salt loads are expected to increase from 135 600 *t.year⁻¹* under ‘current’ conditions to 312 100 *t.year⁻¹* by 2100.

Average annual EC is predicted to rise from $680 \mu S.cm^{-1}$ to $1\,550 \mu S.cm^{-1}$ by 2100. The average salinity assessed for cap conditions is already approaching the desirable WHO guideline value of $800 \mu S.cm^{-1}$ for drinking and will exceed it by 2020. It is noted that the guideline is already exceeded under ‘current’ conditions. The patterns of average monthly salt exports and ECs throughout the year are presented in Figure 5.7p for the end of system. The cumulative distributions of salt load and EC for ‘current’ and target dates at the end of system are presented in Figures 6.3b and 6.3c respectively.



Even under ‘current’ conditions and cap scenario flows adjusted to the 1975 to 1995 time series, river salinity is shown to remain less than the WHO of $800 \mu S.cm^{-1}$ on average in only 78% of months. There is a significant reduction in predicted average monthly EC remaining beneath this guideline value, decreasing to 55%, 37% and 21% of months in 2020, 2050, and 2100 respectively.

The distribution of ECs at end of stream in the Namoi River is similar but not identical to that at the last balance point due to additional inputs of salt from base flow and washoff in the alluvial reach between Boggabri and the Barwon River. The distribution at Boggabri is therefore more indicative of the salinity in the diversions for irrigation as well as losses to wetlands and overbank flood flows in the intervening reach. At Boggabri, the average monthly EC is predicted to remain less than $800 \mu S.cm^{-1}$ in 80%, 61%, 52% and 47% of months at present, 2020, 2050 and 2100, respectively. Wetlands that fill during infrequent floods may receive higher quality water initially during such events. However, the salt loads associated with the flood will be at the highest levels within the distribution. As wetlands dry out, salinity within the wetland will increase due to concentration of the initial salt load. Under ‘current’ conditions, salt loads remain less than $30\,000 t.month^{-1}$ in 90% of all months. Salt loads are predicted to remain less than 47 000, 56 000, and 70 000 $t.month^{-1}$ in 90% of all months at 2020, 2050 and 2100 respectively. Cumulative distribution functions calculated at all balance points and gauging stations analysed within the catchment are included in Appendix 3.



Groundwater pumping for irrigation is largely responsible for preventing widespread rising water tables in the alluvial areas at the lower end of the Namoi system. These aquifers are recharged during floods and the quality of the groundwater is dependent on the quality of the surface floodwaters.

Station/ catchment	1998 <i>t.km⁻².year⁻¹</i>	2020 <i>t.km⁻².year⁻¹</i>	2050 <i>t.km⁻².year⁻¹</i>	2100 <i>t.km⁻².year⁻¹</i>
419 045	24	31	38	45
R6	18	26	32	39
419 016	15	20	24	28
R7	5	10	12	16
419 035	18	25	30	36
R8	7	13	15	19
419 043	12	18	22	26
R1	9	15	18	22
419 005	10	13	16	19
R2	10	10	10	10
R3	8	15	18	18
419 027	9	14	16	20
R4	3	5	6	7
R5	2	4	5	6
419 032	3	4	6	6
419 051	7	10	13	15

Table 6.7 Namoi River contributing sub-catchment salt loads for ‘current’ and future conditions using individual scaling factors, area weighted for geology

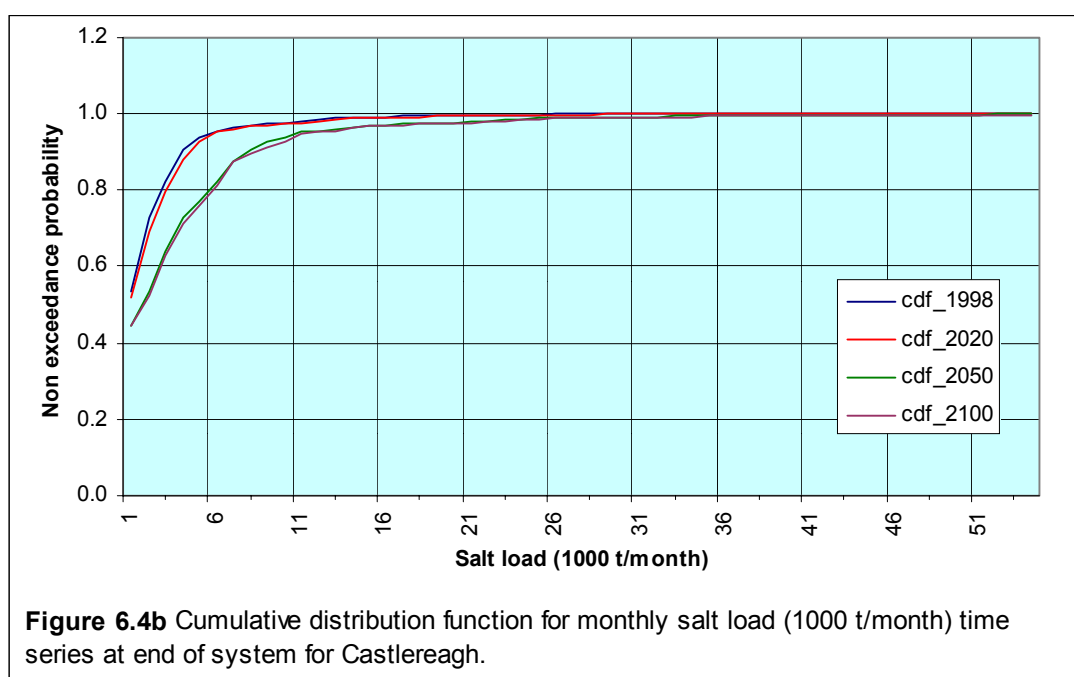
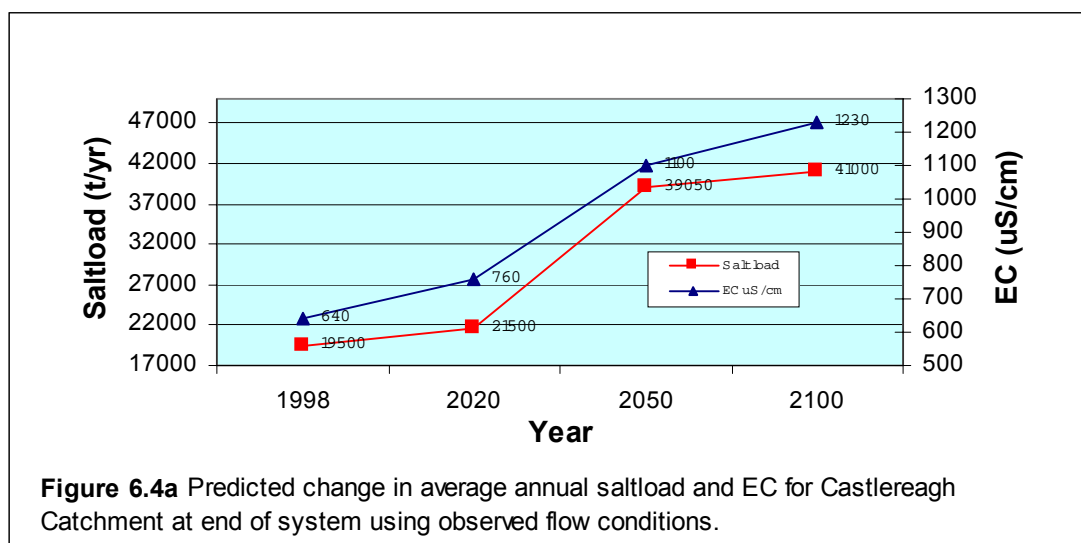
Individual scaling factors are applied to each of the contributing third order catchments to calculate the loads in *t.km⁻².year⁻¹* given in Table 6.7. The initial relative differences in salt load per square kilometre for each sub-catchment reflect the combined effects of the rainfall and runoff characteristics on the range of flows, as well as the ‘current’ expression of salt wash off from the soil store and groundwater contributions. Differences in the rates of change for each reflect the area weighting of contributions from the geologies located within sub-catchments.

Sub-catchment contributions for the Namoi are shown relative to the inputs from contributing third order catchments in all other second order catchments across the State with the exception of the Murray in Figures 6.8 to 6.11.

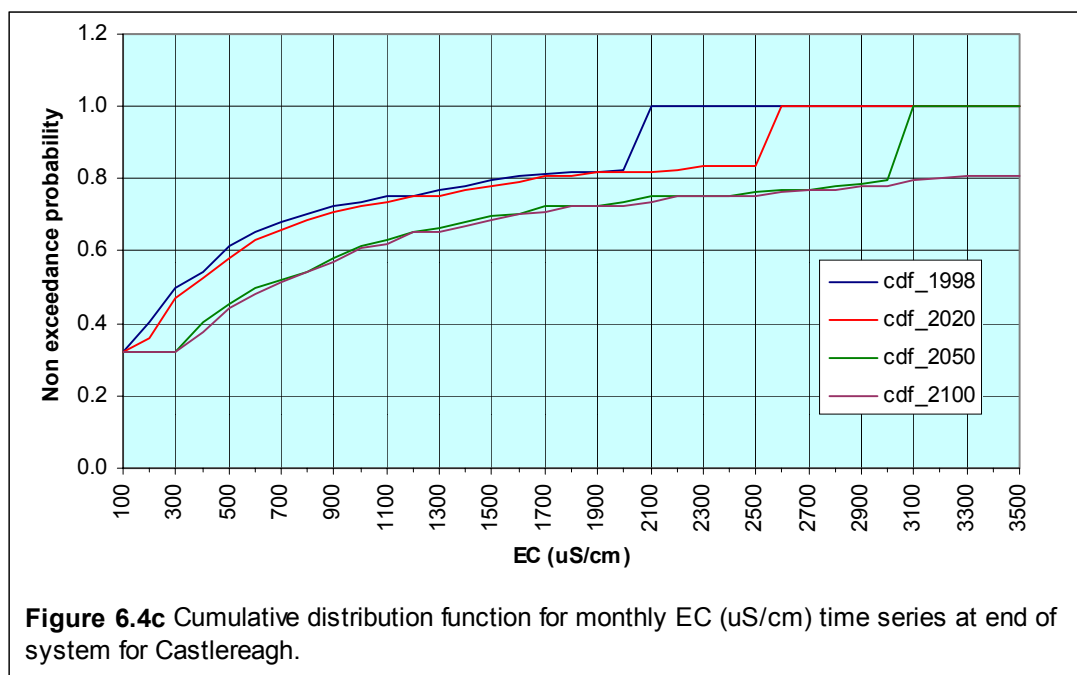
6.5 Castlereagh River—Future Salt Exports

There is insufficient data available to estimate salt loads in the Castlereagh River on the basis of third order contributing catchments. Instead, salt loads for the whole of the contributing area at Coonamble (station 420 005) on the mainstream for ‘current’ and future conditions are scaled up using the basin wide factors from Table 6.1. In the absence of any other data, values obtained at Coonamble are used also to represent exports from the end of system. Diversions are assumed to be insignificant in the Castlereagh. The changes in average annual salt load and EC using observed flow conditions for the

period 1975 to 1995, projected to the target dates are depicted in Figure 6.4a. Salt loads are expected to increase from 19 500 $t.year^{-1}$ under ‘current’ conditions to 41 000 $t.year^{-1}$ by 2100.



Average annual EC is predicted to rise from 640 $\mu S.cm^{-1}$ to 1230 $\mu S.cm^{-1}$ by 2100. WHO drinking water quality guideline value of 800 EC will be exceeded on an average annual basis by 2050 and within years on a monthly average basis a lot sooner. The pattern of average monthly salt export and EC throughout the year is presented in Figure 5.8c for the end of system. The cumulative distributions of salt load and EC at the end of system for ‘current’ conditions and target dates are presented in Figures 6.4b and 6.4c respectively. The average annual observed flow at the end of system for the period 1975 to 1995 was 105.5 $GL.year^{-1}$.



Under ‘current’ conditions calibrated to the 1975 to 1995 time series, river salinity is shown to remain less than the WHO of $800 \mu S.cm^{-1}$ on average in only 70% of months. There is a deterioration in the frequency of predicted average monthly EC remaining beneath this limit decreasing to 69%, 54% and 54% of months in 2020, 2050, and 2100 respectively.

The probability distribution of EC at end of system is assumed to be equivalent to that at the last balance point and therefore applies to losses to wetlands and overbank flood flows in the intervening reach. Wetlands that fill on infrequent flood events may receive higher quality water initially during such events. However, the salt loads associated with the flood events will be at the highest levels within the distribution. As wetlands dry out, salinity within the wetland will increase due to concentration of the initial salt load. Under ‘current’ conditions salt loads remain less than $4500 t.month^{-1}$ in 90% of all months. Salt loads are predicted to remain less than 5000, 9000, and $9000 t.month^{-1}$ in 90% of all months at 2020, 2050 and 2100 respectively.

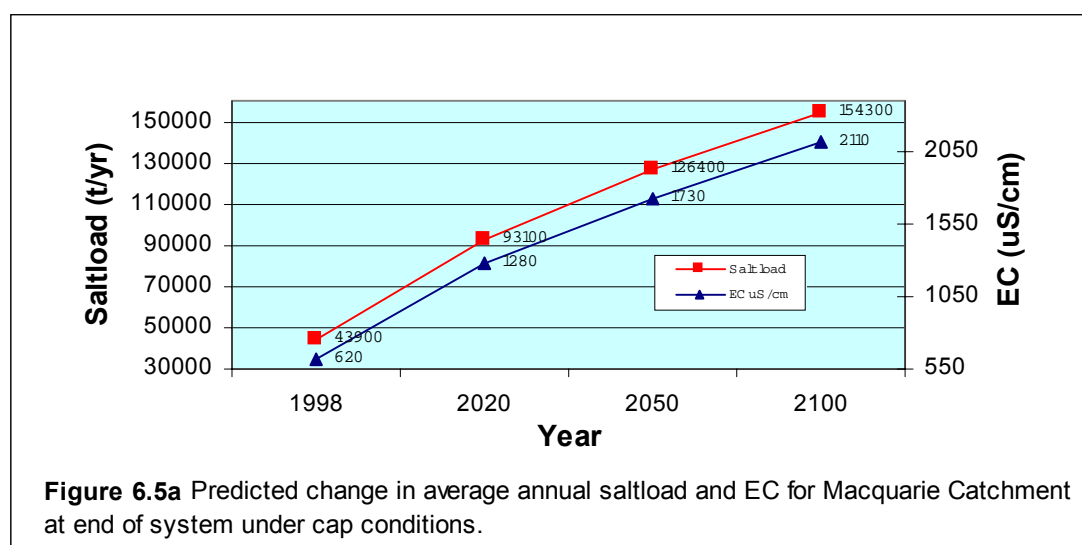
General impacts on river ecology and the health of the wetlands are discussed in Section 8.

6.6 Macquarie Basin—Future Salt Exports

The salt balances for the Macquarie and the Bogan Rivers are dealt with separately in the analysis of the Macquarie River Basin.

6.6.1 Macquarie River—future salt exports

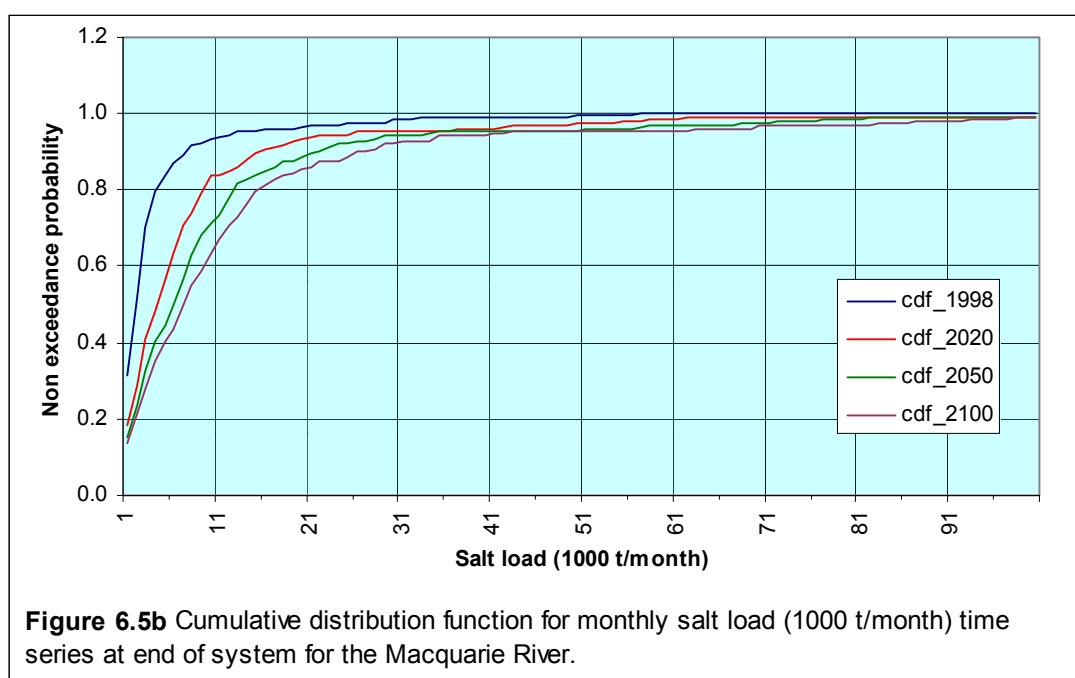
Twenty one gauged and residual third order sub-catchments contribute to salt loads above the final balance point at gauging station 421 006 (Macquarie R at Narromine) in the Macquarie River Catchment prior to translation of the salt loads to the end of system. Individual scaling factors derived from an area weighting for each geology are applied to the contributing third order catchments for each of the target dates and balanced downstream to Narromine before translation to the end of system and adjustment to cap flow conditions. The change in average annual salt load and EC using cap flow conditions for the calibration period 1975 to 1995, projected to the target dates is depicted in Figure 6.5a. Salt loads are expected to increase from 43 900 $t.year^{-1}$ under ‘current’ conditions to 154 300 $t.year^{-1}$ by 2100. Average annual EC is predicted to rise from 620 $\mu S.cm^{-1}$ to 2100 $\mu S.cm^{-1}$ by 2100. The WHO drinking water quality standard of 800 EC will be exceeded on an average annual basis by 2020 and within years on a monthly average basis a lot sooner. The patterns of average monthly salt exports and ECs throughout the year for the end of system are presented in Figure 5.10m. The cumulative distributions of salt load and EC for ‘current’ and target dates at the end of system are presented in Figures 6.5b and 6.5c, respectively. The average annual flow at the end of system under cap conditions for the period 1975 to 1995 is 150 $GL.year^{-1}$.



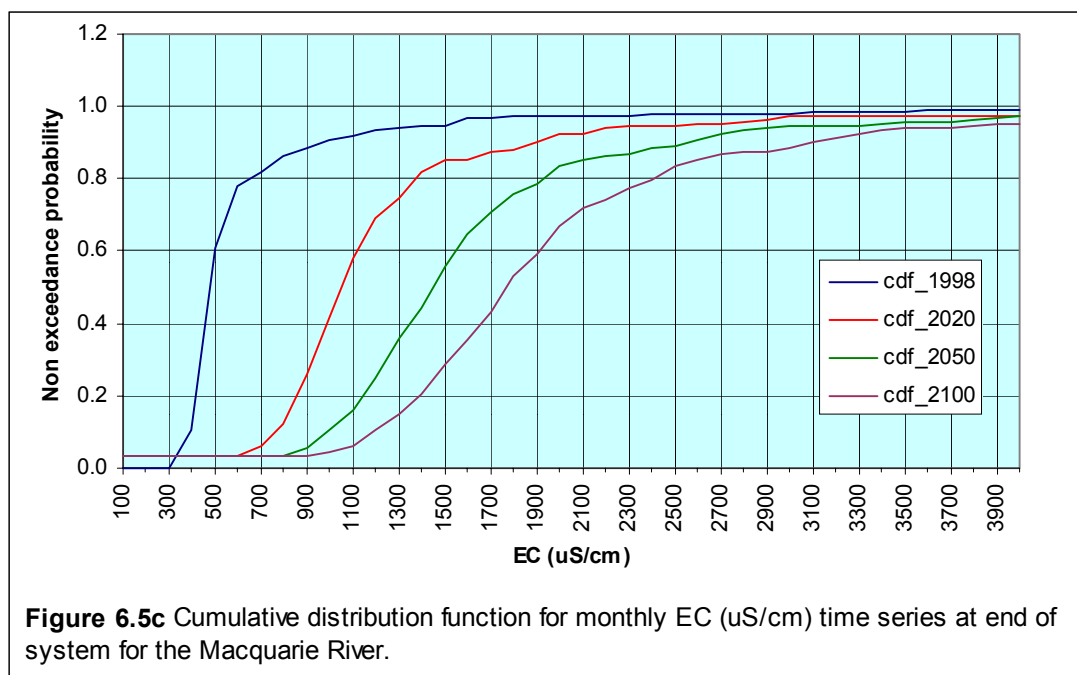
Under ‘current’ conditions and cap scenario flows calibrated to the 1975 to 1995 time series, river salinity is shown to remain less than the WHO of 800 $\mu S.cm^{-1}$ on average in only 87% of months. There is predicted to be a significant deterioration in the frequency of average monthly EC remaining beneath this limit, decreasing to 12%, 3% and 3% of months in 2020, 2050, and 2100, respectively. The distribution of EC at end of stream is not equivalent to that at the last balance point in this case, and therefore distributions at Narromine are more applicable to the diversions for irrigation as well as

losses to wetlands and overbank flood flows in the intervening reach. The distribution of EC at Narromine is shown in Appendix 4 (Figure A4a). Wetlands that fill on infrequent flood events may receive higher quality water initially during such events. However, the salt loads associated with the flood events will be at the highest levels within the distribution. As wetlands dry out, salinity within them will increase due to concentration of the initial salt load. Some of this salt may be flushed out again from the Macquarie Marshes in high flows. Under ‘current’ conditions and cap flow scenario at the end of systyem salt loads remain less than $7000 \text{ t.month}^{-1}$ in 90% of all months. Salt loads are predicted to remain less than 16 000 , 21 000, and 26 000 t.month^{-1} in 90% of all months at 2020, 2050 and 2100 respectively. Cumulative distribution functions calculated at all balance points and gauging stations analysed within the catchment are included in Appendix 4.

The likely impact on river ecology and the health of the wetlands is addressed in Section 8.4.4.



The initial relative differences in salt load per square kilometre for each third order catchment reflect the combined effects of the rainfall and runoff characteristics on the range of flows, as well as the ‘current’ expression of salt wash off from the soil store and groundwater contributions.



Station/ catchment	1998 $t.km^{-2}.year^{-1}$	2020 $t.km^{-2}.year^{-1}$	2050 $t.km^{-2}.year^{-1}$	2100 $t.km^{-2}.year^{-1}$
421 101	13	28	38	46
421 035	9	19	25	30
R1	13	23	31	38
421 072	16	34	47	56
R2	12	22	29	37
421 079	9	15	19	23
R4	8	16	21	25
421 058	12	23	31	38
421 026	16	31	42	50
421 041	22	42	55	66
421 052	15	23	29	39
421 073	11	23	32	38
R3	11	11	33	40
421 018	19	39	52	64
421 059	18	38	52	63
R5 & R6	12	24	33	39
R7	4	8	10	12
421 055	10	16	20	23
R8 & R9	8	14	19	22
421 042	5	9	12	14

Table 6.8 Macquarie River contributing sub-catchment salt loads for ‘current’ and future conditions using individual scaling factors, area weighted for geology

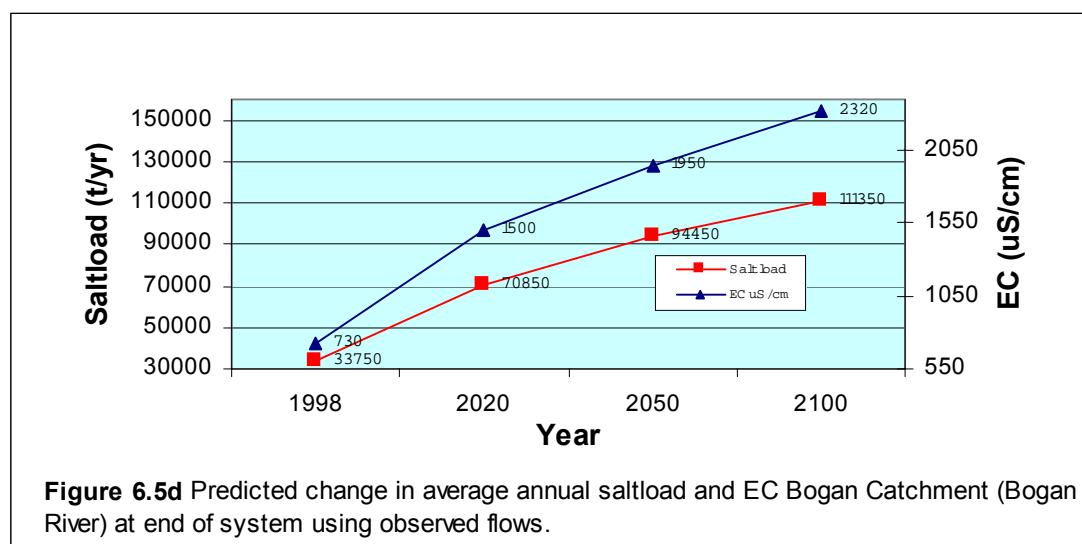
Individual scaling factors are applied to each of the contributing sub-catchments to calculate the loads in $t.km^{-2}.year^{-1}$ shown in Table 6.8.

Differences in the rates of change for each third order catchment reflect the area weighing of contributions from the geologies located within catchments.

Sub-catchment contributions to the Macquarie are shown relative to the inputs from contributing third order catchments in all other second order catchments across the State, with the exception of the Murray, in Figures 6.8 to 6.11.

6.6.2 Bogan River—future salt exports

The Bogan River Catchment is treated as a single unit with calculations based on observed salt loads at the end of system gauging station 421 023 (Bogan R. at Gongolgon). The Bogan is not affected by diversions. Factors for the whole Macquarie basin shown in Table 6.1 are used to scale the loads to the target dates.



The changes in average annual salt load and EC using observed flow conditions for the calibration period 1975 to 1995, projected to the target dates are depicted in Figure 6.5d. Salt loads are expected to increase from $33\,750\ t.year^{-1}$ under ‘current’ conditions to $111\,350\ t.year^{-1}$ at the end of the 21st century. Average annual EC is predicted to rise from $727\ \mu S.cm^{-1}$ to $2\,319\ \mu S.cm^{-1}$ by 2100. WHO drinking water quality standards will be exceeded on an average annual basis by 2020 and on a monthly average basis a lot sooner. The patterns of average monthly salt exports and ECs throughout the year for the end of system are presented in Figure 5.10n. The cumulative distributions of salt loads and ECs at the end of system for ‘current’ conditions and required target dates are presented in

Figures 6.5e and 6.5f, respectively. The observed annual average flow for the period 1975 to 1995 is $234.5 \text{ GL} \cdot \text{year}^{-1}$.

Under ‘current’ conditions and observed flows at end of system calibrated to the 1975 to 1995 time series, river salinity is shown to remain less than the WHO standard of $800 \mu\text{S} \cdot \text{cm}^{-1}$ on average in only 68% of months. There is a significant deterioration in the frequency of predicted average monthly ECs remaining beneath this limit, decreasing to 45%, 25% and 17% of months in 2020, 2050, and 2100, respectively.

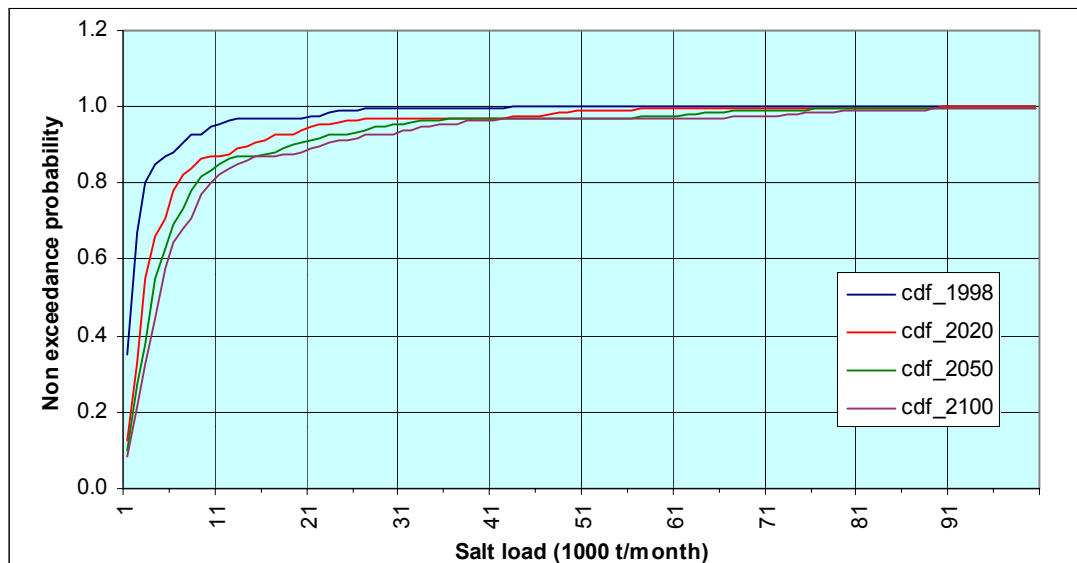


Figure 6.5e Cumulative distribution function for monthly salt load (1000 t/month) time series at end of system for the Bogan River.

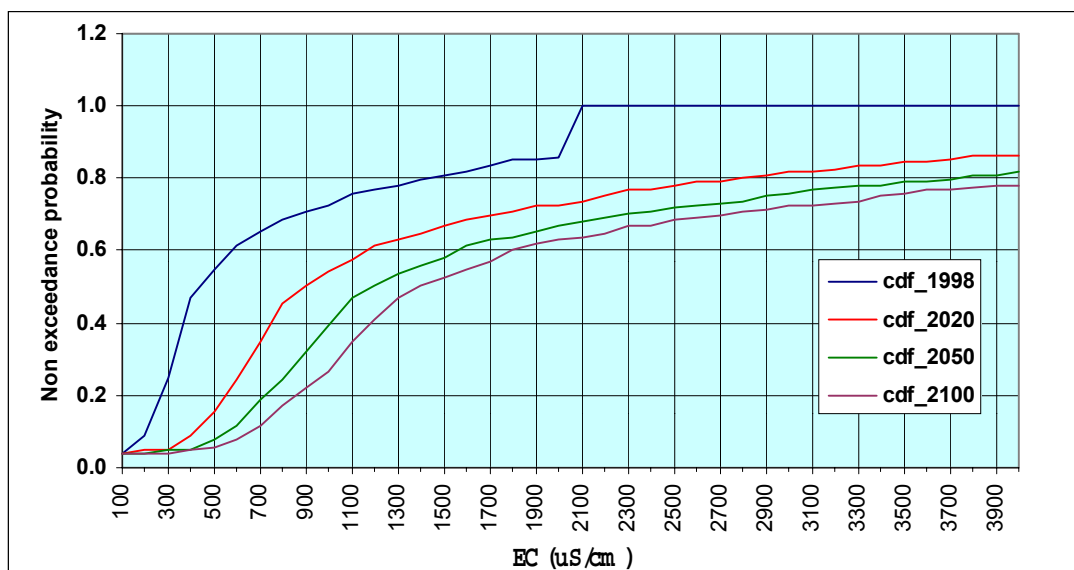


Figure 6.5f Cumulative distribution function for monthly EC (uS/cm) time series at end of system for the Bogan River.

The distribution of EC at end of system is indicative only of the potential salinity impacts of flows to wetlands and overbank flood flows along the length of the river. Wetlands that fill in infrequent floods may receive lower salinity water during such events. However, the salt loads associated with floods will be at the highest levels within their cumulative probability distribution. As wetlands dry out, salinity within the wetland will increase due to concentration of the initial salt load. Under ‘current’ conditions, salt loads remain less than $7000 \text{ t.month}^{-1}$ in 90% of all months. Salt loads are predicted to remain less than 16 000, 21 000, and 24 000 t.month^{-1} in 90% of all months at 2020, 2050 and 2100 respectively.

Likely impacts on river ecology and the health of the wetlands are discussed in Section 8.

6.7 Lachlan River—Future Salt Exports

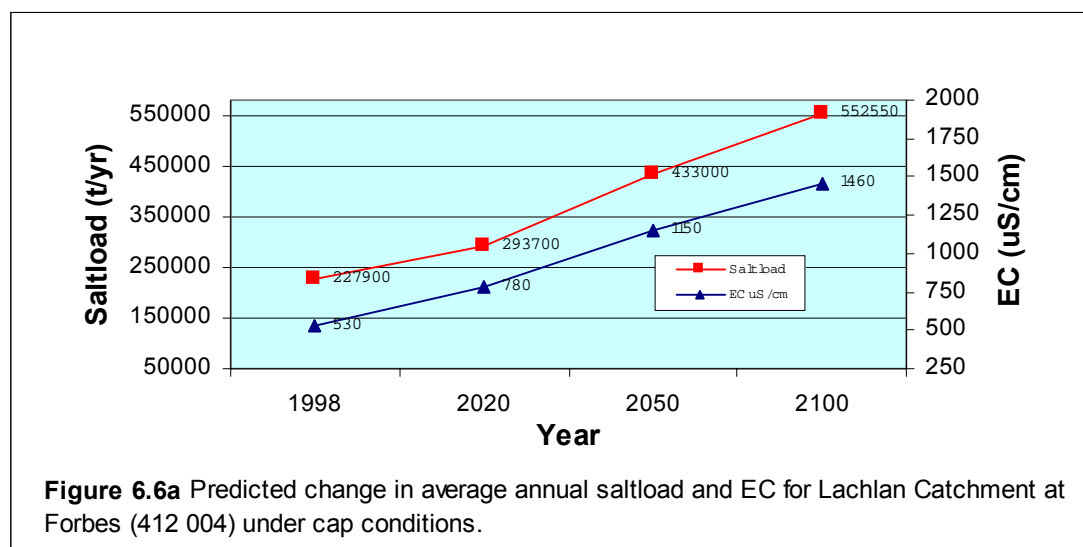
The Lachlan River under most conditions is a terminal system where flows escape to the lower reaches of the Murrumbidgee System only during extreme floods. For this reason end of system analysis is not attempted. Salt loads are balanced downstream to Forbes (412 004) to assess export rates entering this terminal area, much of which comprises environmentally significant wetlands (eg the Great Cumbung Swamp).

The changes in average annual salt loads and ECs using cap flow conditions for the calibration period 1975 to 1995, projected to the target dates are depicted in Figure 6.6a. Average annual salt loads are expected to increase from $227\,900 \text{ t.year}^{-1}$ under ‘current’ conditions to $552\,550 \text{ t.year}^{-1}$ by 2100. Average annual EC is predicted to rise from $530 \mu\text{S.cm}^{-1}$ to $1460 \mu\text{S.cm}^{-1}$ by 2100. WHO drinking water quality standards will be exceeded on an average annual basis by 2020 and within years on a monthly average basis a lot sooner. The pattern of average monthly salt export and EC throughout the year is presented in Figure 5.12l for Forbes. The cumulative distributions of EC for ‘current’ and target dates at Forbes are presented in Appendix 5 (Figure A5a). Cumulative distribution functions calculated at all balance points and gauging stations analysed within the catchment are included in Appendix 5.

The likely impact on river ecology and the health of the wetlands, particularly the Great Cumbung Swamp is discussed in Section 8.4.2. The average annual flow at Forbes under cap conditions for the period 1975 to 1995 is $1147 \text{ GL.year}^{-1}$.

Individual scaling factors are applied to each of the contributing sub-catchments to calculate the loads in $\text{t.km}^{-2}.\text{year}^{-1}$ shown in Table 6.9. The initial relative differences in salt load per square kilometre for each sub-catchment reflect the combined effects of the rainfall and runoff characteristics on the range of flows, as well as the ‘current’ expression of salt wash off from the soil store and

groundwater contributions. Differences in the rates of change for each reflect the area weighing of contributions from the geologies located within catchments.



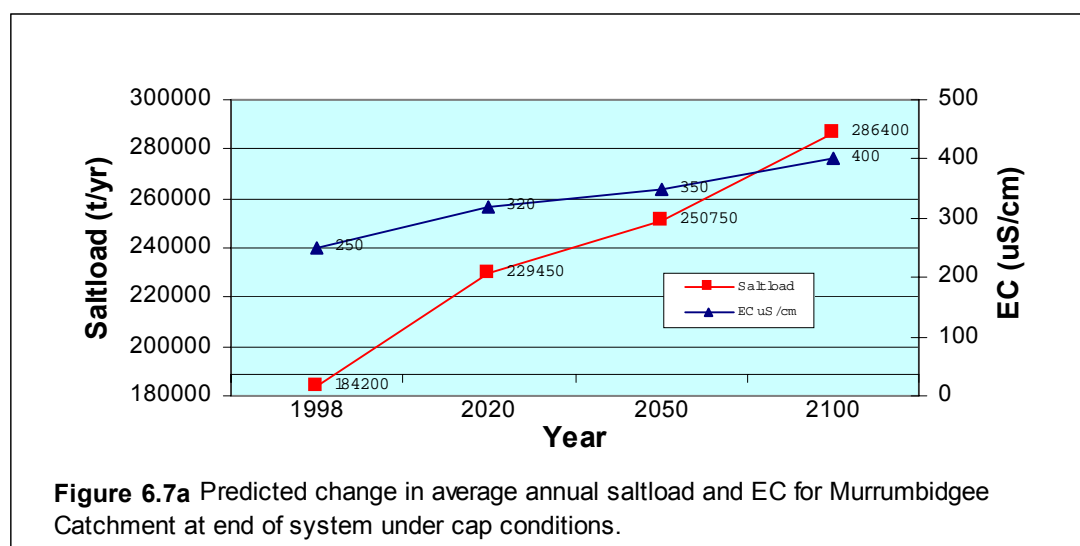
Station/ catchment	1998 <i>t.km⁻².year⁻¹</i>	2020 <i>t.km⁻².year⁻¹</i>	2050 <i>t.km⁻².year⁻¹</i>	2100 <i>t.km⁻².year⁻¹</i>
412 065	19	25	36	45
412 050	21	27	40	49
412 083	20	26	38	47
412 028	12	15	22	28
R1	16	21	31	38
412 029	21	30	44	53
R2	25	33	49	62
412 072	11	14	21	26
412 055 (R4 & 009)	26	34	50	63
R3	8	10	14	20
412 030	18	23	34	44
R5	26	31	47	65
R6	35	40	61	87
412 043	6	7	11	15

Table 6.9 Lachlan River contributing sub-catchment salt loads for ‘current’ and future conditions using individual scaling factors, area weighted for geology

Sub-catchment contributions to the Lachlan are shown relative to the inputs from contributing third order catchments in all other second order catchments across the State with the exception of the Murray in Figures 6.8 to 6.11.

6.8 Murrumbidgee River—Future Salt Exports

There are sixteen gauged and residual sub-catchments that contribute to salt mobilisation above the final balance point at station 410 001 (Murrumbidgee R. at Wagga Wagga) in the Murrumbidgee River Catchment prior to translation of the salt loads to the end of system. Individual scaling factors derived from an area weighting for each geology are applied to the contributing sub-catchments for each of the target dates and balanced downstream to Wagga Wagga before translation to the end of system and adjustment to cap flow conditions. The change in average annual salt load and EC using cap flow conditions for the calibration period 1975 to 1995, projected to the target dates is depicted in Figure 6.7a. Salt loads are expected to increase from 184 200 $t.year^{-1}$ under ‘current’ conditions to 286 400 $t.year^{-1}$ at the end of the 21st century. However, in contrast to the other catchments in the basin average annual EC is predicted to rise only from 250 $\mu S.cm^{-1}$ to 400 $\mu S.cm^{-1}$ by 2100. Although the salt loads predicted for 2100 are the second highest across the State, salinities are expected to remain low. Greater flow in the Murrumbidgee maintains a high level of dilution within the river (average annual cap flows equals 1 350 $GL.year^{-1}$). The pattern of average monthly salt export and EC throughout the year is presented in Figure 5.14j for the end of system. The cumulative distributions of salt load and EC for ‘current’ and target dates at the end of system are presented in Figures 6.7b and 6.7c respectively.



In general, salinity is much less of an issue in the Murrumbidgee than for other catchments across the State. Under ‘current’ conditions and cap scenario flows calibrated to the 1975 to 1995 time series, river salinity is shown to remain less than the WHO standard of 800 $\mu S.cm^{-1}$ continuously in the Murrumbidgee. There is very little deterioration in the frequency of predicted average monthly EC

remaining beneath this limit decreasing to 97%, 95% and 93% of months in 2020, 2050, and 2100 respectively. Cumulative distribution functions calculated at all balance points and gauging stations analysed within the catchment are included in Appendix 6.

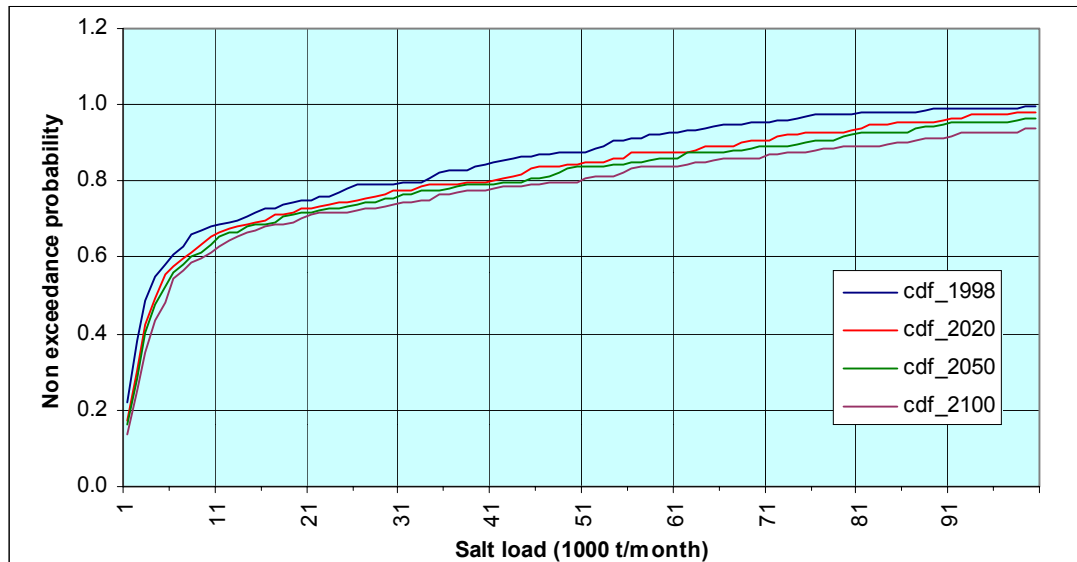


Figure 6.7b Cumulative distribution function for average monthly salt load (1000 t/month) time series at end of system for the Murrumbidgee River.

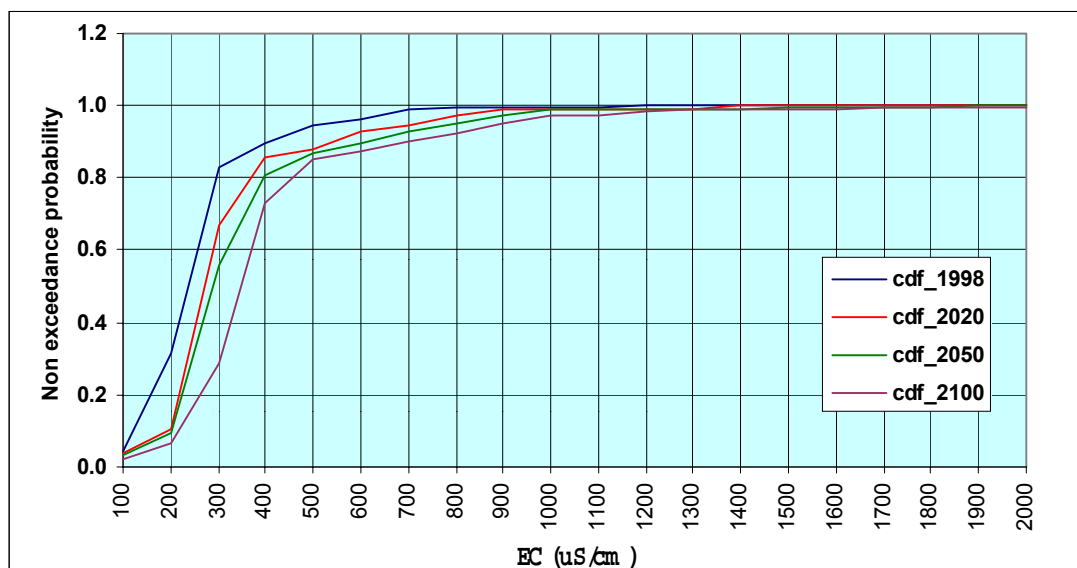


Figure 6.7c Cumulative distribution function for monthly EC (uS/cm) time series at end of system for the Murrumbidgee River.

The distribution of EC at end of stream is equivalent to that at the last balance point and therefore applies to the diversions for irrigation as well as losses to wetlands and overbank flood flows in the

intervening reach. Wetlands that fill on infrequent flood events may receive higher quality water initially during such events. However the salt loads associated with the flood events will be at the highest levels within the distribution. As wetlands dry out, salinity within the wetland will increase due to concentration of the initial salt load. Under 'current' conditions salt loads remain less than 55 000 $t.month^{-1}$ in 90% of all months. Salt loads are predicted to remain less than 69 000, 76 000, and 86 000 $t.month^{-1}$ in 90% of all months at 2020, 2050 and 2100 respectively.

The relative differences in salt load per square kilometre for each sub-catchment reflect the combined effects of the rainfall and runoff characteristics on the range of flows, as well as the current expression of salt wash off from the soil store and groundwater contributions. A comparison between Tarcutta Creek (station 410 047) and Kyeamba Valley (station 410 048) suggests that land use differences are playing a significant role. Both catchments have similar geology, soil landscapes and rainfall, although they are substantially different in size. Tarcutta Creek, on the one hand, has approximately 32% of the land area covered in forest. On the other hand, Kyeamba Valley has only approximately 6% forest, while the remainder of both catchments is predominantly pasture. Differences in the predicted rates of change for each sub-catchment across the Murrumbidgee reflect the area weighing of contributions from the geologies located within catchments and do not account for the modifying effects of changing land use.

Station/ catchment	1998 $t.km^{-2}.year^{-1}$	2020 $t.km^{-2}.year^{-1}$	2050 $t.km^{-2}.year^{-1}$	2100 $t.km^{-2}.year^{-1}$
410 073	22	27	30	33
410 059	8	9	11	12
410 057	10	12	13	15
410 071	4	4	5	6
R1	4	5	5	7
410 008	11	14	15	18
410 025	25	32	35	40
410 044	23	29	32	37
410 038	13	16	17	20
R2	19	24	26	30
410 061	48	59	65	65
410 043	32	40	44	44
410 042	48	59	65	74
410 045	9	11	13	13
410 047	16	20	22	22
410 048	38	51	57	57
R3	4	11	12	12

Table 6.10 Murrumbidgee River contributing sub-catchment salt loads for 'current' and future conditions using individual scaling factors, area weighted for geology

Sub-catchment contributions to the Murrumbidgee are shown relative to the inputs from contributing third order catchments in all other second order catchments across the State with the exception of the Murray in Figures 6.8 to 6.11.

6.9 Murray River—Future Salt Exports

The great majority of the upper Murray Catchment lies in Victoria. In NSW, only Jingellic Creek and the Tooma River have sufficient data available to make an estimate of salt contributions in the Upper Murray Catchment. Although Billabong Creek further downstream is often sometimes considered part of the Murrumbidgee Catchment, it actually flows into the Edward River, before entering the Murray River. The Coleambally outfall drain and Yanco Creek also influence the flows in the lower reaches of the Billabong Creek. The Edward River is heavily influenced by diversions coming from the Murray River and Diversions out again to the irrigation districts. The investigation of dryland catchment contributions to the Murray River is therefore limited to Jingellic Creek, the Tooma River and upper Billabong Creek at Walbundrie.

The Jingellic Creek Catchment has an area of 378 km^2 and an average annual salt load of $12.2 \text{ t.km}^{-2}.\text{year}^{-1}$ under ‘current’ conditions. Using the basin wide scaling factors from Table 6.1 the predicted salt loads from Jingellic Creek at 2020, 2050 and 2100 are 17, 19 and $29 \text{ t.km}^{-2}.\text{year}^{-1}$ respectively.

The Tooma River Catchment is 1890 km^2 in area and carries an average annual salt load of $8.5 \text{ t.km}^{-2}.\text{year}^{-1}$ under ‘current’ conditions. Using the basin wide scaling factors from Table 6.1 the predicted average annual salt loads from the Tooma River Creek at 2020, 2050 and 2100 are 12, 13 and $20 \text{ t.km}^{-2}.\text{year}^{-1}$ respectively.

The upper Billabong Catchment above Walbundrie has an area of 3065 km^2 and an average annual salt load of $10.2 \text{ t.km}^{-2}.\text{year}^{-1}$. Using the basin wide scaling factors from Table 6.1 the predicted average annual salt loads from the upper Billabong Creek at 2020, 2050 and 2100 are 14, 15 and $19 \text{ t.km}^{-2}.\text{year}^{-1}$ respectively. Redistribution of predicted salt loads within the landscape

In each second order catchment, with the exception of the Castlereagh and Bogan Rivers, substantial diversions for irrigation occur. Consequently, salt mobilised in the upland third order catchments by dryland salinity processes is redistributed back into the landscape in irrigation water. Where a catchment contains large wetland areas, salt is also deposited back into the landscape and additional redistribution occurs over the floodplain during floods. A simple breakdown of the gross annual average salt loads accumulating in these areas is presented in Table 6.11.

The split of salt loads beyond the last balance point in each second order catchment between losses in diversions for irrigation and wetland and other losses has been calculated as a simple ratio of flow.

The breakdown of flow into each component was made on the basis of cap scenario flows modelled for the last balance point, diversions and at the end of system. Diversion flows and stock and domestic volumes not available from modelled catchments were taken from published values (MDBC, 1995). Wetland and other losses have been regarded together as the remainder unaccounted for above. For the Gwydir the total flow out of Gil Gil Creek was subtracted from the flow at the last balance point. Therefore, accessions to the Gwydir wetlands may be underestimated by this simplified method. In the Namoi there are additional salts entering the stream between Boggabri and the end of system making the ratio method inappropriate. The salt load estimated in diversions is calculated from the salt load per gigalitre at Boggabri plus Maules Creek and the annual average diversion flow.

Figure 6.8. Average annual salt contribution by contributing subcatchments, 1998

Figure 6.9. Average annual salt contribution by contributing subcatchments, 2020

Figure 6.10. Average annual salt contribution by contributing subcatchments, 2050

Figure 6.11. Average annual salt contribution by contributing sub-catchments, 2100

Many towns within the Murray-Darling Basin use surface water from the rivers and creeks solely or in conjunction with groundwater for domestic and industrial purposes. All towns with a population of 500 inhabitants or more using surface water or bore water affected by the river system have been identified in Appendix 7. The probability of exceedence of threshold salinities of 800 and 1600 EC in the river reach from which each town draws its water has also been indicated. In addition, a preliminary estimate of each town's potential urban salinity hazard has been included. This is not intended to be a complete assessment of current salinity status or salinity hazard, but simply an indication of the already widespread and 'indiscriminate' occurrence of urban salinity that, in view of the rising groundwater trends identified in this study, can only get worse.

Catchment	Average Annual Cap Scenario Flow (GL)					Average Annual Salt load @ the end of system (tonnes per year)				Average Annual Salt load @ the last balance point (tonnes per year)				Average Annual Salt Load in Irrigation Diversions (tonnes per year)				Average Annual Salt Load entering Wetlands plus other losses			
	At the End Of System	Last Balance Point	Annual Diversions Irrigation	Stock & Domestic Water	Wetland & Other Losses	1998	2020	2050	2100	1998	2020	2050	2100	1998	2020	2050	2100	1998	2020	2050	2100
Border Rivers/ Macintyre	760	1029	209	1	59	95400	95400	95400	95400	112000	112000	112000	112000	12897	12897	12897	12897	3641	3641	3641	3641
Gwydir River	56	737	319	1	252	12350	13300	16200	17300	149400	159560	191200	203200	81953	87465	104663	111184	64740	69094	82681	87832
Namoi River#	503	770	240	4	0	135600	208200	255900	312100	177200	266900	325700	394800	55231	83184	101518	123055	0	0	0	0
Castlereagh River	105.5	105.5	0	0	0	19500	21500	39050	41000	19500	21500	39050	41000	0	0	0	0	0	0	0	0
Macquarie River	150	1287	463	6	668	43900	93100	126400	154300	234400	508400	677400	818900	77574	169115	224374	270633	111921	243993	323719	390460
Bogan River	234.5	234.5	0	0	0	33750	70850	94450	111350	33750	70850	94450	111350	0	0	0	0	0	0	0	0
Lachlan River	0	1147	306	0	841	0	0	0	0	227900	293700	433000	552550	60800	78354	115517	147411	167100	215346	317483	405139
Murrumbidgee River	1350	4592	2424	19	799	184200	229450	250750	286400	401800	482300	529100	607400	162697	189053	208119	240007	53628	62316	68600	79111

Values at the Last Balance point include the Namoi River at Boggabri plus Maules Creek

* Wetland estimates account for flows exiting Gil Gil Creek

Table 6.11 Redistribution of salt load in the landscape by catchment

7 Catchment Scale Salt Balance Study (CATSALT)

This section briefly describes the components of the *Catchment Scale Salt Balance Model*—CATSALT and results of its implementation on the Kyeamba Creek Catchment, a third order catchment located in the Murrumbidgee River basin. Refer to Tuteja and Beale (1999, in press) for a detailed discussion on model development, validation and sensitivity analysis. The CATSALT model (Figure 7.1) is a quasi-physical model and has been developed to obtain salt balances for medium sized catchments (500–1500 km^2) ie third order catchments. The model includes three components: 1. The Soil Moisture Accounting and Routing Model—SMAR (O’Connell *et al.*, 1970; Kachroo, 1992; Tuteja and Cunnane, 1999), a lumped conceptual rainfall runoff water balance model with soil moisture accounting as its central theme; 2. A salt mobilisation and washoff component for estimating salt delivery to the stream with surface runoff and groundwater; and 3. A Fourier Transform based stochastic component to estimate in-stream salt exported at the catchment outlet. The model also allows for prediction of future salt balance changes in response to rising groundwater and soil salinisation.

The SMAR model consists of two components in sequence, namely, a water balance component and a routing component (Figure 7.2). The water balance component divides the soil column into horizontal layers, which contains a certain prescribed amount of water at their field capacities. Evaporation from soil layers is treated in a way that reduces the soil moisture storage in an exponential manner from a given potential evapotranspiration demand. The routing component transforms the surface runoff generated from the water balance component to the catchment outlet by a Gamma Function Model form (Nash, 1960), a parametric solution of the differential routing equation in a single input single output system. The generated groundwater runoff is routed through a single linear reservoir and provides the groundwater contribution to the stream at the catchment outlet. The SMAR model contains 5 water balance parameters and 4 routing parameters. The routed surface and the groundwater runoff from the SMAR model are used in the salt mobilisation and washoff component of CATSALT to estimate the associated salt load.

The salt mobilisation and salt washoff component is combined with a catchment salinity hazard map (Bradd, 1994), which is based on the weight of evidence that dryland salinity already exists for a given combination of catchment attributes. The attributes used in this case are soil landscape unit, geology, slope class and landform. The salinity hazard map is combined with a map overlay of groundwater contours in the catchment to identify saline or non-saline areas in the catchment, and takes into account salt entering the streamflow by desorption from the soil matrix and in groundwater flow. The salinity hazard mapping is used to partition the catchment into four classifications depending on their hazard potential. The overlaid groundwater contour of less than 2 m depth under

‘current’ conditions, or at target dates is then used to further sub-divide each hazard category into saline or the non-saline areas. Soil salinity values are then assigned to each one of the eight resultant sub-areas (saline or non-saline areas in each hazard category). The surface salts from each sub-area are washed off with the associated area weighted surface runoff using a single desorption function described by the Freundlich isotherm. The salts entering the river with base flow are estimated using the groundwater flow (from SMAR) and an assigned groundwater salinity while allowing for resistivity between the aquifer-river exchange. This model component contains three parameters of which two parameters are associated with the Freundlich isotherm for salt washoff with surface runoff and one parameter is associated with the salt contribution from the groundwater system.

The stochastic component of the CATSALT model was developed to estimate the daily salt load time series by modelling the statistical structure of the daily streamflow and discrete salt concentration/load data. A detailed description of this component is given in Section 3.2 and the governing equations are shown in Equations 3.1 to 3.18. The stochastic component of the model has been used on a statewide basis to obtain the ‘current’ in-stream salt balance for all second order valleys. The daily salt load time series thus obtained from the stochastic model using observed flow and EC data is called the observed salt load time series and is used to derive the estimated total daily salt loads associated with the surface runoff and groundwater runoff. A simultaneous calibration of the water balance and the salt balance components is not undertaken to avoid the influence of uncertainties in salt balance parameters on the water balance parameters (SMAR). The water balance component is calibrated first and, thereafter, the salt balance component is calibrated.

The salt balance analysis for Kyeamba Creek at Ladysmith (530 km^2) has been undertaken on a daily basis for the period 1975–92 (18 years). The salinity hazard map for the Kyeamba Creek Catchment with an overlay of 2 m and 5 m contours of groundwater depth below the soil surface is shown in Figure 7.3. The relative proportion of areas of different soil types (Isbell classification) in the Kyeamba Creek and their general position in the landscape are: Sodosols—35.8% (drainage lines), Chromosols—25.6% (mid slope), Kurosols—2.4% (mid slope), Dermosols—5.2% (mid slope), Kandosols—7.4% (mid slopes), and Rudosol—23.6% (ridges and crests) (Chen and McKane, 1997).

Soil salinity values are assigned on the basis of soil type and salinity hazard category using data from the following sources:

1. Monavale Catchment, a fourth order catchment located in Kyeamba Creek (Fogarty, P. 1996);
2. Wattle Retreat Catchment, a 10 km^2 catchment located in the Lachlan Catchment close to its boundary with the Murrumbidgee Catchment (Barker P. J., unpublished);
3. Soils data from Geeves, *et al.* (1995);

4. Six saline sites across NSW (Semple, *et al.*, 1997), and;
5. The DLWC soils database for NSW.

The areas of each hazard category and the associated soil salinity values used in CATSALT are presented in Table 7.1.

Hazard category	Area	Soil salinity—saline area		Area	Soil salinity—non saline area	
	km^2	$dS.m^{-1}$	$g.kg^{-1}$	km^2	$dS.m^{-1}$	$g.kg^{-1}$
Very high	12.00	3.00	1.92	61.30	1.10	0.704
High	8.10	3.00	1.92	82.00	0.70	0.456
Moderate	7.24	2.13	1.36	59.60	0.70	0.456
Low	6.92	1.25	0.80	364.58	0.50	0.314
Total	34.26			567.48		

Table 7.1 Area of each hazard category under ‘current’ conditions and associated soil salinity values in Kyeamba Creek Catchment

The rainfall and groundwater salinity values used are 4.56 g.m^{-3} and 4000 g.m^{-3} respectively. The saline area (less than 2 m) and the non saline area for Kyeamba valley based on the groundwater trends analysis for ‘current’ conditions and the target dates are presented in Table 7.2.

Hazard category	‘Current’		2020		2050		2100	
	<i>Sal</i>	<i>Nsal</i>	<i>Sal</i>	<i>Nsal</i>	<i>Sal</i>	<i>Nsal</i>	<i>Sal</i>	<i>Nsal</i>
Very high	12.00	61.30	39.29	34.00	47.97	25.33	62.89	10.41
High	8.10	82.00	33.27	56.80	49.46	40.61	65.62	24.45
Moderate	7.24	59.60	23.00	43.80	35.32	31.48	47.31	19.49
Low	6.92	364.58	20.00	351.57	101.21	270.36	158.09	213.48
Total	34.26	567.48	115.56	486.17	233.96	367.78	333.91	267.83

Sal : Saline area (km^2), *Nsal* : Non saline area (km^2)

Table 7.2 Saline and non-saline area (km^2) under ‘current’ conditions and at target dates Kyeamba Creek at Ladysmith

The water balance simulation for the period 1975–92 on a daily basis for Kyeamba Creek at Ladysmith shows that the streamflow predictions using SMAR are accurate to a level of 66%. By including an error updating procedure in the form of an Autoregressive Moving Average Model (Box and Jenkins, 1976; Salas *et al.*, 1980; Tuteja, 1992), the accuracy improves to 72%. The SMAR calibrations indicate that about 128 mm change in total soil moisture storage contributes to the runoff generation mechanisms.

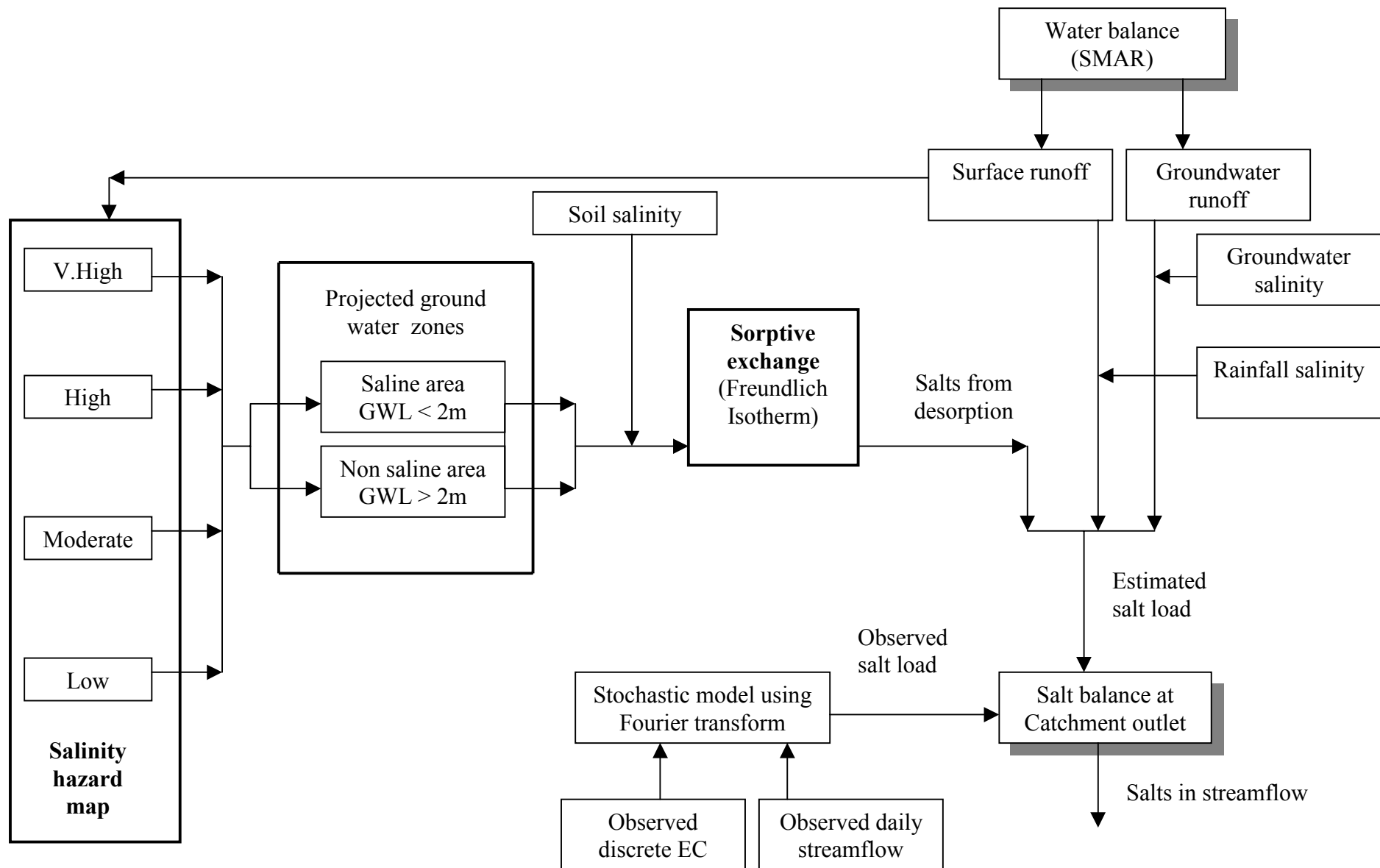


Figure 7.1 Schematic diagram of the CATSALT model

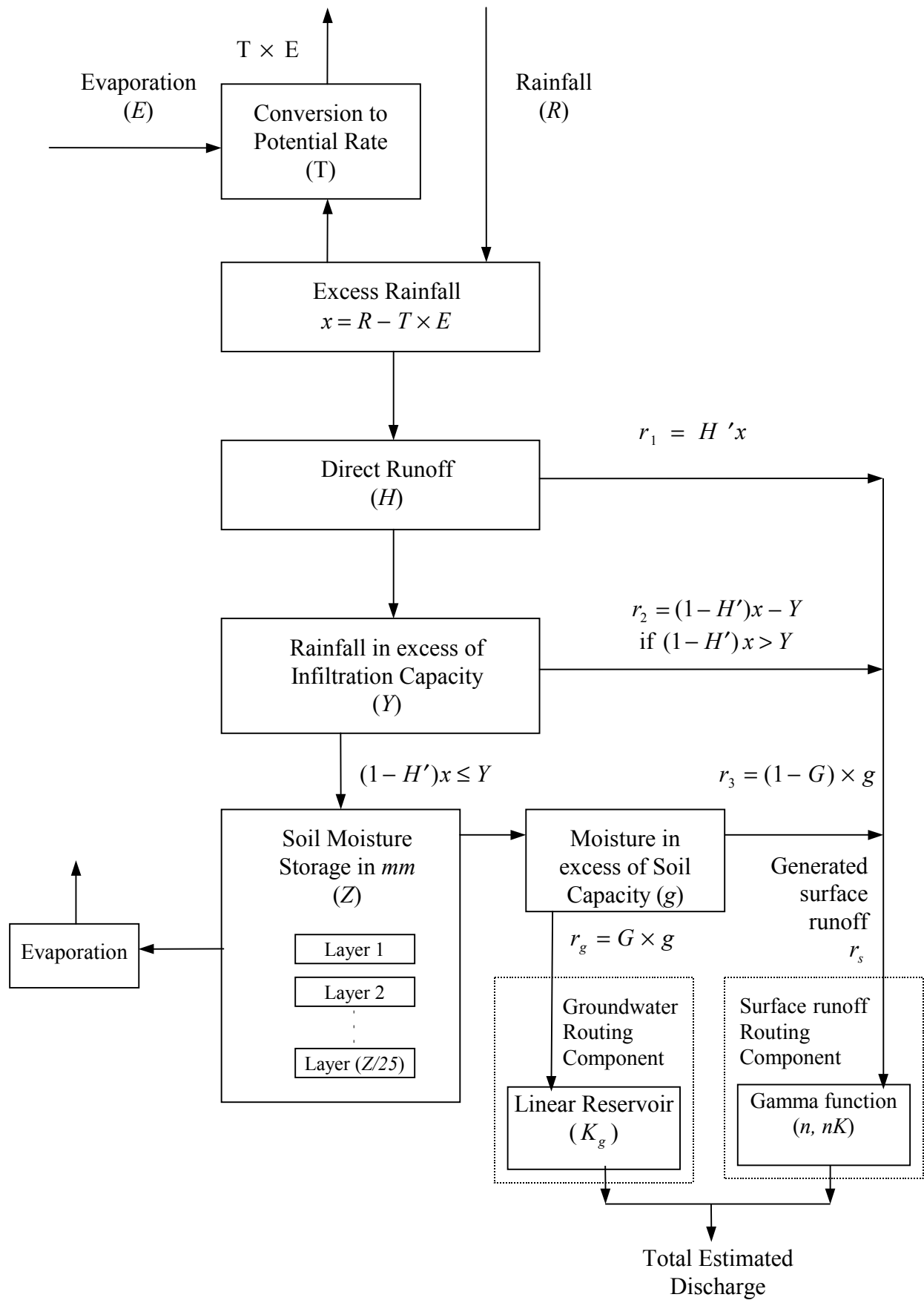


Figure 7.2 Schematic diagram of the SMAR model

Figure 7.3 Kyeamba salinity hazard plot

This agrees well with soil moisture measurements from 19 sites at Wagga Wagga Research Centre for the period February 1998 to June 1999 which show an average variation in soil moisture storage of about 125 mm. The soil moisture data were averaged across the upper slope, mid slope and the low slope and provide an extra check on the SMAR calibrations.

The calibrated SMAR parameters show that about 28% of the effective rainfall contributes to runoff (overland flow plus unsaturated lateral flow) and the remaining amount infiltrates into the soil. The infiltrated amount first satisfies the effective soil moisture storage (128 mm). Then approximately 44% of any excess infiltration becomes groundwater runoff and the remaining amount is added to the generated surface runoff as saturated lateral throughflow. The lag times (system memories) of generated surface runoff and groundwater runoff, are 1 day and 365 days respectively. The soil moisture storage depletion rate to meet the daily evapotranspiration demand can be described by an exponential function of the form 0.663^{i-1} , where i refers to the successive soil layers. An illustration of the streamflow prediction from the SMAR calibration with the Autoregressive Moving Average Model as an error updating model for the year 1988 is shown in Figure 7.4. The monthly rainfall data and actual evapotranspiration and streamflow at Ladysmith (obtained from SMAR simulations on a daily basis and integrated over a month) for the period 1975–92 are shown in Figure 7.5. The break up of the total streamflow into surface runoff and groundwater runoff is shown in Figure 7.6. These figures show that evapotranspiration is the major water balance component and of the total streamflow, surface runoff (overland flow plus the unsaturated and saturated throughflow) is the major constituent. Therefore, it is logical to presume the salt contribution from surface runoff is the predominant source of in-stream salt load (but not necessarily salinity).

The soil salinity and the saline and non-saline area values for each hazard category from Table 7.1, daily surface runoff and groundwater runoff from SMAR simulations, and groundwater and rainfall salinity values of 4000 g.m^{-3} and 4.56 g.m^{-3} respectively, are used to calibrate the salt balance component of the CATSALT. The model is calibrated on a daily basis for the period 1975–92 for a total of 3 parameters, of which 2 parameters are associated with the Freundlich isotherm (sorptive exchange) and 1 parameter is associated with the aquifer-river exchange. The overall salt balance for Kyeamba Creek is accurate to a level of about 69%. A comparison of the observed and the predicted salt loads from the CATSALT model is shown in Figure 7.7. The model is sensitive to the parameters associated with the salt washoff function due mainly to the fact that the bulk of the in-stream salt loads are associated with surface runoff. A comparison of the cumulative distribution function (*cdf*) of the observed and the estimated daily salt load time series shows that in addition to good

predictions, the statistical structure of the daily salt load time series is preserved (Figure 7.8) at least for the calibration period.

Using the predicted saline and non-saline areas for the target dates from groundwater trends analysis (Table 7.2) and the calibrated water and salt balance parameters, the daily salt exports are estimated for catchment conditions at target dates using the CATSALT model and the 1975–92 climate pattern. The *cdfs* of the daily salt load series for ‘current’ conditions and required target dates are shown in Figure 7.9. The plots show the variation of daily salt load over a period of 100 years. As an example, about 95% of the time the salt load in Kyeamba Creek at Ladysmith is less than 200 t.day^{-1} under ‘current’ conditions, as against 480 t.day^{-1} under likely catchment conditions in 2100.

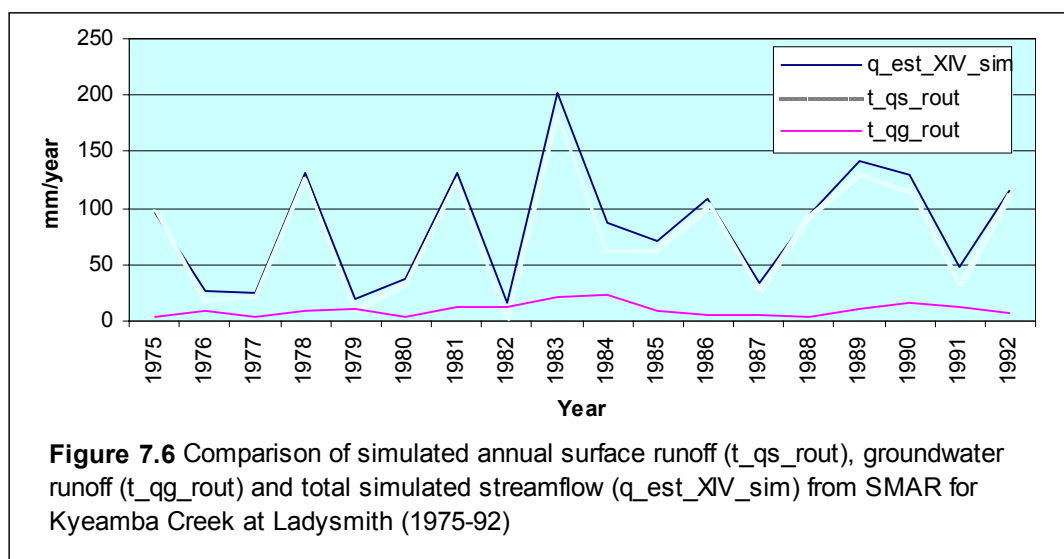
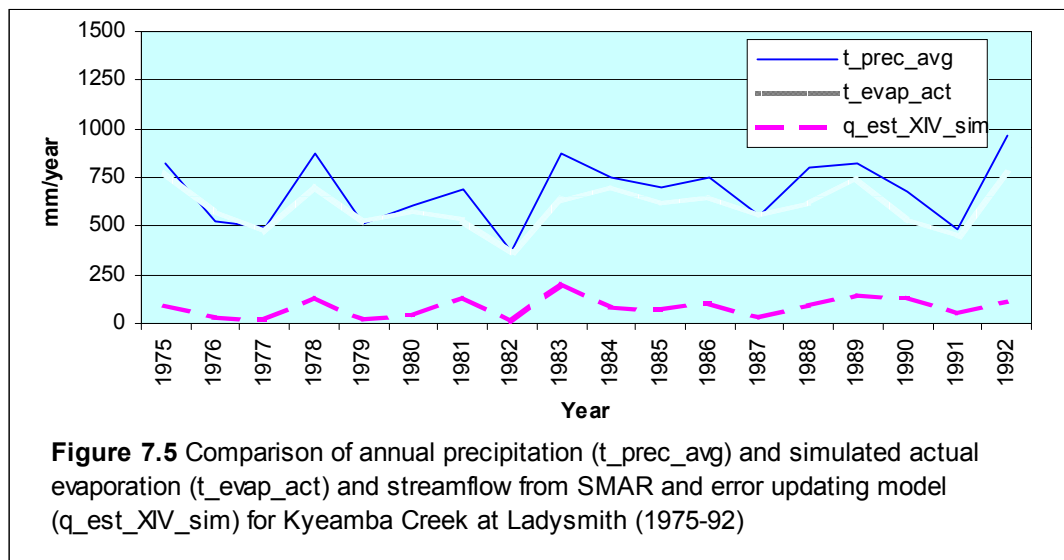
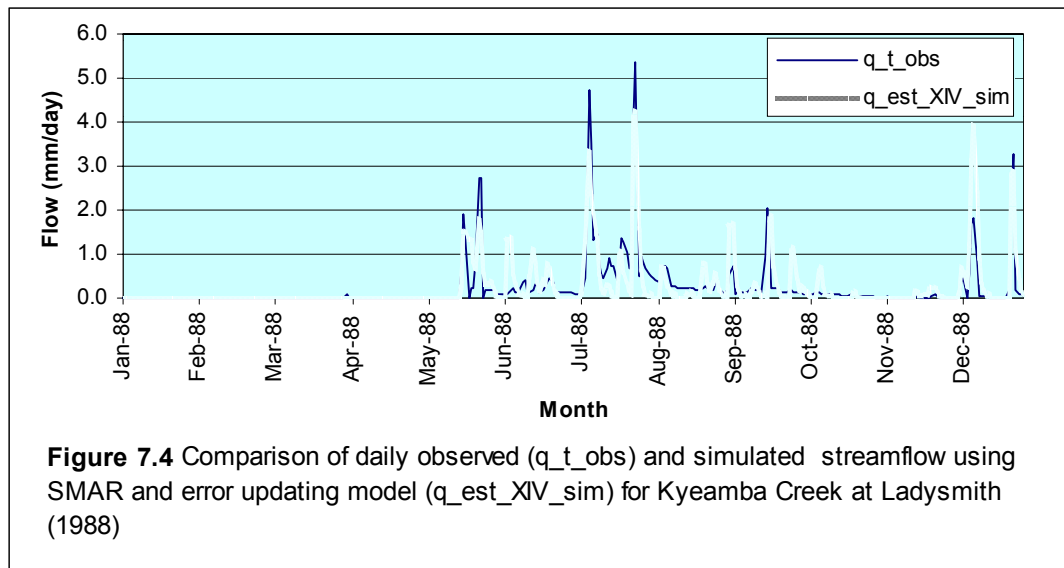
The methodology for the statewide analysis for all the major rivers (Section 3) uses only the stochastic component of the CATSALT model and scaling factors (Equation 3.28) to predict the salt export rates in future. The processes associated with salt delivery from the groundwater system to the soil surface and consequent soil salinisation and salt washoff are not explicitly taken into account. The implementation of the CATSALT model on the Kyeamba Creek Catchment explicitly accounts for these processes. A comparison of the average annual salt load for Kyeamba Creek with and without the CATSALT model under ‘current’ conditions and at the required target dates is shown in Table 7.3. The results indicate that the prediction for Kyeamba Creek using the statewide methodology (ie. without process accounting for soil salinisation and salt washoff) overestimates the salt load for 2020 conditions but that, with time, the predictions from the two methodologies agree. Sensitivity analysis with CATSALT indicates a substantial shift in the relative contributions of salt from saline and non- saline areas, between ‘current’ and 2020 conditions not evident in the statewide analysis. The differences tend to disappear with time as washoff from salinised areas becomes dominant.

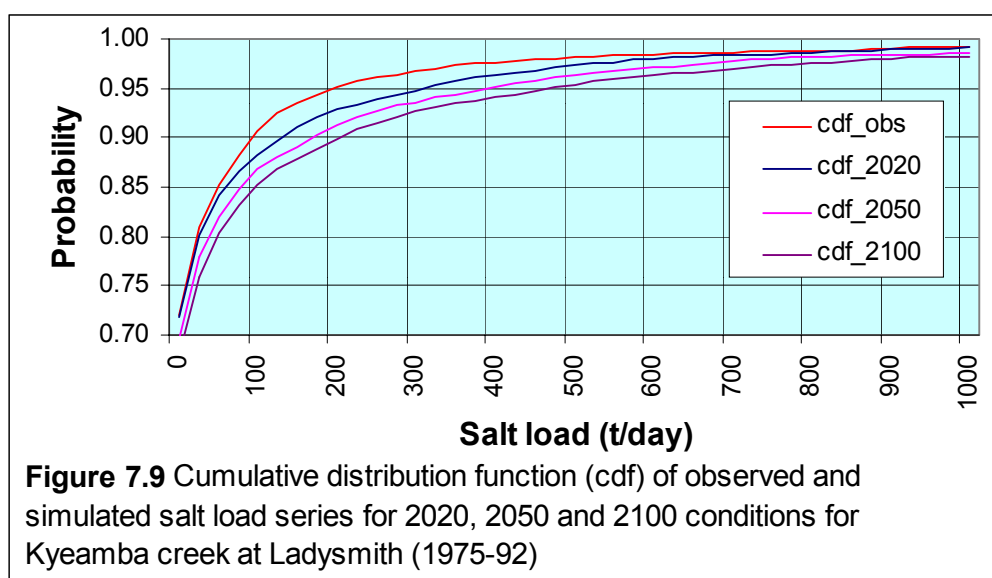
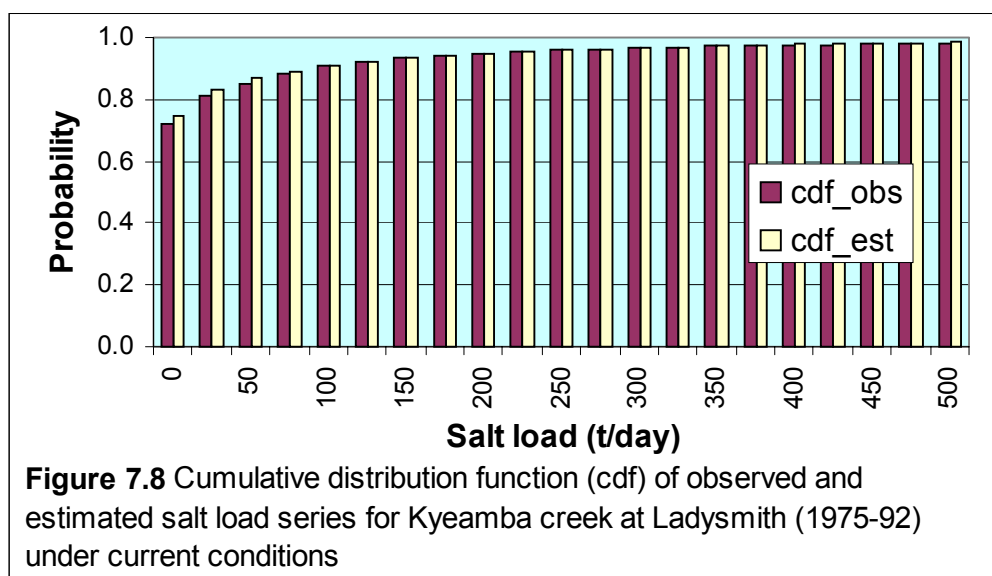
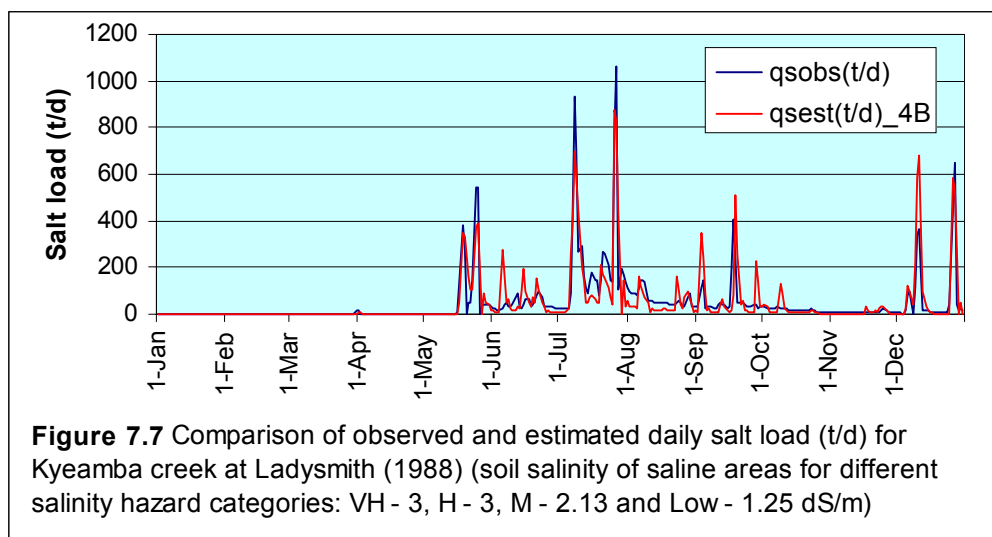
Assessment period	With CATSALT		Without CATSALT
	Salt load (t.year^{-1})	Factor wrt ‘current’	Factor wrt ‘current’
‘current’	19660		
2020	23960	1.22	1.32
2050	29590	1.51	1.47
2100	34980	1.78	1.77

Table 7.3 Comparison of average annual salt load with and without CATSALT model for Kyeamba Creek at Ladysmith for 1975–92 climatic conditions

To implement the CATSALT model on a more widespread basis across the State, the availability of data at an appropriate resolution required for production of the salinity hazard map may be limiting. However, any robust tool that accounts for topography and has less stringent data requirements for

assessment of the hazard potential could be used with CATSALT and implemented on a statewide basis.





8 Potential environmental consequences of increasing dryland salinity in streams and wetlands

8.1 Introduction

This section provides an assessment of the potential environmental impacts of expected increases in salinity levels within streams and wetlands due to dryland salinity. It is not intended, given the data available, to provide detailed specific impacts for any single location, individual species or ecosystem. Impacts on a number of end of system or flow through wetlands (Macquarie Marshes, Gwydir Wetlands and the Great Cumbung Swamp) have been interpreted from the estimated salinity increases (presented in Section 6) to act as a guide to expected environmental implications.

The environment within the Murray-Darling Basin has been affected by alterations in both the flow regimes of rivers and salinity levels. This report indicates that within each catchment and between sub-catchments, the expected levels of salinity increase from the present to 2100 (based on averages) are expected to vary from moderate (as in the case of the Murrumbidgee: 250 to 400 $\mu S.cm^{-1}$) to severe (as with the Macquarie and Bogan Rivers 620 to 2110 $\mu S.cm^{-1}$ and 730 to 2320 $\mu S.cm^{-1}$, respectively).

Salinity levels outside these ranges will undoubtedly occur from time to time because these estimates are based on the monthly average. Both high and low salinity levels can be expected to occur. These may reflect previously high salinity levels encountered in any stream, but the duration and frequency of these extremes might be expected to increase.

Notwithstanding the actual or potential ecological impacts of salinisation throughout semi-arid regions of the world, surprisingly few investigations of the nature of ecological impacts (as distinct from economic, agricultural and other impacts) have taken place (GHD, 1999). Similarly, there is considerable scientific uncertainty as to what degree of increase over natural levels will impact on individual species, communities or populations (Metzeling *et al.*, 1995). A review by Hart *et al.*, (1991) also noted a general lack of data on the sensitivity of freshwater plants and animals to salinity increases.

There is, however, work on this topic currently being finalised at Monash University (under Paul Bailey, pers. com., Department of Biological Science) for the Land and Water Resources Research and Development Corporation. This involves the review and implication of salinity impacts on riverine and aquatic biota. A salt sensitivity database for aquatic biota is also being developed as part of this work and is nearing finalisation.

Salinity impacts on a species depend on the specific tolerance of the species. These may vary regionally. Salinity is an important limiting factor in the distribution of many aquatic animals (ANZECC, 1999).

Salinity requirements can also vary for particular species depending on their lifecycle stage (ANZECC, 1999). Salinity affects the temperature requirements of some species as well. There is, however, a lack of understanding of temperature-salinity interactions and the effects of changing the ionic ratios for many species (Tomasso, 1993 in ANZECC, 1999). Outside of their natural salinity ranges, aquatic animals must expend considerable energy on osmoregulation (the water and salt balance) at the expense of other processes, such as growth (ANZECC, 1999).

According to the ANZECC Draft Guidelines (1999) salinity tolerance varies significantly between species so no specific guidelines can be recommended. The ANZECC Draft Guidelines (1999) suggest interim trigger levels for assessing risks of adverse effects due to salinity (EC). This includes a $500 \mu\text{S.cm}^{-1}$ increase in lowland rivers, a $110 \mu\text{S.cm}^{-1}$ increase in upland rivers and a $60 \mu\text{S.cm}^{-1}$ increase for freshwater lakes and reservoirs. No data is provided for wetlands.

From a chemical and biological viewpoint there is no firm value to distinguish ‘saline’ from ‘fresh’ water: many important chemical and biological features of water show only gradual change with increasing salinity. However, aquatic ecologists have generally accepted a value of 3000 mg.L^{-1} TDS (Total Dissolved Solids) (approximately $5000 \mu\text{S.cm}^{-1}$) as conventionally dividing fresh from salt water. Waters with salinity above 3000 mg.L^{-1} TDS are typically inhabited by a distinct biota unlike that found in waters of lower salinity. Above 3000 mg.L^{-1} TDS, communities comprise only halo-tolerant (or saline tolerant) freshwater forms or forms restricted to saline waters, and both species richness and diversity decreases (GHD, 1999).

According to Hart *et al.* (1991) direct adverse biological effects are likely to occur in Australian river, stream and wetland ecosystems if salinity is increased to around 1000 mg.L^{-1} TDS (approximately $1500 \mu\text{S.cm}^{-1}$). The increase in the salinity levels of many of the northern rivers would be expected to have a significant impact on the biota. This would be either directly through the individual species’ salinity tolerance or indirectly through impacts on breeding/nesting areas or food sources.

There are considerable differences between the structures of biological communities in fresh and saline ecosystems, illustrated by differences in taxonomic composition, species richness and diversity (GHD, 1999). Salinity can be therefore regarded as a determinant (either directly or indirectly) of biological community structure in inland waters, with the degree of importance being dependent upon the complexity of the original community structure and salinity level (GHD, 1999).

Aquatic ecosystems are highly diverse and complex systems that do not lend themselves to simple management solutions (ANZECC, 1999). To apply a meaningful water quality guideline to a water

resource usually requires additional site-specific studies so that the guideline can be modified to suit the local condition (ANZECC, 1999).

8.2 Sensitivity of Aquatic Biota

8.2.1 Fish

Adult Australian freshwater fish are generally tolerant to salinities up to or greater than $\sim 10\,000\text{ mg.L}^{-1}$ TDS (approximately $15\,000\text{ }\mu\text{S.cm}^{-1}$). However, larval fish seem more sensitive than adults, and eggs more tolerant than larva (Hart *et al.*, 1991; Ryan *et al.*, 1999)

A study by Anderson *et al.* (1989) in the Wimmera River (Victoria), found that saline groundwater intrusion into lowland reaches of the river accumulated under low-flow conditions and formed stable ‘saline pools’. Water in these saline pools had conductivity up to seawater levels ($>55\,000\text{ }\mu\text{S.cm}^{-1}$) and led to salinity related density stratification. Stable stratification and associated severe hypoxia, rendered much of the water in the pools uninhabitable by fish and other aerobic organisms. The habitable area in many pools being confined to the upper layers and shallow pool margins.

Anderson *et al.* (1989) noted that environmental degradation from intrusions of saline groundwater from high regional water tables might also occur in the other rivers in the Murray-Darling Basin. Streams with extended periods of low flow, either naturally or from flow regulation, are most likely to be susceptible to environmental damage from saline water.

Further investigations on habitat degradation associated with saline stratification was undertaken by Ryan *et al.* (1999) in the Wimmera and Loddon/Little Murray Rivers (Victoria) and the Wakool River (New South Wales). Saline stratification (either directly from intrusion of saline water from groundwater aquifers or indirectly from the accumulation of saline water) can lead to the deoxygenation of the lower portion of the water column in low flow conditions and can effectively eliminate large volumes of aquatic habitat from aerobic biota (Ryan *et al.*, 1999). These highly saline and anoxic conditions beneath the stratification can, according to Ryan *et al.*, (1999), subsequently result in a decline in productivity and biodiversity. This investigation showed that without adequate flow saline stratification can form in rivers with conductivities as low as $1\,200\text{ }\mu\text{S.cm}^{-1}$.

Ryan *et al.* (1999) provides the available salinity tolerances of fish species (adults, larvae and eggs) utilised in the in-situ tolerance investigations.

8.2.2 Aquatic plants

Many aquatic plants are salt sensitive, with salinities of $1000\text{ to }2000\text{ mg.L}^{-1}$ (1500 to

3000 $\mu\text{S.cm}^{-1}$) likely to be lethal. Aquatic plants also exhibit many sub-lethal responses to increasing salinity including loss of vigour and reduced species diversity (Hart *et al.*, 1991). This was supported by James *et al.* (1993), who showed that a progressive depression of growth rate and plant size was observed in four species of freshwater aquatic plants (*Myriophyllum crispatum*, *Eleocharis acuta*, *Potamogeton tricarlinatus* and *Triglochin procera*) when grown at salinities greater than 1 000 mg.L^{-1} . *Phragmites australis* (common reed) tolerates slightly brackish, but not saline, water (Hart *et al.*, 1991). However, at elevated salinity, productivity features were found to decline including shoot height, density and dry weight, and probably the production of viable seed. This reduced the resistance of the reed bed to other adverse conditions such as wind, wave and 'current' action and fluctuating water levels (Hart *et al.*, 1991).

A relatively small group of plant species dominate temporary saline wetlands. The aquatic flowering plants that thrive are limited to salt marsh species on the terrestrial-aquatic ecotones of wetlands, as well as several species of two submerged aquatic genera *Ruppia* and *Lepilaena* (Boulton *et al.*, 1999; M Brock, pers. com., DLWC, Armidale).

Hart *et al.*, (1991) provide information on the salt sensitivity of some important aquatic plants in Australian inland streams (compiled from a variety of sources).

8.2.3 Riparian vegetation

Many species of riparian plants are salt sensitive, with adverse effects apparent at salinities above 2000 mg.L^{-1} TDS (3000 $\mu\text{S.cm}^{-1}$). Considerable variation in salt sensitivity can exist between populations of the same species (Hart *et al.*, 1991).

8.2.4 Waterbirds

Salinity tolerance varies greatly between waterbird species. Many waterbird species are able to feed in saline waterbodies. However, most must have fresh water nearby to drink (Hart *et al.*, 1991).

Where waterbirds are directly dependent upon aquatic plants (for nesting and cover) and invertebrates (for food) these groups are likely to be adversely affected at salinities well below those causing direct effects on waterbirds (Hart *et al.*, 1991).

The short-term impacts of increasing salinity may not be noticeable but, with time, there may be a shift in preferred breeding and feeding habitats as more salt-tolerant species dominate key wetland areas, or movement towards more suitable and existing habitats. This could result in changes in some waterbird species usage of an area.

Environments with salinities equal to, or higher than seawater, can be utilised by some wading birds (Hart *et al.*, 1991). In these situations it is not the salinity but other factors, such as food resources (which could be influenced by salinity) and water depths, that may be the determining factors.

For example, wetlands in the Paroo River Catchment support large numbers of some waterbird species in some years. Up to 10 times as many occur on a salt lake (such as Lake Wyara) as a freshwater lake (such as Lake Numalla), which appears to be related to the available food for different species of waterbird (Kingsford *et al.*, 1999). However, the presence of a freshwater lake could assist in providing water to drink whilst a salt lake provides the food source. The wetlands in the Paroo system could be seen as an example of how the future impacts of increasing salinity might apply to other systems within the Murray-Darling Basin.

8.2.5 Frogs

No studies of the salinity tolerance of tadpoles or frogs of any Australian native species have been made, so our understanding of salt tolerance in frogs must be based entirely on overseas studies (Hart *et al.*, 1991).

Published data on the impact of salinity on frogs in Australia is limited to investigations of adult *Bufo marinus* (Cane Toad, an introduced species). There is evidence from overseas studies that a difference in susceptibility to salinity is common both within and between species. However, in general, frogs are not adapted to life in saline environments (Ferraro *et al.*, 1993). Indeed Hart *et al.*, (1991) suggest that tadpoles and amphibian egg-masses might be sensitive indicators of salinity increases in wetlands.

8.2.6 Invertebrates

Information on the salt tolerance of freshwater invertebrates is sparse. However, according to Hart *et al.*, (1991), it is clear that in freshwater invertebrates, factors such as 'condition', degree of acclimatisation, life stage and temperature can all influence sensitivity to salinity increases.

Invertebrates seem to be amongst the most sensitive of freshwater animals to increases in salinity, with adverse effects apparent for some species at salinities as low as 1 000 mg.L⁻¹ TDS (1 500 µS.cm⁻¹) (Hart *et al.*, 1991). The most sensitive groups are simple multi-cellular organisms, and certain groups of insects and molluscs.

Hart *et al.*, (1991) provide information on the salt sensitivity of some important invertebrate groups in Australian inland rivers (compiled from a variety of sources).

8.2.7 Other species

Nothing is known of the salt tolerance of the platypus (*Ornithorhynchus anatinus*). The water-rat (*Hydromys chrysogaster*), likewise, has been little studied in this respect, but since it occurs in fresh, brackish and even marine situations, its tolerance to salt is highly clear (Hart *et al.*, 1991).

Freshwater turtles may be able to cope with increasing salinity levels to some extent, especially if salt glands are found in species other than the eastern long-necked turtle (*Chelodina longicollis*). Where salt glands are absent, the length of time that turtles can survive may be limited, especially in juveniles and smaller species (Hart *et al.*, 1991).

8.2.8 Implications

The period of acclimatisation can also influence the tolerance of individuals. Generally, the longer an animal has been acclimatised to a particular salinity regime, the more it may tolerate higher salinity levels (Hart *et al.*, 1991). This matter is particularly important in considering situations where pulses of saline water discharge into freshwater environments (Hart *et al.*, 1991). This would also apply where rapid variations in salinity occur.

GHD (1999) concluded that many plants and animals typical of fresh waters in the River Murray are able, at least for short periods, to tolerate salinities which exceed 3000 mg.L^{-1} TDS ($5000 \mu\text{S.cm}^{-1}$). According to Hart *et al.*, (1991) it is suggested that direct adverse biological effects are likely to occur in Australian river, stream and wetland ecosystems if salinity is increased to around 1000 mg.L^{-1} TDS ($1500 \mu\text{S.cm}^{-1}$).

However, the ability of individuals (often adults) to tolerate elevated salinities for short periods should not be taken as indicating that the species to which they belong can maintain viable populations at those salinity levels over the long term. Sub-lethal effects, differential survival abilities according to age (juveniles are often less tolerant than adults), a lack of halo-tolerance in food species, and other factors may combine to extinguish populations at elevated salinities (GHD, 1999).

It should be noted, however, that there is no simple threshold below which the impact of salinity is benign, or above which the impact is unacceptable. The impacts are by degree, and establishing that degree is hampered by natural variability within both the species and the system (B. Lawrence, pers. com., Murray-Darling Basin Commission).

8.3 Water Quality Implications

Increasing salinity levels within streams may influence other aspects of water quality. These include:

- High salinity levels within streams can cause flocculation of sediments and thus reduce turbidity. This may lead to increased algal growth because of increased light penetration through the water column (DWR—1993/4 Darling River Salinity—Algae Pilot Study).
- Salinity directly affects the level of dissolved oxygen: the higher the salinity, the lower the dissolved oxygen level at a given water temperature. (ANZECC, 1999).
- Salinity also affects the temperature requirements of some species. There is, however, a lack of understanding of temperature-salinity interactions and the effects of changing the ionic ratios for many species (Tomasso, 1993 in ANZECC, 1999).
- Saline stratification (either directly from intrusion of saline water from groundwater aquifers or indirectly from the accumulation of saline water) can lead to the deoxygenation of the lower portion of the water column in low flow conditions, and can effectively eliminate large volumes of aquatic habitat from aerobic biota (Ryan *et al.*, 1999). These highly saline and anoxic conditions beneath the stratification can, according to Ryan *et al.*, (1999), subsequently result in a decline in productivity and biodiversity.
- In a review of literature on the influence of salinity on the toxicity of various classes of chemicals to aquatic biota, Hall *et al.*, (1995) found that there was generally no consistent trend for the toxicity of most organic chemicals with salinity. The one exception to this was reported with organophosphate insecticides, the toxicity of which appeared to increase with increasing salinity (Hall *et al.*, 1995).

8.4 Impacts on End of System Wetlands

8.4.1 Wetland impacts of increased salinity levels

Wetlands affected by in-stream salinity levels vary from terminal systems (where water enters and is trapped in-situ) to flow through systems (where the water level of the flood flow maintains the water height in the wetlands). Often wetlands can be considered partly terminal (the area of the depression which holds water when flood flows recedes) and partly flow through systems.

The implications of salinity levels are more important when water is trapped in the wetland and under evapo-transpiration the water quantity is reduced whilst the salinity concentration increases. This can lead to extremely high salinity levels occurring in the wetland and to the central (or deeper) areas of the wetlands having critical salinity levels for remaining aquatic biota. These effects can lead to severe salt scalding within a wetland, and to a buildup of salt within the wetland system if flushing does not occur in subsequent flooding or filling events. These areas if flushed could also be

considered as salt sinks on the floodplains that during subsequent floods add to the salinity levels in the floodwaters.

If the 'current' flood flow salinity levels are increased even slightly by contributions from dryland salinity, then the implication to floodplain wetlands could be significant. A change in flood flow salinities from 500 to 750 $\mu S.cm^{-1}$ may not appear to impact on a range of biota. However, if the concentration rate of salinity within a wetland was (for example) 2.5, then at 500 $\mu S.cm^{-1}$ this would lead to salinity levels within the wetland to approach 1250 $\mu S.cm^{-1}$. At this level some changes might be expected to be detected in the biota. However, at 750 $\mu S.cm^{-1}$, this would lead to salinity levels of 1875 $\mu S.cm^{-1}$, at which level changes in the biota may become significant. Warwick *et al.* (1996) indicate that in Victoria, a wetland of 2 $mg.L^{-1}$ can reach 6 $mg.L^{-1}$ by the end of summer, which supports these concentrating rates.

However, it needs to be reinforced that there is no simple threshold below which the impacts of salinity are negligible or above which the impacts are significant. The impacts are by degree, and establishing the degree is complicated by natural variability within both the species and the system. This can be further complicated by other water quality parameters (e.g. dissolved oxygen) or life stage of the species.

The interaction of wetlands with groundwater is not clearly understood. In some locations, there may be a direct connection between river and groundwater levels, whilst in other areas this may not occur. Groundwater mounds (caused by a range of factors) could be influencing the water source of particular wetlands and either directly contributing water (and hence salinity) into the wetland or preventing the water from entering the natural groundwater and causing salinity levels to increase as the water is concentrated under evapo-transpiration.

8.4.2 The Great Cumbung Swamp

Although the Great Cumbung Swamp is considered a terminal basin, the salinity within the wetland is not significantly higher than in the inflowing waters from the Lachlan River. This is generally explained by the seepage of water into the underlying shallow groundwater aquifer. This results in the subsequent leaching of salt from the root zones. This process appears to have been operational during the period of the swamp's development and maintenance.

The average annual salinity levels for the terminal wetlands of the Lachlan (based on the Forbes gauge) is expected to rise from 530 $\mu S.cm^{-1}$ to 1 460 $\mu S.cm^{-1}$ in the year 2100, as a result of dryland salinity alone (see Section 6.7). This exceeds the ANZECC (1999) trigger levels of 500 $\mu S.cm^{-1}$ increase. Other factors may also lead to increasing salinity levels in this area. Based on monthly salinity levels, the probability of flow exceeding 1600 EC in the Lachlan at Forbes changes from 0%

in 1998 to 13% in 2100. This means that if 1600 EC is taken to be the level at which significant changes may occur to the biota (noting that changes will occur below this level) then for 13% of the time (or approximately one and a half months per year) that would adversely affect the Great Cumbung Swamp. Daily or weekly variations in salinity levels could also be significant depending on flow regime and source of saline inputs.

The impact on the Great Cumbung Swamp, given these average variations, could be a potential change in species composition (particularly in the aquatic plant communities) and reduction in species diversity. The Common Reed (*Phragmites australis*) would appear to continue to exist in the swamp given the salinity levels expected. However, the area's suitability as a habitat for specific waterbird breeding (particularly for colonial species that rely on fresh water for drinking and invertebrates for feeding) could be reduced.

This would change significantly if the groundwater mound in the area prevented further seepage into the groundwater and led to the area becoming a truly terminal system with increasing salinity concentrations due to evapo-transpiration.

The impact of increasing salinity on the groundwater requires further investigation. The long term potential for groundwater within parts of the swamp, to rise to levels, that effectively reduce or reverse the 'current' leaching of salt, should be urgently assessed since this appears to be the greatest threat to conservation of the 'current' wetland values.

8.4.3 The Gwydir Wetland

The Gwydir Wetlands could be considered a flow through system as opposed to a terminal basin during floods and the impacts will probably be localised to individual areas within the system as the water evaporates and salinity is concentrated into pools or depressions.

The expected average annual salinity levels for the Gwydir River entering the Gwydir Wetlands are expected to rise from 560 $\mu S.cm^{-1}$ to 740 $\mu S.cm^{-1}$ in 2100 (see Section 6.3). Based on monthly salinity levels, the probability of flows exceeding 1600 EC in the Gwydir at Pallamallawa changes from 3% in 1998 to 12% in 2100. This means that if 1600 EC is taken to be the level at which significant changes may occur to the biota (noting that changes will occur below this level) then for 12% of the time (or approximately one and a half months per year) that flows would adversely affect the Gwydir Wetlands. Note that daily or weekly variations in salinity levels could also be significant depending on flow regime and source of saline inputs.

This rise in salinity levels, although not significant in the context of annual average salinity level, appears to be significant in the context of the probability of exceedance of the 1600 EC levels (3% to 12%). This would occur predominantly in low flow situations and would have impacts on the

instream biota. Given these values there could be a potential change in species composition (particularly in the aquatic plant communities) and reduction in species diversity.

The high salinity levels if allowed to enter into the wetland areas would also lead to increasing salinity within wetlands, with potential salt scalding occurring in areas as the saline waters are further concentrated. Again, the long-term groundwater level condition needs to be assessed with respect to opportunity for downward leaching of residual salt.

8.4.4 The Macquarie Marshes

The Macquarie Marshes are a predominantly flow through system as opposed to a terminal basin and the impacts will be localised to individual areas within the system as water is concentrated into pools or depressions and evaporates leaving the salt behind.

The expected average annual salinity levels for the Macquarie River on entering the Macquarie Marshes is expected to rise from $620 \mu S.cm^{-1}$ to $2110 \mu S.cm^{-1}$ in the year 2100 (see Section 6.6). This exceeds the ANZECC (1999) trigger levels. Based on monthly salinity levels, the probability of flow exceeding 1600 EC (#) in the Macquarie River at Narromine changes from approximately 4% in 1998 to 23% in 2100. This means that if 1600 EC is taken to be the level at which significant changes may occur to the biota (noting that changes will occur below this level) then for 23% of the time (or approximately three months per year) that flows would adversely affect the Macquarie Marshes. This could be assumed to occur in low flow but could still significantly affects instream biota (and hence the recruitment of biota into and between wetland areas).

This would have a significant impact on the Marshes with expected loss of species diversity and composition (which would begin to be impacted at $1600 \mu S.cm^{-1}$ or lower, beginning in 2020 or later). The high salinity levels would also lead to increasing salinity within wetlands isolated from the main river channel with potential salt scalding occurring in these areas as the saline waters are further concentrated. One implication of this change in salinity levels in the Macquarie River could be that the 'current' 50 GL environmental water allocation for the Marshes might have to be used for water quality control for flushing these saline areas if they occur.

8.4.5 Other wetlands (both floodplain and upland areas)

Impacts on floodplain wetlands may differ significantly from the upland wetlands depending on the time of filling, maintenance flows and salinity levels entering these systems. Where groundwater with high salinity is directly discharged into upland wetlands that previously received fresh inflows, the impacts may be significant compared to the inflow of flood flows (with lower salinity levels) into the

floodplain wetlands. Nevertheless, these floodplain wetlands may still attain high salinity levels if they do not fully drain.

8.5 Further Research Needs

GHD (1999) concluded that the biota of the Murray River most at risk was that of floodplain water bodies and that a comprehensive investigation of the aspect is warranted and should be undertaken with some urgency. Such a comprehensive investigation should, according to GHD (1999), include the following aspects:

- More comprehensive, rigorous and focused field and laboratory investigations to determine the halo-tolerance of 'keystone' plant and animal species in the river and associated wetlands.
- Investigation of the importance of salinity as a determinant of biological structure in aquatic ecosystems.
- Identification and assessment of appropriate management options to maintain floodplain wetlands as ecologically sustainable ecosystems.

Ryan *et al.*, (1999) recommend that all life history stages of fish species should be investigated for salinity tolerance and low dissolved oxygen levels, especially the eggs and larvae of those species that appear to be sensitive or are in decline (such as silver perch, freshwater catfish and trout cod).

This was also raised in Hart *et al.*, (1991), where it was identified that, because of the considerable uncertainty in the scientific information used to assess the effects of salinity increase on lowland river and wetland ecosystems, detailed biological studies should be mandatory in all cases.

Particularly where salinity control measures are proposed that could lead to increase salinity in a receiving river, stream or wetland.

The ANZECC Draft Guidelines (1999) recommend that targeted research be commissioned to investigate the sub-lethal and long-term effects of change of salinity on key wetland and lowland river plants and animals.

Other research needs include:

- Cross section sampling of wetlands to check salinity distribution, and
- Better understanding of wetland/groundwater relationships, including predictions, for all significant wetlands
- That a comprehensive database be established and maintained detailing the salinity tolerance of different biota (as this information becomes available) and that this database be well publicised

between researchers and managers (further to recommendations from Centre for Stream Ecology, 1989).

It should be noted that some work is currently being finalised at Monash University (under Paul Bailey, pers. com., Department of Biological Science) for the Land and Water Resources Research and Development Corporation. This involves the review and implication of salinity impacts on riverine and aquatic biota. A salt sensitivity database for aquatic biota is also being developed as part of this work and is nearing finalisation for known species salt tolerance.

The following conversion of TDS to EC was adopted for interpretation.

In GHD (1999) 1 TDS in water ($mg.L^{-1}$) = 0.6 * EC ($\mu S.cm^{-1}$)

In Hart *et al.*, (1991) 1 TDS in water ($mg.L^{-1}$) = 0.68 * EC ($\mu S.cm^{-1}$).

In Sections 5 and 6 1 TDS in water ($mg.L^{-1}$) = 0.64 * EC ($\mu S.cm^{-1}$)

However, for the purpose of this section (due to variations in conversion factors between authors) the following conversion was adopted for ease of interpretation in Sections 8.4, and 8.5.

For TDS in water $1\ 000\ mg.L^{-1} = 1600\ \mu S.cm^{-1}$ (or $0.625 * EC$)

9 Discussion

9.1 Overview

This is the first study to provide comprehensive predictions of in-stream salt load and salinity for the major river valleys in the NSW portion of the Murray-Darling Basin under ‘current’ and likely future conditions at 2020, 2050 and 2100. The study provides a realistic assessment of salt contribution to streams from second and third order catchments for the whole of the NSW portion of the Murray Darling Basin. Rates of groundwater level rise from bores in each geological unit for each second order catchment are used as a basis of estimating the salt load delivered to the ground surface at the target dates that is potentially available for washoff to streams. In-stream salt balances are established for each second order catchment and coupled with the potential salt load to predict the rate of change in salt export. The assessment period 1975–95, adjusted for cap flow condition, is used to establish the ‘current’ salt balance and predict likely patterns of salt export at target dates on a monthly basis.

The salt loads and salinities in all second order catchments, with the exception of the Macintyre River Catchment, are rising at rates that vary between geologies. The groundwater assessment suggests that there is no expected change for the Macintyre River component of the Border Rivers system.

However, salt entering from the Gwydir Catchment through Carole Creek is expected to increase the average annual salt load from 106 000 $t.year^{-1}$ in 1998 to 109 000 $t.year^{-1}$ by 2100. Changes in average annual salt load between 1998 and 2100 under the MDBC cap conditions for the Gwydir, Namoi, Castlereagh, Macquarie, Bogan, and Murrumbidgee are expected to increase from 12 000 to 17 000 $t.year^{-1}$, 135 600 to 312 100 $t.year^{-1}$, 20 000 to 41 000 $t.year^{-1}$, 44 000 to 154 000 $t.year^{-1}$, 34 000 to 111 000 $t.year^{-1}$, and 184 000 to 286 000 $t.year^{-1}$ respectively. The associated changes in average annual salinity for the Gwydir, Namoi, Castlereagh, Macquarie, Bogan, and Murrumbidgee are expected to increase from 560 to 740 $\mu S.cm^{-1}$, 680 to 1550 $\mu S.cm^{-1}$, 640 to 1230 $\mu S.cm^{-1}$, 620 to 2110 $\mu S.cm^{-1}$, 730 to 2320 $\mu S.cm^{-1}$, and 250 to 400 $\mu S.cm^{-1}$ respectively. Much higher salinity is expected in these rivers on an individual monthly basis. The Lachlan River flows into the Murrumbidgee only during floods of approximately 1 in 20 years ARI or greater, and is generally considered a terminal system. Salt loads assessed at Forbes increase from 227 900 to 552 550 $t.year^{-1}$ and salinity is expected to increase from 530 to 1460 $\mu S.cm^{-1}$.

The highest rising trends in salt load and in-stream salinity are identified as being in the Macquarie-Bogan system. However, the highest salt loads in future are expected to be in the Namoi followed, respectively, by the Murrumbidgee, Macquarie-Bogan, Border Rivers, Castlereagh and Gwydir.

For all second order catchments, the accuracy of the salt balances improves from the first to the last balance point. Lumping of inputs tends to compensate for the three possible sources of error. These sources include water balance errors introduced from modelling of residual area inputs and losses, regional estimation of the stochastic model parameters for determining the salt load from residual areas, and high levels of sampling variance associated with flow and EC data particularly in the north of the State. The influence of seasonality affects the choice of model used for determining daily salt load. The Murrumbidgee in the south shows marked seasonality in flow and EC, but a greater influence of summer dominant rainfall in the north produces flashy peaks in flow and salt washoff making the inclusion of the seasonal component somewhat redundant.

Beyond the last balance point for all catchments, diversions for irrigation substantially reduce the salt loads in the main streams. In the Murrumbidgee, which under 'current' conditions carries the highest salt load in the State, about 30 to 67% of monthly average salt loads are diverted into the irrigation areas depending on demand. In this study, diversions are assumed to reduce salt loads at the end of system but not salinity. This is based on the premise that the irrigation areas are acting as a sink for some of the exported salt downstream of the last balance point. Changes in the hydrologic balance for these areas may mean that they eventually become an increasing source of salt via irrigation returns to the lower end of the system. The combination of high salt loads adding to this sink and rapidly deteriorating water quality used to flush salts away from the root zone may substantially limit production of crops for all irrigation areas outside of the Murrumbidgee.

The prediction of future in-stream salt loads is dependent on the validity of the groundwater derived potential salt load estimates and the assumption that rates of in-stream change are proportional to the increase in salinised land area and salt delivery from the rising groundwater table. The small number of bores available in particular geologies and catchments with sufficient temporal record for making an assessment of the rate of rise is of particular concern. In many cases less than ten bores are available in a geological unit within a second order catchment. The assessment of the area salinised using only the bores without being able to account for topography and additional recent data, which may be available for improved spatial coverage, is also of concern.

Although the surface water database is more comprehensive, the scant availability of EC data particularly in the northern rivers of the basin owing to high sampling variance is of concern. The Murrumbidgee is the only catchment in the study where continuous salinity data is comprehensive enough during the assessment period on which various model formulations were extensively tested before implementing these across the State. The study highlights the need for improved monitoring network design and increased sampling frequency. Monitoring at certain key locations was discontinued during the 1975 to 1995 assessment period causing further difficulty in accurately establishing salt balances.

9.2 Strengths

Despite limitations the study draws strength from the rigorous manner in which the groundwater trends and salt washoff are coupled. The objective handling of the in-stream salt balances provides a comprehensive improvement on the first cut estimates from the groundwater study. The methodology takes into account the scale of the problem by using the third order catchment as the basic unit and handling salt estimation daily and the salt balance monthly. For the first time, salt contributions from each third order catchment in the NSW component of the Murray-Darling Basin are estimated, aiding prioritisation of catchments for remediation. As more salinity data of better quality becomes available with time, the salt export rate from third order catchments will improve. The salt export rates from these third order catchments should be interpreted as a synthesis of salt mobilisation and runoff mechanisms. Further analysis may reveal third order catchments with high salt mobilisation but low levels of salt washoff with implications for soil salinity.

9.3 Additional Perspective on using the CATSALT Model

Comparison of the statewide assessment of rates of change with those produced by the CATSALT model for Kyeamba Creek at Ladysmith suggests that salt washoff from non saline soils accounts for a substantial proportion of the current in-stream salt load. Increasing areas of land salinisation are expected to contribute proportionally more of the salt load as time progresses but CATSALT suggest that the rates of change in the early part of the coming century may be slower than indicated otherwise. CATSALT results for Kyeamba Creek also indicate that uncertainties in the results of the statewide study are greater for 2020 than for the 2050 and 2100 estimates.

The study in its present form makes no general assessment of the impact of land use change on either the salt mobilisation or washoff mechanisms contributing to the in-stream salt load. However, a comparison of in-stream salt loads expressed in tonnes per square kilometre, between two third order catchments in the Murrumbidgee (Tarcutta Creek and Kyeamba Creek) suggests that land use differences are playing a significant part. Both catchments have similar geology, soil landscapes and rainfall, although they are substantially different in size. The catchment of Tarcutta Creek on the one hand has approximately 32% of the land area covered in forest. On the other hand the Kyeamba Creek has only approximately 6% forest. The remainder of both catchments is predominantly pasture. Kyeamba Creek is producing approximately twice the salt load per square kilometre observed in Tarcutta Creek.

Further improvement of the estimates obtained in this study could be gained using a tool that incorporates topography to estimate the salinised area, and that includes the effects of land use and salt transport mechanisms at a third order catchment scale instead of CATSALT. To be useful at a

third order catchment scale, such a tool should be quasi-physical and semi-distributed in nature, and should allow for feedback from more intensive process based mechanistic hydrologic models. Such an approach would allow salinity management options with implications for water quality in rivers to be investigated in detail. The development and successful implementation of the CATSALT model on the Kyeamba Creek Catchment, as a sub-component of this project is a step in this direction. Difficulties were encountered in fulfilling data requirements for salinity hazard mapping on a third order catchment scale on which CATSALT depends for assessment of the hazard potential. Any robust tool that accounts for topography and has less stringent data requirements for assessment of the hazard potential will be a necessary pre-requisite before CATSALT can be implemented on a statewide basis.

9.4 Data Availability and Resolution

The scale of mapping used in the study is appropriate given the limited spatial coverage of the groundwater level data. However, finer resolution data sets for soil and geology coupled with digital terrain analysis in a GIS framework is desirable for further analysis of salinity hazard at the third order catchment scale. There is also a pressing need to augment the existing groundwater level data with the additional data from existing and new bores installed since the reconnaissance survey. This would help not only in improvising the groundwater level rise trends, but also in better assessing the areas currently influenced by salinity. Additional in-stream salinity monitoring stations are required at strategic locations and some discontinued stations need to be re-commissioned.

9.5 Variability of Salinity

This study is also the first to present comprehensive details of the salinity status of NSW rivers in more than just average annual or median terms. Further, as this study attaches robust estimates of salt loads across the full range of flows observed in the rivers, the averages given are a better estimate of central tendency than published values based on the median or average of a limited number of discrete samples. The analysis of exceedance probabilities for threshold salinity values of 800 and 1600 EC for all third order catchments and mainstream reaches is a major step forward in evaluating the likely impacts of dryland salinity on irrigated agriculture, town water supplies and the health of wetland ecosystems.

9.6 Town Water Supply Impacts

Salinity impacts on towns can be divided into at least three distinct categories:

- Water supply quality;
- Built infrastructure damage, and;

- Loss of environmental amenity.

In terms of the first, the river salinity predictions in this report may be interpreted against the ‘current’ extractions from rivers, creeks and even bores that extract from aquifers, which recharge rapidly from rivers.

Many towns and industries already use groundwater as their main supply, some are connected to systems that have the ability to mix surface and groundwater or switch from one to the other. A few towns rely on local catchment runoff for which this study does not provide information other than an indication of that catchment’s potential to become saline. Some of these groundwater supplies are likely to exceed the WHO salinity limit of 800 EC units, and there is no doubt that there is tolerance to exceed this limit by adaptation to a level as high as 1500 EC units. However, there will be costs associated with such acceptance.

Table 1 in Appendix 7 lists towns with 500 or more people that depend at least partly on surface water supplies and the expected change in average annual salinity of their supply from good to poor to non potable at the benchmark dates of this study. It should be noted that this categorisation is indicative only and that obviously seasonal variability in salinity values, ability to store fresh flushes and access to good quality groundwater will determine for each case when supplies become untenable.

As salinity increases there will be increased cost through corrosion of infrastructure and industrial and domestic appliances as well as the cost of adaptation (e.g. use of plastics, construction of borefields or storages, purchase of fresh water for sensitive applications, etc).

In terms of damage to urban infrastructure and environmental amenity, from rising groundwater and soil salinity, this study indicates only which catchments are expected to experience increased incidence of shallow water tables. Urban salinity is a groundwater imbalance condition caused mainly by inappropriate but otherwise fairly standard water use practices, and it is to be expected that many towns in apparently low hazard catchments will nevertheless experience waterlogging and salinity problems before the general catchment does.

It should be noted that it is not necessary to have very high salinity concentration in these water logged areas to experience much of the damage to foundations, roads, pipelines, sporting fields and parks, gardens, wetlands, etc., that generates most of the cost and loss of urban salinity. The ‘urban salinity’ column, in Table 1, Appendix 7, is not intended to be a complete assessment of current salinity status or salinity hazard. It is simply an indication of the already widespread occurrence of urban salinity which, in view of the groundwater rise trends identified in this study, can only get worse if it is not specifically and proactively addressed.

9.7 Irrigation Impacts

While irrigated crops exhibit a fairly wide range of tolerances to salinity (e.g. horticulture low tolerance and cotton and rice high tolerance), there are other factors such as irrigation method, soil properties and growth stage (some highly tolerant crops are susceptible in the germination and seedling stage) that will strongly affect the tolerance in each situation. Conservatively, the same threshold used in this report to identify the danger level for urban water supply quality (800 EC) can be used for irrigation. In irrigation both the seasonal average and the risk of extremes (spikes) during the season are important as the former determines longer term accumulation and the latter can cause instant crop damage response.

Generally speaking, as river salinity increases over time, irrigators will start to experience difficulty with gradual salt build-up in their soils. This is generally controlled by applying a degree of over irrigation (leaching fraction) to flush salt below the root zone. This practice may contribute to accelerated groundwater level rise and the risk of bringing the accumulated salts back to the surface in non-irrigated and lower lying sections of the landscape. In the past this scenario has always led to calls for introduction of drainage and river disposal of salt. The irrigation industry will no doubt develop more salt tolerant crop varieties but this will inevitably lead to greater salt accumulation in the landscape. Ultimately, abandoned irrigated lands will leave a legacy of vast salt stores at or near the surface. At 800 EC, approximately 500 kg of salt is contained in every megalitre of irrigation water and at 1600 EC the rate is 1 tonne per megalitre. The amount of water used varies between crops and with the efficiency of individual irrigators.

In many cases irrigation will experience difficulties with high salinity spikes before impacts of long term accumulation are realised. Irrigators will seek to avoid such spikes, which means these will be passed on downstream, and there will a tendency to build more and larger on-farm storages to intercept fresher flows. If that is allowed to happen in the more upstream sections of river systems, there could be very serious environmental consequences in the unregulated stressed and semi stressed river sections.

It is also conceivable that water users will start challenging water access rules volumetric allocation when their access to water is restricted on the basis of unsuitable quality. They could demand dilution flows on regulated rivers and compensating changes in access rules on unregulated rivers. If allowed, these actions would lead to lower reliability for all users including erosion of environmental flows.

In areas where large-scale groundwater pumping controls groundwater levels and provides downward leaching of salts, conditions for sustained irrigation conjunctive with relatively saline surface water supplies would appear to be an option. However, insufficient research has been done to assess the very long-term reliability of water quality in these deeper aquifers.

Where salinity becomes so high that irrigation has to be abandoned, the otherwise diverted volume would be returned to the river, causing salt loads to move downstream and making dilution of downstream supplies more difficult. In trying to preserve irrigator water entitlements, transfers to fresher within valley or inter-valley river sections would be sought. This, of course, would accelerate degradation of quality and volume for downstream users in those rivers. Given these bleak scenarios, the irrigation industry would have to include consideration of investment in salt containment at source, i.e. in upstream dryland catchments, among their response options.

The toxicity of some agricultural chemicals is also known to increase when mixed in saline water. Conversely some are rendered less effective. Patterns of chemical use and exposure risks to the environment and humans may possibly change.

Given these bleak scenarios, the irrigation industry would have to include consideration of investment in salt containment at source, i.e. in upstream dryland catchments, among their response options.

9.8 Wetland Impacts

This report identifies that the current knowledge of salinity impacts on the Australian stream and wetland biota is not well known, based on reviews by Hart *et al.*, (1991) and GHD (1999). It could be assumed that in some catchments the impacts of the increase in salinity levels on the biota could be significant. However, the actual impacts would be difficult to predict given the time frame over which this increase would occur and the variation in extreme salinity levels in these streams.

The need for further investigations of the salinity tolerance (both sub-lethal and lethal levels) for Australian biota is an urgent research need for use by land and water resource managers (both within government agencies and the community). This research however, must have an applied interpretation to address current and future land and water management issues. The interaction with other confounding factors (e.g. changing water regime within a wetland and its interactions with changes in the salinity levels; impact of land management activities including vegetation removal on salinity levels) also requires detailed investigations. This is discussed in more detail in Section 8.5.

10 Conclusions

This is the first study in NSW to combine groundwater trends and groundwater derived salt loads with in-stream salt load data in an objective manner on a statewide basis. The rates of groundwater rise and the associated salt load delivered to the land surface for each geology in each valley have been established. The in-stream salt balances for each second order valley (e.g. Namoi) are established using third order catchments as the basic units, which provides an appropriate scale for prioritising catchments for implementing management decisions to control the likely adverse effects of dryland salinity. Estimates of the ‘current’ and likely salt export rates at target dates from third order catchments across the State are based upon the ‘do nothing’ scenario and are not related to the effects of land use.

A quasi-physical salt balance model, CATSALT, has been developed and successfully implemented on the Kyeamba Creek Catchment, a third order catchment in the Murrumbidgee, to establish the salt balance on a daily basis. CATSALT models the transport of salt from the land surface to the stream in washoff including surface runoff, shallow sub-surface through flow and groundwater runoff using estimates of the area affected by soil salinisation derived from projected ground-water contours and areas of salinity hazard. The model can be coupled with process models to examine land use scenarios at a third order catchment scale. Model simulations indicate that the rates of change in in-stream salt load established in the statewide methodology are robust particularly in the longer term for Kyeamba Creek.

This study is also the first to present comprehensive details of the salinity status of the NSW rivers in more than just annual average or median terms. The analysis of exceedance probabilities for threshold salinity values of 800 and 1600 EC for all third order catchments and mainstream reaches is a major step forward in evaluating the likely impacts of dryland salinity on irrigated agriculture, town water supplies and the health of wetland ecosystems. Assessment of the salt load redistributed in the landscape through irrigation diversions has also been made for each valley in the NSW component of the Murray Darling Basin. Towns with more than 500 people affected currently by adverse water quality and those likely to be affected in future have been identified for taking appropriate remedial actions. A general assessment of the impact of increasing trends in salt load and stream salinity on wetlands has also been undertaken (e.g. the Great Cumbung Swamp, the Gwydir Wetlands and the Macquarie Marshes).

11 Recommendations for Further Work

Recommendations for further work are based on consideration of the limitations of this study together with the strategic need to address the primary issues relating to dryland salinity on a statewide basis. The recommendations are:

- Improve the estimate of areas likely to be salinised and the rates of groundwater table rise by including the effects of topography using the 25 m Digital Elevation Model (DEM) that is now available in DLWC. Additional bore data held by the Regions, over and above the existing 1560 bores used in the ‘current’ analysis, should be included in an enhanced study.
- The assumption that the rate of groundwater table rise is linear and that it will continue to rise at the same rate even after reaching the near soil surface (less than 2 m depth) should be corrected using process modelling for a variety of soil types and land use. The use of synthetic stochastically generated climate series (50 years or more) should also be investigated to assess the implications for rates of rise of groundwater tables, within the bounds of possible long-term climate variability and change.
- Estimates of the ‘current’ and likely future salt export rates at target dates from the third order catchments all across the State are based upon the ‘do nothing’ scenario and are not related to the effects of land use. Future studies of this nature should relate the established current salt export rates to land use and also assess the impact of changes in land use on the likely salt export rates at the required target dates i.e. 2020, 2050 and 2100.
- The current study is based on the in-stream salt balances in second order rivers (*using third order streams as the basic aggregation unit*). Balances are established for ‘current’ conditions independent of the groundwater analysis. The study does not include salt balance on a third order catchment scale where the groundwater delivery of salts to the surface, consequent soil salinisation and salt transport to the stream from washoff with surface runoff and with groundwater runoff are coupled. Results from full implementation of the CATSALT model on the Kyeamba Creek Catchment, which includes all these processes, are very encouraging. However, the Salinity Hazard Mapping, on which CATSALT depends for assessment of the hazard potential, needs to be replaced with a tool that is more robust and has less stringent data requirements, before CATSALT can be applied on a statewide basis.
- Soil salinity profiles and their spatial variation, which form an integral part of the stream salinity and groundwater interactions, should be obtained for some data rich catchments in all major valleys. Further analysis of the processes of soil salinisation and mobilisation to the river systems will require detailed soils information.

- A monitoring program for collecting continuous salinity data and ion balance analysis should be initiated by all Regions using the appropriate protocols at least at all stations in each valley used for establishing in-stream salt balance (Section 5). Studies similar to the one currently being undertaken in the Macquarie River basin by DLWC through an NHT funded project should be undertaken in all major valleys in NSW.
- The impact of redistribution of salt loads on irrigation areas through diversions, including the investigation of the likely shift in hydrologic balance, should be investigated under a separate project.
- There is a clear need for applied research to investigate the salinity tolerance of Australian biota and the impact of increasing salinity on wetlands, to support addressing natural resource management issues.

12 References

- Allison, G.B. and Schonfeldt, C.B. (1989). Sustainability of water resources of the Murray-Darling Basin, 12th invitation symposium: Murray-Darling Basin — a resource to be managed., *Australian Academy of Technological Sciences and Engineering*, reprint No 8: 149–161.
- Anderson, J.R., and Morison, A.K. (1989). Environmental consequences of saline groundwater intrusion into the Wimmera River, Victoria. *BMR Journal of Australian Geology and Geophysics*, 11: 233–252.
- ANZECC (1999). National water quality management strategy—Draft Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.
- Beven, K.J. and Kirkby, M.J. (1979). A physically-based variable contributing area model of basin hydrology. *Hydrol. Sci. Bull.*, 24(1–3): 43–69.
- Bish, S. and Gates, G. (1991). Groundwater reconnaissance survey Forbes-Condobolin-Lake Cargelligo. Department of Water Resources, NSW, TS 91.033.
- Bish, S. (1993). Groundwater reconnaissance survey Gunnedah-Narrabri-Coonabarabran Area, NSW. Department of Water Resources, NSW, TS 93.034.
- Blackburn, G. and McLeod, S. (1983). Salinity of Atmospheric Precipitation in the Murray-Darling Drainage Division, Australia. *Aust. J. Soil Research*, 21: 411–434.
- Boulton, A.J., and Brock, M.A. (1999). Australian freshwater ecology: processes and management. Gleneagles Publishing, Adelaide.
- Box, G.E.P. and Jenkins, G.M. (1976). Time series analysis, forecasting and control. Holden Day, California.
- Bradd, J.M., Milne-Home W.A., and Gates, G.W.B. (1997). Overview of factors leading to dryland salinity and its potential hazard in New South Wales, Australia. *Hydrogeology Journal* 5 (1): 51–67.
- Bradd, J.M. and Gates, G.W.B. (1995). The progression from site investigations to GIS analysis to map dryland salinity hazard in NSW. Murray Darling 1995 Groundwater and the Community workshop. AGSO Record No. 1995/61: 50–55.
- Centre for Stream Ecology (1989). Biological effects of saline discharges to streams and wetlands. Report prepared by Centre for Stream Ecology, Chisholm Institute of Technology, Melbourne.

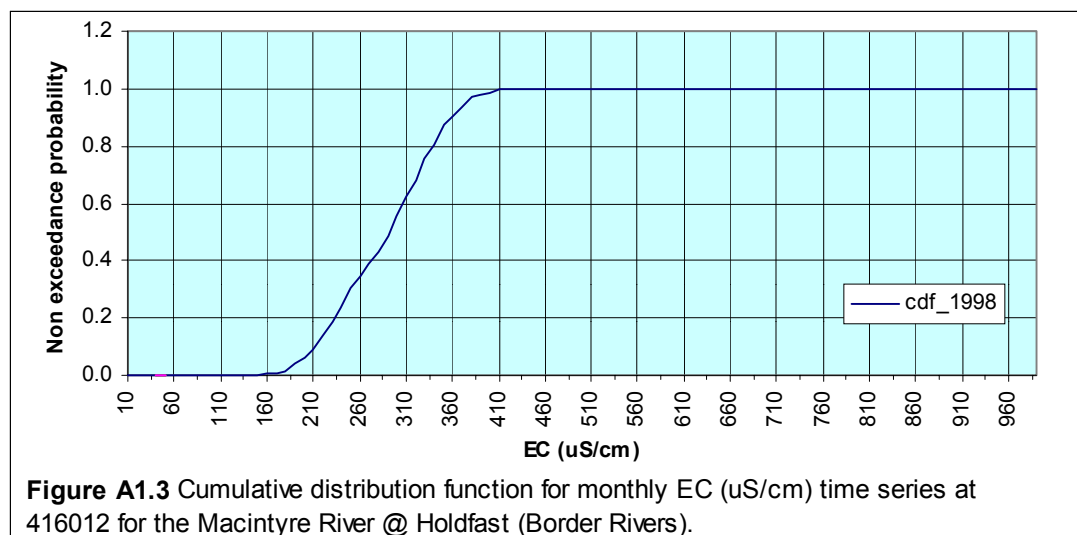
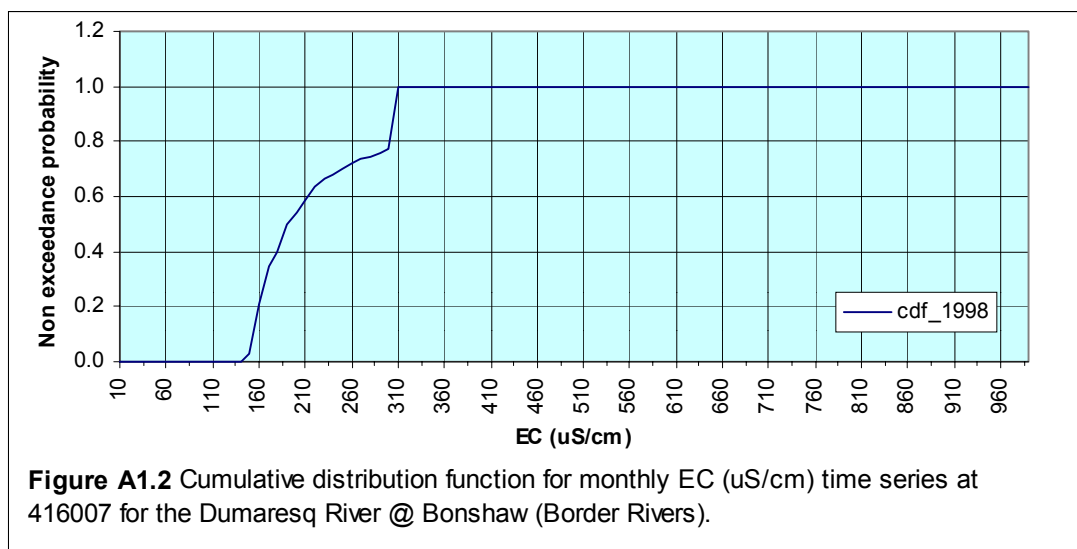
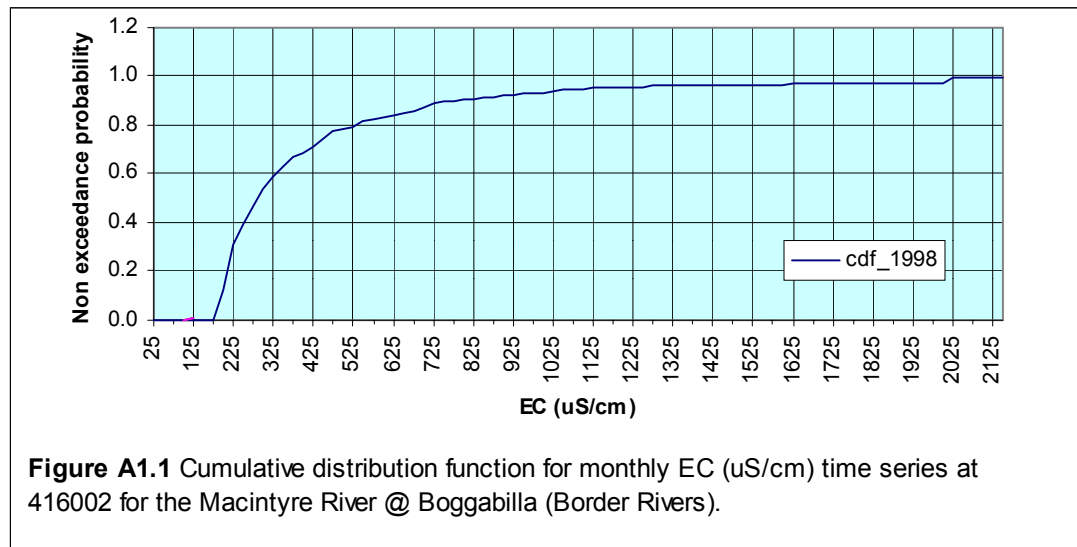
- Chen, X.Y. and McKane, D.J. (1997). Soil landscapes of the Wagga Wagga 1:100 000 sheet. Department of Land and Water Conservation, Sydney.
- Cook P.G., Kennett-Smith A.K., Walker G.R., Budd G.R., Williams R.M. and Anderson R. (1997). The impact of dryland agriculture on land and river salinisation in the western lands, New South Wales. *Journal of Soil and Water Conservation*, 10 (1): 29–36.
- Crabb, P. (1997). Murray Darling Basin Resources. Murray Darling Basin Commission, ISBN 1 875209 58 1.
- DWR (1994). Draft 1993/4 Darling River salinity—algae pilot study. Department of Water Resources, Sydney.
- Ferraro, T.A.J. and Burgin, S. (1993). Review of environmental factors influencing the decline of Australian frogs. *In* Herpetology in Australia—A Diverse Discipline. (Ed. D. Lunney and D. Ayers), Surrey Beatty & Sons.
- Fogarty, P. (1996). The Soils of Mona Vale and Tambea Experimental Catchments, Wagga Wagga, NSW. NSW Department of Land and Water Conservation Soil Survey Unit Miscellaneous Report No. 6.
- Gates, G.W.B., and Williams, R.M. (1988). Dryland Salinity Study—Changes in Groundwater Levels. Department of Water Resources, NSW, TS 88.010.
- Geeves, G.W., Cresswell, H.P., Murphy, B.W., Gessler, P.E., Chartres, C.J., Little, I.P., and Bowman, G.M. (1995). The physical, chemical, and morphological properties of soils in the wheat belt of southern NSW and northern Victoria. NSW Department of Conservation and Land Management / CSIRO Aust. Division of Soils Occasional report.
- GHD (1999). Murray-Darling Basin Commission—Salinity Impact Study, Final Report. Gutteridge Haskins and Davey Pty Ltd for the Murray-Darling Basin Commission, Canberra.
- Hall, L.W., and Anderson, R.D. (1995). The influence of salinity on the toxicity of various classes of chemicals to aquatic biota [Review]. *Critical Reviews in Toxicology*, 25 (4): 281–346.
- Hamilton, S. (1992). Lake Goran Catchment Groundwater Study. Department of Water Resources, NSW, TS 92.009.
- Hart, B.T., Bailey, P., Edwards, R., Hortle, K., James, K., McMahon, A., Meredith, C. and Swadling, K. (1991). A review of the salt sensitivity of the Australian Freshwater biota. *Hydrobiologia*, 210: 105–144.
- James, K.R., and Hart, B.T. (1993). Effects of salinity on four freshwater macrophytes. *Australian Journal of Marine and Freshwater Research*, 44 (5): 769–777.

- Kachroo R.K. (1992). River flow forecasting, part 5, applications of a conceptual model. *Journal of Hydrology*, 133: 141–178.
- Kingsford, R.T. and Porter, J. (1999). Wetlands and waterbirds of the Paroo and Warrego Rivers. In ‘A free-flowing river—the ecology of the Paroo River’. (Ed. R.T. Kingsford). National Parks and Wildlife Service, NSW.
- Kirkby, M.J. (ed.) (1978). Hillslope Hydrology. John Wiley & Sons.
- Lytton, L., Williams, R.M., and Gates, G. (1993). Groundwater Reconnaissance Survey Wagga-Narrandera. Department of Water Resources, NSW, TS 93.003.
- MDBMC (1995). An Audit of Water Use in the Murray-Darling Basin. Murray-Darling Basin Commission ISBN 1 875209 32 8.
- Metzeling, L., Doeg, T. and O’Connor, W. (1995). The impact of salinization and sedimentation on aquatic biota. In ‘*Conservation biodiversity: Treats and solutions*’. (Ed. R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney and D.P. Silvertsen) pp. 126–136, (Surrey Beatty and Sons, London)
- NSW Vegetation Forum (1996). Report on Native Vegetation Management in NSW. *NSW Department of Land and Water Conservation*, ISBN 0 7310 2378 1.
- O’Connell, P.E., Nash, J.E. and Farrel, J.P. (1970). Riverflow forecasting through conceptual models, part 2, the Brosna Catchment at Ferbane. *Journal of Hydrology*, 10: 317–329.
- Prathapar, S.A., Williams, R.M., and Punthakey, J.F. (1994). Optimising the short to medium term salinisation consequences of land clearing in the NSW Mallee, Australia. CSIRO Divisional Report 94/2.
- Punthakey, J.F., Prathapar, S.A., Somaratne, N.M., Merrick, N.P., Lawson, S., and Williams, R.M. (1996). Assessing impacts of basin management and environmental change in the Eastern Murray Basin. *Env. Software* 11 (1–3): 135–142.
- Ryan, T., Gasior, R., and Steegstra, D. (1999). Habitat degradation associated with saline stratification. A Report for the Murray-Darling Basin Commission—Natural Resource Management Strategy Project V238. Arthur Rylah Institute for Environmental Research, Victoria.
- Salas, G., Groundwater Reconnaissance Survey Dubbo-Orange. Department of Water Resources, NSW, unpublished report.
- Salas, J.D., Delleur, J.W., Yevjevich, V., and Lane, W.L. (1980). Applied Modeling of Hydrologic Time Series. Water Resources Publ., Colorado.

- Semple, W., Beale, G.T.H., Cole, I., Franklin, J., Koen, T., LeLievre, R., Parker, B., Phillips, B., Reynolds, K., Sides, T., Thearle, L. and Windellama Landcare Group (1997). Evaluation of the performance of perennial grasses on saline sites in eastern NSW—preliminary report on the Autumn 1996 sowings. NSW Department of Land and Water Conservation Central West Region, Research / Investigations report CW 96/5.
- Sinclair Knight Merz (1998). Murray Darling Water management Plan, Hydrogeological Study., Stage one Draft Report (Draft B). Sinclair Knight Merz.
- Taylor, S. (1993). Dryland Salinity: Introductory Extension Notes—Second edition NSW Department of Conservation and Land management, ISBN 0 7310 1124 4.
- Tuteja, N.K. and Beale, G.T.H (1999). A New Salt Balance Model for Medium Sized Catchments (CATSALT)—model development, validation and sensitivity analysis. Department of Land and Water Conservation unpublished report.
- Tuteja, N.K., and Cunnane, C. (1999). A quasi physical snowmelt runoff modelling system for small catchments. *Hydrol. Processes*. 13(12/13): 1961–1975.
- Tuteja, N.K. (1992). General Stochastic Model for Irish Rivers. M.Sc. Thesis submitted to the National University of Ireland.
- Warwick, N., and Bailey, P. (1996). The effect of increasing salinity on wetlands. *Trees and Natural Resources*, 38 (3): 9-10.
- Williams, R.M., and Saunders, B.J. (1990). Groundwater Reconnaissance Survey: Inverell District. Department of Water Resources, NSW, TS 90.031.
- Williams, R.M. (1990). Groundwater Reconnaissance Survey: Howlong District. Department of Water Resources, NSW, TS 90.082.
- Williamson, D., Gates, G., Robinson, G., Linke, G., Seker, M. and Evans, W. (1997). Salt Trends: Historic Trend in Salt Concentration and Saltload of Stream Flow in the Murray-Darling Drainage Basin. Dryland Technical Report No. 1, Murray-Darling Basin Commission.
- Woolley, D.R., Bish, S., Bradd, J.M., Dwyer, J., O'Neill, D. and Williams, R.M. (1999). Murray-Darling Basin Salinity and Drainage Strategy: Groundwater derived saltloads in NSW. Department of Land and Water Conservation, NSW, CNR 99.004.
- Woolley, D.R. (1991). Kyeamba Landcare Area: Groundwater. Department of Water Resources, NSW, TS 91.043.

Appendices: Cdf's for catchments

Appendix 1 Macintyre Catchment



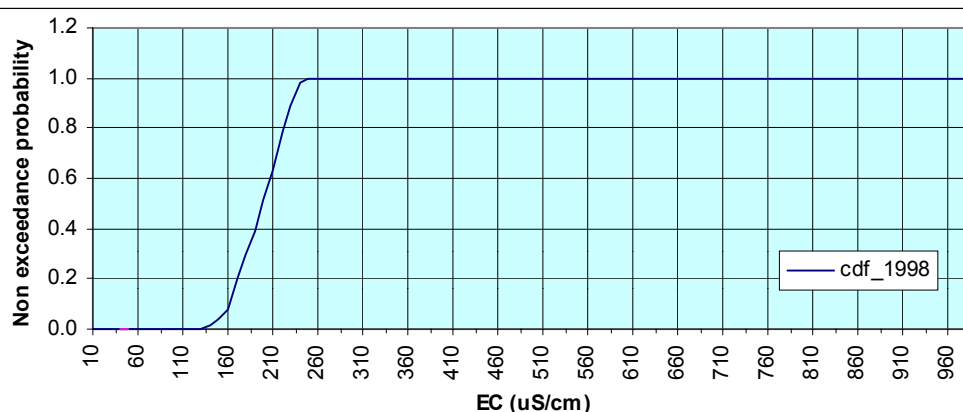


Figure A1.4 Cumulative distribution function for monthly EC (uS/cm) time series at 416006 for the Severn River @ Ashford (Border Rivers).

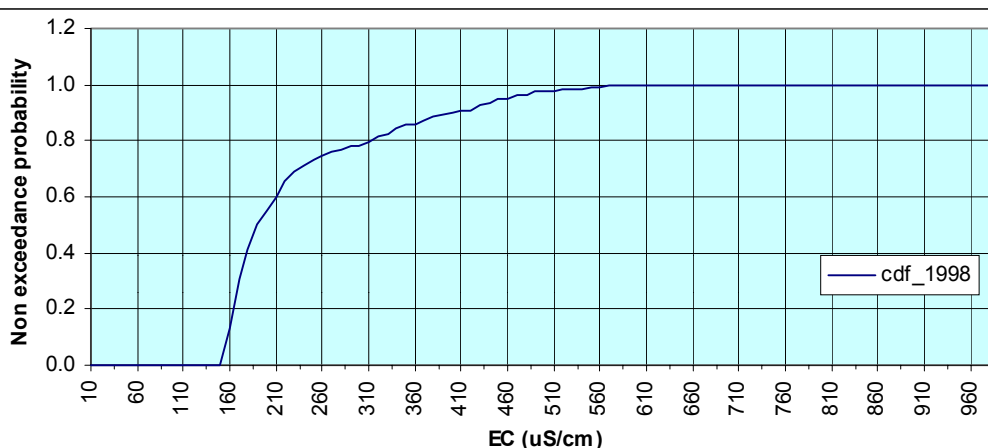


Figure A1.5 Cumulative distribution function for monthly EC (uS/cm) time series at 416019 for the Severn River @ Pindari (Border Rivers).

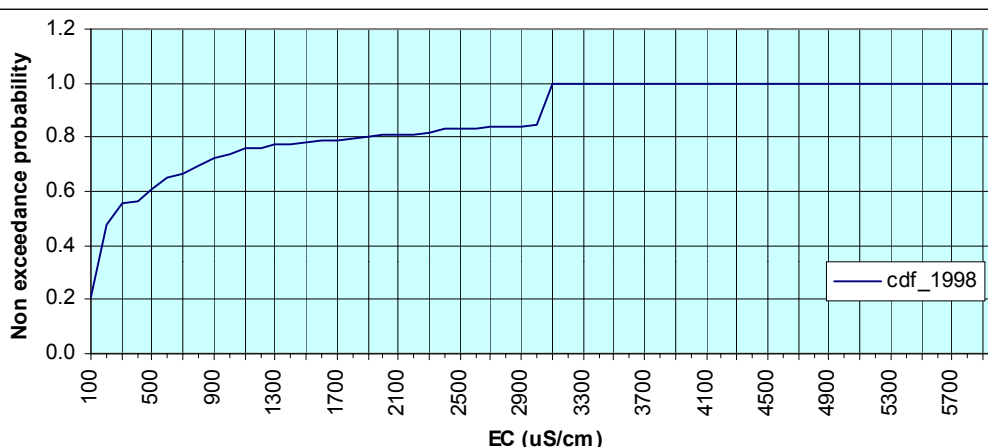


Figure A1.6 Cumulative distribution function for monthly EC (uS/cm) time series at 416008 for the Beardy River @ Haystack (Border Rivers).

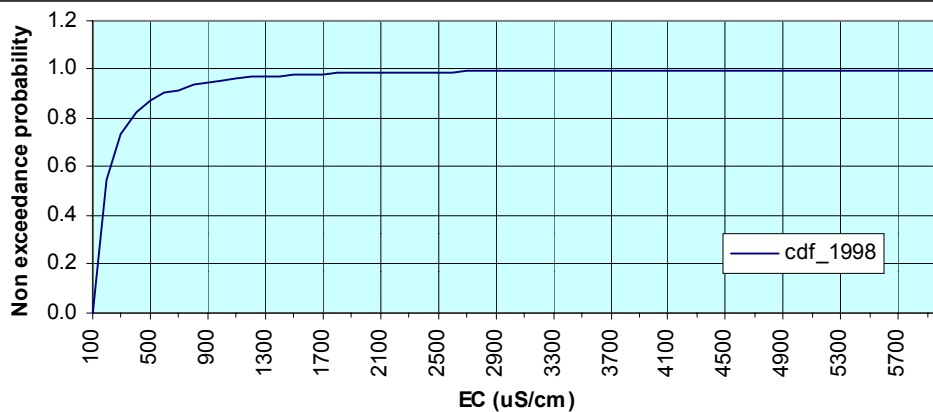


Figure A1.7 Cumulative distribution function for monthly EC (uS/cm) time series at 416011 for the Dumaresq River @ Roseneath 2 (Border Rivers).

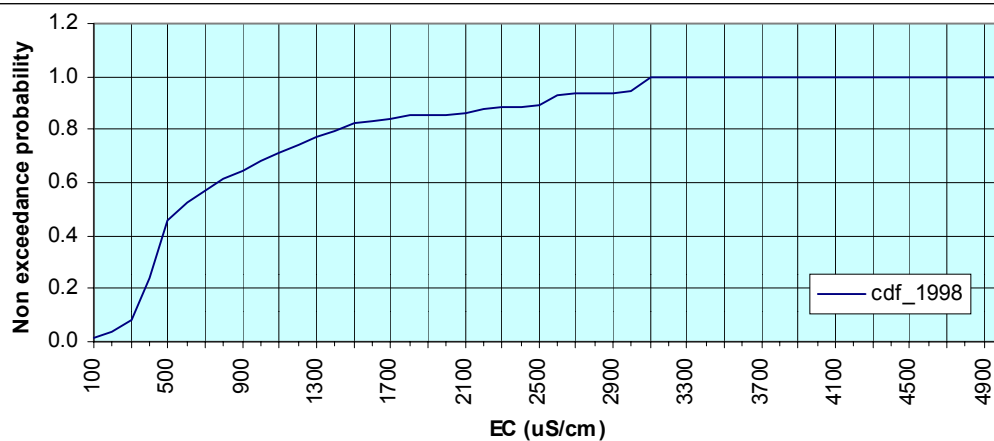


Figure A1.8 Cumulative distribution function for monthly EC (uS/cm) time series at 416020 for Ottleys Creek @ Coolatai (Border Rivers).

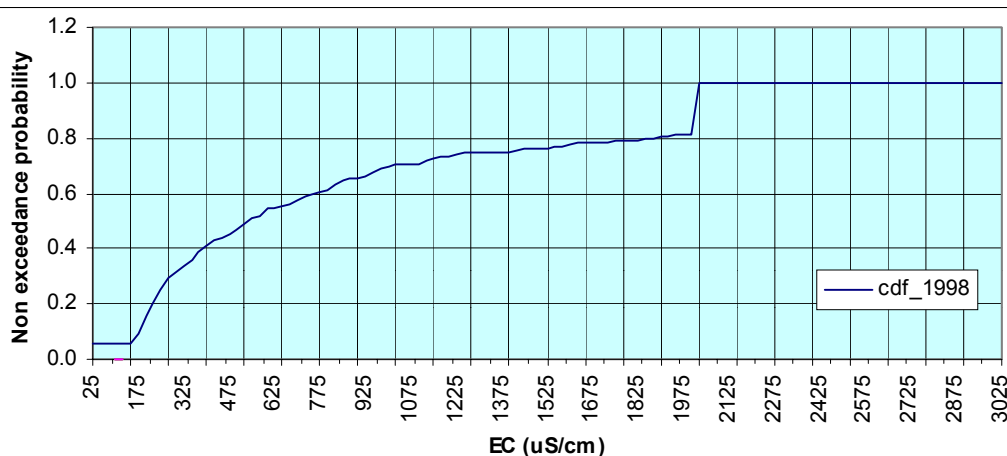


Figure A1.9 Cumulative distribution function for monthly EC (uS/cm) time series at 416010 for the Macintyre River @ Wallangra (Border Rivers).

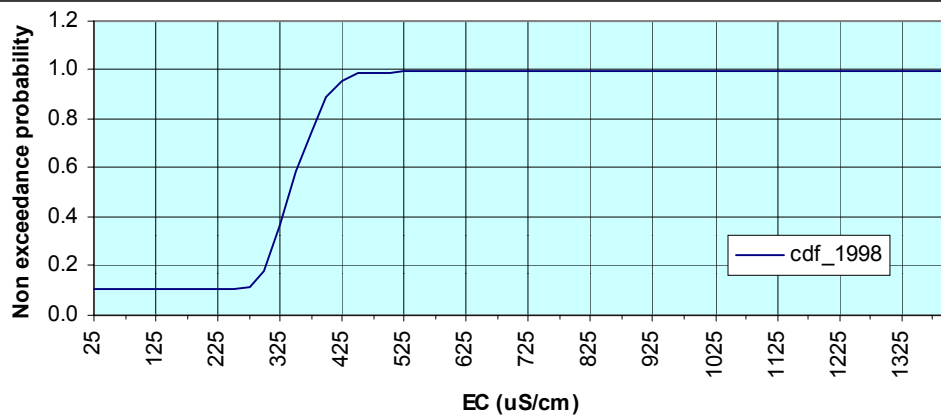


Figure A1.10 Cumulative distribution function for monthly EC (uS/cm) time series at 416021 for Frazers Creek @ Ashford (Border Rivers).

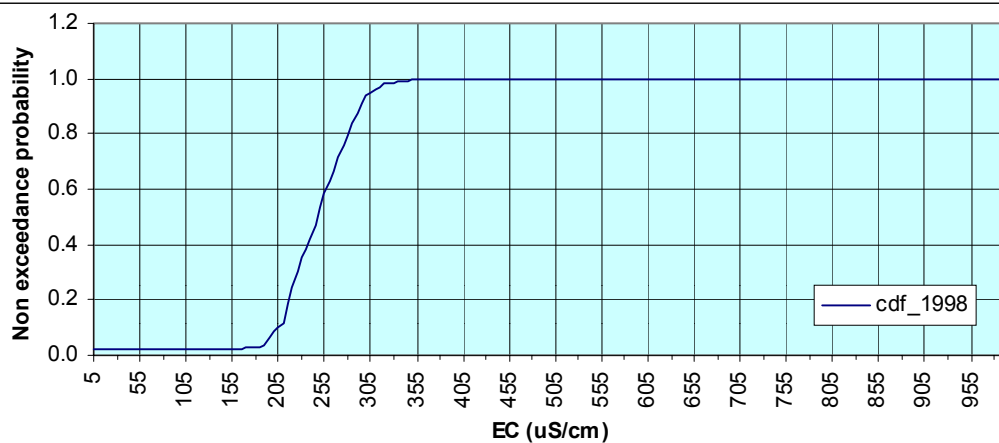
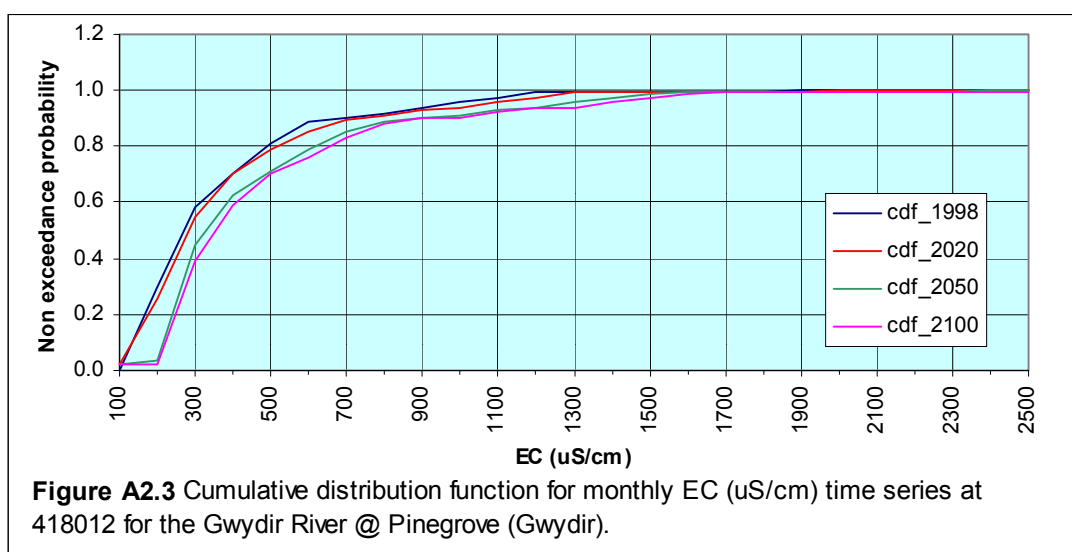
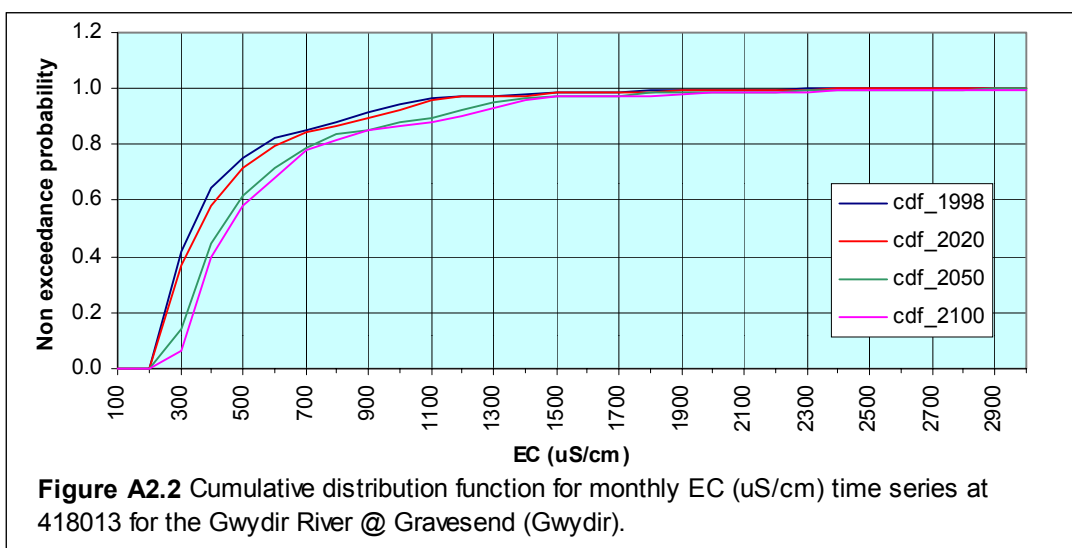
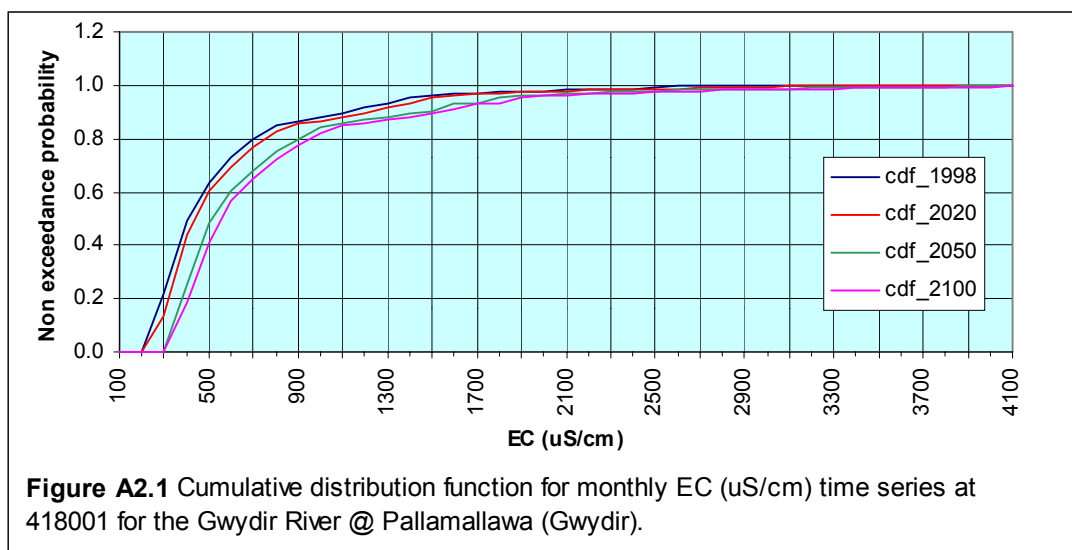
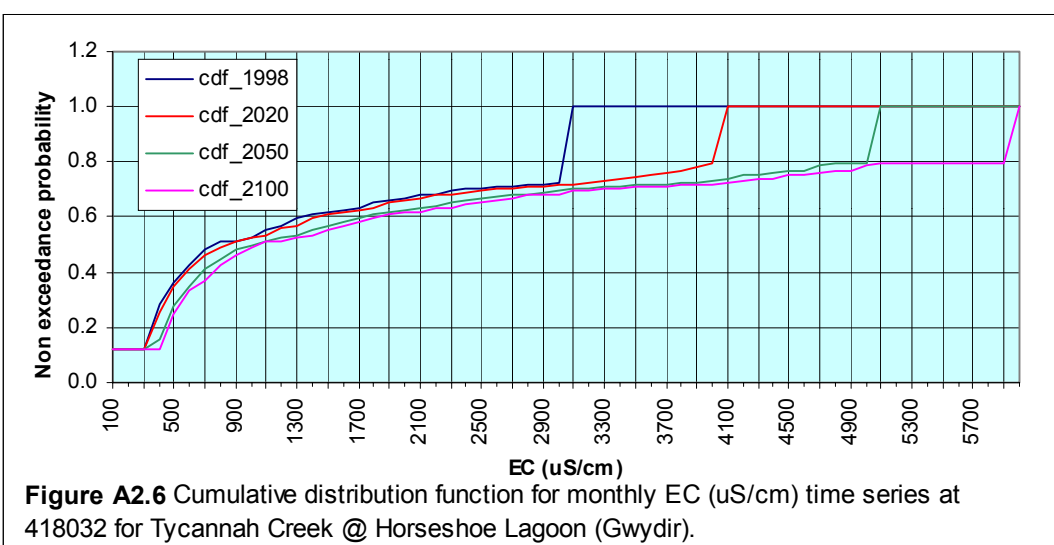
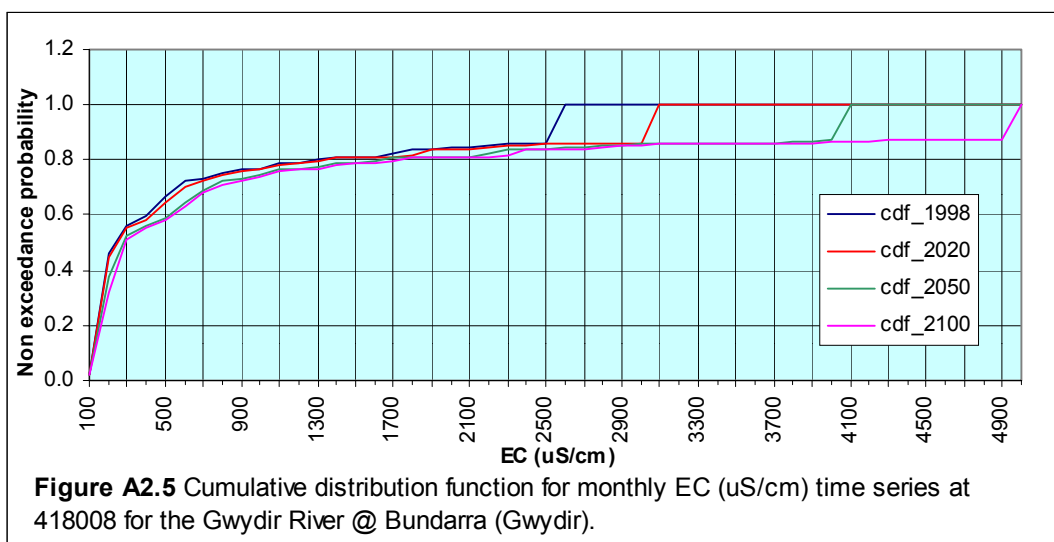
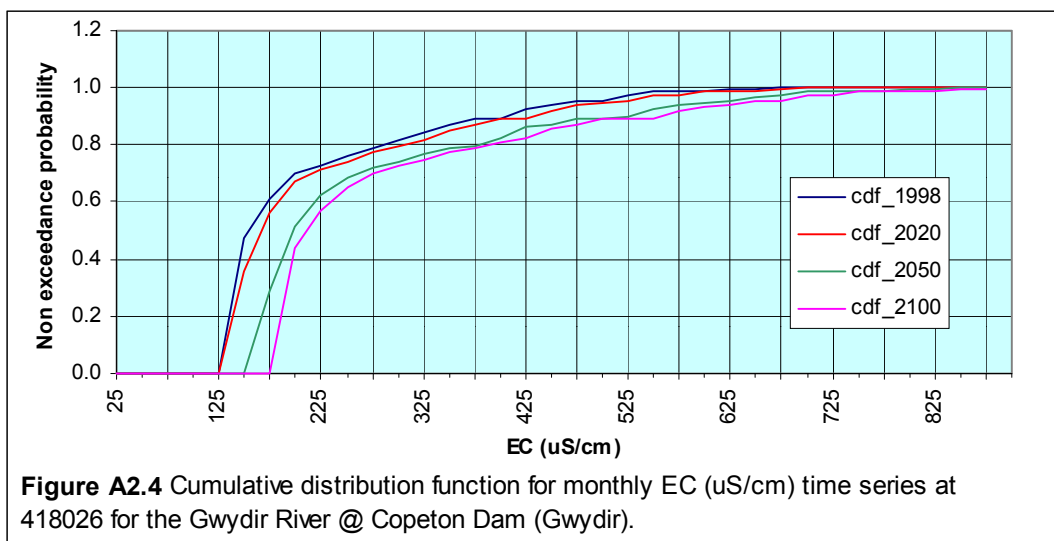


Figure A1.11 Cumulative distribution function for monthly EC (uS/cm) time series at 416039 for the Severn River @ Strathbogie (Border Rivers).

Appendix 2 Gwydir Catchment





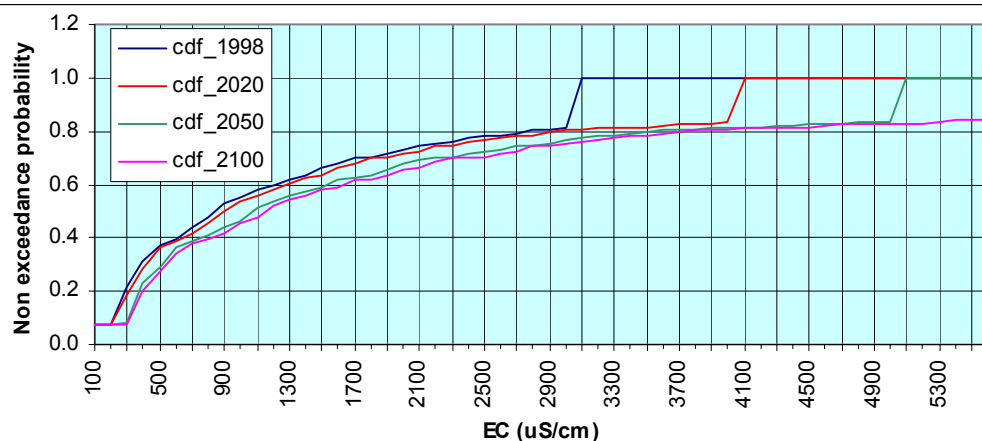


Figure A2.7 Cumulative distribution function for monthly EC (uS/cm) time series at 418016 for Warialda Creek @ Warialda (Gwydir).

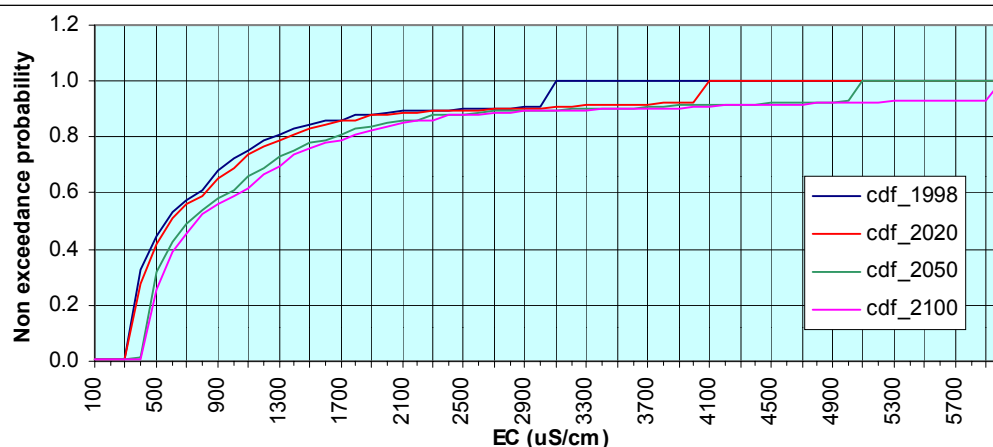


Figure A2.8 Cumulative distribution function for average EC (uS/cm) time series at 4180015 for the Horton River @ Rider (Killara) (Gwydir).

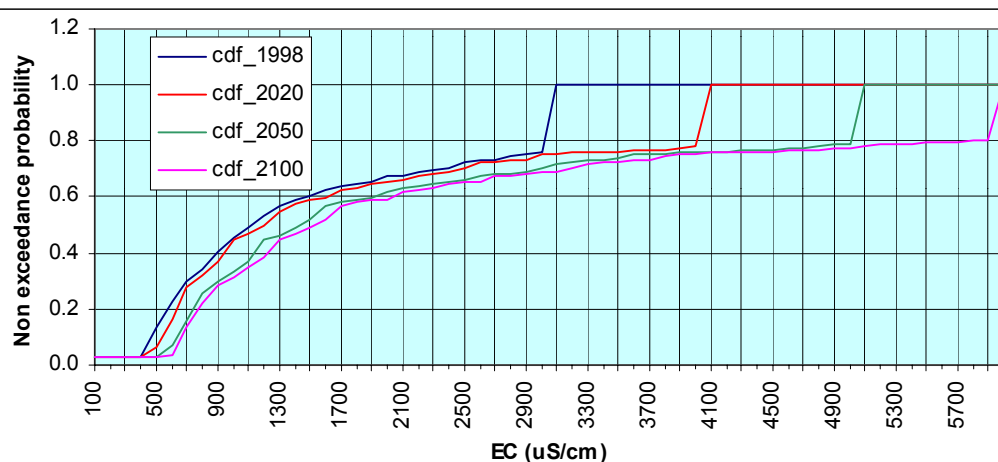


Figure A2.9 Cumulative distribution function for monthly EC (uS/cm) time series at 418017 for Myall Creek @ Molroy (Gwydir).

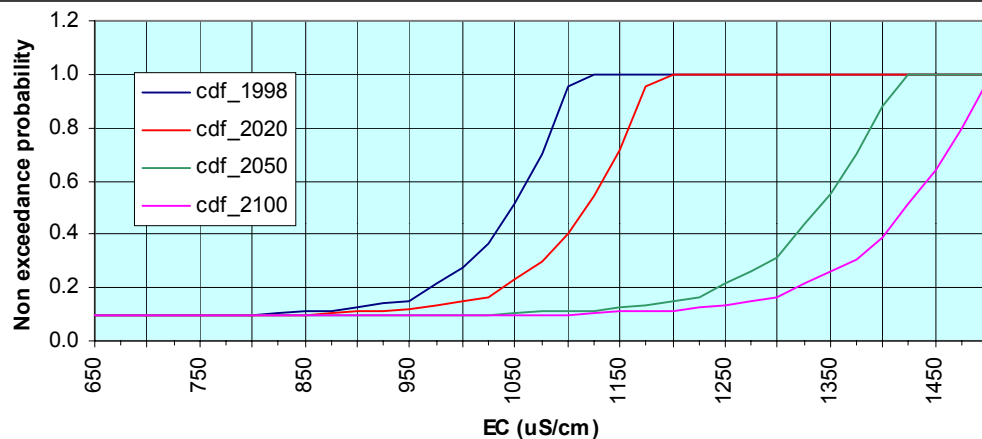


Figure A2.10 Cumulative distribution function for monthly EC (uS/cm) time series at 418025 for Halla Creek @ Bingara (Gwydir).

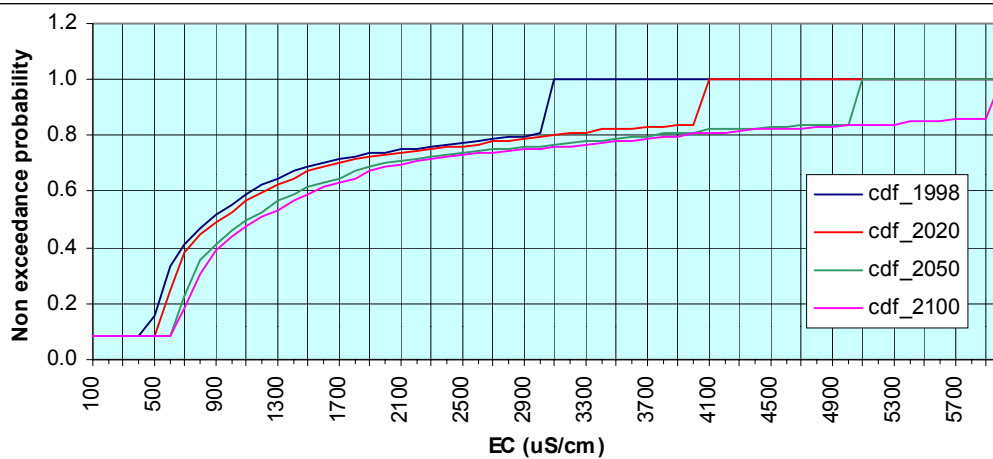


Figure A2.11 Cumulative distribution function for monthly EC (uS/cm) time series at 418018 for Keera Creek @ Keera (Gwydir).

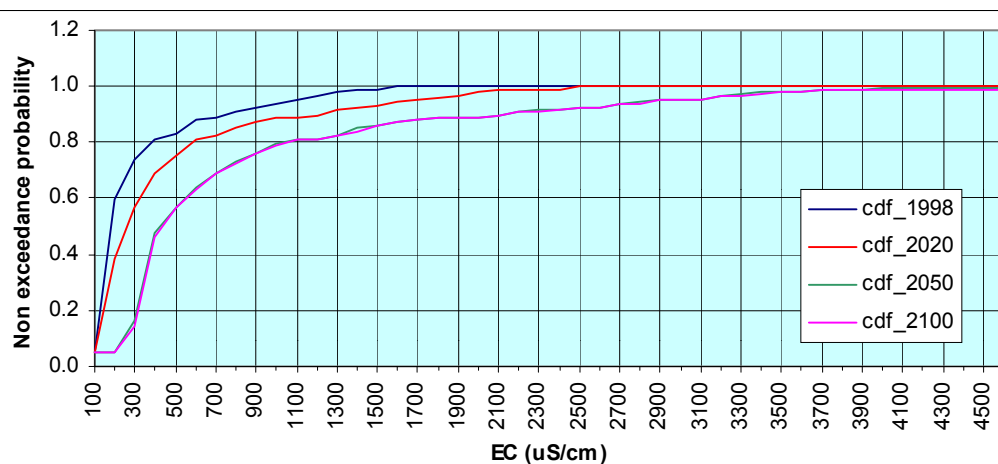


Figure A2.12 Cumulative distribution function for monthly EC (uS/cm) time series at 418005 for Copes Creek @ Kimberley (Gwydir).

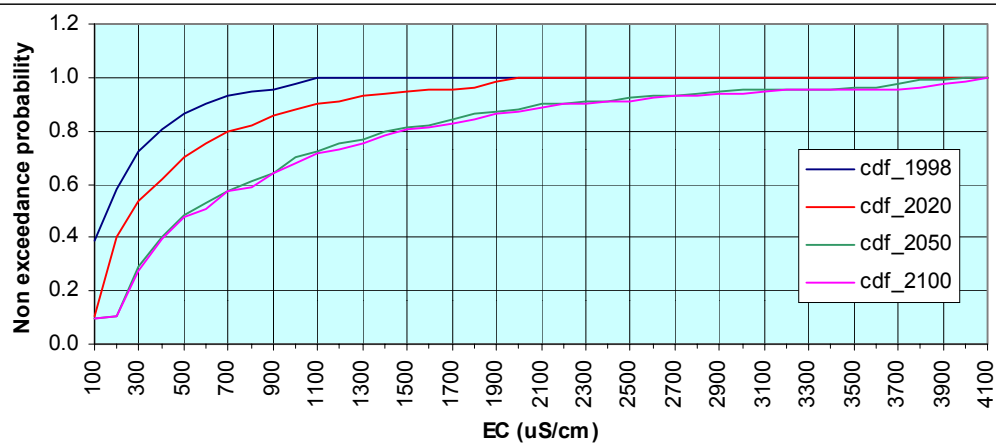


Figure A2.13 Cumulative distribution function for monthly EC (uS/cm) time series at 418033 for Bakers Creek @ Bundarra (Gwydir).

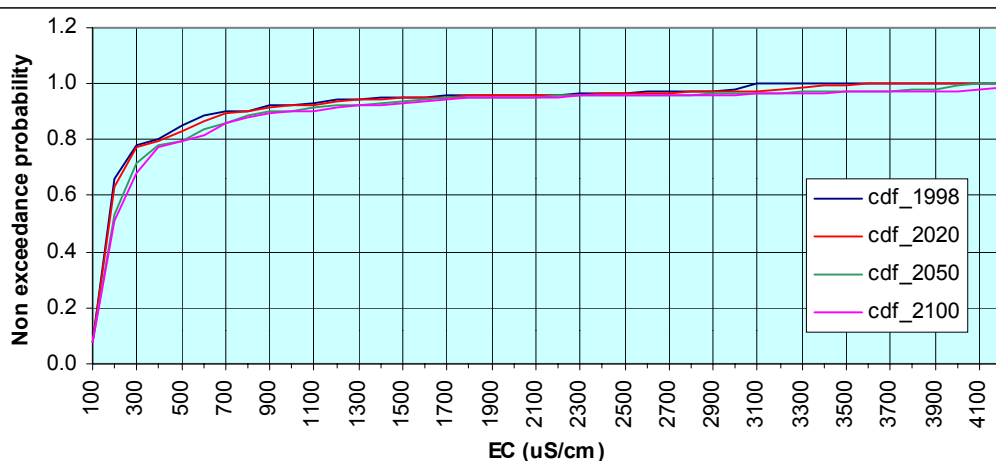


Figure A2.14 Cumulative distribution function for monthly EC (uS/cm) time series at 4180023 for Moredum Creek @ Bundarra (Gwydir).

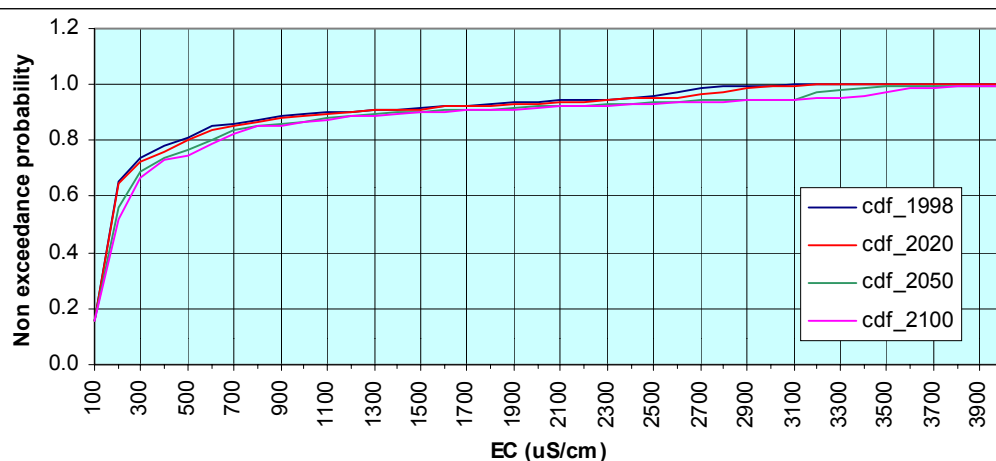


Figure A2.15 Cumulative distribution function for monthly EC (uS/cm) time series at 418022 for Georges Creek @ Clerkness (Gwydir).

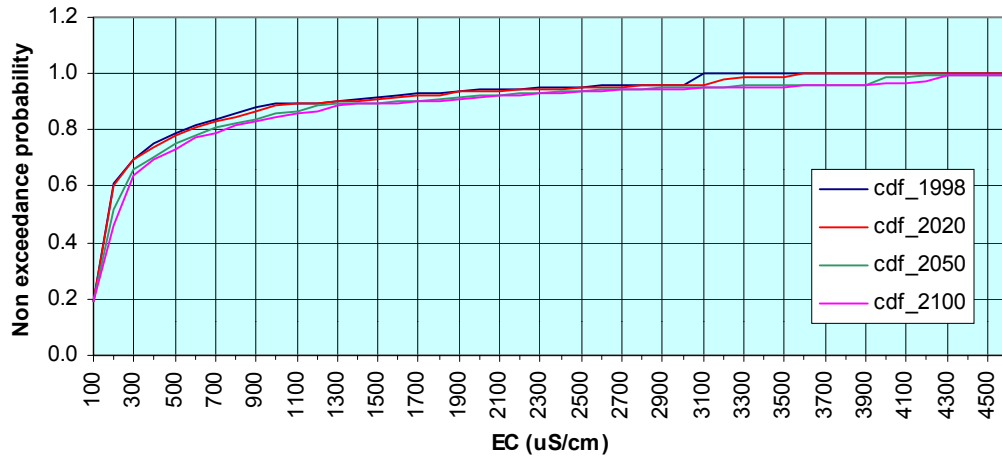


Figure A2.16 Cumulative distribution function for monthly EC (uS/cm) time series at 4180021 for Laura Creek @ Laura (Gwydir).

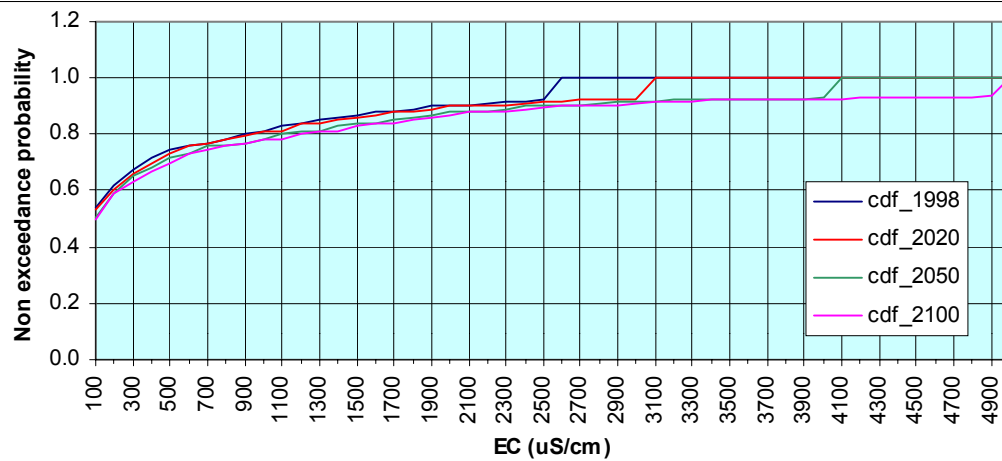


Figure A2.17 Cumulative distribution function for monthly EC (uS/cm) time series at 418029 for the Gwydir River @ Stonybatter (Gwydir).

Appendix 3 Namoi Catchment

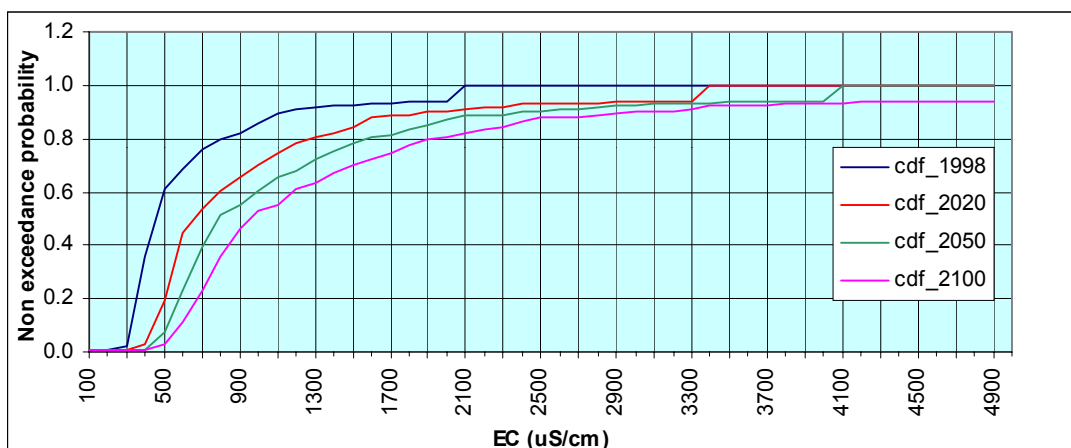


Figure A3.1 Cumulative distribution function for monthly EC (uS/cm) time series at 419012 for the Namoi River @ Boggabri (Namoi).

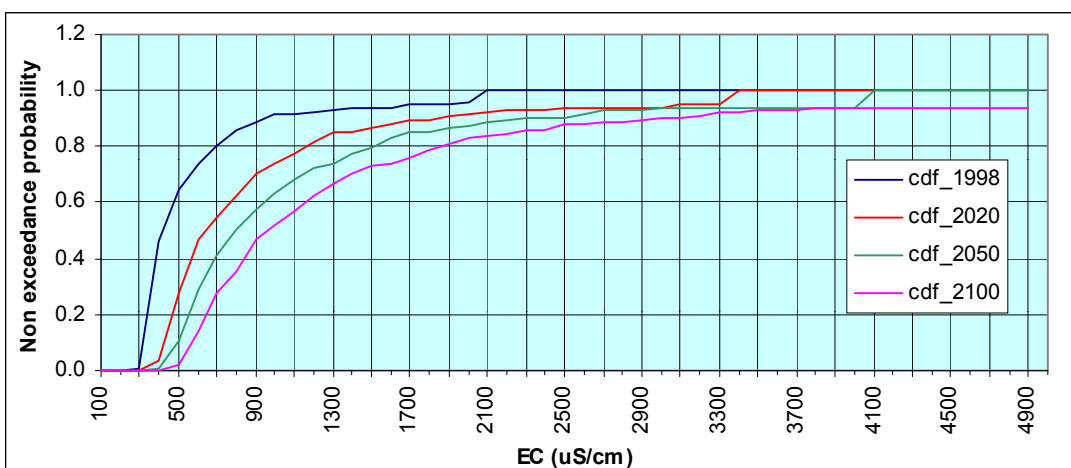


Figure A3.2 Cumulative distribution function for monthly EC (uS/cm) time series at 419001 for the Namoi River @ Gunnedah (Namoi).

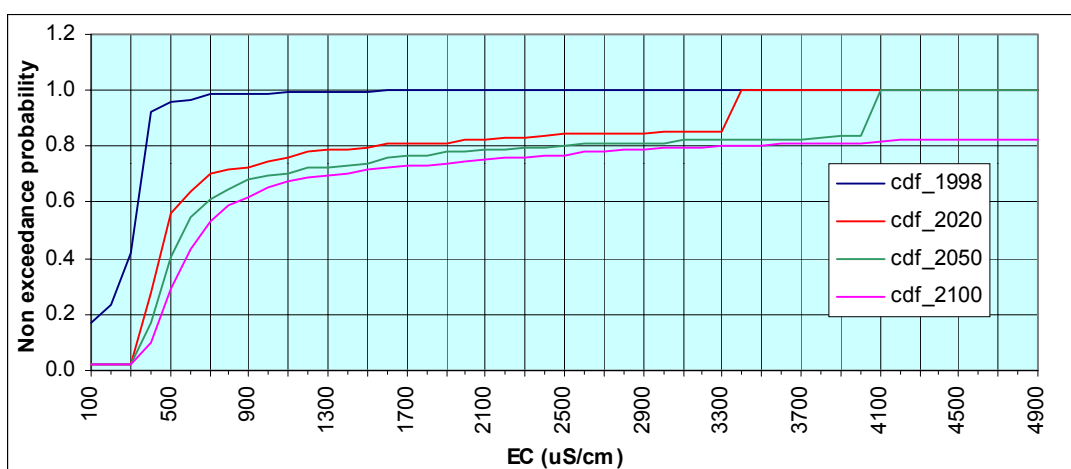
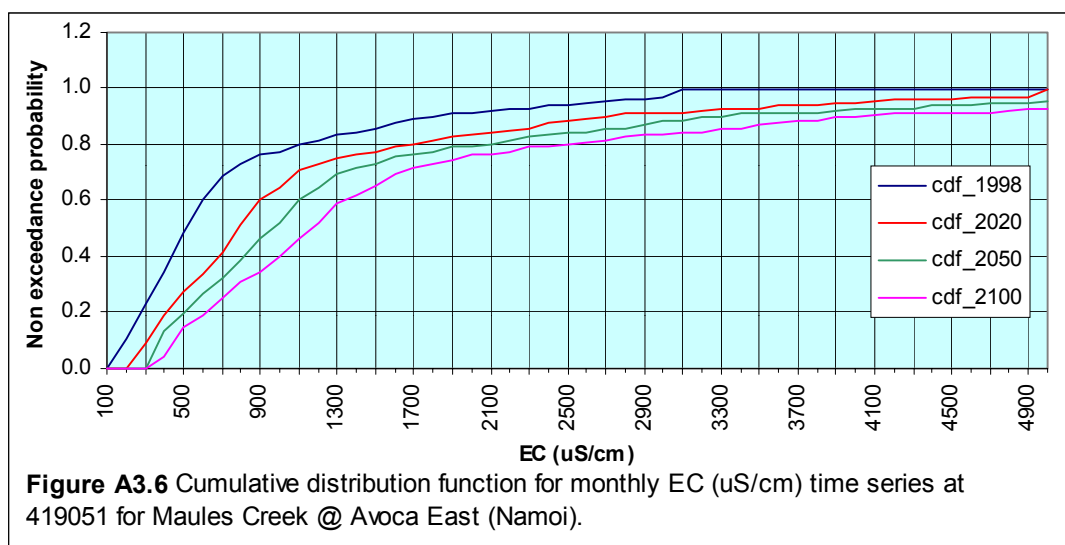
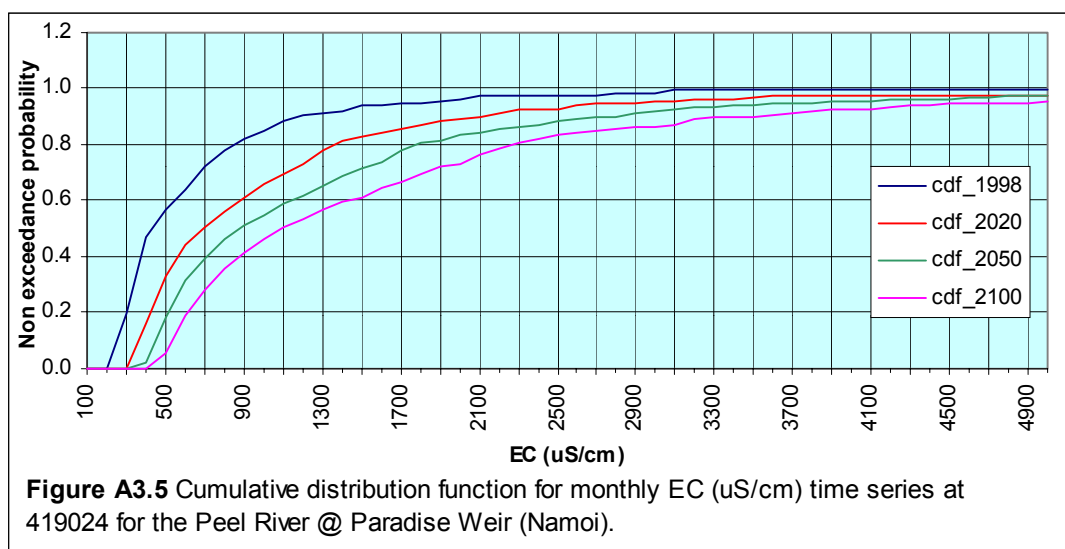
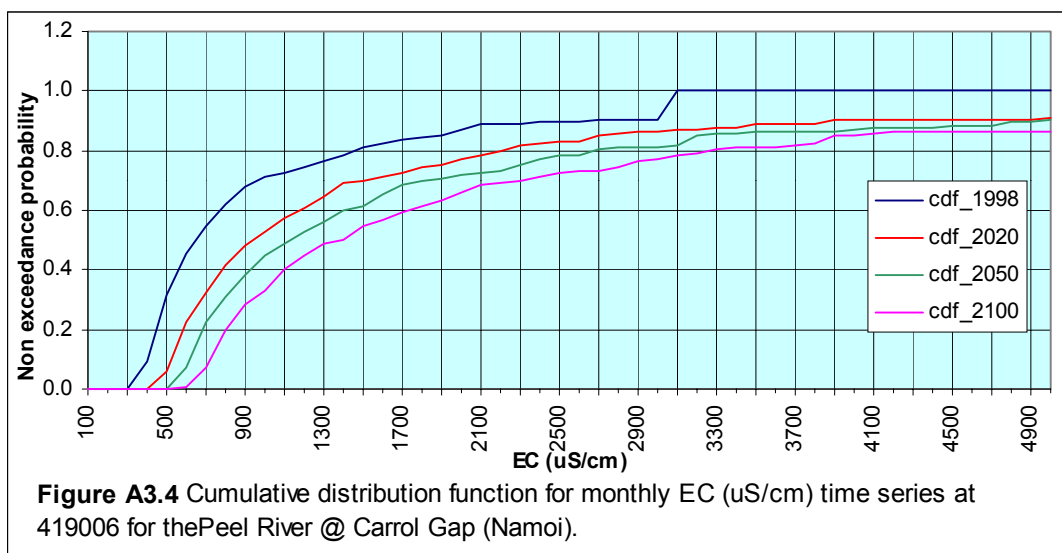


Figure A3.3 Cumulative distribution function for monthly EC (uS/cm) time series at 419007 for the Namoi River @ Keepit Dam (Namoi).



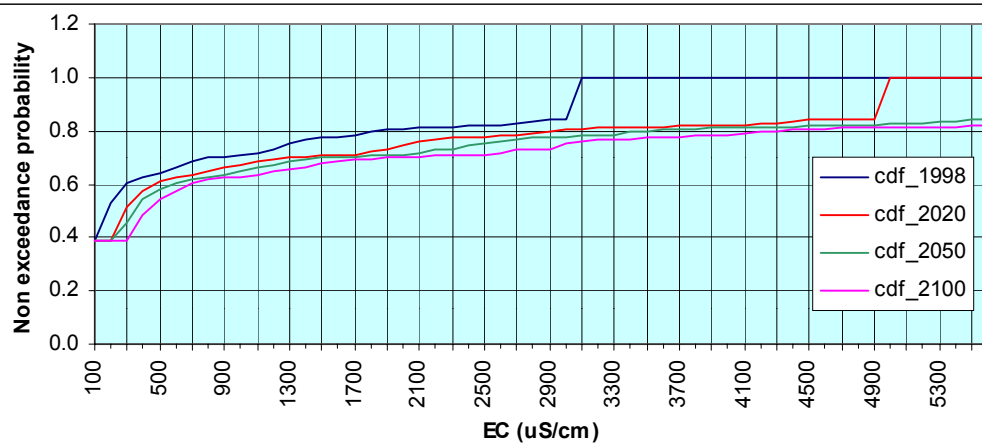


Figure A3.7 Cumulative distribution function for monthly EC (uS/cm) time series at 419032 for Coss Creek @ Boggabri (Namoi).

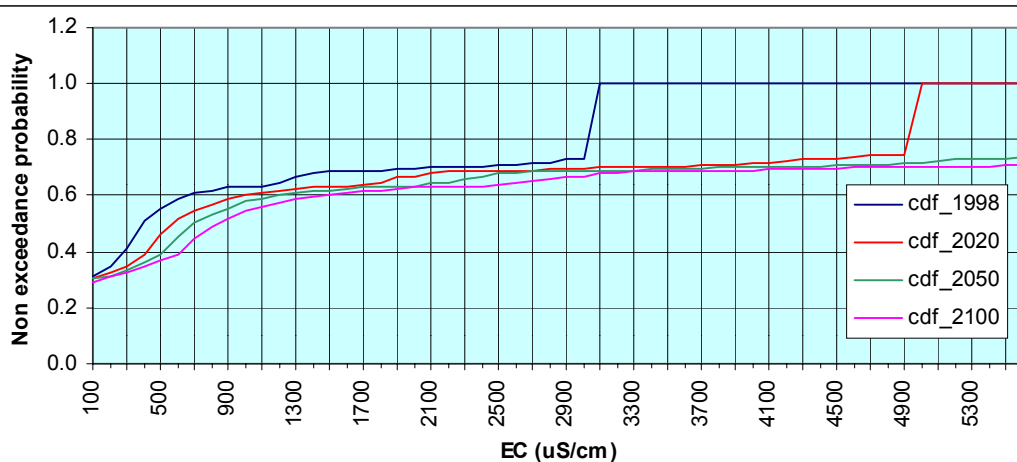


Figure A3.8 Cumulative distribution function for monthly EC (uS/cm) time series at 419027 for the Mooki River @ Breeza (Namoi).

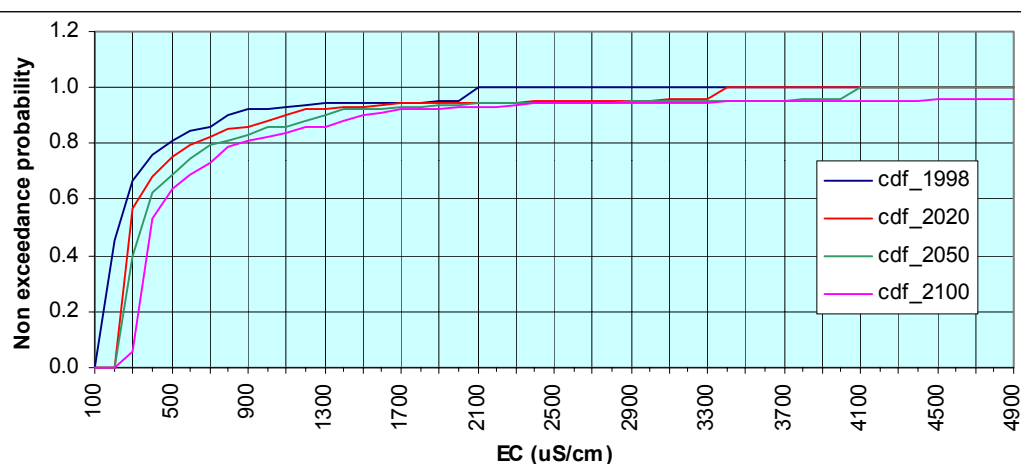
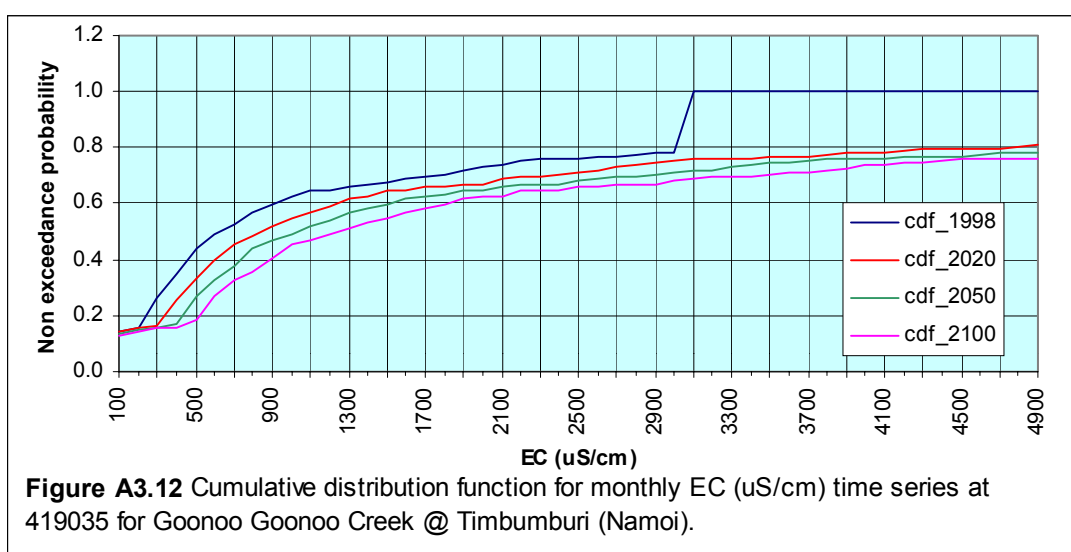
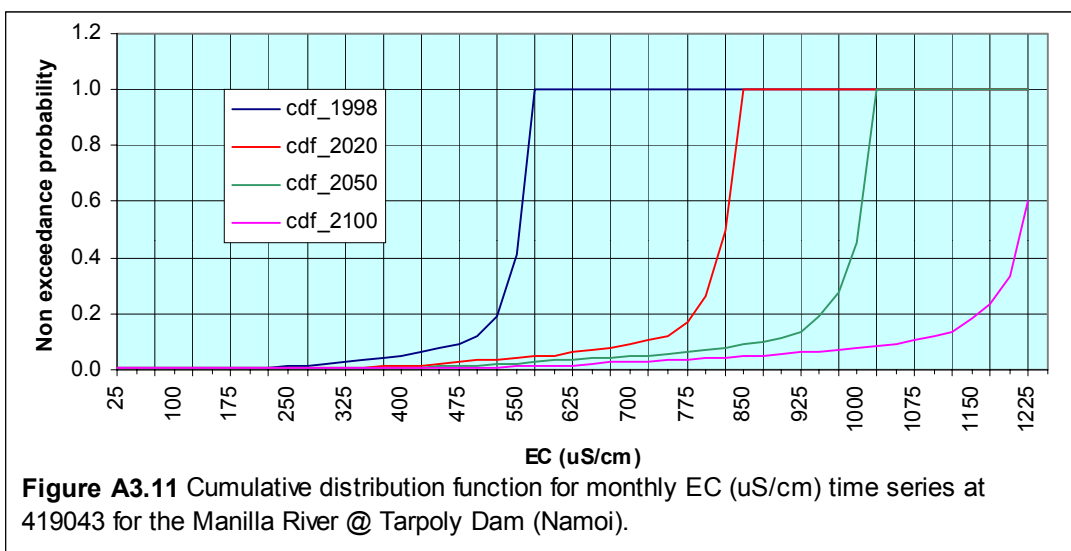
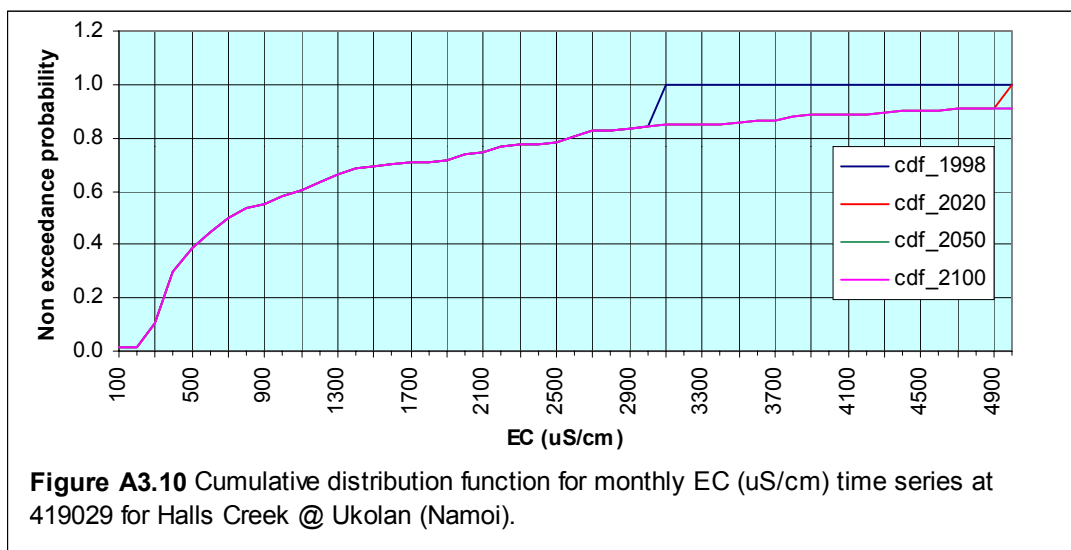


Figure A3.9 Cumulative distribution function for monthly EC (uS/cm) time series at 419005 for the Namoi River @ North Cuerindi (Namoi).



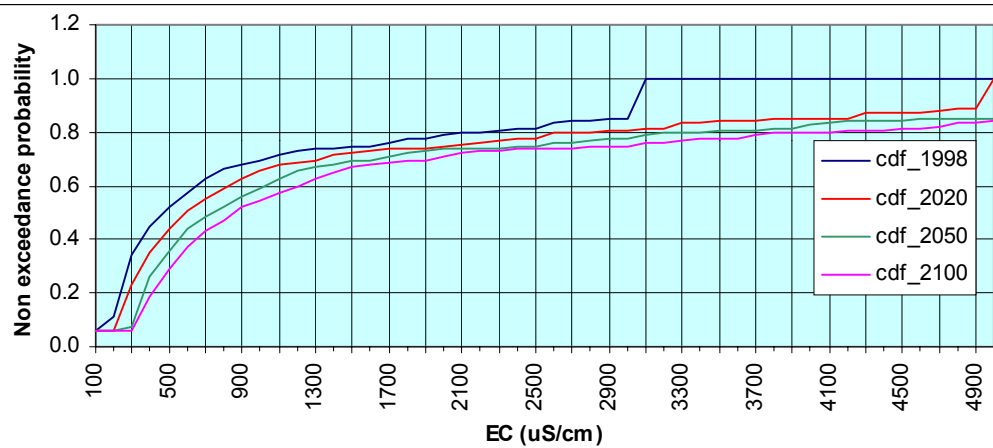


Figure A3.13 Cumulative distribution function for monthly EC (uS/cm) time series at 419016 for the Cockburn River @ Mulla Crossing (Namoi).

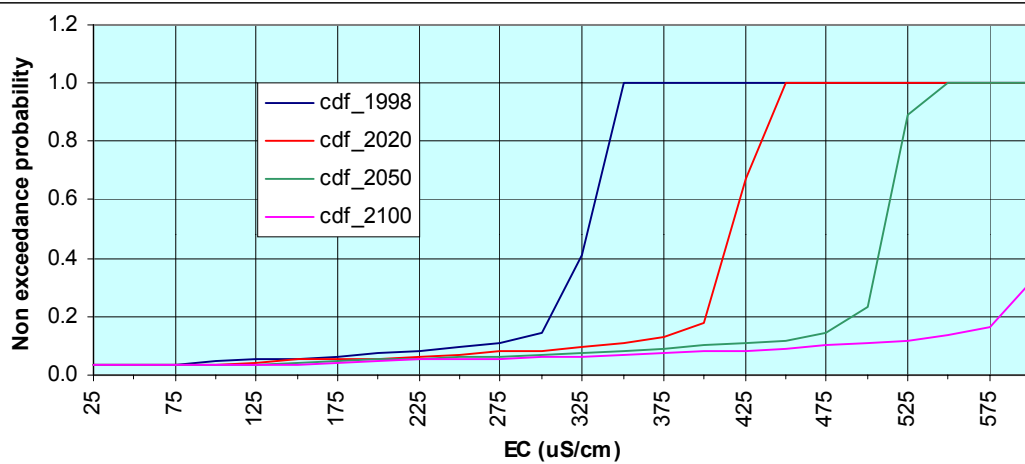


Figure A3.14 Cumulative distribution function for monthly EC (uS/cm) time series at 419045 for the Peel River @ Chaffey Dam (Namoi).

Appendix 4 Macquarie Catchment

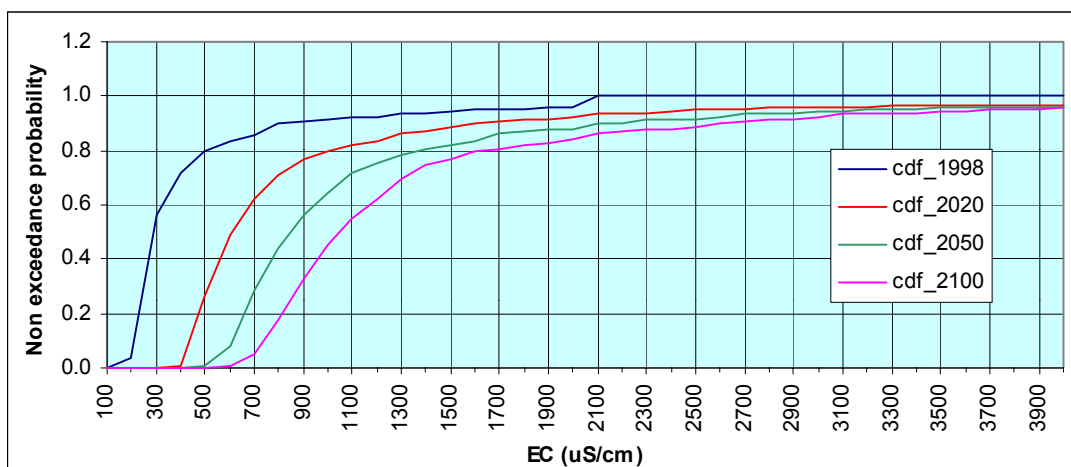


Figure A4.1 Cumulative distribution function for monthly EC (uS/cm) time series at 421006 for the Macquarie River @ Narromine (Macquarie).

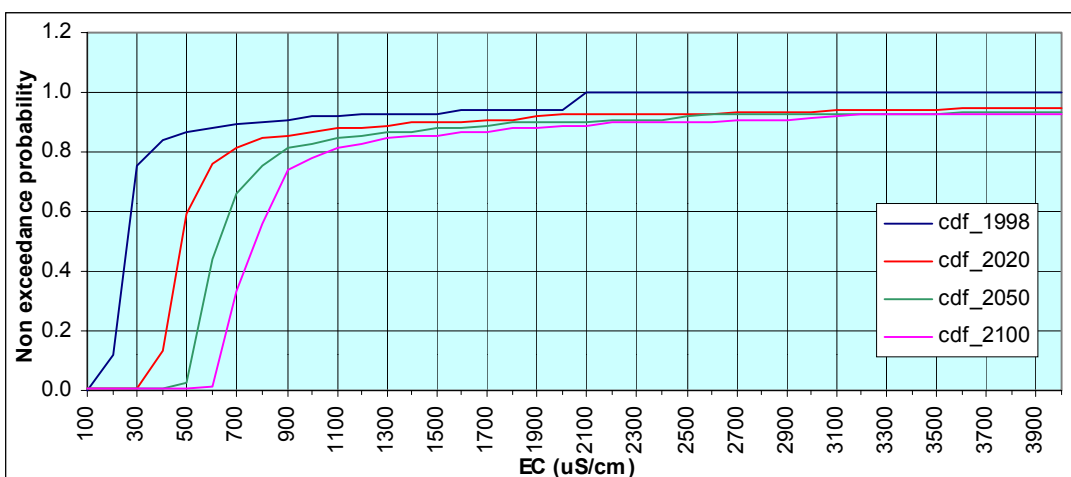


Figure A4.2 Cumulative distribution function for monthly EC (uS/cm) time series at 421040 for the Macquarie River @ d/s of Burrendong Dam (Macquarie).

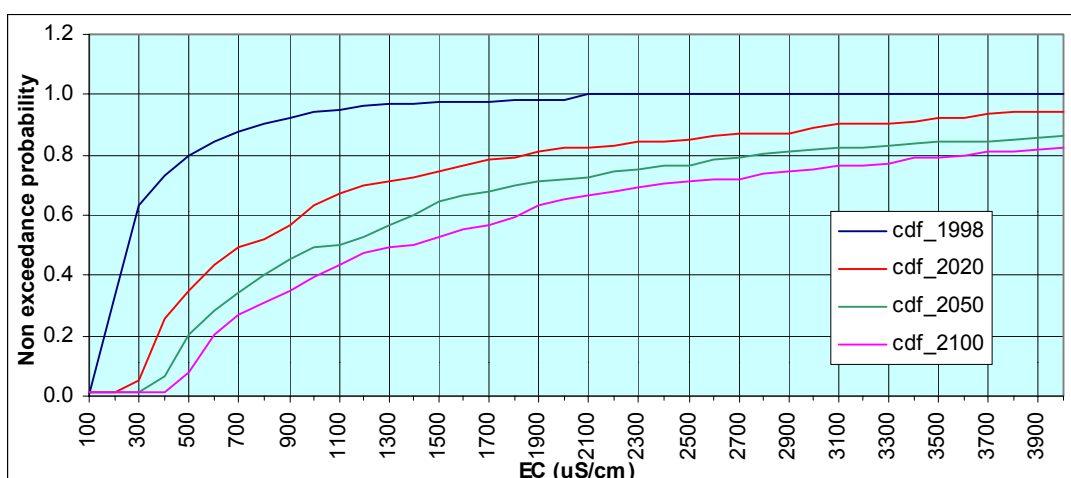
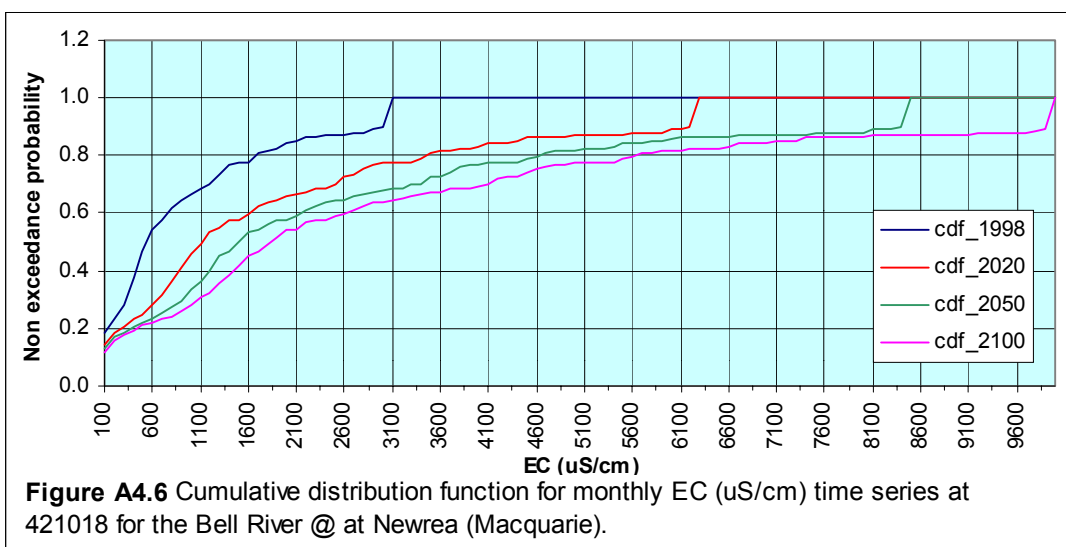
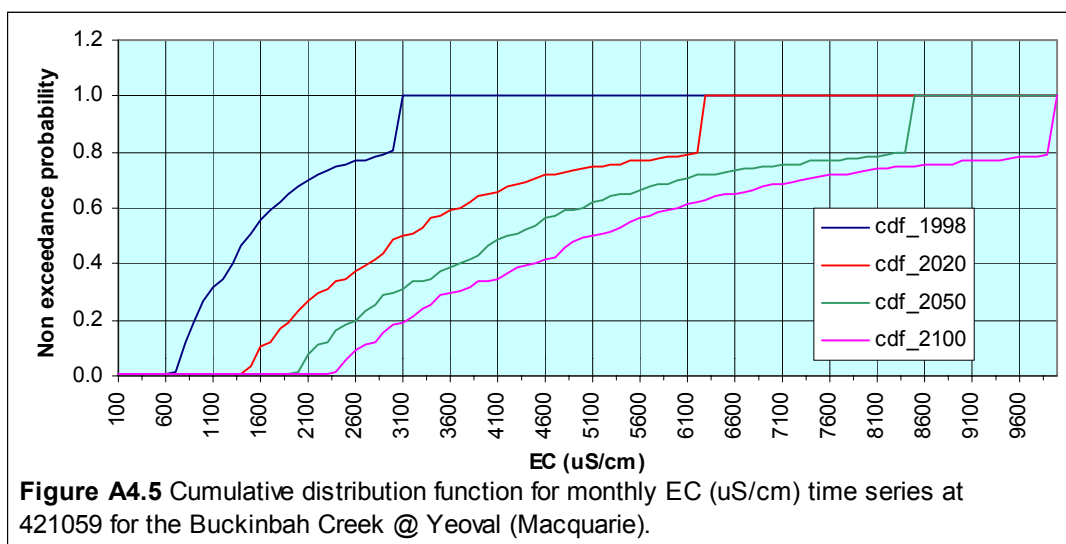
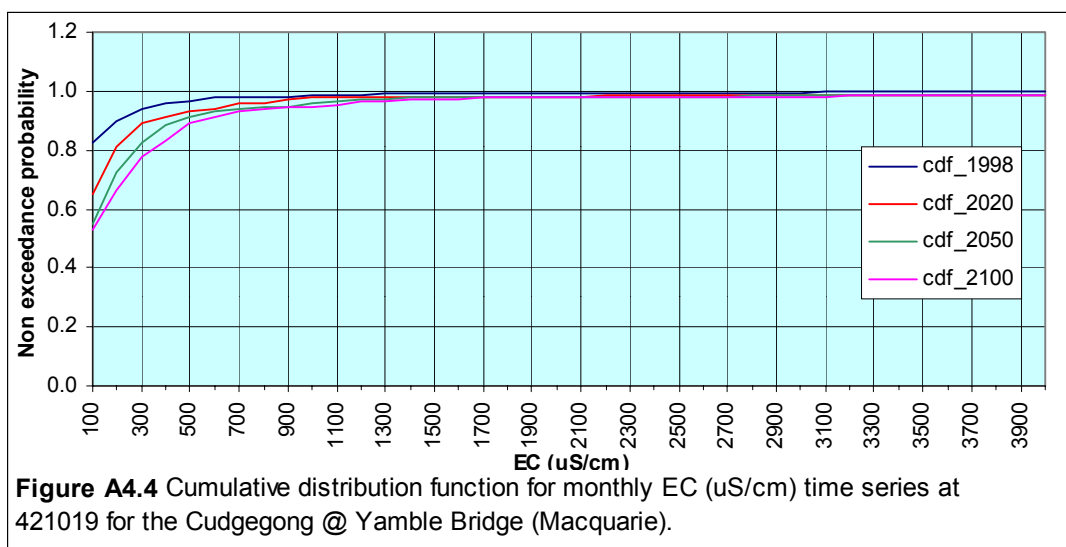
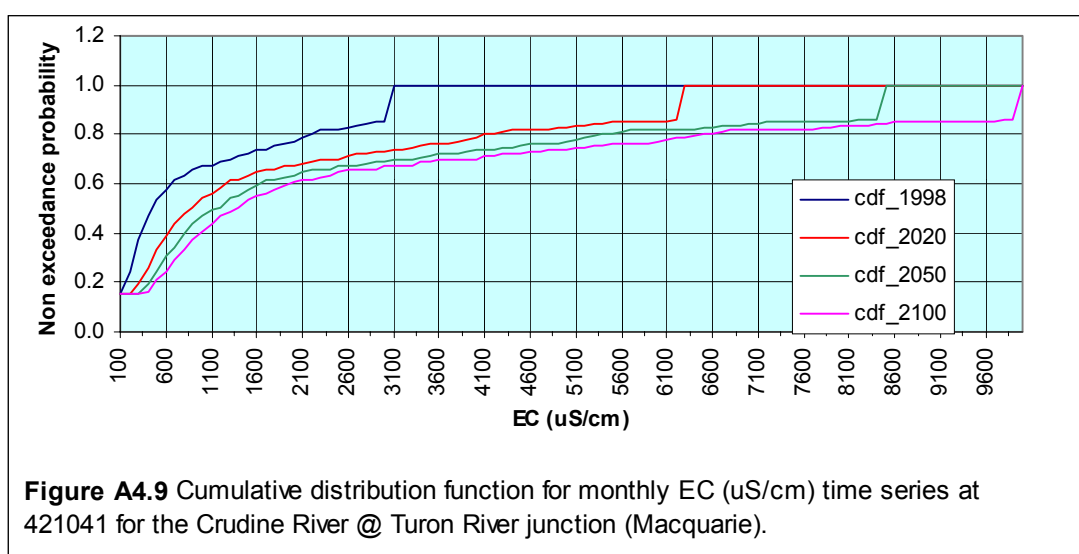
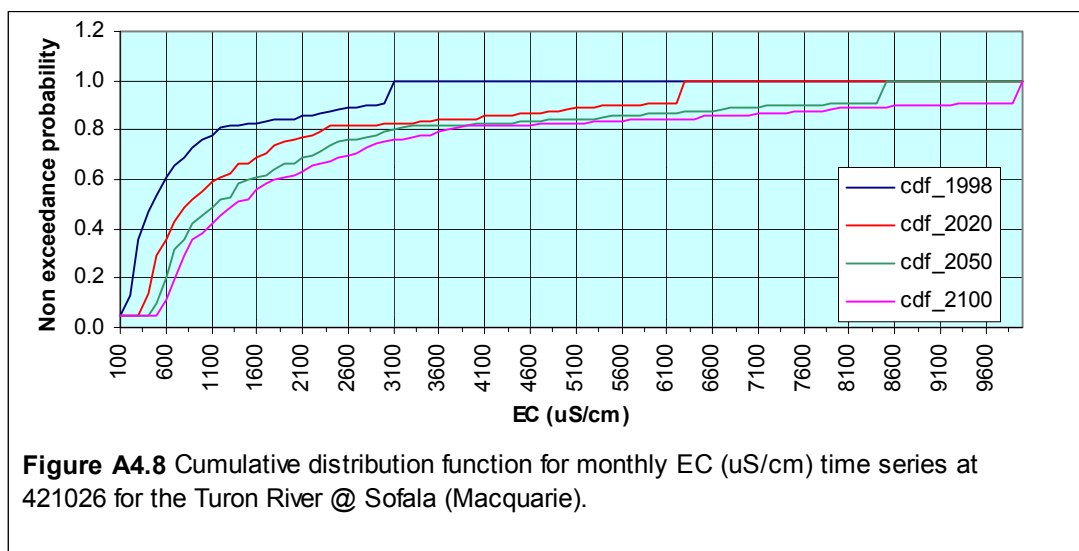
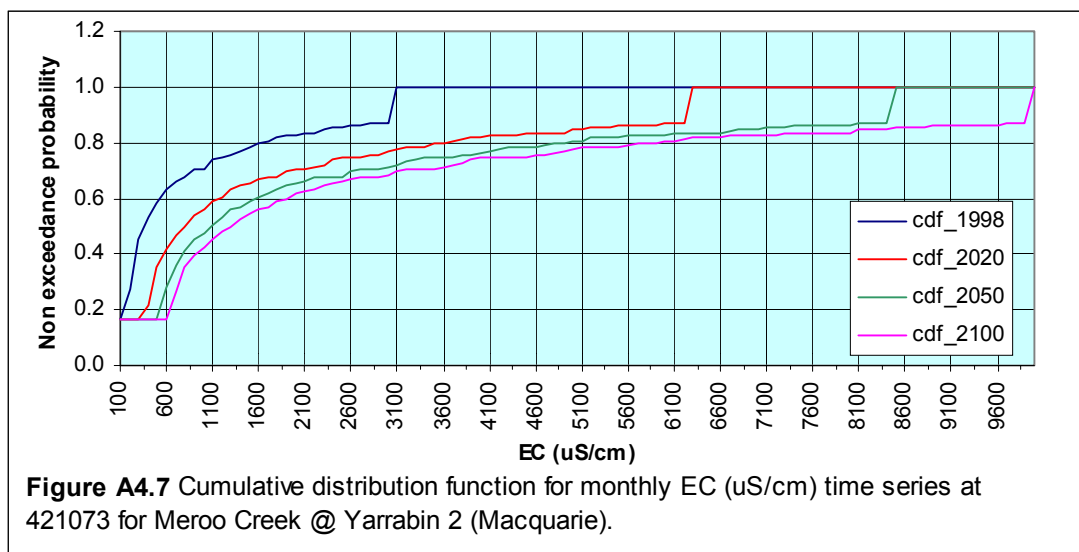


Figure A4.3 Cumulative distribution function for monthly EC (uS/cm) time series at 421025 for the Macquarie River @ Bruinbun (Macquarie).





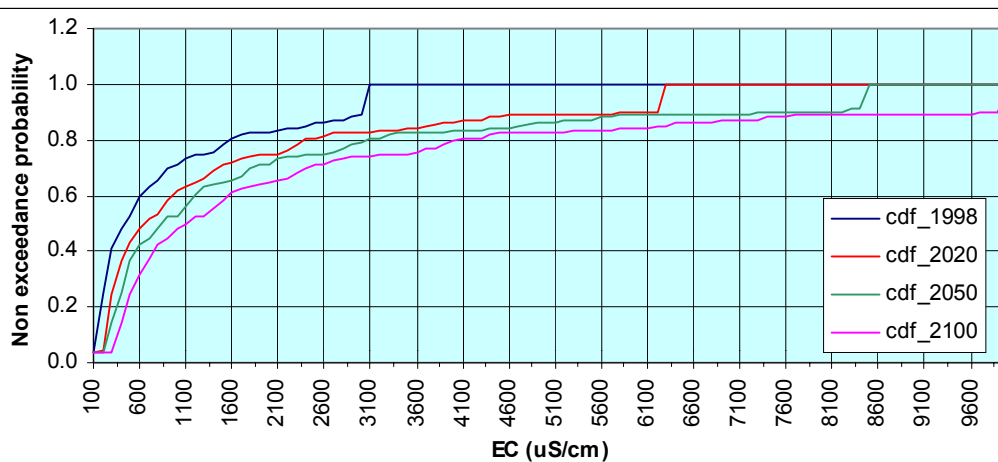


Figure A4.10 Cumulative distribution function for monthly EC ($\mu\text{S}/\text{cm}$) time series at 421052 for Lewis Ponds Creek @ Ophir (Macquarie).

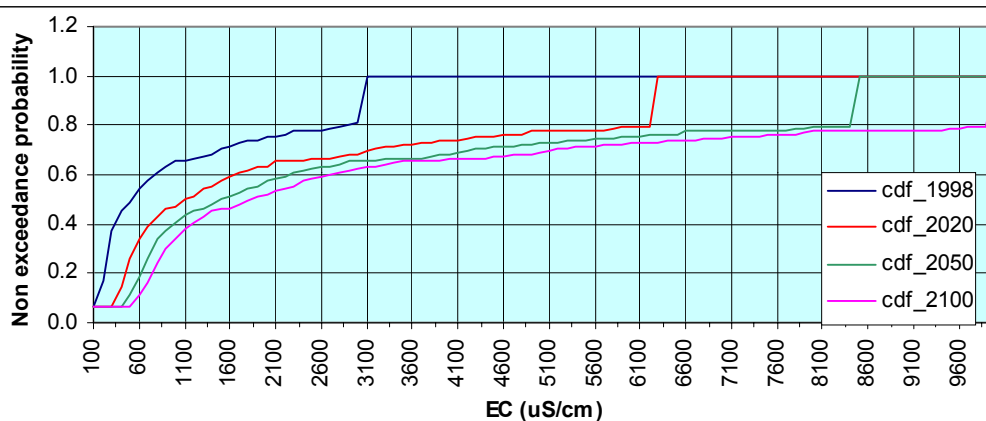


Figure A4.11 Cumulative distribution function for monthly EC ($\mu\text{S}/\text{cm}$) time series at 421072 for Winburndale River @ Howards Brid (Macquarie).

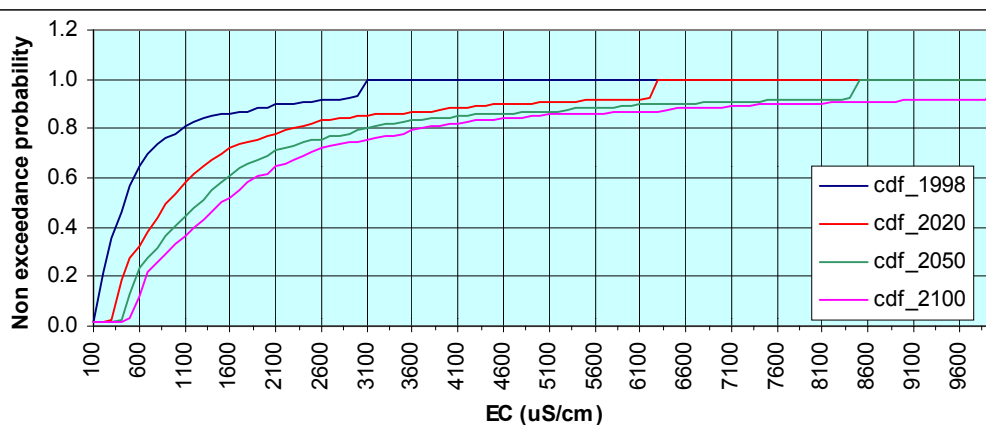
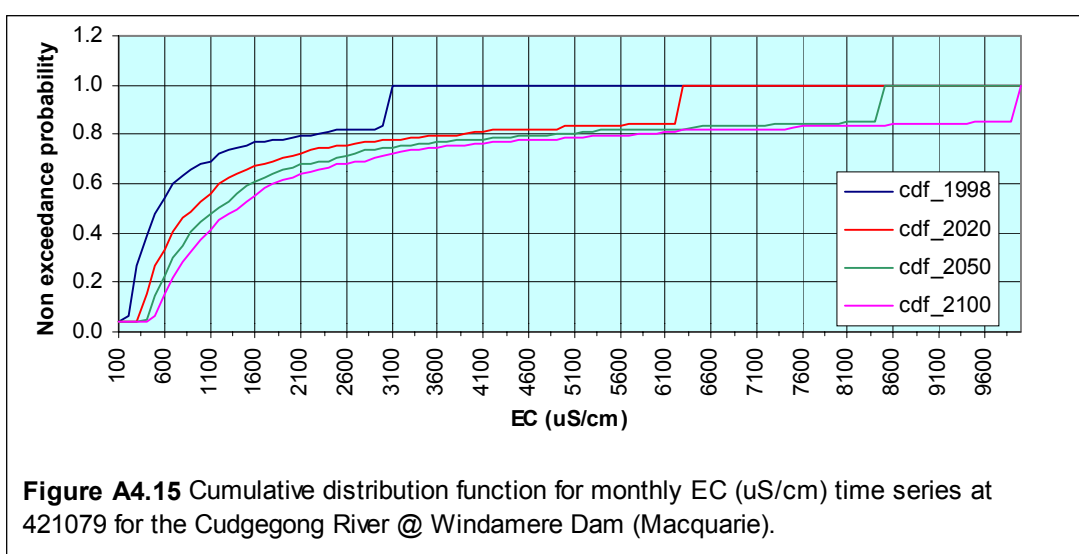
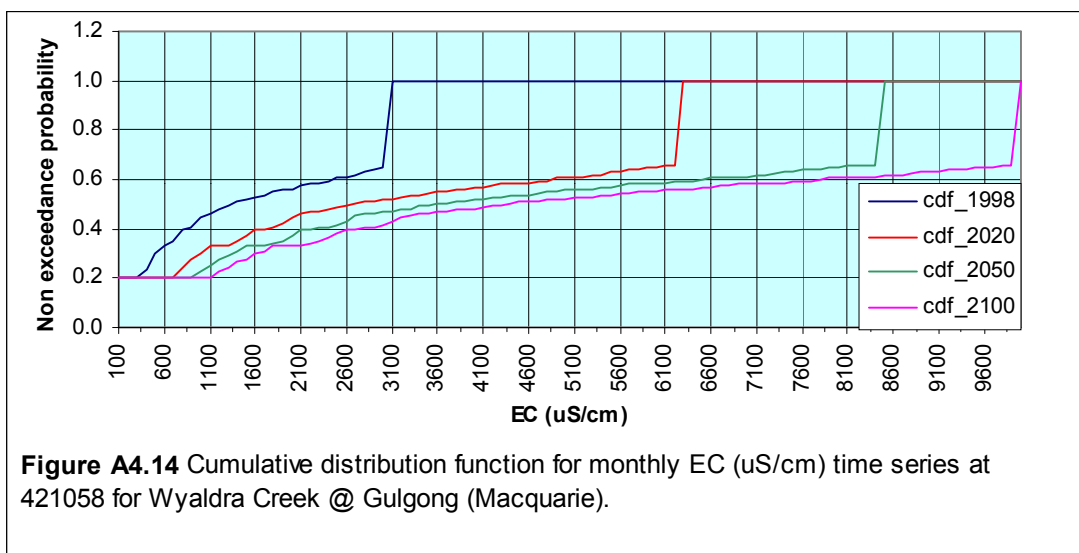
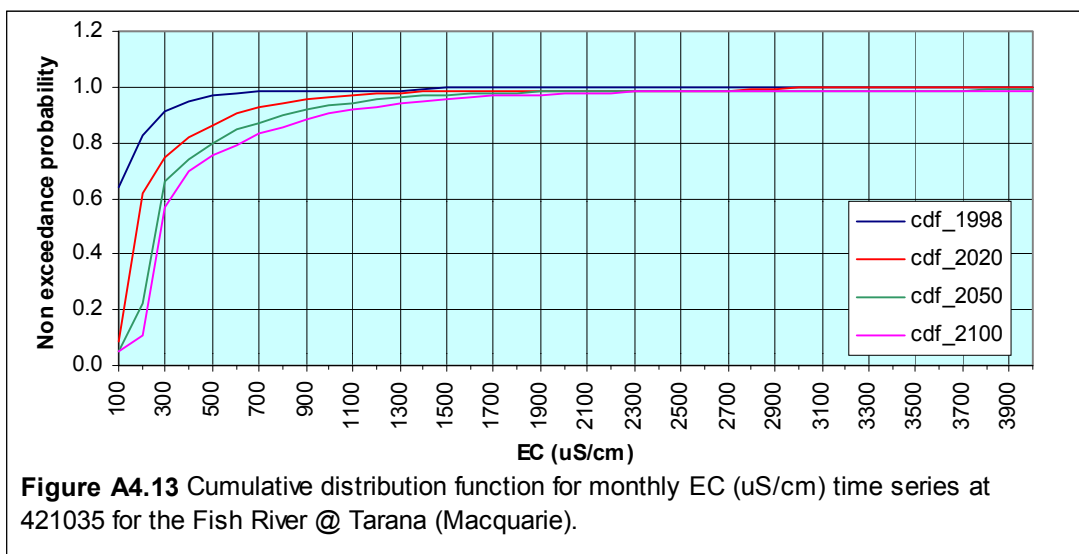


Figure A4.12 Cumulative distribution function for monthly EC ($\mu\text{S}/\text{cm}$) time series at 421101 for the Cambells River u/s Ben Chifley Dam (Macquarie).



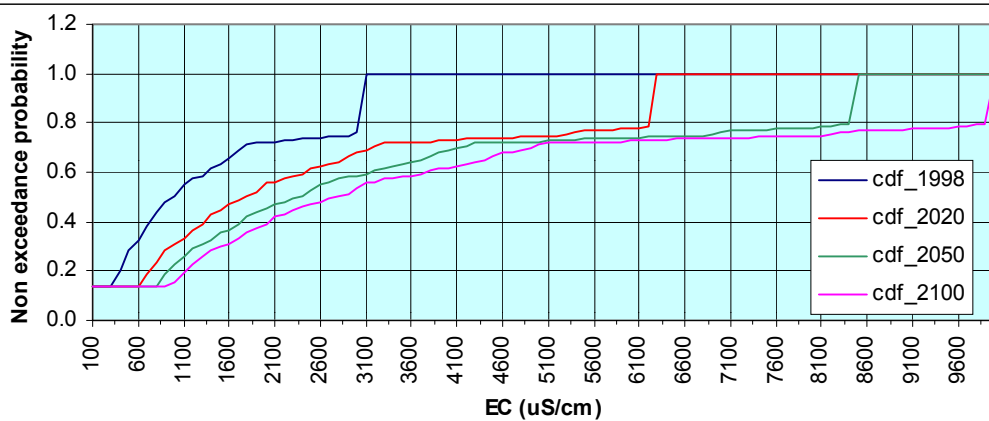


Figure A4.16 Cumulative distribution function for monthly EC (uS/cm) time series at 421042 for the Talbragar River @ Elong Elong (Macquarie).

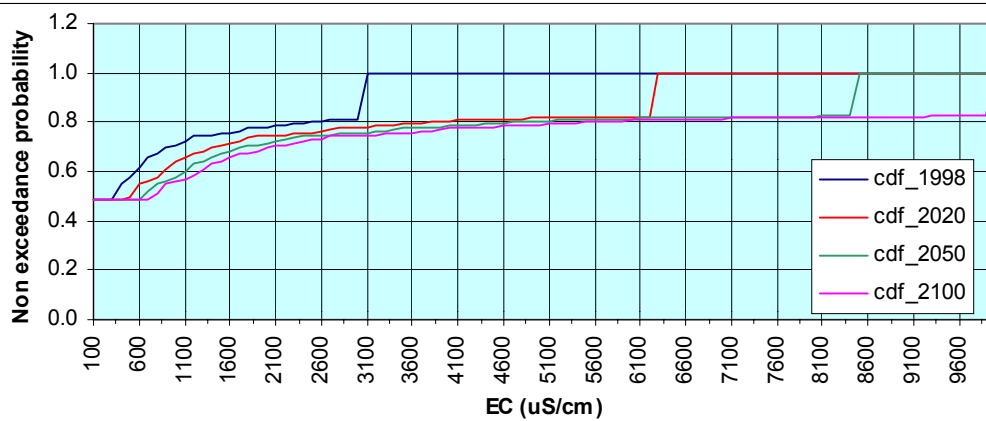


Figure A4.17 Cumulative distribution function for monthly EC (uS/cm) time series at 421055 for the Coolabagie Creek @ Rawsonville (Macquarie).

Appendix 5 Lachlan Catchment

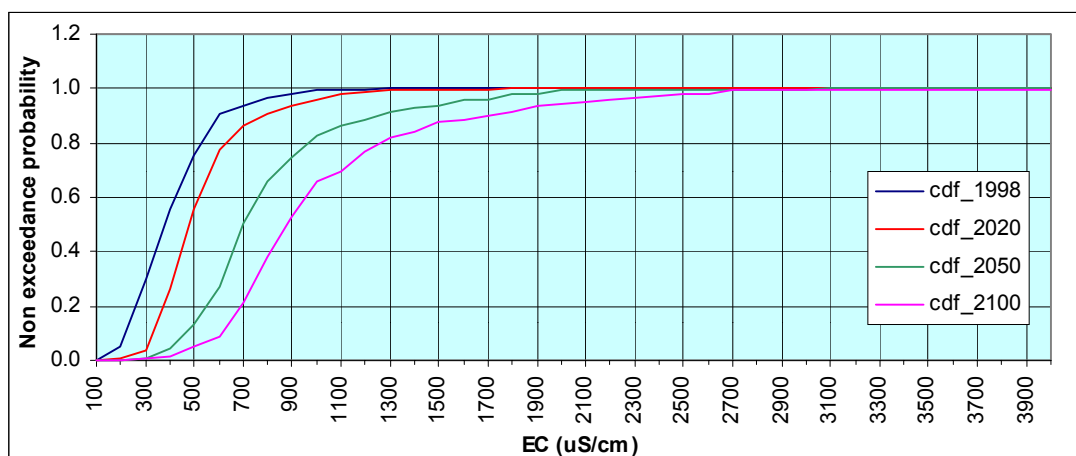


Figure A5.1 Cumulative distribution function for monthly EC (uS/cm) time series at 412004 for the Lachlan River @ Forbes (Lachlan).

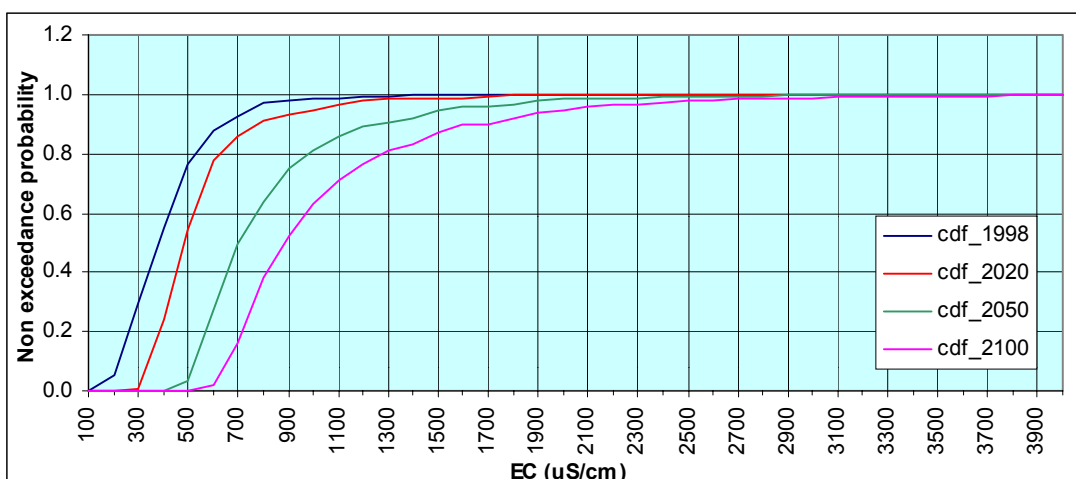


Figure A5.2 Cumulative distribution function for monthly EC (uS/cm) time series at 412057 for the Lachlan River @ Nanami (Lachlan).

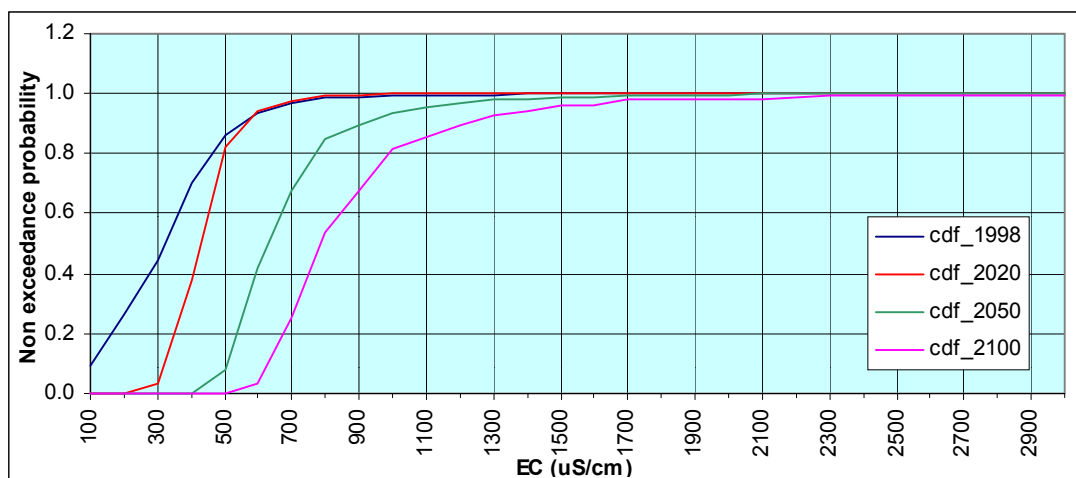


Figure A5.3 Cumulative distribution function for monthly EC (uS/cm) time series at 412002 for the Lachlan River @ Cowra (Lachlan).

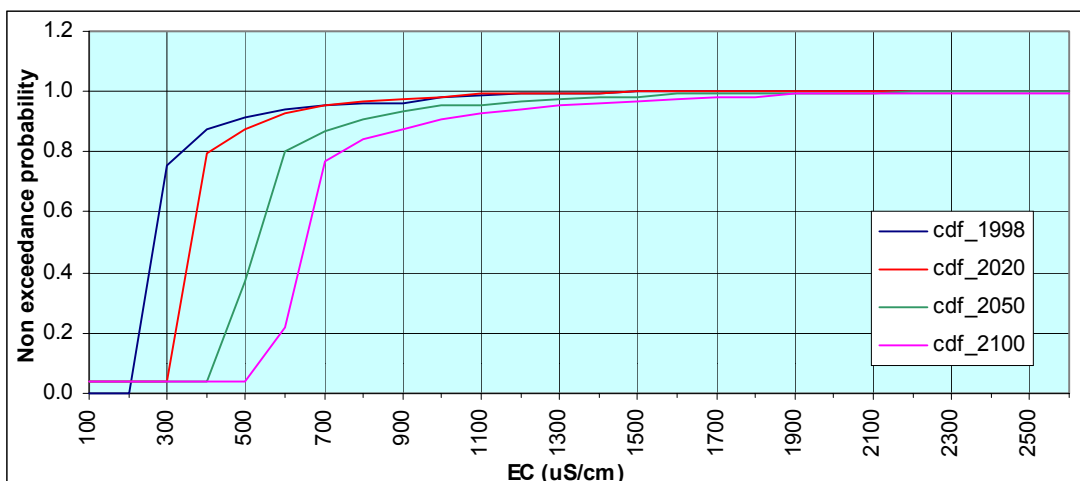


Figure A5.4 Cumulative distribution function for monthly EC (uS/cm) time series at 412067 for the Lachlan River @ Wyangala (Lachlan).

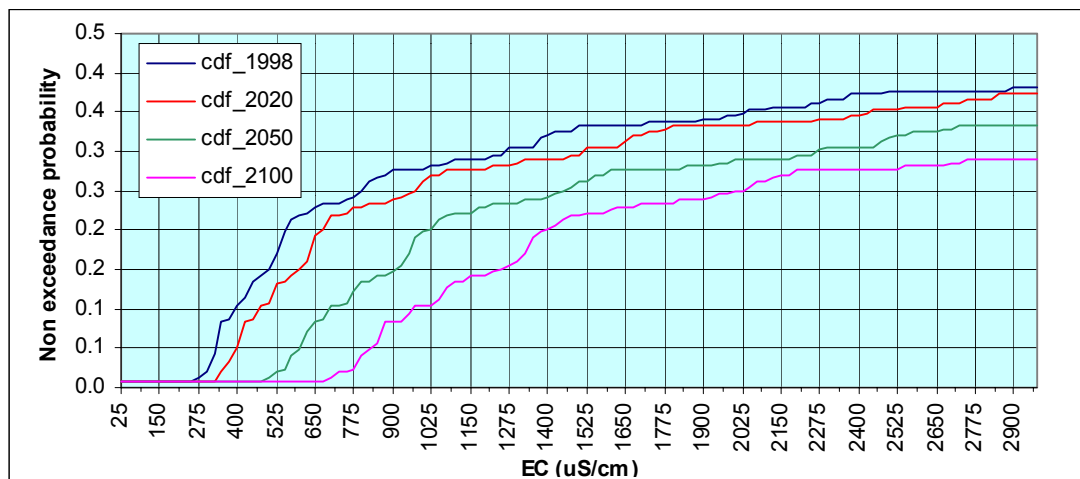


Figure A5.5 Cumulative distribution function for monthly EC (uS/cm) time series at 412043 for Goobang Creek @ Darbys Dam (Lachlan).

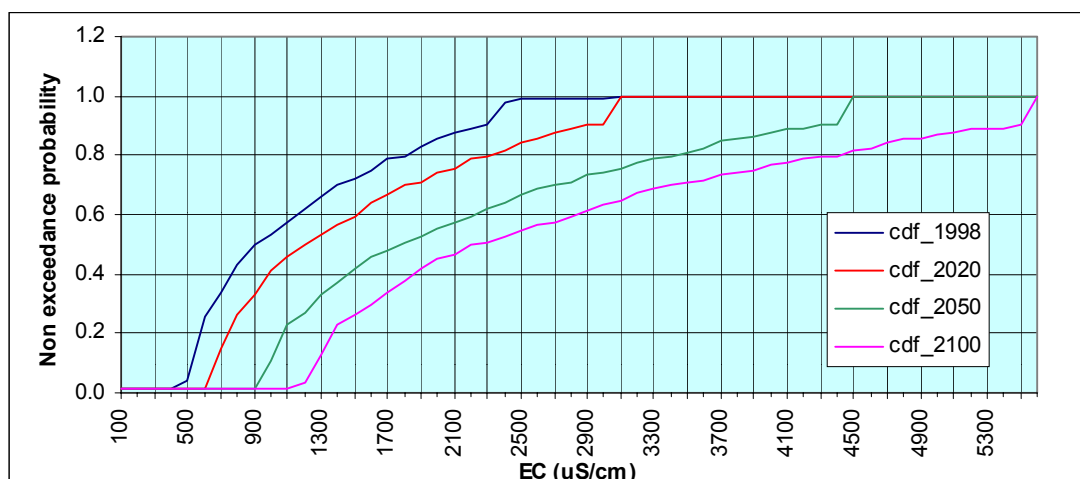


Figure A5.6 Cumulative distribution function for monthly EC (uS/cm) time series at 412030 for Mandagery Creek @ Eugowra (Smithfield) (Lachlan).

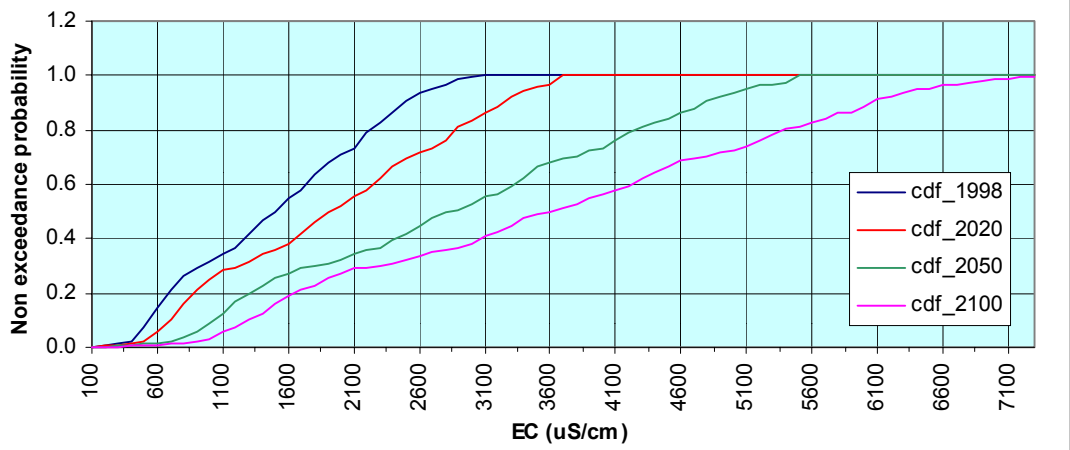


Figure A5.7 Cumulative distribution function for monthly EC (uS/cm) time series at 412055 for the Belubula River @ Bangaroo Bridge (Lachlan).

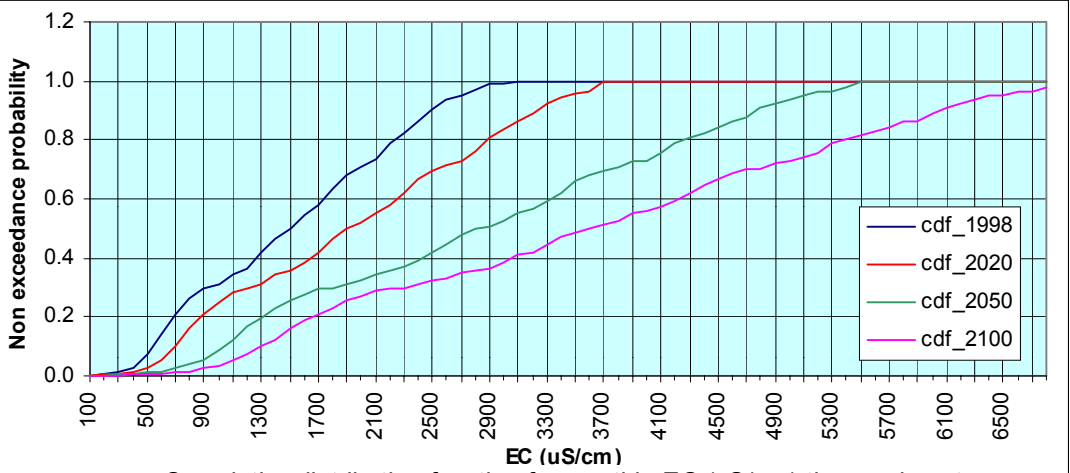


Figure A5.8 Cumulative distribution function for monthly EC (uS/cm) time series at 412072 for Black Creek @ Koorawatha (Lachlan).

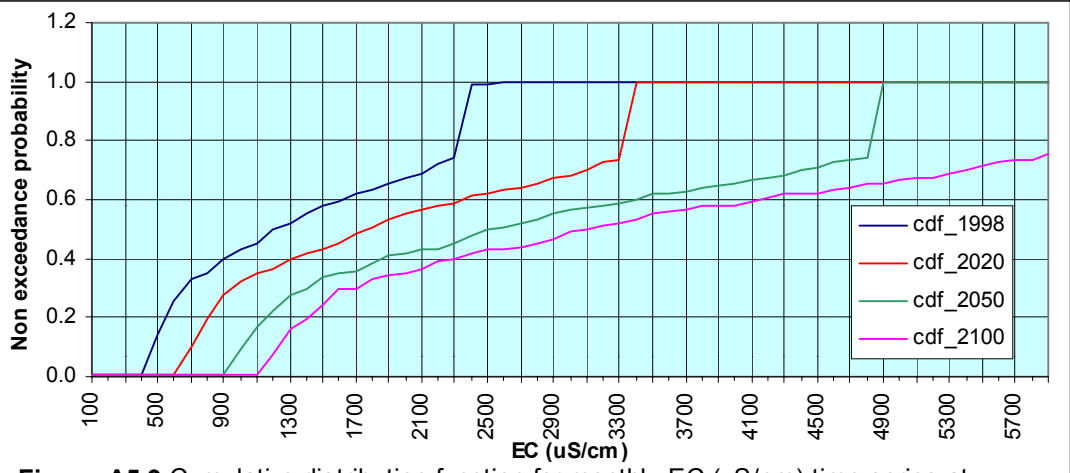


Figure A5.9 Cumulative distribution function for monthly EC (uS/cm) time series at 412029 for the Boorowa River @ Prossers Crossing (Lachlan).

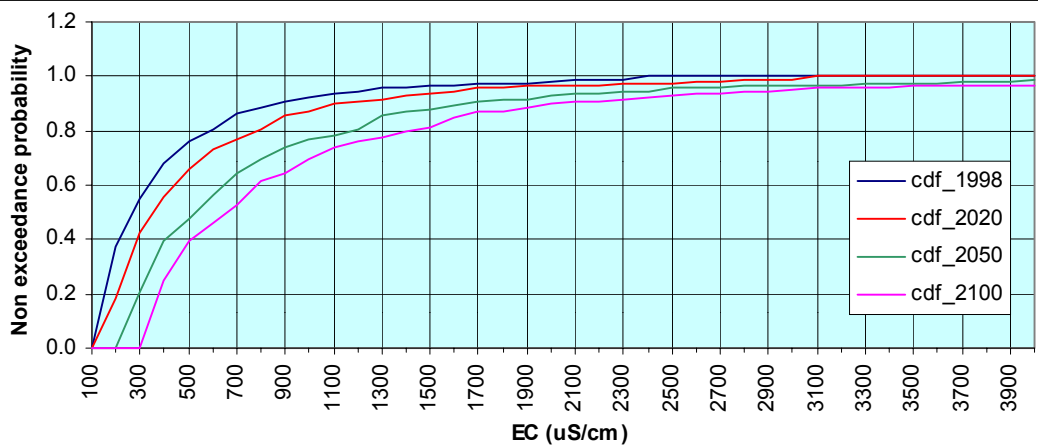


Figure A5.10 Cumulative distribution function for monthly EC (uS/cm) time series at 412028 for the Abercrombie River @ Abercrombie (Lachlan).

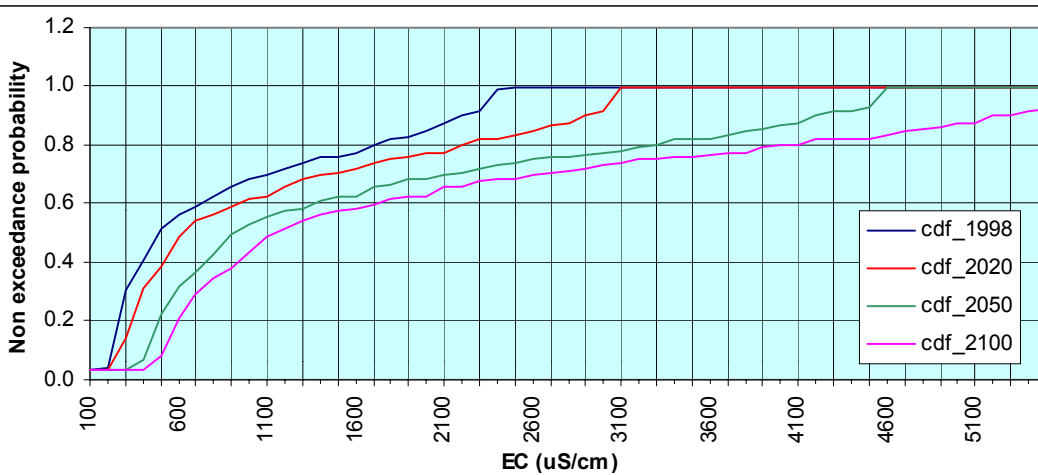


Figure A5.11 Cumulative distribution function for monthly EC (uS/cm) time series at 412083 for Tuena Creek @ Tuena (Lachlan).

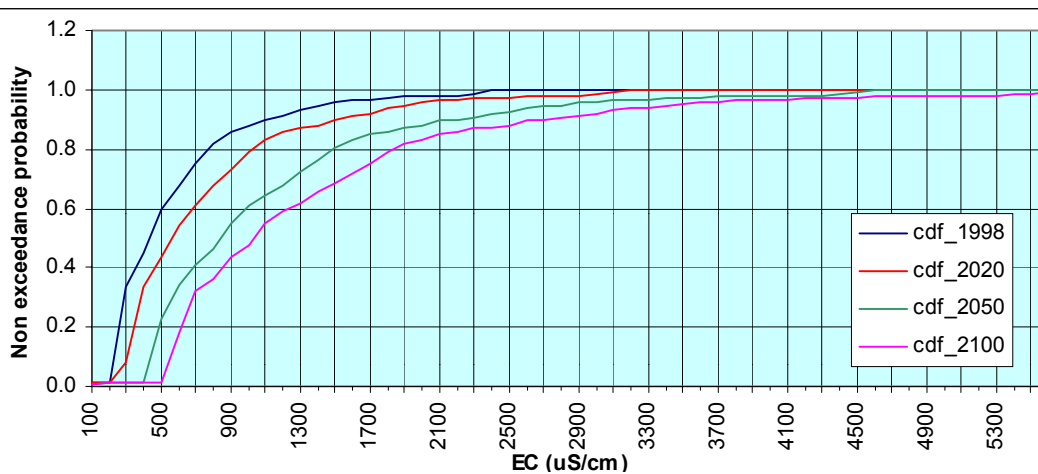


Figure A5.12 Cumulative distribution function for monthly EC (uS/cm) time series at 412050 for the Crookwell River @ Narrawa North (Lachlan).

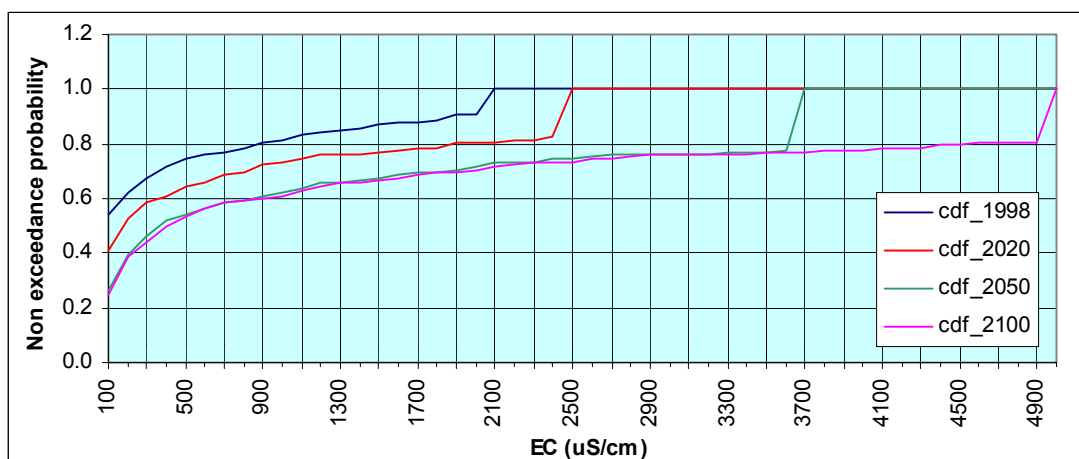
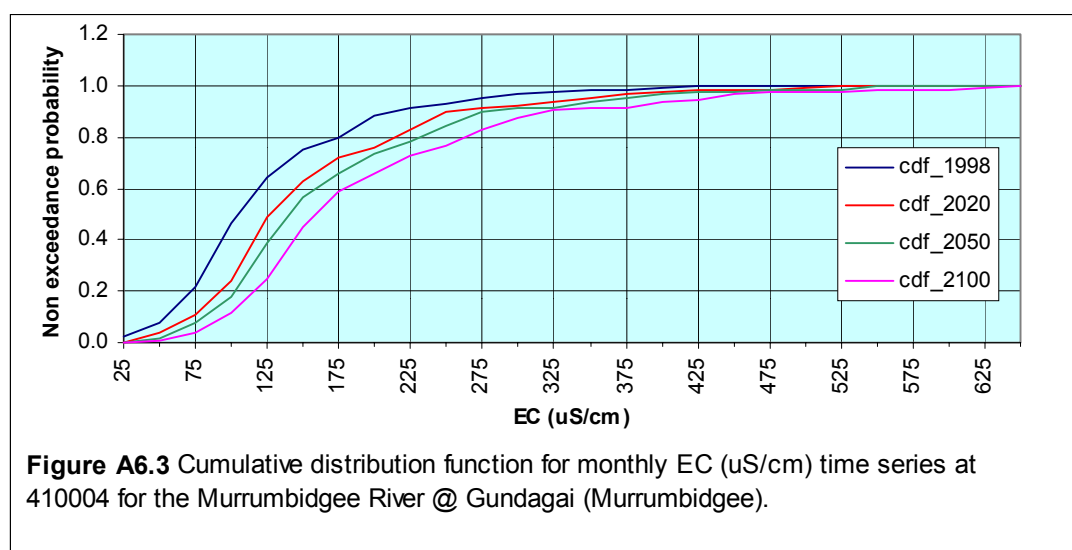
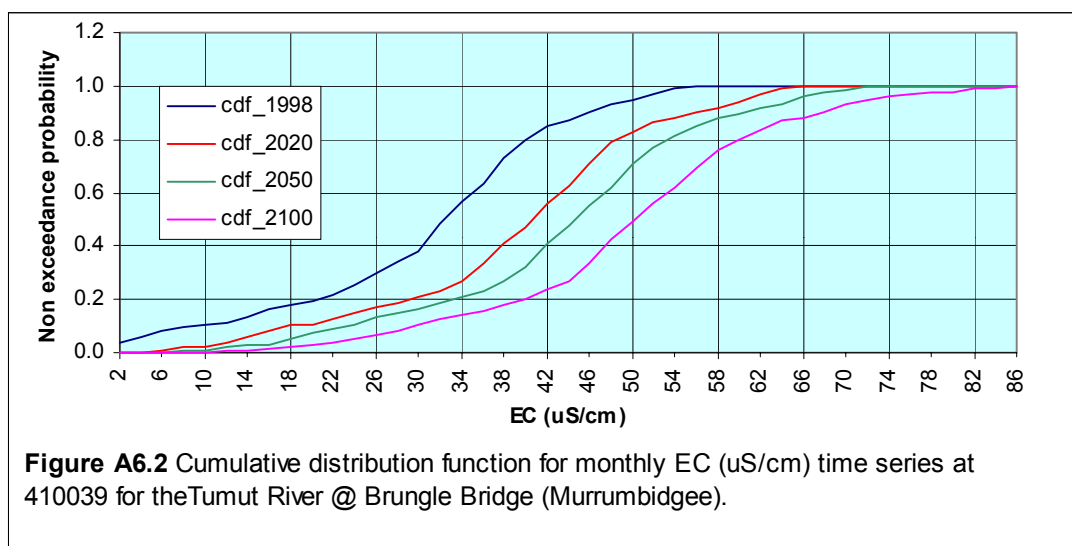
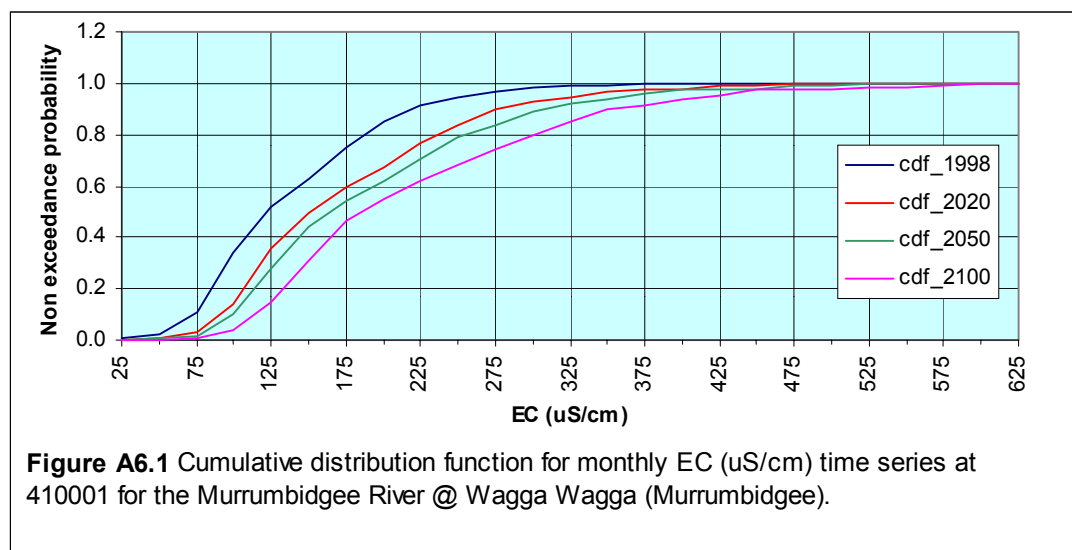


Figure A5.13 Cumulative distribution function for monthly EC (uS/cm) time series at 412065 for the Lachlan River @ Narrawa (Lachlan).

Appendix 6 Murrumbidgee Catchment



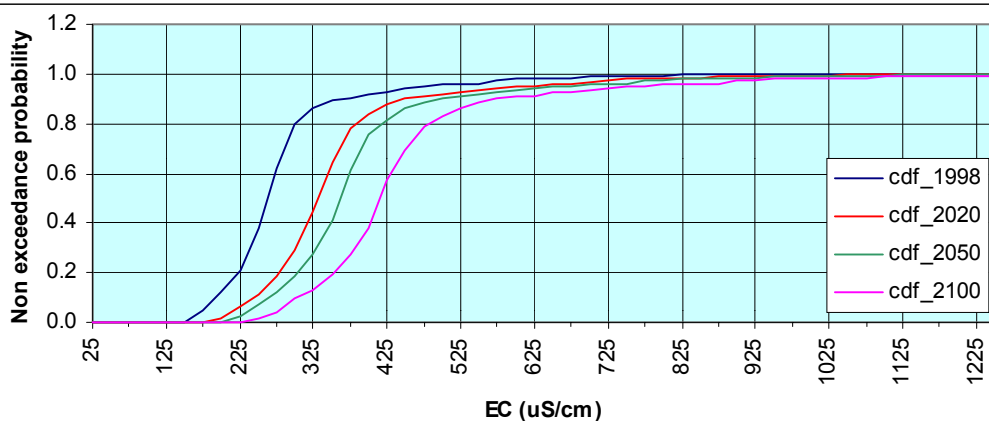


Figure A6.4 Cumulative distribution function for monthly EC (uS/cm) time series at 416047 for Tarcutta Creek @ Old Borambola (Murrumbidgee).

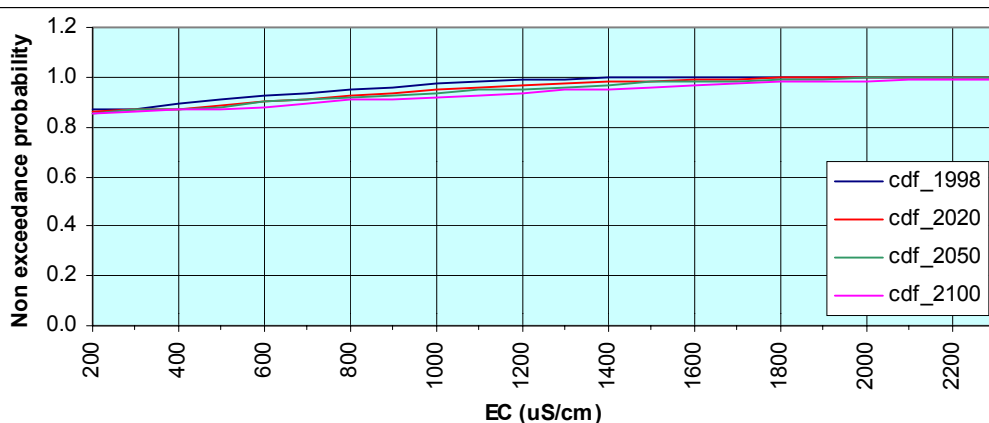


Figure A6.5 Cumulative distribution function for monthly EC (uS/cm) time series at 416045 for Billabung Creek @ Sunny Side (Murrumbidgee).

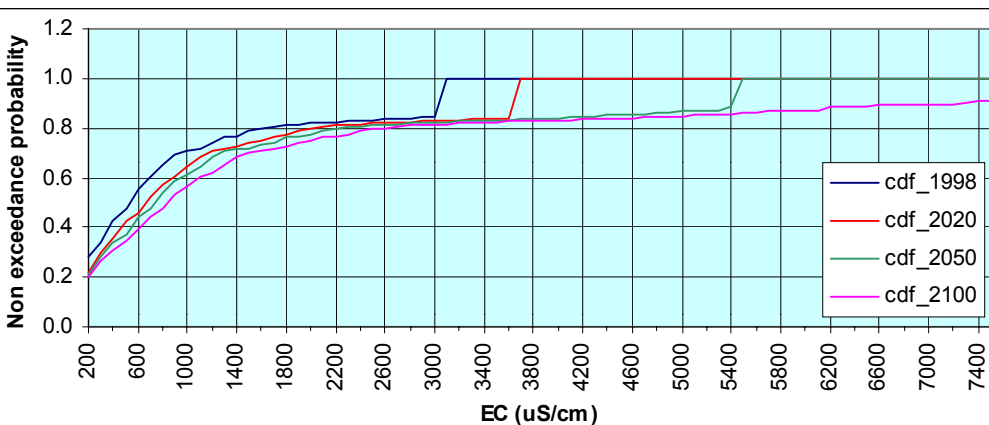


Figure A6.6 Cumulative distribution function for average monthly EC (uS/cm) time series at 416044 for Muttama Creek @ Coolac (Murrumbidgee Catchment).

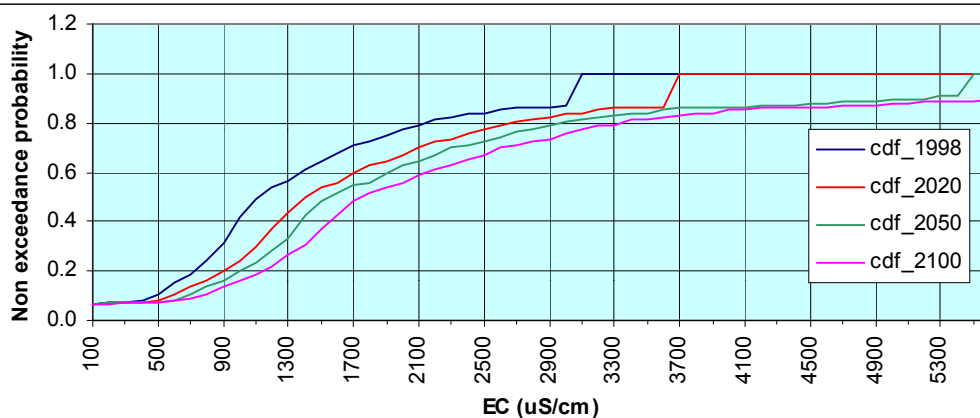


Figure A6.7 Cumulative distribution function for monthly EC (uS/cm) time series at 410025 for Jugiong Creek @ Jugiong (Murrumbidgee).

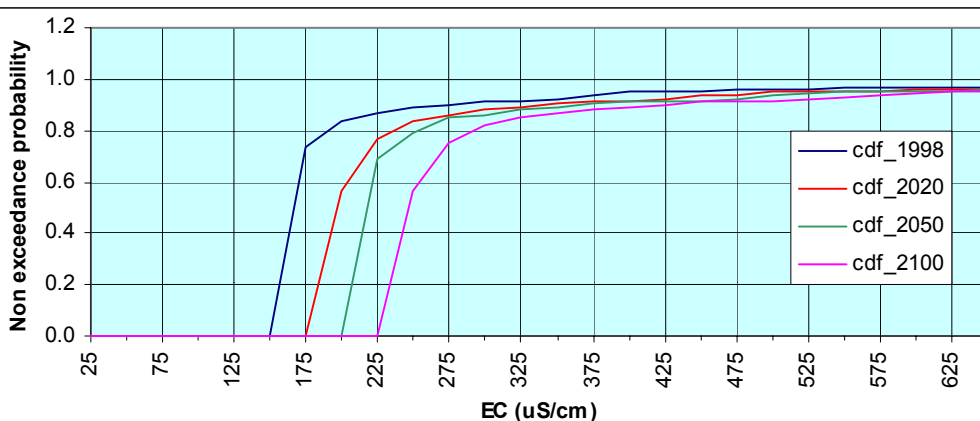


Figure A6.8 Cumulative distribution function for monthly EC (uS/cm) time series at 410008 for Murrumbidgee River @ Burrinjuck Dam (Murrumbidgee).

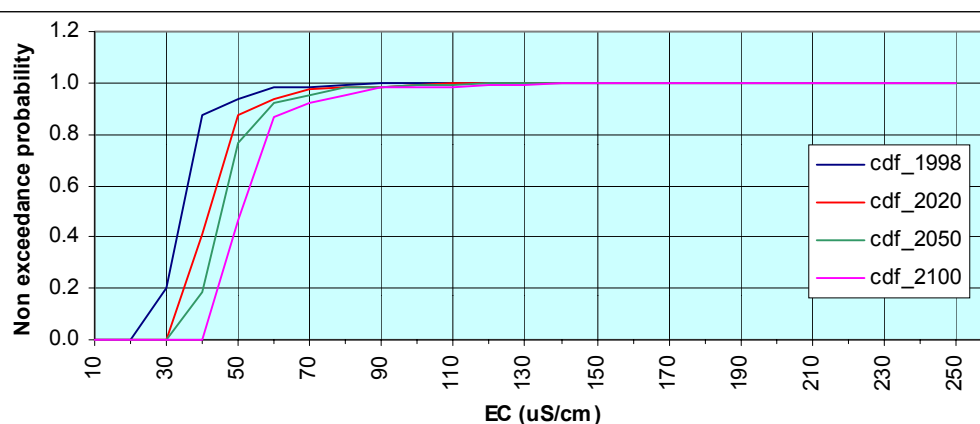


Figure A6.8 Cumulative distribution function for monthly EC (uS/cm) time series at 410073 for the Tumut River @ Oddys Bridge (Murrumbidgee).

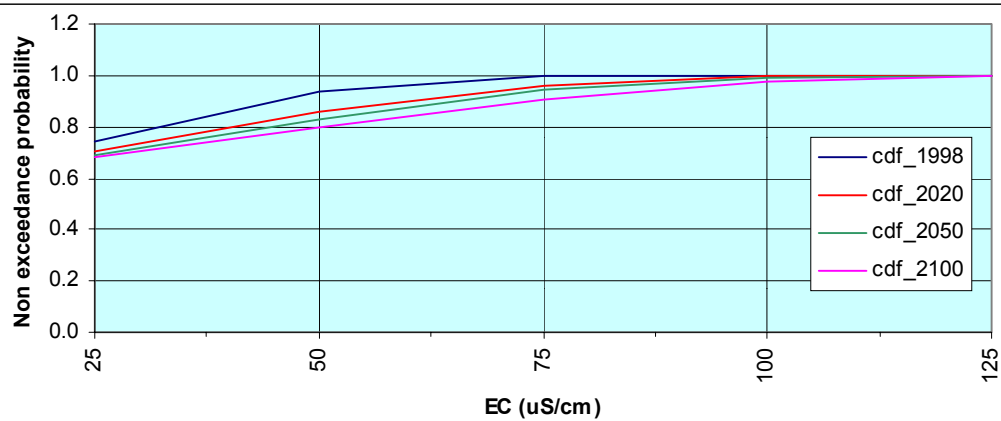


Figure A6.9 Cumulative distribution function for monthly EC (uS/cm) time series at 410059 for Gilmore Creek @ Gilmore (Murrumbidgee).

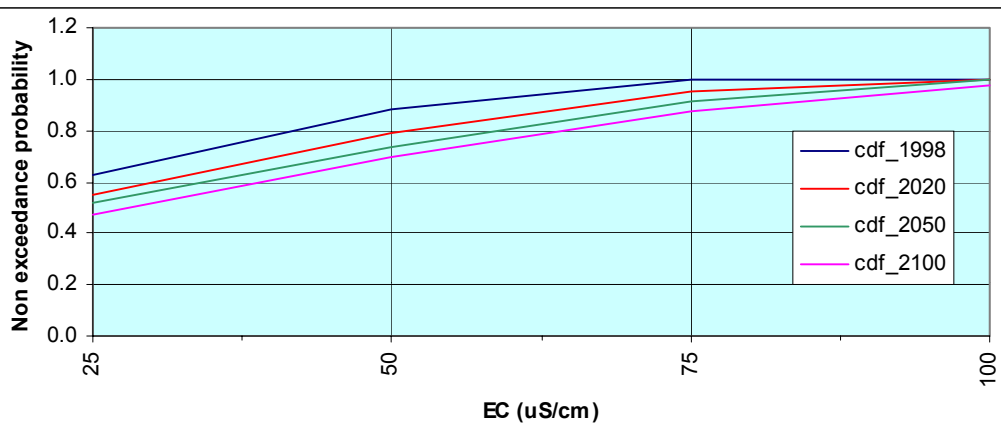


Figure A6.10 Cumulative distribution function for monthly EC (uS/cm) time series at 410057 for the Goobarragandra River @ Lacmalac (Murrumbidgee).

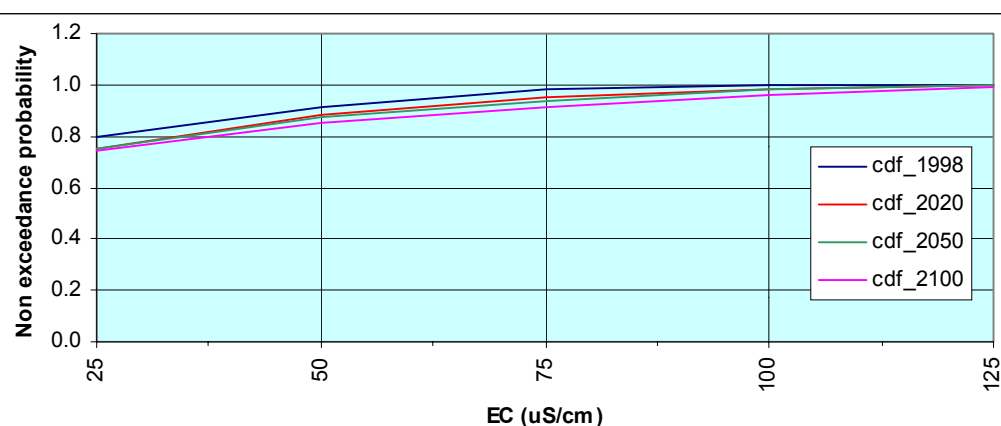
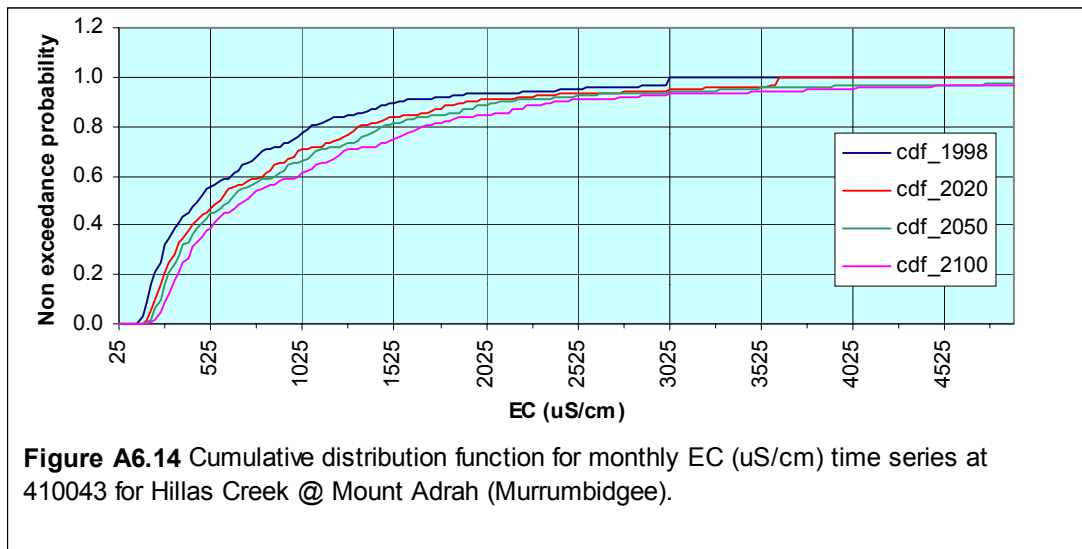
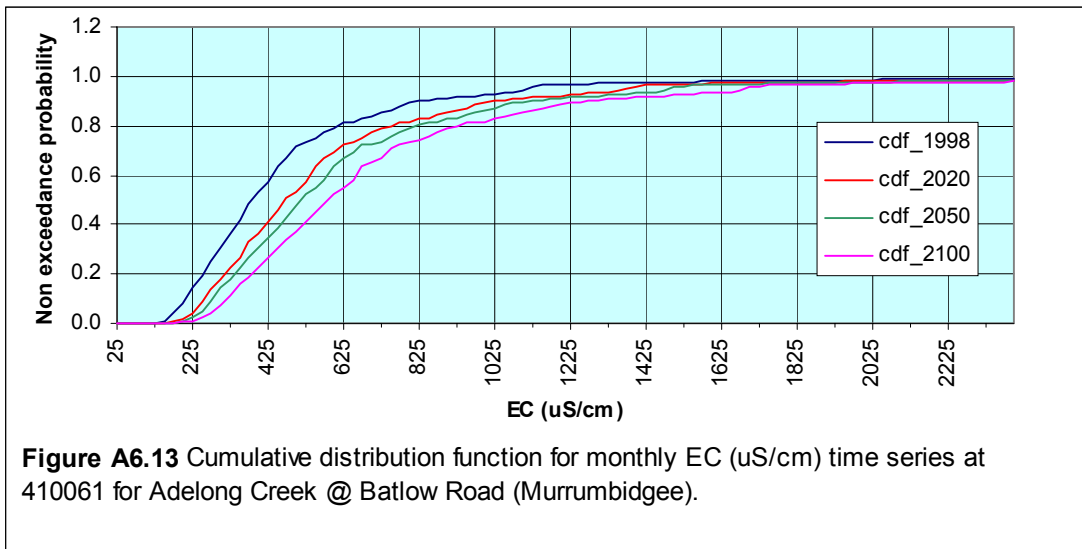
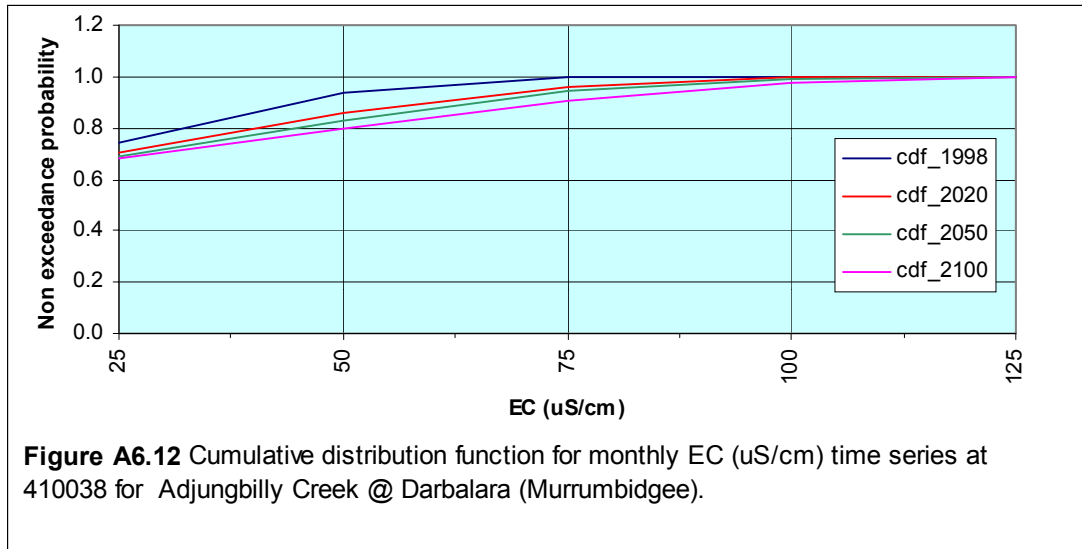


Figure A6.11 Cumulative distribution function for monthly EC (uS/cm) time series at 410071 for Brungle Creek @ Red Hill (Murrumbidgee).



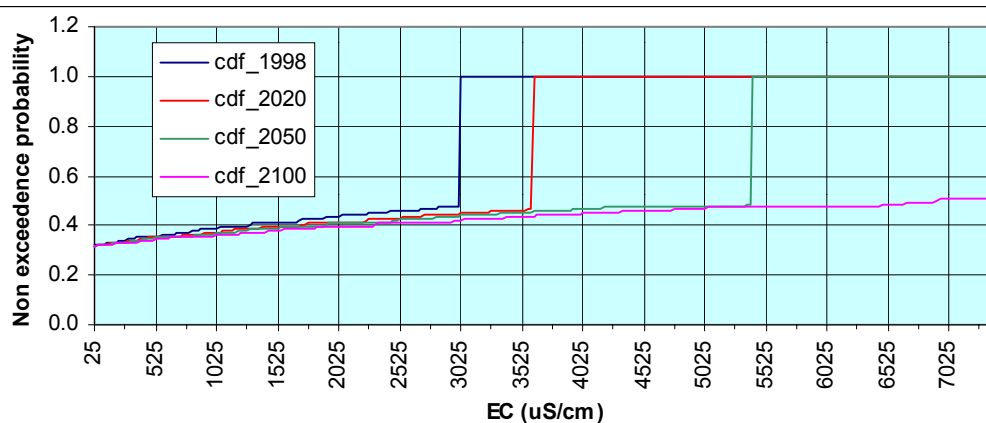


Figure A6.15 Cumulative distribution function for monthly EC (uS/cm) time series (1975-1992) at 410048 for Kyeamba Creek @ Ladysmith (Murrumbidgee).

Appendix 7 Town water supply in relation to source, predicted in-stream salinity and urban salinity hazard. (Population >500 only)

Valley	Section or Tributary	TOWN	Population	SOURCE			% time threshold salinity exceeded								Groundw	
				1	2	3 VIA	current		2020		2050		2100		Salinity	
							800	1600	800	1600	800	1600	800	1600		Risk
Murray	Tumbarumba	Tumbarumba	500	riv		dam	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	to M'bidgee Jn	Albury	44500	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L-M
Murray	to M'bidgee Jn	Howlong	1700	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	to M'bidgee Jn	Corowa	5100	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	to M'bidgee Jn	Mulwala	1700	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	to M'bidgee Jn	Tocumwall	1750	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	to M'bidgee Jn	Berrigan	1000	riv		irr chan	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L-M
Murray	to M'bidgee Jn	Finley	2250	riv		irr chan	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H
Murray	to M'bidgee Jn	Moama	3200	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	to M'bidgee Jn	Barham	1207	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Murray	to Darling J	Euston	400	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Murray	to Darling J	Buronga	555	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	to Darling J	Gol Gol	620	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	to Darling J	Dareton	1000	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Murray	to S Australia	none					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Murray	Edward	Mathoura	650	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	Edward	Deniliquin	8000	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	Edward	Moulamein	500	riv		dam	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Murray	Billabong C	Jerilderie	1000	riv		dam	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
M'bidgee	to Burrinjuck	Cooma	8000	riv			1	1	1	1	3	3	4	4	4	?
M'bidgee	to Burrinjuck	Queanbeyan	27000	riv		storage	1	1	2	2	3	3	4	4	4	M
M'bidgee	to Burrinjuck	Canberra	305000	riv		storage	1	1	2	2	3	3	4	4	4	?
M'bidgee	to Burrinjuck	Bungendore	1500	bore			0	0	0	0	0	0	0	0	0	L
M'bidgee	Yass R	Yass	5500	riv			1	1	2	2	3	3	4	4	4	H
M'bidgee	Burri to Wagga	Gundagai	2500	riv			1	1	2	2	3	3	4	4	4	?
M'bidgee	at Jugiong	SWT & NRCC	35000	rivbore (1)	riv		0	0	1	1	2	2	3	3	3	
M'bidgee	at Jugiong	Jugiong	200	rivbore (1)	riv	SWT	0	0	1	1	2	2	3	3	3	?
M'bidgee	at Jugiong	June	4000	rivbore (1)	riv	SWT	0	0	1	1	2	2	3	3	3	H
M'bidgee	at Jugiong	Murrumbucca	2100	rivbore (1)	riv	SWT	0	0	1	1	2	2	3	3	3	M
M'bidgee	at Jugiong	Temora	4600	rivbore (1)	riv	SWT	0	0	1	1	2	2	3	3	3	L
M'bidgee	at Jugiong	Barmedman	500	rivbore (1)	riv	SWT	0	0	1	1	2	2	3	3	3	?
M'bidgee	at Jugiong	Cootamundra	8000	rivbore (1)	riv	SWT	0	0	1	1	2	2	3	3	3	H
M'bidgee	at Jugiong	W Wyalong	3300	rivbore (1)	riv	SWT	0	0	1	1	2	2	3	3	3	L
M'bidgee	at Jugiong	Young	11500	rivbore (1)	riv	SWT	0	0	1	1	2	2	3	3	3	H
M'bidgee	at Jugiong	Coolamon	1200	rivbore (1)	riv	bore	NRCC	0	0	1	1	2	2	3	3	?
M'bidgee	at Wagga	Forest Hill	2500	rivbore (2)			SRCC	0	0	1	1	2	2	3	3	M
M'bidgee	at Wagga	Wagga Wagga	53400	rivbore (2)	riv		SRCC	0	0	1	1	2	2	3	3	H
M'bidgee	at Wagga	SRCC	10000+	rivbore (2)				0	0	1	1	2	2	3	3	
M'bidgee	at Wagga	Kapooka	1500	rivbore (2)			SRCC	0	0	1	1	2	2	3	3	L
M'bidgee	at Wagga	Urana	450	rivbore (2)			SRCC	0	0	1	1	2	2	3	3	L
M'bidgee	at Wagga	Lockhart	1000	rivbore (2)			SRCC	0	0	1	1	2	2	3	3	L
M'bidgee	at Wagga	Holbrook	1400	rivbore (2)	bore		SRCC	0	0	1	1	2	2	3	3	L
M'bidgee	at Wagga	Henty	990	rivbore (2)			SRCC	0	0	1	1	2	2	3	3	M
M'bidgee	at Wagga	The Rock	740	rivbore (2)			SRCC	0	0	1	1	2	2	3	3	L
M'bidgee	at Wagga	Culcairn	1300	rivbore (2)			SRCC	0	0	1	1	2	2	3	3	L
M'bidgee	at Wagga	Uranquinty	600	rivbore (2)			SRCC	0	0	1	1	2	2	3	3	L
M'bidgee	at Wagga	Walla Walla	530	rivbore (2)	bore		SRCC	0	0	1	1	2	2	3	3	M
M'bidgee	at Narrandera	Narrandera	4700	bore				0	0	1	1	2	2	3	3	L
M'bidgee	at Narrandera	Yanco	650	riv		MIA		0	0	1	1	2	2	3	3	L

M'bidgee	at Narrandera	Leeton	6300	riv		MIA	0	0	1	1	2	2	3	3	M
M'bidgee	at Narrandera	Griffith	22000	riv		MIA	0	0	1	1	2	2	3	3	L
M'bidgee	at Narrandera	Yenda	1200	riv		MIA	0	0	1	1	2	2	3	3	L
M'bidgee	N to Balranald	Darlington Pt	750	rain	bore		0	0	1	1	2	2	3	3	H
M'bidgee	N to Balranald	Hay	2800	riv			0	0	1	1	2	2	3	3	L
M'bidgee	N to Balranald	Balranald	1500	riv			0	0	1	1	2	2	3	3	M
M'bidgee	Tumut trib	Batlow	1200	creek			0	0	0	0	0	0	0	0	L
M'bidgee	Tumut R	Tumut	6000	riv	dam		0	0	0	0	0	0	0	0	L
Lachlan	to Wyangala	Gunning	500	riv			22	12	25	22	41	36	42	37	M
Lachlan	W to Forbes	Cowra	8500	riv			1	0	2	0	12	3	60	4	M
Lachlan	W to Forbes	Forbes	7000	riv			4	0	11	1	35	6	63	12	H
Lachlan	W to Forbes	Tottenham/Tullamore	750	riv		Forbes	4	0	11	1	35	6	63	12	?
Lachlan	W to Forbes	Trundle	700	riv		Forbes	4	0	11	1	35	6	63	12	M
Lachlan	F to Hillston	Condobolin	3500	riv			4	0	11	1	35	6	63	12	H
Lachlan	F to Hillston	L Cargelligo	1200	riv			4	0	11	1	35	6	63	12	H
Lachlan	F to Hillston	Hillston	1100	bore			4	0	11	1	35	6	63	12	H
Lachlan	Kentgrove Ck	Crookwell	2500	creek		dam	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Lachlan	Boorowa R	Boorowa	1200	riv		dam	67	41	80	55	100	67	100	72	H
Lachlan	Burrangong R	Grenfell	2300	riv		dam	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Lachlan	local	Millthorpe	640	lake *	bore	CTW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Lachlan	local	Blayney	2600	lake *	bore	CTW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H
Lachlan	local	Canowindra	1720	lake *	bore	CTW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H
Lachlan	local	Manildra	530	lake *	bore	CTW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H
Lachlan	local	Eugowra	570	lake *	bore	CTW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Lachlan	Goobang Ck	Parkes	10000	bore	lake	dam	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H
Lachlan	Goobang Ck	Peak Hill	1500	bore	lake	dam	Parkes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Macquarie	??creeks	Orange	35000	lake *	dams		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Macquarie	to W'ton D	Bathurst	30000	store			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Macquarie	Cudgegong	Kandos	1600	riv		Rylstone	37	22	57	32	70	39	75	47	H
Macquarie	Cudgegong	Rylstone	730	riv		dam	37	22	57	32	70	39	75	47	M
Macquarie	Cudgegong	Mudgee	7000	riv	bore		2	0	4	1	6	3	8	4	H
Macquarie	Cudgegong	Gulgong	2000	riv	bore	creek	60	47	75	60	79	68	79	71	H
Macquarie	W to Warren	Wellington	6000	riv			12	5	30	11	55	16	80	21	M
Macquarie	W to Warren	Dubbo	34500	riv	bore		12	5	30	11	55	16	80	21	H
Macquarie	W to Warren	Narromine	2800	bore			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Macquarie	W to Warren	Warren	2300	riv	bore		12	5	30	11	55	16	80	21	H
Macquarie	Bell R	Molong	1600	riv		dam	40	22	62	41	72	50	75	55	M
Macquarie	Talbragar R	Coolah	900	rivbore			55	35	74	52	88	65	88	70	M
Macquarie	Talbragar R	Dunnedoo	900	rivbore			55	35	74	52	88	65	88	70	M
Macquarie	Bogan+Mcq	Nyngan	2500	Bogan	Macquar		12	5	30	11	55	16	80	21	L
Macquarie	Bogan+Mcq	Cobar	5500	Bogan	Macquar		12	5	30	11	55	16	80	21	L
Castlereagh	Castlereagh	Binnaway	600	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Castlereagh	Castlereagh	Coonabarabran	3500	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Castlereagh	Castlereagh	Gilgandra	3000	bore			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Castlereagh	Castlereagh	Coonamble	3900	bore			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Namoi	Peel R	Tamworth	34500	rivstore			22	8	43	14	52	28	65	35	M
Namoi	Cockburn R	Kootingal	2000	bore			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H
Namoi	Manilla R	Manilla	2290	riv	rivstore		0	0	0	0	0	0	0	0	M
Namoi	Manilla R	Barraba	1500	rain	riv		0	0	0	0	0	0	0	0	L
Namoi	Manilla R	Curlewis	610	bore			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Namoi	Mooki R	Quirindi	3050	bore			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Namoi	Mooki R	Werris Cr	2000	riv			37	32	45	35	47	37	50	39	M
Namoi	Namoi	Gunnedah	9560	rivbore			14	6	35	12	50	16	62	25	H
Namoi	Namoi	Boggabri	1000	bore	riv ?		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L/M
Namoi	Namoi	Narrabri	7500	bore	riv ?		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Namoi	Namoi	Wee Wah	2000	bore	riv ?		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L

Namoi	Namoi/Barwon	Walgett	2600	Namoi	Barwon	bore	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Gwydir	to Copeton D	Uralla	2800	riv			23	12	24	13	25	16	28	18	M
Gwydir	to Copeton D	Guyra	1800	riv			15	10	17	11	18	12	19	13	M
Gwydir	C to Barwon	Bingara	1400	riv			12	2	13	3	18	4	19	4	M
Gwydir	C to Barwon	Moree	10500	bore			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Gwydir	C to Barwon	Warialda	1500	rivbore			12	2	13	3	18	4	19	4	L/M
Macintyre	Tenterfield Ck	Tenterfield	3300	creek			5	2	N/A	N/A	N/A	N/A	N/A	N/A	L
Macintyre	Beardy/Mann	Glen Innes	6500	riv			32	21	N/A	N/A	N/A	N/A	N/A	N/A	L
Macintyre	Severn	Ashford	600	riv			0	0	N/A	N/A	N/A	N/A	N/A	N/A	M/H
Macintyre	McIntyre	Inverell	12000	riv		storage	0	0	N/A	N/A	N/A	N/A	N/A	N/A	H
Macintyre	McIntyre	Tingha	850	riv		Inverell	0	0	N/A	N/A	N/A	N/A	N/A	N/A	L
Macintyre	McIntyre	Boggabilla	850	riv			11	5	N/A	N/A	N/A	N/A	N/A	N/A	M
Barwon	to Gwydir	Mungindi	1200	riv ? bore ?			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Barwon	G to Namoi	Collarenebri	920	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Darling	N to Bogan	Brewarrina	1500	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	H
Darling	B to Menindee	Bourke	4220	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Darling	B to Menindee	Wilcannia	1000	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	L
Darling	B to Menindee	Menindee	1000	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Darling	B to Menindee	Broken Hill	23000	riv		crkstore	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M
Darling	GDABranch	Stock & Domest	5000	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Darling	M to Murray	Wentworth	1500	riv			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M/H

(1) bore on Gumly Gumly island in M'bidgee river

(2) Wagga east, west & north borefields

* lake collects local runoff only

N/A Not Assessed in this project

riv = river