

Project 054121: Surface Water – Groundwater
Interactions in River Murray Wetlands and
Implications for Water Quality and Ecology

Final Report to the Centre for Natural Resource
Management

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Water for a Healthy Country Flagship Report
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1. INTRODUCTION

In the Murray Darling Basin, one of the largest environmental impacts is the decline of riparian vegetation in the lower River Murray (South Western NSW, North-West Victoria and SA). River regulation and consumptive use has greatly changed the pattern of flow in the River Murray in South Australia with serious consequences for the ecological values of water-dependent ecosystems. The river is now effectively an ensemble of stepped weir-pools resembling a series of elongated lakes. Low-lying wetlands that were formerly temporarily inundated are now permanently flooded. Furthermore, those wetlands at higher elevations on the floodplain, and away from the River Murray, have been adversely affected by reduced flooding frequency. The construction of weirs and locks has also raised floodplain groundwater levels, as have increases in groundwater inflows to the floodplain due to adjacent irrigation areas. The raised groundwater levels have increased saline groundwater discharge and the reduction in flooding has restricted the supply of fresh water. In combination, these two effects have increased the risk of salinisation of the wetlands.

Recent estimates have suggested that 30% to 50% of the floodplain in the lower River Murray in South Australia will be affected by salinisation within 50 years. The protection of the health of the floodplain and wetlands from salinity impacts associated with irrigation development, regional groundwater discharge and changes to the River Murray flow regime are key management goals for the lower River Murray in South Australia (SA River Murray Salinity Strategy, River Murray Water Allocation Plan, SA Murray-Darling Basin Integrated Natural Resource Management Plan). Similarly, minimising “the effects of salinity on biodiversity in water courses, wetlands and riparian zones ... through maintenance of adequate environmental flows and appropriate management in irrigation areas to minimise irrigation-induced salinity” is a national goal (ANZECC). In many cases, the preferred management option for these wetlands is to mimic the natural variability of river flows by reintroducing wetting and drying cycles to these wetlands by constructing regulation structures on the connections between the river and the wetlands. However, how this would impact groundwater – surface water (GW-SW) interactions in floodplain wetlands has not been considered.

Floodplain wetlands are potentially a significant source of salt and other contaminants to the river, due to their role in intercepting saline groundwater discharge. While there has been some research in relation to wetland surface-groundwater hydraulic relationships (e.g. Townley and Trefry, 2000), the role that surface water-groundwater interactions play in wetland soil and water chemistry and the resultant biotic responses is largely unknown. The connectivity of the surface water – groundwater systems will depend on the regional hydrogeology and wetland geomorphology, and will also be affected by management such as wetland wetting and drying cycles and groundwater interception. Regional groundwater is highly saline, but also anoxic and reduced, potentially affecting wetland water quality and habitat. The current lack of understanding of GW-SW interactions in wetlands, particularly in relation to wetland water quality and its impact on ecology and biodiversity, is a significant shortcoming in our ability to assess/determine the most appropriate way of managing the wetlands of the lower River Murray.

The overall aim of CNRM Project 054121 was to improve the understanding of the interactions of saline groundwater with surface water in lower River Murray wetlands and to assess the implications for wetland ecology. The key scientific question or hypothesis that was tested in this project was:

“Can the characterisation of the physical habitat of wetlands (which is controlled by water regime – wetland flooding and drying, surface water – groundwater interactions, geomorphology, aquifer salinity, etc...) be used to predict aquatic and terrestrial ecological health response?”

2. PROJECT SUMMARY

There were four main components to the work of this project: a literature review (Jolly et al., 2008); a characterisation framework for wetlands of the Lower River Murray (Crosbie et al., 2008a); a spatial model developed from the characterisation framework (Crosbie et al., 2008a); and, a field study of three end-member wetlands (Crosbie et al., 2008b). The findings of these components and the overall conclusions of the project are summarised below.

2.1. Literature Review

In arid/semi-arid environments, where rainfall is seasonal, highly variable and significantly less than evaporation, groundwater discharge can be a major component of the water and salt balance of a wetland, and hence a major determinant of wetland ecology. Under natural conditions, wetlands in arid/semi-arid zones occasionally experienced periods of higher salinity as a consequence of the high evaporative conditions and the variability of water flow. However, due to the impacts of human population pressure and the associated changes in land use, surface water regulation and water resource depletion, wetlands in arid/semi-arid environments are now often experiencing extended periods of high salinity. A comprehensive review of the current knowledge of the role that GW-SW interactions play in the ecology of arid/semi-arid wetlands had the following key findings:

GW-SW interactions in wetlands are highly dynamic, both temporally and spatially. Groundwater that is low in salinity has beneficial impacts on wetland ecology which can be diminished in dry times when groundwater levels and hence inflows to wetlands are reduced or even cease. Conversely, if groundwater is saline, and inflows increase due to raised groundwater levels caused by factors such as land use change and river regulation, then this may have detrimental impacts on the ecology of a wetland and its surrounding areas.

GW-SW interactions in wetlands are mostly controlled by factors such as differences in head between the wetland surface water and groundwater, the local geomorphology of the wetland (in particular the texture and chemistry of the wetland bed and banks), and the wetland and groundwater flow geometry. The GW-SW regime can be broadly classified into three flow regime types: (i) recharge - wetland loses surface water to the underlying aquifer; (ii) discharge - wetland gains water from the underlying aquifer; or (iii) flow through - wetland gains water from the groundwater in some locations and loses it in others. However, it is important to note that individual wetlands may temporally change from one type to another depending on how the surface water levels in the wetland and the underlying groundwater levels change over time in response to climate, land use and river management.

The salinity in wetlands of arid/semi-arid environments will vary naturally due to high evaporative conditions, sporadic rainfall, groundwater inflows, and freshening after rains or floods. However, wetlands are often at particular risk of secondary salinity because their generally low position in the landscape exposes them to increased saline groundwater inflows caused by rising water tables. Terminal wetlands are potentially at higher risk than flow through systems as there is no salt removal mechanism.

Secondary salinity can impact on wetland biota through changes in both salinity and water regime which result from the hydrological and hydrogeological changes associated with secondary salinity. Whilst there have been some detailed studies of these interactions for some Australian riparian tree species, the combined effects on aquatic biodiversity are only just beginning to be elucidated, and are therefore a future research need.

Rainfall/flow pulses, which are a well recognised control on ecological function in arid/semi-arid areas, also have an important indirect role through their impacts on wetland salinity. Freshwater pulses can be the primary means by which salt stored in both the water column and in the underlying sediments are flushed from wetlands. Conversely, increased runoff is also a commonly observed consequence of secondary salinity and so wetlands can experience increased surface water inflows that are higher in salinity than under natural conditions. Moreover, changes in rainfall/flow pulse regimes can have significant impacts on

wetland GW-SW interactions. It is possible that, in some instances, groundwater inflow to a wetland may become so large that it could become a major component of the water balance and hence mask the role of natural pulsing regimes. However, if the groundwater is low in salinity, this may provide an ecological benefit in arid/semi-arid areas by assisting in maintaining water in wetlands that become aquatic refugia between flow pulses.

There has been almost no modelling of GW-SW interactions in arid/semi-arid wetlands with respect to water fluxes, let alone salinity or ecology. Therefore, there is a clear need to develop modelling capabilities for the movement of salt to, from and within wetlands to provide temporal predictions of wetland salinity which can be used to assess ecosystem outcomes.

A concerted effort has been undertaken in Australia to collect and collate data on the salinity tolerance/sensitivity of freshwater aquatic biota and riparian vegetation but there are many shortcomings and knowledge gaps in these data, a fact recognised by many of the authors of this work. Particularly notable is that there is very little time series data, which is a serious issue because wetland salinities are often highly temporally variable. There is also a concern that many of the data are from very controlled laboratory experiments which may not represent the highly variable and unpredictable conditions experienced in the field. In light of these, and the many other shortcomings identified, our view is that the data are a useful guide but must be used with some caution.

2.2. Characterisation Framework

There are over 2000 wetlands in the lower River Murray of South Australia, and increasing community awareness of their ecological value is driving a need for an active management approach. It is not feasible for detailed hydrological measurements to be taken at every wetland and so a characterisation approach is proposed to predict the impact of management intervention on a wetland.

Previous classifications of the wetlands of the lower River Murray have focused upon the physical and chemical properties of the wetlands as they relate to their ecology. The present study differs from previous work in that its focus is on the hydrology and salinity of the wetlands and uses this to infer the ecological status. The current study has used existing physical data (SKM, 2004; SKM, 2006) to develop a characterisation scheme (Figure 1) and existing biological data (SKM, 2004; SKM, 2006) to test if the categories meet the objectives of the study.

The use of only eight categories has enabled the characterisation scheme to be kept simple while providing enough explanatory power to predict the hydrological regime and salinity of the wetlands. The eight classes were based on a hierarchical structure (Brinson, 1993) with the wetland type as the first level and the number of connections to the river as the second level. The wetland types were grouped into four classes (anabranches, backwaters, billabongs and fringing wetlands) and the connections to the river grouped into three classes (no connection to the river at pool level, one connection at pool level and two or more connections at pool level).

On the basis of the number of species present, it was found that the ecological health of the wetlands increases with decreasing salinity. The characterisation scheme also predicts that wetlands will have greater species diversity with an increasing number of connections to the river at pool level for all wetland types. The species diversity of wetland types increases in the order: fringing wetlands, billabongs, backwaters and anabranches.

The characterisation scheme thus developed, questions conventional wisdom on the benefits of introducing wetting and drying cycles to permanently inundated wetlands in the lower River Murray and therefore highlights the need for further study.

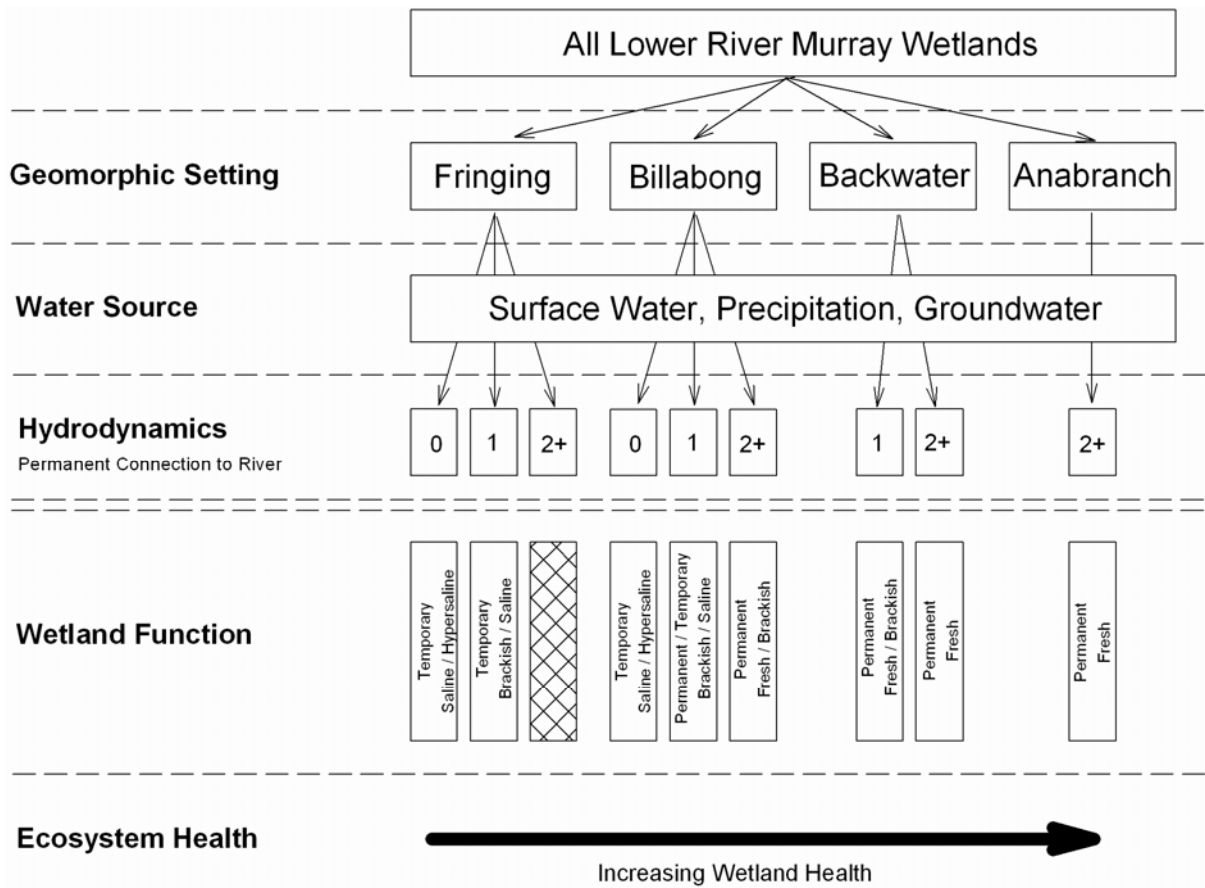


Figure 1. Characterisation scheme developed for the lower Murray Wetlands.

2.3. Spatial Model

All the wetlands of the lower River Murray have been classified into the characterisation scheme (Figure 1) through the interpretation of aerial photography (MDBC, 1998), existing wetland polygons (Miles and Bevan, 2006) and the Floodplain Inundation Model (Overton, 2005). A summary of the outcomes of this process is shown in Table 1. The most numerous category was “billabongs without a permanent connection to the river” which comprised almost half the total number of wetlands but only one seventh of the total area. The least numerous category was “fringing wetlands with two or more connections to the river” where no examples were found.

The wetlands (with the exception of the fringing wetlands) that have a permanent connection to the river have the potential to have managed wetting and drying cycles by regulating the connection with the river. These wetlands represent 23% by number and 39% by area of the total wetlands of the lower River Murray. It is these wetlands, in particular, where the classification scheme described here could be useful as a management tool.

In all cases, the introduction of a wetting and drying cycle to a wetland will result in a shift to the left in Figure 1, because the wetland will go from being a permanently inundated wetland to a temporary wetland. A shift to the left corresponds to a decrease in ecological health.

Table 1. Matrix of number of wetlands in each category from Figure 1, figure in brackets refers to area in hectares.

	Fringing Wetlands	Billabongs	Backwaters	Anabranches	Total
0 Permanent Connections	213 (8,719)	915 (5,270)			1,128 (13,989)
1 Permanent Connection	404 (7,392)	259 (5,270)	126 (6,859)		789 (19,521)
2+ Permanent Connections	0 (0)	9 (397)	2 (79)	66 (1,294)	77 (1,770)
Total	617 (16,111)	1,183 (10,937)	128 (6,938)	66 (1,294)	1,994 (35,280)

2.4. Field Study

The field study investigated three wetlands with contrasting surface hydrological regimes:

- 1) Lake Littra is an ephemeral wetland that has no connection to the river except during flood events
- 2) Hart Lagoon has one connection to the river at pool level, thereby providing a limited exchange of water and solutes
- 3) Banrock Station wetland has two connections to the river at pool level, one on either side of a weir / lock, thereby providing a substantial flow of surface water through the wetland.

A range of methods were utilised for investigating the surface water – groundwater interactions of these wetlands including EM surveys, analysis of hydrometric observations and the analysis of water samples taken from river water, wetland surface water, and groundwater.

When inundated, Lake Littra and Banrock Station wetland were groundwater recharge features (Figure 2), while Hart Lagoon was a groundwater flow through system. After the surface water had been removed, there was a reversal of the hydraulic gradients and all three wetlands became groundwater discharge features (Figure 2). The transformation of these wetlands to groundwater discharge features after the removal of surface water means that wetland managers must be careful not to induce further salinisation of lower River Murray wetlands when re-introducing wetting and drying cycles.

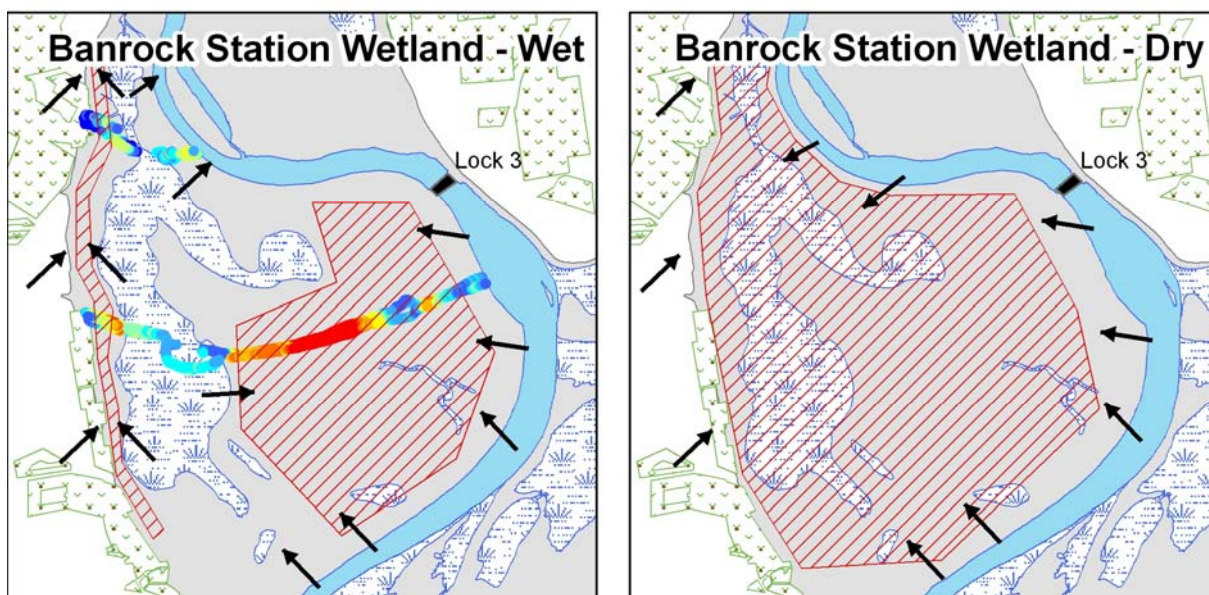


Figure 2. Conceptual models of groundwater flow and discharge for Banrock Station wetland under conditions of being inundated and dry.

The picture of the wetland when inundated also shows the results of the EM surveys – blue is low conductivity, red is high conductivity. Arrows show the direction of groundwater flow and red hatched areas show groundwater discharge areas. When inundated, the wetland acts as a recharge feature and creates a fresh water lens below the wetland, when dry the wetland is a discharge feature and at risk of salinisation.

2.5. Overall Conclusions

The results of the field study explained the results of the characterisation framework. A wetland without water is a groundwater discharge feature and will accumulate salt. From the literature review, it was found that increasing salinity leads to decreasing ecological health. A wetland that is inundated may be a groundwater recharge feature contributing fresh water from the river to the groundwater. However, it is the strength of connection to the river that determines the ecological health of the wetlands of the Lower River Murray. Introducing wetting and drying cycles severs the link from the wetland to the river thereby leading to increased salinity and decreased ecological health.

3. FURTHER APPLICATION OF RESEARCH RESULTS

One of the original goals of this project was to inform any future development of the Floodplain Impacts Model (Overton et al., 2003). This model was updated to include wetlands before the present study was undertaken (Holland et al., 2005). The results of this study could be used to inform the wetland leakage parameter in FWIP. However, the finding of this study that the interactions between groundwater and wetlands are transient suggests that a steady state model such as FWIP may not be appropriate for detailed modelling of GW-SW interactions in wetlands.

The results of this study are transferrable to other areas that have similar conditions. The results will be particularly relevant where wetlands are connected to a fresh surface water body and are underlain by shallow saline groundwater. These conditions occur along the River Murray in NSW and Victoria downstream of the confluence with the Darling River. The wetlands along this stretch of river are under the same stresses as those in South Australia and will respond similarly if allowed to dry out. The re-introduction of wetting and drying

cycles to these wetlands will lead to an increased risk of salinisation. Other areas where the findings of this project may be relevant include the wetlands of the Upper South East where there is fresh surface water from flood filled wetlands overlying saline groundwater. Whilst the differing geomorphological, hydrogeological and climatic conditions in this region prevent direct application of the results from the lower River Murray wetlands, the underlying GW-SW interaction processes are likely to be similar. For example, for wetlands that become groundwater discharge areas when they are dry, maintaining surface water in them for longer periods of time may help prevent their long-term salinisation and therefore potentially provide ecological benefits.

4. REPORTING AGAINST MILESTONES

- 1) ***A wetland characterisation framework that uses a set of rules to characterise the ecological health of each wetland in terms of the physical habitat. This part of the project will be reported in the June 2006 Progress Report.***

A Characterisation scheme was developed that is capable of predicting the relative species richness of a wetland. It is based upon the premise that the ecological health of a wetland can be predicted from its hydrological and salinity regimes and that these can be predicted by the strength of connection of the wetland to the river. The characterisation scheme was presented as an attachment to the June 2007 Progress Report.

- 2) ***A literature review of physical habitat requirements of aquatic and terrestrial wetland species and the relationship between the physical habitat of wetlands and the water regime, surface water – groundwater interactions and resultant wetland salinity levels. This review will be published as a CSIRO Technical Report and summarised in the December 2006 Annual Report and Presentation.***

A review of existing literature was conducted to determine the impact of hydrological and salinity regimes upon wetland ecology in semi-arid areas. This review was published as a CSIRO Science Report in December 2006 and as a paper in the international journal *Ecohydrology* in January 2008. The Science Report was presented as an attachment to the December 2006 Progress Report and the journal paper was presented as an attachment to the September 2007 Progress Report.

- 3) ***Conference papers and presentations to communicate (a) project aims and objectives; and (b) development, application and testing of the wetland characterisation framework. This conference paper and presentation will be included in the December 2006 Annual Report and Presentation.***

The aims and objectives of the project were communicated at the 10th Murray-Darling Basin Groundwater Workshop held in Canberra during September 2006. The wetland characterisation scheme was presented at the 2nd International Salinity Forum held in Adelaide during April 2008. A summary of the complete findings of the project will be presented at *HydroPredict 2008* to be held in Prague in September 2008. The conference paper summarising the aims and objectives of the project were presented as an appendix to the December 2006 Progress Report. Conference paper describing the characterisation framework was presented as an attachment to the June 2007 Progress Report.

- 4) ***Paper (draft journal paper 1) describing the development and application of the rule-based wetland characterisation framework, and its testing against detailed field measurements to determine whether it can be used to predict the state of the ecological health and if so, how well? This paper will be summarised in the December 2006 Annual Report and Presentation.***

A paper describing the characterisation scheme has been written and submitted to the international journal *River Research and Applications*. A draft version of this paper was presented as an attachment to the June 2007 Progress Report, the paper

as submitted was presented as an attachment to the December 2007 Progress Report.

- 5) A report of field measurements, interpretation of data and details of the development of conceptual models for each wetland and the implications that water regime and surface water – groundwater interactions have on wetland salinity and ecological health. This part of the project will be published as a CSIRO Technical Report and summarised in the June 2007 Progress Report.**

A CSIRO Water for a Healthy Country Science Report was published on the field work undertaken during this project. This report contained a record of all measurements taken, an interpretation of the data and the development of conceptual models of water and salt movement under conditions of the three wetlands being inundated and dry. This report was presented as an attachment to the September 2007 Progress Report.

- 6) Student project reports or theses comprising a literature review, results of field work, wetland salt and water balance and the implications that water regime and surface water – groundwater interactions have on wetland salinity and ecological health, summarised in the December 2006 Annual Report and Presentation.**

Kamilla Moe undertook her Honours research at Banrock Station Wetland investigating the spatial differences in the interactions between groundwater and the wetland. Her thesis was presented as an attachment to the December 2006 Progress Report.

- 7) Paper (draft journal paper 2) that compares and contrasts end member wetlands in terms of ecological health and physical habitat to clearly articulate the hydrogeologic and surface water controls on wetland health. This paper will be summarised in the Final Project Report and Presentation in September 2007.**

A journal paper has been written that describes how altering the surface water in a wetland will lead to changes in the groundwater and will lead to an increased risk of salinisation in the wetland. A draft of this paper was presented as an attachment to the December 2007 Progress Report. This paper has been submitted to the international journal *Hydrological Processes*.

- 8) A spatial model that links to DWLBC wetland management salinity assessment model to predict implications of wetland and groundwater management for wetland ecology and salinity. Model details and results will be reported in the Final Project Report and Presentation in September 2007.**

The timelines of the DWLBC model development team and this project did not coincide and so this objective in its original form could not be met. This was highlighted in the March 2007 Progress Report and CNRM agreed that the milestone could be revised to applying the wetland characterisation framework spatially (using GIS) to all of the lower River Murray floodplain wetlands to predict their likely salinity and water regimes, and therefore infer their relative biodiversity. This work was detailed in the journal paper that was presented as an attachment to the December 2007 Progress Report.

- 9) Final Report and Presentation in September 2007 summarising the detailed scientific findings of the project, including a discussion of their use in improving other models and management planning in the SA Murray Darling Basin INRM; assisting interstate groups responsible for management of wetlands in similar biophysical conditions in the Tri-State region; and providing a guide for other SA INRM Groups as to the realistic benefits to terrestrial and aquatic species of changes to wetland water regime and surface water – groundwater interactions.**

This report is the final report and a summary of the scientific findings of the project and how they can be used outside of the lower River Murray are presented in Sections 2 & 3. A formal presentation of the final results of the project by Russell Crosbie was made at the CNRM Murray-Darling Basin Science Forum held in Adelaide on November 29, 2007.

5. PROJECT PUBLICATIONS

This project has generated a number of publications that are used to communicate the findings to various audiences, they are listed below. There is one journal paper that has been published and two more in submission. There have been two conference papers presented and one to be presented in September 2008. There have been three reports published.

5.1. Journal Papers

- Crosbie, R.S., Jolly, I.D., McEwan, K.L. and Holland, K.L., 2008. The characterisation of the hydrology and salinity regimes of the wetlands of the Lower River Murray, Australia. Submitted to River Research and Applications.
- Crosbie, R.S., McEwan, K.L., Jolly, I.D., Holland, K.L., Lamontagne, S., Moe, K.G. and Simmons, C.T., 2008. Salinisation risk in semi-arid floodplain wetlands subjected to altered hydrology and active management. Submitted to Hydrological Processes.
- Jolly, I.D., McEwan, K.L. and Holland, K.L., 2008. A review of groundwater - surface water interactions in arid / semi-arid wetlands and the consequences of salinity for wetland ecology. *Ecohydrology*, DOI: 10.1002/eco.6.

5.2. Conference Papers

- Crosbie, R.S., Jolly, I.D., McEwan, K.L. and Holland, K.L., 2008. A Framework for the characterisation of the hydrology and salinity regime of wetlands of the Lower River Murray, 2nd International Salinity Forum, Adelaide.
- Crosbie, R.S., Jolly, I.D., McEwan, K.L., Holland, K.L. and Lamontagne, S., 2008. Surface water - groundwater interactions in River Murray wetlands and implications for water quality and ecology, Hydro Predict 2008, Prague, Czech Republic.
- McEwan, K.L., Holland, K.L. and Jolly, I.D., 2006. Surface water - groundwater interactions in River Murray wetlands and implications for water quality and ecology, 10th Murray-Darling Basin Groundwater Workshop, Canberra.

5.3. Reports

- Crosbie, R.S., McEwan, K.L., Jolly, I.D., Holland, K.L. and Lamontagne, S., 2007. Surface water – groundwater interactions in three River Murray floodplain wetlands: Results from field studies., CSIRO Water for a Healthy Country Flagship report, Adelaide.
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