Assessment of Historical Data for the Murray-Darling Basin Ministerial Council’s End-of-Valley Target Stations

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EXECUTIVE SUMMARY

The Murray-Darling Basin Salinity Management Strategy 2001 – 2015 (BSMS; MDBMC, 2001) aims to guide communities and Governments in working together to control salinity and protect key natural resource values within their catchments. A key feature of the BSMS is the adoption of End-of-Valley (E-O-V) salinity targets for each tributary valley and a Basin target at Morgan. Setting End-of-Valley targets, and establishing their contribution to the Basin salinity target, will provide the basis for Basin-wide system of salinity credits and debits similar to that used for the existing Salinity and Drainage Strategy for the River Murray (MDBMC, 1989; MDBC, 1999).

An important component in establishing a Basin-wide system of salinity credits and debits is determining the baseline river salinity, saltload and flow regimes at the time of commencement of the BSMS (1 January 2000). The MDBC and the States have agreed that the effect of management actions will be assessed with models using an agreed climatic/hydrologic sequence known as the “benchmark period” which runs from July 1975 to June 2000. The decision to use a modelling approach was based on the reality that most of the End-of-Valley targets stations had a very sparse or non-existent salinity record for the benchmark period. However, as with all modelling, it is important to calibrate and validate the models against actual measured data, where they exist.

This report presents details of an investigation of the existing historical stream salinity data to determine the catchment salt and water balances and stream salinity trends of the End-of-Valley target stations within the Murray-Darling Basin (MDB). The key specific objectives of this study were as follows:

- Provide a detailed assessment and exploration of the stream flow and salinity data at each of the Murray-Darling Basin End-of-Valley target stations.
• Where possible, establish historical trends for stream salinity and catchment salt balances in the Murray-Darling Basin End-of-Valley target stations.
• Report the limitations of the methods used in this report to calculate salt trends and balances.

These objectives were achieved through use of the following methodology:
• Collation of all available flow and electrical conductivity (EC) data for the 32 Murray-Darling Basin End-of-Valley target stations for the benchmark period (1975-2000);
• Exploration of the raw data with the use of flow, EC, and saltload exceedence curves for the benchmark period, where data were available;
• Estimation of historical stream salinity trends for the benchmark period, where data were available; and
• Estimation of historical catchment salt balances for the last 15 years of the benchmark period (1985-2000), where data were available.

The study was constrained by the lack of stream EC data, and in some cases flow data, at many of the stations. There was only sufficient data to carry out the above analyses at 16 of the 32 End-of-Valley target stations.

A summary of the flow, EC and saltload statistics for each station is shown in Table A. The mean (1985-2000) salt output to input ratios and stream salinity trends (1975-2000) for each station are shown in Table B. It was also observed that catchment SO/SI ratios vary greatly for individual years, presumably due to climatic influences, diversions and other river and land management practices.
Table A. Statistical summary for the MDB E-O-V target stations. Note: Flow data is only reported where EC data were available.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Salinity</th>
<th>Flow</th>
<th>Approximate Saltload</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Median</td>
<td>80%ile</td>
</tr>
<tr>
<td>410130 - Murrumbidgee @ Balranald</td>
<td>187</td>
<td>175</td>
<td>250</td>
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<tr>
<td>412045 - Lachlan @ Corrong</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>421023 - Bogan @ Gongolgon</td>
<td>339</td>
<td>348</td>
<td>470</td>
</tr>
<tr>
<td>421012 - Macquarie @ Carinda</td>
<td>457</td>
<td>444</td>
<td>540</td>
</tr>
<tr>
<td>420020 - Castlereagh @ Gungalman Bridge</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>419026 - Namoi @ Goangra</td>
<td>406</td>
<td>396</td>
<td>525</td>
</tr>
<tr>
<td>418058 - Mehi @ Bronte</td>
<td>344</td>
<td>313</td>
<td>500</td>
</tr>
<tr>
<td>416001 - Barwon @ Mungindi</td>
<td>250</td>
<td>253</td>
<td>320</td>
</tr>
<tr>
<td>425008 - Darling @ Wilcannia Mn Ch</td>
<td>415</td>
<td>343</td>
<td>555</td>
</tr>
<tr>
<td>421004 - Lachlan River @ Forbes</td>
<td>450</td>
<td>414</td>
<td>550</td>
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<tr>
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</tr>
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<td>N/A</td>
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<td>422015 - Culgoa River @ Brenda</td>
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<td>198</td>
<td>280</td>
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<tr>
<td>422012 - Narran River @ New Angledool</td>
<td>197</td>
<td>170</td>
<td>230</td>
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<td>417204a - Moonie River @ Fenton</td>
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<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Station ID</td>
<td>Station Name</td>
<td>Value 1</td>
<td>Value 2</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
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<tr>
<td>422211a</td>
<td>Ballandool River @ Woolergilla-Hebel Rd</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>422209a</td>
<td>Bohkara River @ Hebel</td>
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<td></td>
<td>Briarie Creek @ Woolergilla-Hebel Rd</td>
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<td>N/A</td>
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<tr>
<td>424201a</td>
<td>Paroo river @ Caiwarro</td>
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<tr>
<td>408203</td>
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<tr>
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<td>850</td>
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<td>Campaspe @ Pumps</td>
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<td>405253</td>
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<td>404217</td>
<td>Broken @ Casey’s Weir</td>
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<td>N/A</td>
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<tr>
<td>403241</td>
<td>Ovens @ Peechelba-East</td>
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<tr>
<td>402205</td>
<td>Kiewa @ Bandiana</td>
<td>48</td>
<td>47</td>
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<tr>
<td>409204</td>
<td>Murray @ Swan Hill</td>
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<td>260</td>
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<tr>
<td>426510</td>
<td>Murray @ Lock 6</td>
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<tr>
<td>426514</td>
<td>Murray @ Lock 4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>426522</td>
<td>Murray @ Murray Bridge</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>426554</td>
<td>Murray @ Morgan</td>
<td>714</td>
<td>605</td>
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Table B. Mean (1985-2000) salt output to salt input (SO/SI) of the MDB E-O-V target stations as a ratio and a category, defined by Low, Medium and High (Low < 2, Medium < 4 and > 2 and High > 4). Overall stream EC trend (1975-2000) of the MDB E-O-V target stations and status denoted as “significantly” rising or falling, or if the trend is “not significant” statistically, denoted by (-).

<table>
<thead>
<tr>
<th>Sites</th>
<th>SO/SI</th>
<th>Trend</th>
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<tr>
<td></td>
<td>Ratio</td>
<td>Category</td>
</tr>
<tr>
<td>410130 - Murrumbidgee @ Balranald</td>
<td>0.07</td>
<td>Low</td>
</tr>
<tr>
<td>412045 - Lachlan @ Corrong</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>421023 - Bogan @ Gongolgong</td>
<td>0.94</td>
<td>Low</td>
</tr>
<tr>
<td>421012 - Macquarie @ Carinda</td>
<td>0.99</td>
<td>Low</td>
</tr>
<tr>
<td>420020 - Castlereagh @ Gungalman Bridge</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>419026 - Namoi @ Goangra</td>
<td>1.59</td>
<td>Low</td>
</tr>
<tr>
<td>418058 - Mehi @ Bronte</td>
<td>0.19</td>
<td>Low</td>
</tr>
<tr>
<td>416001 - Barwon @ Mungindi</td>
<td>7.69</td>
<td>High</td>
</tr>
<tr>
<td>425008 - Darling @ Wilcannia Mn Ch</td>
<td>0.23</td>
<td>Low</td>
</tr>
<tr>
<td>421004 - Lachlan River @ Forbes</td>
<td>3.43</td>
<td>Medium</td>
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<tr>
<td>423005 - Cuttuburra Ch @ Turra</td>
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<td>N/A</td>
</tr>
<tr>
<td>423004 - Warrego River @ Barrington No. 2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>422015 - Culgoa River @ Brenda</td>
<td>0.28</td>
<td>Low</td>
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<td>422012 - Narran River @ New Angledool</td>
<td>0.13</td>
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<td>422209a - Bohkara River @ Hebel</td>
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<td>Briarie Creek @ Woolgilla-Hebel Rd</td>
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<tr>
<td>Station Code</td>
<td>River/Branch</td>
<td>Location</td>
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<tr>
<td>426554</td>
<td>Murray @ Morgan</td>
<td>0.53</td>
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</tbody>
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For the period 1985-2000, the major contributors of saltload to the Murray River at Morgan were the Murray River upstream of Swan Hill (42%), Darling River (22%) and the Murrumbidgee River (3%). Note that these only account for 67% of the total salt output that is observed at Morgan. Factors such as: (i) diversions; (ii) the locations of some of the End-of-Valley stations were not at the end of the river valleys; and (iii) groundwater inputs at the lower end of the River Murray have not been accounted for, could account for the other 33%.

A number of issues arose while undertaking this study, mostly concerned with the poor data record at many of the End-of-Valley target stations:

- Confidence of the techniques used to determine the salt inputs and outputs for catchment salt balances.
- Confidence of the exceedence curves, where the data set contains sparsely sampled data.
- The exclusion of salt diversion effects for both salinity trends and balances due to lack of data and time constraints.

In relation to the catchment salt balance and source of inaccuracy was the method used to carry out the infilling of missing saltload data. To determine the accuracy of the technique used in this study, results for two stations that contained daily EC data for a length of their record were compared with those obtained from the regression approach. The results showed that the regression technique did introduce some error into the total saltloads in the order of 9-14%.

The final source of inaccuracy concerns the rainfall salinity data used for the catchment salt inputs. We have used the most complete data set covering the MDB (Blackburn and McLeod, 1983) however there is still only a small number of stations covering a very large area. Moreover, the Blackburn and McLeod study was conducted during 1974-75, a period when rainfall was well above average in the eastern segments of the MDB, but as much as 20% below average elsewhere. Therefore, the rainfall salt concentrations may be biased to these particular conditions during this short sampling period, and not necessarily represent long-term average conditions.
Confidence in the use of EC exceedence curves was assessed by analysing good quality data for the River Murray @ Morgan. Exceedence curves for a 35 year period of record (1965-2000) were generated for 5, 10 and 15 year intervals of the record. These showed that climatic variability affected the curves derived from 5 year data periods more than land use or management changes. When 10 year data periods were used the impacts of the major salt interception schemes implemented under the Salinity and Drainage Scheme began to become apparent. However, 15 year data periods were required to clearly observe the impact of the major salt interception schemes as compared to the effects of climatic variability. This suggests that for the End-of-Valley targets for the drier major tributaries at least 15 years of data will be required to observe land use impacts without the aid of modelling. The 10 and 15 year analyses clearly show that greatest differences between the periods prior to and after commencement of interceptions schemes occurs at higher EC levels (i.e.> 500 µS/cm). A corollary of this is that higher percentile targets will be more sensitive to the length of record. At the 15 year record length there does not appear to be much difference between using the 80th, 90th or 95th percentile for a target.

Diversions for water supplies (irrigation, urban, industrial, etc.) result in the removal of water and salt that might otherwise leave the catchment through the End-of-Valley station. Due to the complexities of the water supply systems, generally poor quality of the flow and salinity data sets, and time constraints, the effect of diversions were not factored into this study. Previous work conducted by Jolly et al., (1997a) calculated salt balances with salt diversion data for the Murrumbidgee, Namoi, Loddon and Campaspe river catchment from 1985 to 1994, and showed that the impact was significant. It is expected that diversions would also impact on the stream salinity trends, however, at present the statistical technique does not account for them and therefore would require modification to describe the impacts.
Finally, on the basis of our range of analyses we have some concerns as to whether just the End-of-Valley stations are sufficient to detect the impacts of land-use change in specific areas of their catchments. This is because the tributary catchments are so large, and the rainfall so variable, that the data collected from End-of-Valley target stations are generally insensitive to the scale of land use change that may be feasible within the 15 year period of the BSM Strategy. This may be overcome to some degree by analysing data from an interpretive gauging station immediately upstream of the major irrigation off-takes in each river valley. This would also avoid the need to incorporate the effects of diversions on both the salt balances and stream salinity trends.

The specific recommendations arising from this study are:

1. Methodologies should be developed to include the impacts of diversions on the salinity trends and salt balances and the data from End-of-Valley target stations should be re-analysed using the revised methodology.

2. Some work be undertaken to ascertain whether modelling together with good hydrological data over a 5 year period can differentiate the influence of land use change from rainfall variability.

3. Further data investigations should be carried out on the Border Rivers End-of-Valley site (416001 Barwon River @ Mungindi) and the associated stations used to establish catchment salt balances (416028 Boomi River @ Neeworra and 416027 Gil Gil Creek @ Weemalah) to determine the reasons for the very high SO/SI ratios in high flow years and low SO/SI ratios in most other years. These appear to be related to flow inaccuracies during floods and/or the saltload infilling procedure, but further investigation needs to take place. This issue could also be a problem in the future for other stations located in floodplain areas where extensive overbank flooding makes accurate flow and EC measurement difficult. It should also be noted that that there were possible problems with the flow data for 1993 to 1995 for stations 421023 Bogan River @
Gongolgon and 412004 Lachlan River @ Forbes, even though the quality codes indicated that the data were satisfactory.

4. Consideration shall be given to carrying out the same analysis at an interpretive station immediately upstream of the major irrigation off-takes in each of the catchments. This would better identify the dryland impacts on river salinity in these catchments.
ACKNOWLEDGEMENTS

The authors would like to acknowledge the following people for supplying flow and salinity data and for general discussion that contributed towards this report: Oscar Mamalai (Murray-Darling Basin Commission), David Malone (Department of Land and Water Conservation, NSW), Rae Moran (Department of Natural Resources and Environment, Victoria), Paul Webb (Department of Natural Resources Management, Queensland), Roderick Dew (Department of Natural Resources Management, Queensland), Bob Newman (Catchment Management Consulting), Geoff Smith and Barbara Dworakowski (Theiss Environmental). Funding for this work was provided by the Murray-Darling Basin Commission.
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1. BACKGROUND

Human-induced salinisation of the land and river systems of southern Australia has been occurring for several decades, with the earliest reported incidences occurring in Western Australia (Bleazby, 1917; Wood, 1924). While there is evidence of periods of natural salinisation throughout the geological record due to climate change (Bowler, 1990), it is well accepted that the recent increases in salinisation are a result of significant clearing of perennial native vegetation and its replacement with annual crops and pastures. This major change in land use has altered the natural water balance, reducing the amount of evapotranspiration and resulting in increased groundwater recharge (Allison and Hughes, 1983). The change in water balance results in substantial increases in groundwater levels and associated land salinisation, and in the accessions of saline groundwater to streams (Allison and Schonfeldt, 1989). This form of salinisation (known in Australia as dryland salinity) has been identified as one of the most serious environmental degradation problems in Australia.

Detailed analysis of large-scale catchment salinisation processes has been made difficult by the irregular and inconsistent nature of historic stream salinity measurement. A lack of broad-scale detailed data in semi-arid, sparsely populated areas often makes it difficult to achieve a rigorous statistical analysis. These problems of large-scale historical assessment are further complicated in Australia, due to the high stream flow variability (Finlayson and McMahon, 1991).

Dryland and irrigation salinity are both widespread in the Murray-Darling Basin (MDB), one of Australia’s most important water and land resources. Occupying an area of some $10^6$ km$^2$, or one seventh of the continent (Figure 1), the Murray-Darling Basin provides approximately 73% of all water used for agriculture and human consumption in Australia (Fleming, 1982). In 1988, the Murray-Darling Basin Commission (MDBC) was formed as an organisation...
through which State government and community management institutions could coordinate planning and management of the water, land and environmental resources within the Basin (Blackmore, 1994). In 1989, the MDBC finalised its *Salinity and Drainage Strategy* to address the predicted future increases in stream salinisation. The strategy did not attempt to cover gradual deterioration in river salinity due to land use changes in non-irrigated (hereafter referred to as dryland) regions (Close, 1992). It was assumed that most of the increase in salinity in the lower Murray River would be the result of deep drainage from irrigation areas rather than from the much larger areas of dryland agriculture.

![Map of Australia](image)

**Figure 1:** Map of Australia, showing the approximate average annual rainfall of the Murray-Darling Basin (Source: Jolly et al., 2001)
The MDBC originally estimated that dryland salinisation would result in an increase in Electrical Conductivity (EC; a widely used surrogate for salinity) of only 40 µS/cm at Morgan over the next 50 years (MDBMC, 1987; MDBC, 1988). Recent studies questioned this estimate, suggesting that dryland salinisation will increase significantly, resulting in higher stream salinities than previously anticipated (e.g. Earl, 1988; Evans, 1994). Allison and Schonfeldt (1989) suggested that the salt contribution from the Victorian Riverine Plains region (in the southern part of the Basin) alone could result in an increase of 60-140 µS/cm at Morgan over the next 50 years.

In order to re-evaluate the current Basin management strategy, a broad analysis of stream salinity was necessary to assist predictions of the increase in the effect and extent of dryland salinity. However, the intermittent and sometimes sparse water quality data set available created certain challenges in establishing sub-Basin and Basin-wide stream salinity trends, which were resolved with the application of modern regression techniques (Morton, 1997). Supplementations of the trends with calculations of catchment salt balances at the same sites adds confidence in the assessment of the historical trends. These techniques will be presented in greater detail further in this report.


A key feature of the BSMS is the adoption of End-of-Valley salinity targets for each tributary valley and a Basin target at Morgan. Setting End-of-Valley targets, and establishing their contribution to the Basin salinity target, will provide the basis for Basin-wide system of salinity credits and debits similar to that used for the existing Salinity and Drainage Strategy for the River Murray.
(MDBMC, 1989; MDBC, 1999). This generates a consistent currency through which trade-offs and Basin-wide accountability can be accommodated, and by convention the currency is EC units at Morgan. It is also important to note that the States are also developing within-valley targets (e.g: NSW Government, 2000) as part of their salinity strategies.

An important component in establishing a Basin-wide system of salinity credits and debits is determining the baseline river salinity, saltload and flow regimes at the time of commencement of the BSMS (1 January 2000). The MDBC and the States have agreed that the effect of management actions will be assessed with models using an agreed climatic/hydrologic sequence known as the “benchmark period” which runs from July 1975 to June 2000. The decision to use a modelling approach was based on the reality that most of the End-of-Valley targets stations had a very sparse or non-existent salinity record for the benchmark period. However, it is important to calibrate and validate the models against actual measured data, where they exist.

This report presents details of an investigation of the existing data to determine the extent and trends of stream salinisation of the End-of-Valley target stations within the Murray-Darling Basin, Australia.
2. OBJECTIVES

This report is aimed at building on the foundations that were established when CSIRO Land and Water analysed data up to 1995 from more than 80 stations in the MDB (Jolly et al., 1997a, 1997b; Williamson et al., 1997; Jolly et al., 2001). This work showed that determination of catchment salt balances and statistical stream salinity trends can be a useful means of understanding historical salinity conditions of the major tributary streams and of the Murray and Darling Rivers themselves. Approximately 40% of the End-of-Valley stations were included in the CSIRO studies. For these stations it would therefore be useful to update the analyses to the end of the “benchmark period” (June 2000). It would also be useful to carry out similar analyses for all of the other End-of-Valley stations, where data exists. The results from these analyses would provide valuable information on the salinity conditions that existed during the “benchmark period” that could assist in the calibration and validation of the catchment and river models used to set the baseline conditions.

These objectives were achieved through use of the following methodology:

- Collation of all available flow and electrical conductivity (EC) data for the 32 Murray-Darling Basin End-of-Valley target stations for the benchmark period (1975-2000);
- Exploration of the raw data with the use of flow, EC, and saltload exceedence curves for the benchmark period, where data were available;
- Estimation of historical stream salinity trends for the benchmark period, where data were available; and
- Estimation of historical catchment salt balances for the last 15 years of the benchmark period (1985-2000), where data were available.

At the 32 BSMS target stations (Table 1 and Figure 2), catchment salt balances and stream salinity trends were calculated over the benchmark period, where sufficient data existed. However, previous studies carried out by CSIRO (Jolly...
et al., 1997a) have shown that in many cases data sets were insufficient to carry out salt balances prior to 1985 (i.e. the 1975-84 period of the “benchmark period” cannot be analysed). In the case of the stream salinity trends, the entire benchmark period were analysed successfully (provided some data existed), and thus stream salinity trends for their entire periods of record were carried out.

### Table 1: End-of-Valley target stations defined by the MDBC in May, 2002

<table>
<thead>
<tr>
<th>ARWC No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>410130</td>
<td>Murrumbidgee River @ Balranald Weir</td>
</tr>
<tr>
<td>412045</td>
<td>Lachlan River @ Corrong</td>
</tr>
<tr>
<td>421023</td>
<td>Bogan River @ Gongolgon</td>
</tr>
<tr>
<td>421012</td>
<td>Macquarie River @ Carinda</td>
</tr>
<tr>
<td>420020</td>
<td>Castlereagh River @ Gungalman Bridge</td>
</tr>
<tr>
<td>419026</td>
<td>Namoi River @ Goangra</td>
</tr>
<tr>
<td>418058</td>
<td>Mehri River @ Bronte</td>
</tr>
<tr>
<td>416001</td>
<td>Barwon River @ Mungindi</td>
</tr>
<tr>
<td>425008</td>
<td>Darling River @ Wilcannia Main Channel</td>
</tr>
<tr>
<td>412004</td>
<td>Lachlan River @ Forbes</td>
</tr>
<tr>
<td>423005</td>
<td>Cuttuburra Channel @ Turra</td>
</tr>
<tr>
<td>423004</td>
<td>Warrego River @ Barringun No 2</td>
</tr>
<tr>
<td>422015</td>
<td>Culgoa River @ Brenda</td>
</tr>
<tr>
<td>422012</td>
<td>Narran River @ New Angledool</td>
</tr>
<tr>
<td>417204a</td>
<td>Moonie River @ Fenton</td>
</tr>
<tr>
<td>422207a</td>
<td>Ballandool River @ Woolgilla-Hebel Road</td>
</tr>
<tr>
<td>422209a</td>
<td>Bohkara River @ Hebel</td>
</tr>
<tr>
<td>422211a</td>
<td>Brierie Creek @ Woolgilla-Hebel Road</td>
</tr>
<tr>
<td>424201a</td>
<td>Paroo River @ Caiwarro</td>
</tr>
<tr>
<td>415200</td>
<td>Wimmera River @ Horsham Weir</td>
</tr>
<tr>
<td>408203</td>
<td>Avoca River @ Quambatook</td>
</tr>
<tr>
<td>407203</td>
<td>Loddon River @ Laanecoorie</td>
</tr>
<tr>
<td>406202</td>
<td>Campaspe River @ Pumps</td>
</tr>
<tr>
<td>405253</td>
<td>Goulburn River @ Goulburn Weir</td>
</tr>
<tr>
<td>404217</td>
<td>Broken River @ Casey's Weir</td>
</tr>
<tr>
<td>403241</td>
<td>Ovens River @ Peechelba-East</td>
</tr>
<tr>
<td>402205</td>
<td>Kiewa River @ Bandiana</td>
</tr>
<tr>
<td>409204</td>
<td>Murray River @ Swan Hill</td>
</tr>
<tr>
<td>426510</td>
<td>Murray River @ Lock 6</td>
</tr>
<tr>
<td>426514</td>
<td>Murray River @ Lock 4</td>
</tr>
<tr>
<td>426554</td>
<td>Murray River @ Morgan</td>
</tr>
<tr>
<td>426522</td>
<td>Murray River @ Murray Bridge</td>
</tr>
</tbody>
</table>
Figure 2: Location of the End-of-Valley target stations plus additional sites used to complete salt balance calculations
The overall consolidated product was statistical salt trends for all stations for the entire "benchmark period" (where data exists) and catchment salt and water balances for the last 15 years of the "benchmark period" (where data existed).

It should be noted that for some of the End-of-Valley target stations, additional stations near the catchment outlet needed to be analysed to obtain complete salt and water balances for their catchments (Table 2).

**Table 2: These are the additional sites that we have used to calculate salt balances for some of the End-of-Valley target stations**

<table>
<thead>
<tr>
<th>ARWC No.</th>
<th>Additional Stations</th>
<th>E-O-V Target Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>416027</td>
<td>Gil Gil Creek @ Weemelah</td>
<td>Barwon River @ Mungindi</td>
</tr>
<tr>
<td>416028</td>
<td>Boomi River @ Neeworra</td>
<td></td>
</tr>
<tr>
<td>421011</td>
<td>Marthaguy Creek @ Carinda</td>
<td>Bogan River @ Gongolgon + Macquarie River @ Carinda</td>
</tr>
<tr>
<td>414211</td>
<td>Mullaroo Creek @ Lock 7, Offtake</td>
<td>Murray River @ Morgan</td>
</tr>
</tbody>
</table>
3. METHODS

The study had four main components:

- collation of all available flow and electrical conductivity (EC) data for the 32 Murray-Darling Basin End-of-Valley target stations;
- exploration of the raw data with the use of flow, EC, and saltload exceedence curves;
- estimation of historical stream salinity trends; and
- estimation of historical catchment salt balances.

Comparison between the last two components allowed increased confidence in the results and showed the spatial distribution of salinisation within the Basin.

3.1. Collation of all available flow and electrical conductivity (EC) data for the Murray-Darling Basin End-of-Valley target stations

This section aimed to provide a quick and simple assessment of the MDBC End-of-Valley target stations. A rating key was developed for each station based on the amount and quality of the data available. The assessment provided was somewhat subjective, being the opinion of the authors. Stations with a rating of U, N or ? were not analysed as there was insufficient data to determine trends and balances.

Rating Codes (confidence in data set for salt trends and balances):

- **H** = High (data yields high confidence in trends and balances)
- **M** = Medium (acceptable data quality over benchmark period)
- **L** = Low (borderline confidence in data over the benchmark period)
- **U** = Unacceptable (insufficient data to determine balances and trends)
- **N** = Not Possible (usually given where there is no data available)
- **?** = Yet to be determined (unsure if it will be an E-O-V target site)
3.1.1. New South Wales End-of-Valley target stations

**410130 – Murrumbidgee River @ Balranald Weir**
- Length of Flow record: 1979 to 2000
- EC data provided by:
  - PINNEENA Database 1993 to 1996 (&1999)
  - Previous CSIRO study 1979 to 1994
  - David Malone (DLWC) 1993 to 1996 (&1999)
- Flow data provided by:
  - PINNEENA Database 1979 to 2000
  - Previous CSIRO study 1979 to 1994
- Additional Notes:
  - Apart from missing few years in the benchmark period this is a good station to analyse.
- **Rating Code: M**

**421023 - Bogan River @ Gongolgon**
- Length of EC record: 1970 to 2000
- Length of Flow record: 1975 to 2000
- EC data provided by:
  - Previous CSIRO study 1970 to 1992
  - David Malone (DLWC) 1970 to 2000
- Flow data provided by:
  - PINNEENA Database 1968 to 2000
  - Previous CSIRO study 1970 to 1992
- Additional Notes:
  - EC data is at monthly intervals 1992 to 2000
  - This site is used with 421012 and 421011 to get balances.
- **Rating Code: M**

**421012 - Macquarie River @ Carinda**
- Length of EC record: 1976 to 2000
- Length of Flow record: 1968 to 2000
- EC data provided by:
  - PINNEENA Database 1999 to 2000
  - Previous CSIRO study 1976 to 1994
  - David Malone (DLWC) 1976 to 2000
- Flow data provided by:
  - PINNEENA Database 1968 to 2000
  - Previous CSIRO study 1976 to 1994
- Additional Notes:
  - EC data is at monthly intervals from 1976 to 1994 after which it is almost continuous.
This site is used with 421023 and 421011 to get balances.

Rating Code: M

420020 - Castlereagh River @ Gungalman Bridge
- Length of EC record: N/A
- Length of Flow record: N/A
- Rating Code: N

419026 - Namoi River @ Goangra
- Length of EC record: 1969 to 2000
- Length of Flow record: 1968 to 2000
- EC data provided by:
  - PINNEENA Database 1995 to 2000
  - Previous CSIRO study 1971 to 1994
  - David Malone (DLWC) 1969 to 2000
- Flow data provided by:
  - PINNEENA Database 1968 to 2000
  - Previous CSIRO study 1971 to 1994
- Additional Notes:
  - EC has been recorded at monthly intervals.
- Rating Code: M

418058 - Mehi River @ Bronte
- Length of EC record: 1981 to 2000
- Length of Flow record: 1979 to 2000
- EC data provided by:
  - David Malone (DLWC) 1981 to 2000
- Flow data provided by:
  - PINNEENA Database 1979 to 2000
- Additional Notes:
  - EC data has been recorded at near monthly intervals
- Rating Code: L

416001 - Barwon River @ Mungindi
- Length of EC record: 1968 to 2000
- Length of Flow record: 1968 to 2000
- EC data provided by:
  - PINNEENA Database 1995 to 2000
  - Previous CSIRO study 1968 to 1994
  - David Malone (DLWC) 1970 to 2000
- Flow data provided by:
  - PINNEENA Database 1968 to 2000
  - Previous CSIRO study 1968 to 1994
- Additional Notes:
  - There is a period of sparse flow and EC data between the years of 1982 and 1990. The sampling intervals within these years less than one month.
- **Rating Code: L**

409016 - Murray River @ Heywoods
- Length of EC record: 1991 to 2000
- EC data provided by:
  - Previous CSIRO study 1991 to 1994
- Flow data provided by:
  - Previous CSIRO study 1991 to 1994
- **Rating Code: U**

425008 - Darling River @ Wilcannia Main Channel
- Length of EC record: 1965 to 2000
- Length of Flow record: 1975 to 2000
- EC data provided by:
  - PINNEENA Database 1992 to 2000
  - Previous CSIRO study 1968 to 1994
  - David Malone (DLWC) 1965 to 2000
- Flow data provided by:
  - PINNEENA Database 1968 to 2000
  - Previous CSIRO study 1968 to 1994
- Additional Notes:
  - EC data between 1971 and 1981 recorded at ~ weekly intervals
- **Rating Code: M**

414204 - Murray River @ Redcliffs
- Length of EC record: N/A
- Length of Flow record: N/A
- **Rating Code: N**

412004 - Lachlan River @ Forbes
- Length of EC record: 1970 to 2000
- Length of Flow record: 1968 to 2000
- EC data provided by:
  - Previous CSIRO study 1970 to 1993
  - David Malone (DLWC) 1970 to 2000
- Flow data provided by:
  - PINNEENA Database 1968 to 2000
  - Previous CSIRO study 1970 to 1999
• Additional Notes:
  o EC data was taken at approximately one monthly intervals throughout the period

• Rating Code: M

423005 - Cuttuburra Channel @ Turra
• Length of EC record: 1997 to 1998
• Length of Flow record: 1995 to 1996
• EC data provided by:
  o Roderick Dew (QDNR) 1997 to 1998
• Flow data provided by:
  o Roderick Dew (QDNR) 1995 to 1996
• Additional Notes:
  o EC Data does not correspond to the same dates as the flow data so no balances could be undertaken.
  o Paul Webb supplied the data on the behalf of Roderick Dew

• Rating Code: U

423004 - Warrego River @ Barringun No 2
• Length of EC record: 1996 to 2000
• Length of Flow record: 1993 to 1994
• EC data provided by:
  o Roderick Dew (QDNR) 1996 to 2000
• Flow data provided by:
  o Roderick Dew (QDNR) 1993 to 1994
• Additional Notes:
  o EC Data does not correspond to the same dates as the flow data so no balances could be undertaken.
  o Paul Webb supplied the data on the behalf of Roderick Dew

• Rating Code: U

416027 – Gil Gil Creek @ Weemelah
• Length of EC record: 1970 to 1989
• Length of Flow record: 1970 to 1989
• EC data provided by:
  o Previous CSIRO study 1970 to 1989
• Flow data provided by:
  o Previous CSIRO study 1970 to 1989
• Additional Notes:
  o Data from the previous CSIRO study is fairly sparse. At best it is taken at monthly intervals over the period.
  o Request additional data from Theiss Environmental

• Rating Code: ?
416028 – Boomi River @ Neeworra
- Length of EC record: 1970 to 1989
- EC data provided by:
  - Previous CSIRO study 1970 to 1989
- Flow data provided by:
  - Previous CSIRO study 1970 to 1989
- Additional Notes:
  - Data is fairly sparse, taken at monthly intervals over the period.
  - Request additional data from Theiss Environmental
- Rating Code: ?

421011 – Marthaguy Creek @ Carinda
- Length of EC record: 1976 to 2000
- EC data provided by:
  - Previous CSIRO study 1976 to 1991
  - David Malone (DLWC) 1976 to 2000
- Flow data provided by:
  - Previous CSIRO study 1976 to 1991
  - PINNEENA Database 1976 to 2000
- Additional Notes:
  - Data from the previous CSIRO study is fairly sparse. At best it is taken at monthly intervals over the period.
  - Request additional data from Theiss Environmental
- Rating Code: M

3.1.2. Queensland End-of-Valley target stations

422015 - Culgoa River @ Brenda
- Length of EC record: 1976 to 2000
- Length of Flow record: 1968 to 2000
- EC data provided by:
  - David Malone (DLWC) 1976 to 2000
- Flow data provided by:
  - Roderick Dew (QDNR) 1968 to 2000
- Additional Notes:
  - Paul Webb supplied the data on the behalf of Roderick Dew
  - EC data is taken at approximately monthly intervals
- Rating Code: M
422012 - Narran River @ New Angledool
- Length of EC record: 1977 to 2000
- Length of Flow record: 1968 to 2000
- EC data provided by:
  o David Malone (DLWC) 1977 to 2000
- Flow data provided by:
  o Roderick Dew (QDNR) 1968 to 2000
- Additional Notes:
  o Paul Webb supplied the data on the behalf of Roderick Dew
  o EC data is taken at approximately monthly intervals
- Rating Code: M

417204a - Moonie River @ Fenton
- Length of EC record: 1973 to 1997
- Length of Flow record: 1973 to 1997
- EC data provided by:
  o Roderick Dew (QDNR) 1973 to 1997
- Flow data provided by:
  o Roderick Dew (QDNR) 1973 to 1997
- Additional Notes:
  o Data was taken at very sparse intervals (~2 per year) and is therefore insufficient to determine trends and balances.
  o Paul Webb supplied the data on the behalf of Roderick Dew
- Rating Code: U

422207a - Ballandool River @ Woolergilla-Hebel Road
- Length of EC record: 1965 to 1998
- Length of Flow record: 1965 to 1998
- EC data provided by:
  o Roderick Dew (QDNR) 1965 to 1998
- Flow data provided by:
  o Roderick Dew (QDNR) 1965 to 1998
- Additional Notes:
  o Data was taken at very sparse intervals (~2 per year) and is therefore insufficient to determine trends and balances.
  o Paul Webb supplied the data on the behalf of Roderick Dew
- Rating Code: U

422209a - Bokhara River @ Hebel
- Length of EC record: 1965 to 1996
- Length of Flow record: 1965 to 1996
- EC data provided by:
  o Roderick Dew (QDNR) 1965 to 1996
• Flow data provided by:
  o Roderick Dew (QDNR) 1965 to 1996
• Additional Notes:
  o Data was taken at very sparse intervals (~1 to 2 per year) and is therefore insufficient to determine trends and balances.
  o Paul Webb supplied the data on the behalf of Roderick Dew
• Rating Code: U

422211a - Briarie Creek @ Woolergilla-Hebel Road
• Length of EC record: 1974 to 1997
• Length of Flow record: 1974 to 1997
• EC data provided by:
  o Roderick Dew (QDNR) 1974 to 1997
• Flow data provided by:
  o Roderick Dew (QDNR) 1974 to 1997
• Additional Notes:
  o Data was taken at very sparse intervals (~1 per year) and is therefore insufficient to determine trends and balances.
  o Paul Webb supplied the data on the behalf of Roderick Dew
• Rating Code: U

424201a - Paroo River @ Caiwarro
• Length of EC record: 1971 to 1998
• Length of Flow record: 1971 to 1998
• EC data provided by:
  o Roderick Dew (QDNR) 1971 to 1998
• Flow data provided by:
  o Roderick Dew (QDNR) 1971 to 1998
• Additional Notes:
  o Data was taken at very sparse intervals (~2 per year) and is therefore insufficient to determine trends and balances.
  o Paul Webb supplied the data on the behalf of Roderick Dew
• Rating Code: U

3.1.3. Victorian End-of-Valley target stations

415200 - Wimmera River @ Horsham Weir
• Length of EC record: 1992 to 2000
• Length of Flow record: 1970 to 2000
• EC data provided by:
  o Theiss Environmental N/A
  o Oscar Mumalai (MDBC) 1992 to 1999
Flow data provided by:
  o Theiss Environmental 1968 to 2000
  o Previous CSIRO study 1970 to 1994

Additional Notes:
  o EC data was taken at approximately one monthly intervals throughout the period

Rating Code: U

408203 - Avoca River @ Quambatook

- Length of EC record: N/A
- Length of Flow record: 1963 to 2000
- Flow data provided by:
  o Theiss Environmental 1963 to 2000

Rating Code: N

407203 - Loddon River @ Laanecoorie

- Length of EC record: 1976 to 2000
- Length of Flow record: 1973 to 2000
- EC data provided by:
  o Theiss Environmental 1977 to 2000
  o Previous CSIRO study 1976 to 1994
- Flow data provided by:
  o Theiss Environmental 1973 to 2000
  o Previous CSIRO study 1976 to 1994
- Additional Notes:
  o EC data is at monthly intervals

Rating Code: M

406202 - Campaspe River @ Pumps (Rochester)

- Length of EC record: 1976 to 2000
- Length of Flow record: 1974 to 2000
- EC data provided by:
  o Theiss Environmental 1976 to 2000
  o Previous CSIRO study 1976 to 1994
- Flow data provided by:
  o Theiss Environmental 1974 to 2000
  o Previous CSIRO study 1976 to 1994
- Additional Notes:
  o EC data is at weekly intervals

Rating Code: M

405253 - Goulburn River @ Goulburn Weir

- Length of EC record: N/A
• Length of Flow record: 1974 to 2000
• Flow data provided by:
  o Theiss Environmental 1974 to 2000
• Rating Code: N

404217 - Broken River @ Casey's Weir
• Length of EC record: N/A
• Length of Flow record: N/A
• Rating Code: N

403241 - Ovens River @ Peechelba-East
• Length of EC record: 1979 to 2000
• Length of Flow record: 1979 to 2000
• EC data provided by:
  o Theiss Environmental 1979 to 2000
  o Previous CSIRO study 1979 to 1994
• Flow data provided by:
  o Theiss Environmental 1979 to 2000
  o Previous CSIRO study 1979 to 1994
• Rating Code: M

402205 - Kiewa River @ Bandiana
• Length of EC record: 1975 to 2000
• Length of Flow record: 1975 to 2000
• EC data provided by:
  o Theiss Environmental 1975 to 2000
  o Previous CSIRO study 1975 to 1994
• Flow data provided by:
  o Theiss Environmental 1975 to 2000
  o Previous CSIRO study 1975 to 1994
• Rating Code: H

409204 - Murray River @ Swan Hill
• Length of EC record: 1976 to 2000
• Length of Flow record: 1976 to 2000
• EC data provided by:
  o Theiss Environmental 1976 to 2000
  o Previous CSIRO study 1976 to 1994
• Flow data provided by:
  o Theiss Environmental 1976 to 2000
  o Previous CSIRO study 1976 to 1994
• Rating Code: H
405200 – Goulburn River @ Murchison
- Length of EC record: 1990 to 2000
- Length of Flow record: 1881 to 2000
- EC data provided by:
  - Theiss Environmental 1990 to 2000
- Flow data provided by:
  - Theiss Environmental 1881 to 2000
- Rating Code: L

407242 – Loddon River @ Murray Valley Hwy Bridge (Kerang)
- Length of EC record: 1975 to 2000
- Length of Flow record: 1975 to 2000
- EC data provided by:
  - Oscar Mumalai (MDBC) 1993 to 2000
  - Previous CSIRO study 1975 to 1993
- Flow data provided by:
  - Oscar Mumalai (MDBC) 1993 to 2000
  - Previous CSIRO study 1975 to 1993
- Rating Code: H

404210 – Broken Creek @ Rices Weir
- Length of EC record: 1977 to 2000
- EC data provided by:
  - Theiss Environmental 1980 to 2000
  - Previous CSIRO study 1977 to 1994
- Flow data provided by:
  - Theiss Environmental 1980 to 2000
  - Previous CSIRO study 1977 to 1994
- Rating Code: M

405232 – Goulburn River @ McCoy Bridge
- Length of EC record: 1977 to 2000
- EC data provided by:
  - Theiss Environmental 1980 to 2000
  - Previous CSIRO study 1977 to 1994
- Flow data provided by:
  - Theiss Environmental 1980 to 2000
  - Previous CSIRO study 1977 to 1994
- Rating Code: M
3.1.4. South Australian End-of-Valley target stations

426510 - Murray River @ Lock 6
- Length of EC record: 1962 to 2000
- Length of Flow record: 1994 to 2000
- EC data provided by:
  - Oscar Mumalai (MDBC) 1962 to 2000
- Flow data provided by:
  - Oscar Mumalai (MDBC) 1994 to 2000
- Additional Notes:
  - Flow data is a problem.
  - Need data for flow and EC from station No. 426200 (Rufus River Junction). This is used to determine flow to SA.
- Rating Code: ?

426514 - Murray River @ Lock 4
- Length of EC record: 1967 to 2000
- Length of Flow record: 1994 to 2000
- EC data provided by:
  - Oscar Mumalai (MDBC) 1967 to 1994
- Flow data provided by:
  - Oscar Mumalai (MDBC) 1994 to 2000
- Additional Notes:
  - Flow data is a problem.
- Rating Code: U

426554 - Murray River @ Morgan
- Length of EC record: 1938 to 2000
- Length of Flow record: 1967 to 2000
- EC data provided by:
  - Oscar Mumalai (MDBC) 1938 to 2000
- Flow data provided by:
  - Oscar Mumalai (MDBC) 1967 to 2000
- Additional Notes:
  - Flow data comes from near by station No. 426902.
- Rating Code: H

426522 - Murray River @ Murray Bridge
- Length of EC record: N/A
- Length of Flow record: N/A
- Additional Notes:
  - Request data from Oscar Mumalai (MDBC).
- Rating Code: ?
3.2. Exploration of the raw data using flow, EC and saltload exceedence curves

A key method of exploring the flow and salinity characteristics of historical stream data is to calculate exceedence curves for flow, EC and saltload, providing sufficient data exists. This is achieved by dividing the data into classes of even amounts. (i.e. if you have a maximum EC level of 800 µS/cm, then you may decide to have 400 classes, starting at 0 and having an increment of 2 µS/cm). From this a frequency distribution is performed over the classes. This calculates how often a value (i.e. EC) occurs within a range of values. For example, if you had ten EC data points, eight had an EC level between 200-400 µS/cm, one had a level of 150 µS/cm and the remaining point had a level of 600 µS/cm, then by performing this analysis you see from Figure 3 that for 80% of the time, EC lies within the 200-400 µS/cm range and only 10% of the time the 400 µS/cm level is exceeded.

![EC exceedence curve](image)

**Figure 3:** Example of a EC exceedence curve where an EC level of 400 µS/cm is exceeded only 10% of the time

In this study, most stations had intermittent data, often worse than weekly in frequency, and in some cases the length of record was very short (<10 years). Two issues arise from the use of exceedence curves for exploring the flow and
salinity characteristics of streams: (i) how frequent do the data have to be recorded to have confidence in the curves; and (ii) how long does the record need to be to differentiate the impacts of management from climate variability. These questions were addressed by analysing data from the benchmark station for the entire MDB (426554, Murray River @ Morgan), which had a long record of daily data (~36 years), and during the period of the record had been influenced by the implementation of salt interception schemes immediately upstream. The first question was answered by reducing the daily data at station 426554 to weekly and monthly intervals. This data set comprised of 13,117 days of EC and flow data. It was reduced from daily to weekly by randomly removing 85.7% of the data leaving 1874 days of record. Similarly, the daily data was reduced to monthly by randomly removing 96.7% of the data leaving 430 days of record. The second question was answered by producing a series of exceedence curves for different lengths of time over the 36-year period of the data record, ranging from 5 to 15 years. The differences in these curves enabled us to determine the length of record required to differentiate the effect of climate variability from the impacts of the salt interception schemes.

3.3. Estimation of historical stream salinity trends

Attempts were made to analyse stream salinity trends at each of the 32 End-of-Valley stream gauging stations. As described above, long term stream salinity monitoring has been infrequent and irregular across most of the Basin, making the establishment of salinity trends difficult in many cases.

The aim of this type of data analysis is to obtain stream salinity trends that are independent of fluctuations in flow and season, and hence are indicative of the impacts of saline groundwater inflows caused by catchment salinisation. A standard approach used in water agencies throughout the world is the non-parametric Seasonal Kendall’s τ and LOESS smoother techniques (Hirsch et al., 1982; Cleveland, 1994). As highlighted in Jolly et al. (2001), problems arise from the application of the Seasonal Kendall’s τ technique when the stream
salinity data are autocorrelated, as was shown to be the case for many of the stations in the MDB. To overcome this problem a new semi-parametric statistical methodology was employed (Morton, 1997) which uses the Generalised Additive Model (GAM) approach (Hastie and Tibshirani, 1990). While corrections for flow and seasonal effects are implicit in the technique, it is important to note that the analysis does not account for long-term climatic variations per se.

In this technique, additive regression terms were fitted to logEC (log µS/cm), the explanatory variables being time (months), logflow (log ML/day) and sinusoidal seasonal terms. This non-linear GAM model represented the response of logEC to time and logflow by arbitrary smooth curves using cubic splines with knots at each data point. The mathematical form of the regression was:

\[
\text{logEC} = \alpha + S(\text{time}; dft) + S(\text{logflow}; df_f) + \beta \sin(2\pi \text{month}/12) + \gamma \cos(2\pi \text{month}/12) + \varepsilon
\]

where logEC was the natural logarithm of EC, logflow was the natural logarithm of flow + 1, time was in years, month had values of 1 to 12, \(S(t; dft)\) was a smoothing spline of logEC versus time with \(dft\) degrees of freedom, \(S(\text{logflow}; df_f)\) was a smoothing spline of logEC versus logflow with \(df_f\) degrees of freedom; \(\alpha, \beta, \gamma\) were linear regression coefficients and \(\varepsilon\) was the residual error. The terms \(dft\) and \(df_f\) are smoothing parameters that determine the shape of the splines fitted to the data.

We followed Morton’s (1997) recommendation that values of 4 for \(dft\) and 2 for \(df_f\) were adequate for data sets of the length used in this project. The term \(S(x; m)\) is the sum of the linear (which is of the form a+b*x) and the non-linear (which has mean zero and no linear trend) components of the trend. By separating the linear and non-linear components of the spline function, Equation (1) was rewritten as:
\[ \log EC = \alpha + \eta \text{time} + C_{\text{time}} + \chi \log \text{flow} + C_{\log \text{flow}} + \beta \sin \left( \frac{2\pi \text{month}}{12} \right) + \gamma \cos \left( \frac{2\pi \text{month}}{12} \right) + \varepsilon \] 

(2)

where \( \eta \) and \( \chi \) were linear coefficients of \text{time} and \log \text{flow} respectively, and \( C_{\text{time}} \) and \( C_{\log \text{flow}} \) were the non-linear components of \( S(\text{time}; df) \) and \( S(\log \text{flow}; df) \) respectively. The linear coefficient of \text{time}, \( \eta \), was used to calculate the percentage change in EC per annum using the formula:

\[
\left\{100 \times \left( e^\eta - 1 \right)\right\}
\]

(3)

Figure 4 shows the two components of the trend. The significance of the non-linear component cannot be determined and as such is qualitative. The significance of the linear component of the trend can be determined quantitatively.
The model fits were carried out using Ordinary Least Squares (referred to as the OLS approach) regression. If autocorrelation of the residuals of the OLS fits were found to be high (>0.2), then fits were carried out with first order autoregressive parameters (referred to as the TSM approach).

The significance of the linear components of the trends at the 5% probability level was estimated as ±2 standard errors. Standard errors for stations with sufficient data to use the TSM approach were taken directly from the statistical output. However, if the number of missing months was too large (>20%), then the TSM approach failed and it was necessary to use the OLS approach with a multiplier applied to the standard errors. This multiplier was derived from likelihood theory and was adjusted both for the magnitude of the autocorrelation and for the amount of missing data:

\[ \left(1 + 2pAR / (1 - AR1)\right)^{1/2} \]  

(4)

where \( p \) was the proportion of available data and \( AR1 \) was the first order autocorrelation coefficient. It should be noted that this multiplier is an approximation based on the assumptions that the missing values have occurred independently and at random.

For each station, all available EC data were used to determine the trends. Obvious outliers, caused be erroneous flow or EC values, were identified by high residual values and were removed from the data set and the trends recalculated. There were never more than five points per station where this was necessary.

### 3.4. Estimation of historical catchment salt balances

The third component of this study was to determine salt balances using the ratio of salt output to salt input (O/I), and total salt output based on area (both tonne/km\(^2\)) and time (tonne/day) for each End-of-Valley target stations in the
Assessment of Historical Data for the Murray-Darling Basin Ministerial Council’s End-of-Valley Target Stations

Basin where sufficient data existed. These data identify those regions which are not in an equilibrium salt balance, particularly those where accumulated salt is being mobilised, and are important contributors to stream saltloads.

Salt O/I ratios were analysed for catchments using annual stream saltload at gauging stations, as well as rainfall salt concentration data. It is important to note that the salt balances reported for each station are for the whole of the catchment upstream of the station. As described in Chapter 2, in some cases additional stations near the catchment outlet were analysed to obtain complete salt outputs for their catchments. The catchment salt balances were calculated annually for a 15-year period (1985-2000). This differs to the calculations of trends where the entire length of the data set was used.

3.4.1. Salt Output

Daily flow data were available for all stations and these were summed to provide the annual water output for each station. Generally there were only small gaps in the daily flow record and no attempt was made to interpolate the missing data (however, periods of missing flow were noted). It should be noted that data with quality codes rated as good were only used. However, there were three cases where some parts of the flow record looked questionable (even though the quality codes suggested that they were satisfactory) and these are highlighted where appropriate.

Stream salinities (mg/L) were estimated from EC (in $\mu$S/cm) measurements and derived from the power relationship $TDS = 0.985 \times EC^{0.914}$ as suggested by White and Wasson (2002). The previous approach of using a conversion factor of 0.6 (Mackay et al., 1988) was not adopted in this study as it has been reported by White and Wasson (2002) that the 0.6 conversion factor may cause an overestimate of saltloads in streams with lower EC or at high flow ends. This is primarily due to the variation of stream salinities, water chemistry and non-linearity of the relation between EC and TDS, throughout the Murray-Darling
Assessment of Historical Data for the Murray-Darling Basin Ministerial Council’s End-of-Valley Target Stations

However, a comparison between saltload calculations was made between the two methods with results indicating differences ranging from 0 to 14%. More specifically, 10 stations differed by between 0-5%, 3 stations differed by 5-10% and 3 stations differed by greater than 10%. Table 3 below shows a simple break down of the results from the two methods used.

Table 3. Saltload calculations for Lachlan River @ Forbes

<table>
<thead>
<tr>
<th>Year</th>
<th>Old SO/SI (0.6 conversion)</th>
<th>New SO/SI (power relationship)</th>
<th>Difference absolute value</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>202571</td>
<td>196788</td>
<td>5783</td>
<td>2.9</td>
</tr>
<tr>
<td>1986</td>
<td>197248</td>
<td>191691</td>
<td>5557</td>
<td>2.9</td>
</tr>
<tr>
<td>1987</td>
<td>47060</td>
<td>45734</td>
<td>1325</td>
<td>2.9</td>
</tr>
<tr>
<td>1988</td>
<td>233849</td>
<td>227243</td>
<td>6606</td>
<td>2.9</td>
</tr>
<tr>
<td>1989</td>
<td>465532</td>
<td>452371</td>
<td>13162</td>
<td>2.9</td>
</tr>
<tr>
<td>1990</td>
<td>1161557</td>
<td>1128722</td>
<td>32835</td>
<td>2.9</td>
</tr>
<tr>
<td>1991</td>
<td>192742</td>
<td>187206</td>
<td>5535</td>
<td>3.0</td>
</tr>
<tr>
<td>1992</td>
<td>62272</td>
<td>60487</td>
<td>1785</td>
<td>3.0</td>
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<tr>
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<td>46968</td>
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<td>3.0</td>
</tr>
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</tr>
<tr>
<td>2000</td>
<td>202192</td>
<td>195610</td>
<td>6583</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Average 3.0 3.5 3.4

With very few exceptions, stream EC data for most stations were intermittent, often no better than monthly in frequency. This necessitated the estimation of daily saltloads by a number of methods. If the gap between electrical conductivity measurements was less than 7 days, the missing data were interpolated and daily saltload was calculated as the product of daily flow and salt concentration. However, where the gaps between electrical conductivity measurements were greater than 7 days, a regression analysis was undertaken to establish a relationship between saltload and stream flow rate, based on all of the available intermittent electrical conductivity data (the sample size generally exceeded 50 points). The resultant regression equation was then used to calculate daily saltloads (tonne/day) for the missing periods using the continuous daily stream flow data, and these were then summed to provide an annual salt.
output for each station (see Figures 5 and 6). Note that with the addition of another 6 years of data, the regressions for the stations previously analysed by Jolly et al. (1997a, 2001) have changed slightly. This combined with using the power law conversion of EC to salinity, means that the saltloads presented here for these stations for the previously analysed years (1985-94) may vary slightly from those previously reported.

**Figure 5: Regressions of saltloads with flow for station 421012 (Macquarie @ Carinda)**

**Figure 6: Regressions of saltloads with flow for station 416028 (Boomi River @ Neeworra)**
For most stations, the relationship between stream saltload and stream flow was very good, with coefficients of determination usually greater than 0.90. However, in those cases where the linearity was not acceptable, particularly at the lower flow rates, it was necessary to either:

- Fit piece-wise regressions for each of the low-flow and high-flow data groups to reflect clear differences between the two flow cases;
- Separate the data set into four sub-sets based on seasonality and construct a regression for each; or to
- Fit a non-linear regression (log-log) in those cases where the above methods were unsuccessful.

It is important to point out that the need for these types of infilling of missing data, means that the saltloads for most stations are approximations only. We have discussed the implications of this in Chapter 5.

### 3.4.2. Salt Input

In this study, the only salt input was that which was contained in the total rainfall incident on the entire catchment upstream of the gauging station. This was estimated using a GIS-based approach which utilised interpolated rainfall surfaces obtained from existing measurements of salt in rainfall from 18 sites within the Basin (Blackburn and McLeod, 1983) considered to be uncontaminated by resuspended terrestrial dust (Simpson and Herczeg, 1994). Daily rainfall data were summed to provide annual rainfall, then projected and clipped to the required digital catchment boundary maps. The area-weighted annual rainfall (and salt in rainfall) for each sub-basin or catchment of interest was then calculated using a GIS batch program.
3.4.3. Diversions

Diversions for water supplies (irrigation, urban, industrial, etc.) result in the removal of water and salt that might otherwise leave the catchment through the End-of-Valley station. Due to the complexities of the water supply systems, generally poor quality of the flow and salinity data sets, and time constraints, the effect of diversions were not factored into this study. The significance that diversions may have on catchment salt balances is discussed in Chapter 5.