Evaluation of *WaterCress* for Assessing Salinity Impacts of Wetland Manipulation

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FOREWORD

South Australia's water resources are fundamental to the economic and social wellbeing of the State. Water resources are an integral part of our natural resources. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of surface and groundwater resources changes the natural balance and causes degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of a resource to continue to meet the needs of users and the environment. Degradation may also be very gradual and take some years to become apparent, imparting a false sense of security.

Management of water resources requires a sound understanding of key factors such as physical extent (quantity), quality, availability, and constraints to development. The role of the Knowledge and Information Division of the Department of Water, Land and Biodiversity Conservation is to maintain an effective knowledge base on the State's water resources, including environmental and other factors likely to influence sustainable use and development, and to provide timely and relevant management advice.

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EXECUTIVE SUMMARY

A simple salt/water balance has been implemented in the *WaterCress* platform as a tool for wetland managers to assess salinity implications of manipulating wetlands. The model has been implemented following a need identified by DWLBC Strategic Policy Division (SPD), who are accountable for reporting salinity impacts in the South Australian Murray Darling Basin (SA MDB).

The model is *simple and generic*, yet underpinned by robust and widely accepted science. The model uses Darcian principles to link groundwater fluxes to the traditional water balance routines. It operates in a transient mode, calculating fluxes and salinities at each time-step. An evaluation of the model was undertaken at the Lake Merreti wetland, north of Renmark in South Australia. Based on this limited evaluation, the model has been shown to replicate fluxes and salinities reasonably well.

No model will ever replace the requirements for accurate and reliable monitoring. However application of the model in the SA MDB should serve to better target and inform monitoring programmes and add value to information collected for decision-making in the management of wetlands for environmental outcomes and their salinity impacts. Further development is proposed to improve the range of functions available in the model and its ease of use.

CONTENTS

FOREWORD I

EXECUTIVE SUMMARY II

1. INTRODUCTION 4

2. BACKGROUND 5
   2.1 Existing Models 5

3. MODEL DESCRIPTION 7
   3.1 Conceptual Model 7
   3.2 Model Assumptions 8
   3.3 Model Data Requirements 9

4. MODEL EVALUATION 11
   4.1 Calibration Review 11

5. DISCUSSION 14
   5.1 Model Strengths 14
   5.2 Model Limitations 16
   5.3 Monitoring 16

6. CONCLUSIONS & RECOMMENDATIONS 17

REFERENCES 18

List of Figures

Figure 3.1: Conceptualised floodplain layout used in *WaterCress*. 7
Figure 3.2: Slice model of the floodplain illustrating various configurations of aquifer properties and river conditions (after Cresswell, D. 2005, pers. comm., 16 August) 8
Figure 4.1: *WaterCress* calibration for water level, 1975 to 2000. 12
Figure 4.2: *WaterCress* calibration for EC, 1975 to 2000. 12
Figure 4.3: Comparison of Lake Merreti water level (modelled and observed) and EC (modelled and observed) for the period 1980 to 1984 13

List of Tables

Table 4.1: River and climatic data sets used in the model. 11
Table 4.2: Lake Meretti calibration data sets used in the model. 11

1. INTRODUCTION

Conservation and community groups in the SA Murray Darling Basin (SA MDB) are increasingly becoming involved in managing wetlands. A number of Wetland Management Plans have been prepared or are in preparation. DWLBC's Strategic Policy Division (SPD) are accountable for reporting any impacts on River salinity resulting from wetland management, and to this end required a simple and robust method with which to assess the salinity impacts of wetland management.

A simple and generic salt/water balance model has been developed using the *WaterCress* program. This report briefly summarises the development of the model and includes a preliminary evaluation using the Lake Merreti wetland, north of Renmark in South Australia, as a trial.

2. BACKGROUND

The Salinity Impacts of Wetland Manipulation (SIWM) Model (AWE and ET 2002a, 2002b) was initially proposed to allow wetland managers to assess salinity implications of managing specific wetlands in the SA MDB. A review of the Model (Murdoch, Greenwood & Cresswell 2005) identified technical and logistic constraints to the use of the SIWM Model for its intended purpose. Notable among these constraints was the penalty imposed by using the Microsoft Excel™ platform in terms of model execution time and the computing power required; and concerns surrounding the protection of key data and formulae in spreadsheet cells.

An alternative method of wetland salinity assessment was sought which would be simple and user-friendly; and yet underpinned by robust and widely accepted science; capable of assessing the changes to salinity in the wetland over time; and, capable of providing reasonable estimates of potential salt loads to the River Murray resulting from managing wetland water levels.

DWLBC Knowledge and Information Division (KID) proposed that a dedicated wetland-groundwater interaction model could be incorporated into the *WaterCress* platform. SPD subsequently agreed to development of *WaterCress* to introduce the required capability.

2.1 Existing Models

A number of existing models are already used in regional floodplain salinity assessment. These include SIMPACT and SIMRAT (MDBC 2005; Rassam, Walker & Knight 2004); and, FIP, FWIP and FRP (Overton, Jolly, Holland & Walker 2003; Holland, K. 2005, pers. comm., 2 August). While these models are useful for assessing regional or whole-of-reach impacts, they are not capable of modelling transient floodplain processes at a resolution required to refine management strategies at the scale of individual floodplain elements.

2.1.1 SIMPACT/SIMRAT

SIMPACT (**S**alinity **Impact**) and SIMRAT (**S**alinity **Im**pact **R**apid **A**ssessment **T**ool) are steady-state analytical models developed to assess impacts on River Murray salinity resulting from new irrigation developments (MDBC 2005). SIMPACT/SIMRAT assumes an irrigation efficiency and, based on this value, allows a portion of irrigation and effective rainfall to pass through the root zone and recharge the unconfined aquifer. For each unit of aquifer recharge there is a corresponding aquifer discharge response at the discharge edge (which, in SA, is assumed to be the floodplain defined by the extent of the 1956 flood). Thus SIMPACT/SIMRAT assess the impact of *highland actions*, and not floodplain actions, on salt returns to the River. Furthermore, SIMPACT/SIMRAT does not give accurate results in a number of commonly encountered situations, such as when there are large groundwater losses on the floodplain through evaporation; or when there are steep groundwater gradients such as observed in major irrigation mounds (MDBC 2005, pp.4-32 - 4-37).

2.1.2 FIP/FWIP/FRP

The FIP (**F**loodplain **I**m**p**acts model), FWIP (**F**loodplain **W**etland **I**m**p**acts model) and FRP (**F**loodplain **R**isk **M**odel) form a suite of related steady-state analytical models for predicting floodplain salinisation risk. The FIP assumes a conceptual floodplain cross-section (not dissimilar to this model) and distributes floodplain groundwater inflows (irrigation recharge and regional fluxes) into seepage at the break of highland slope, evapotranspiration across the floodplain, and base flow to the River for some 3500 cross-sections (called *divisions*). FIP does this based on assumed aquifer thicknesses and regional aquifer properties (Overton et. al 2003).

The FWIP is a logical development of the FIP, which allows the inclusion of one wetland in each division, which is calibrated based on an empirical factor (Holland, K. 2005, pers. comm., 2 August).

FIP and FWIP utilise outputs from the SIMPACT model (Section 2.1.1 above) and a third model, FIM (**F**loodplain **I**nundation **M**odel). Models relying on modelled data for inputs invariably raise questions surrounding a compounding series of uncertainties.

The FIP, FWIP and FRP have application on a regional scale, and while their output may be regionally reasonable, they are unlikely to accurately reflect the physical reality in any one location.

3. MODEL DESCRIPTION

WaterCress (**Water** **C**ommunity **R**esource **E**valuation and **S**imulation **S**ystem; Cresswell, undated) is in itself not a model, but a PC based water management platform that incorporates a number of generic and project-specific hydrological models and functionalities for use in assessing water resources and designing and evaluating water management systems. The groundwater slice model described in this report sits within *WaterCress* alongside Boughton, Sacramento and others, providing significant capability in rainfall-runoff and surface water–groundwater interaction modelling. With the prudent use of appropriate data, the model is capable of representing the salt and water interchanges within complex river-wetland-floodplain-groundwater systems, typical of the SA MDB.

3.1 Conceptual Model

The model is conceptualised as illustrated in Figure 3.1. On the floodplain, a layer of Coonambidgal Clay overlies Monoman Sands, while the highland consists of the Upper Loxton Sands. The floodplain and highland are underlain by the relatively impervious Lower Loxton Sands. The permeability of the aquifer is described by the *hydraulic conductivity*, K, in the horizontal (K_x) and vertical (K_y) directions. The value of K_y used in the model represents the degree of connectivity between the wetland and the aquifer, and will vary considerably depending on whether the base of the wetland lies in the Coonambidgal Clay or the Monoman Sands.

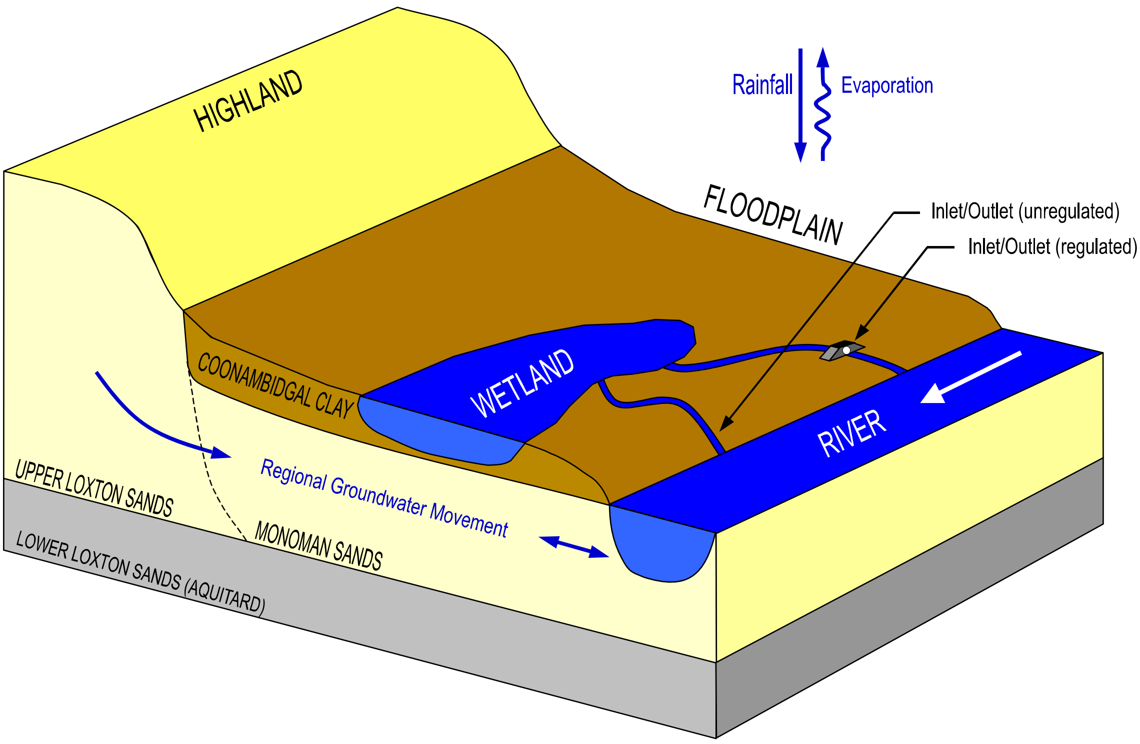
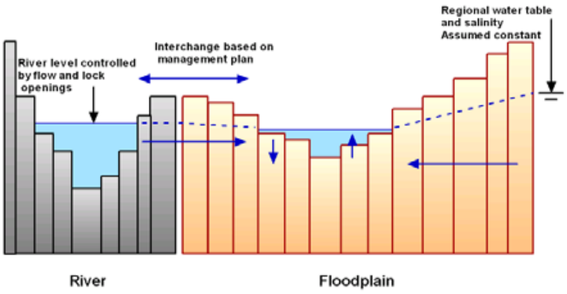


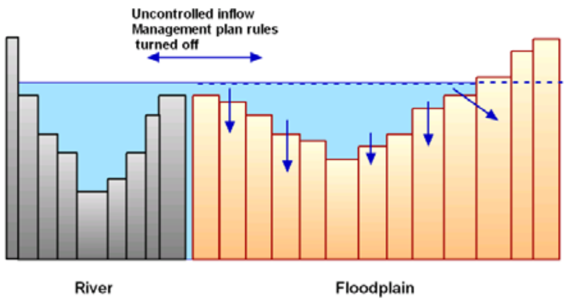
Figure 3.1: Conceptualised floodplain layout used in *WaterCress*.

A detailed mathematical description of the model is beyond the scope of this evaluation. In simple terms, *WaterCress* uses Darcian principles (eg Freeze and Cherry 1979, Chapter 2) to link groundwater fluxes to water balance routines (eg Dingman 1994, Chapter 2) on a daily or hourly time-step. The model operates in a transient mode calculating fluxes and heads at each time-step.

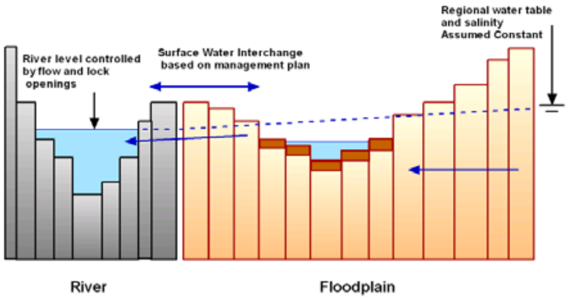
Water enters the model as river flow, rainfall or groundwater accession and leaves the model as river flow, evaporation or loss to groundwater. River water will interchange with the wetland (Figure 3.2(a) and (c)) through inlets/outlets (regulated or unregulated), or via seepage, within the confines of the *management plan* (operating rules). When river levels rise above the floodplain elevation, overbank flows inundate distal parts of the floodplain, permitting aquifer recharge around the wetland and across the floodplain, which mimics groundwater losses and, on flood recession, drive salt returns to the wetland-river system (Figure 3.2(b) and (d)).



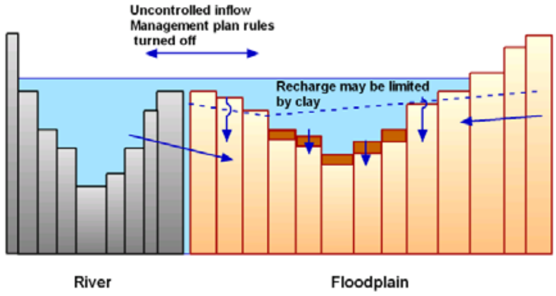
(a) normal river conditions (pool level)



(b) overbank flow conditions (flood)



(c) as for (a), but groundwater gradient affected by impermeable clays



(d) as for (b), but groundwater gradient and aquifer recharge affected by impermeable clays

Figure 3.2: Slice model of the floodplain illustrating various configurations of aquifer properties and river conditions (after Cresswell, D. 2005, pers. comm., 16 August).

3.2 Model Assumptions

The model relies heavily on empirical data such as river discharges, rainfall, and evaporation. The following assumptions are made:

1. The aquifer is homogeneous and conforms to conventional Darcian assumptions (eg Freeze and Cherry 1979, pp. 69-75). Groundwater flows in the aquifer obey

Darcy's Law (Equation 1) where Q is the groundwater flux in the aquifer $[L^3T^{-1}]$; K is the hydraulic conductivity of the aquifer $[LT^{-1}]$; i is the hydraulic gradient of the aquifer [dimensionless]; and, A is the cross-sectional area of the aquifer $[L^2]$.

$$Q = -KiA \qquad \textbf{Equation 1}$$

2. Loss of groundwater through evapotranspiration, ET [L] is approximated using the function described by Equation 2, where P is the potential evapotranspiration [L]; d_{gw} is the depth to groundwater [L]; d_{cap} is the depth limit of capillary action [L]; and, c is a factor [dimensionless] which determines the shape of decline in evapotranspiration with depth.

$$ET = P\left(1 - \frac{d_{gw}}{d_{cap}}\right)^c \quad \text{for} \quad d_{gw} \le d_{cap} \qquad \textbf{Equation 2(a)}$$

$$ET = 0 \quad \text{for} \quad d_{gw} > d_{cap} \qquad \textbf{Equation 2(b)}$$

3. River stages are determined through a discharge-stage function derived through regression of known river discharges at some point (eg SA border) against known or estimated river stages at the subject location. The assumption here is that the derived function is a reasonable representation of actual river stages.

4. Wetland depth, surface area and volume are approximated in the model through a depth-volume relationship and a surface area-volume relationship. These relationships are derived based on available bathymetric survey. The assumption is that these functions are a reasonable representation of wetland depth and surface area for a given wetland volume.

3.3 Model Data Requirements

The model requires the following data sets and input parameters to describe the river, floodplain and aquifer. Like any hydrologic model, *WaterCress* will give the best results when populated with accurate local data. However, where specific local data is not available, the model can be run using regional values and regional data sets.

1. Inflow hydrograph and river salinities. 'Flow to SA' coupled with daily read salinities at Locks represent the best available long-term data.
2. Discharge-stage relationship. Necessary to relate the inflow hydrograph to river levels at the wetland. If specific local data is not available then a relationship can be developed by interpolation between Lock levels. At present a polynomial of up to fourth-order, or a piecemeal (on two ranges) power function can be used.
3. Rainfall and evaporation data. Daily rainfall data is required. If daily evaporation data is not available, monthly data can be used.
4. A description of the river bathymetry. Cross section derived from existing digital terrain models or bathymetric surveys.
5. A relation between the wetland surface area-volume and surface area-depth. At present polynomials of up to fourth-order, or a piecemeal (on two ranges) power function can be used.

6. A description of floodplain topography. Cross section derived from existing digital terrain models or topographic maps.
7. Initial estimates of wetland salinity and volume. Precise values are not important, as the model will stabilise over several time-steps.
8. Details of the inlet/outlet channels and regulating structures. Dimensions and gradients.
9. Initial estimates of groundwater levels and salinities. Regional values can be used if local data is not available. Precise values are not important, as the model will stabilise over several time-steps.

4. MODEL EVALUATION

Lake Merreti was considered for a model trial, being one of the few managed wetlands with any available water level, EC, and bathymetry data available. (Murdoch et al. 2005). A piezometer network around the Lake also meant that the local groundwater gradient and groundwater salinities could be estimated.

4.1 Calibration Review

The model was populated with the most appropriate and available climatic data (Table 4.1) and run over a 25-year period from 1975 to 2000 (the MDBC benchmark period). Calibration data was only available over a considerably shorter period (refer Table 4.2).

Bathymetric survey of the lake was obtained courtesy of SAWC (Carpenter, G. 2005, pers. comm., 11 May) and processed in ArcGIS™ to derive the necessary depth-volume and surface area-volume relationships.

Table 4.1: River and climatic data sets used in the model.

Parameter	Data Source	Recording Frequency
River flow	A4261001 Calculated Flow to SA	Daily calculation
River salinity	AW426512 River Murray at Lock 5 US	Daily read
Rainfall	M024016 Renmark BoM Meteorological Station	Daily read
Evaporation	AW426904 Lake Victoria Meteorological Station	Daily read

Table 4.2: Lake Merreti calibration data sets used in the model.

Parameter	Period of Record	Recording Frequency	Remarks
Surface water level	February 1981 to September 1996	Random	Probably contains isolated erroneous readings
	September 1996 to February 2004	Continuous	Some missing periods
Surface water EC	February 1981 to January 1987	Random	Probably contains isolated erroneous readings
Groundwater level	July 1995 to March 2005	Continuous	Some missing periods

The model responds to influxes quite well (see Figure 4.1), although underestimates peaks slightly. This is probably due to the mathematical functions used to describe flow through the inlets and outlets. As the river approaches bank-full discharge, regulating structures drown out and inlet channels begin to break out. The respective hydraulic formulae for structures and open channel flow will underestimate the volume of water passing to the wetland. The planned inclusion of a 'rating table' type inlet/outlet in the model should address this issue (see Section 5.1.4).

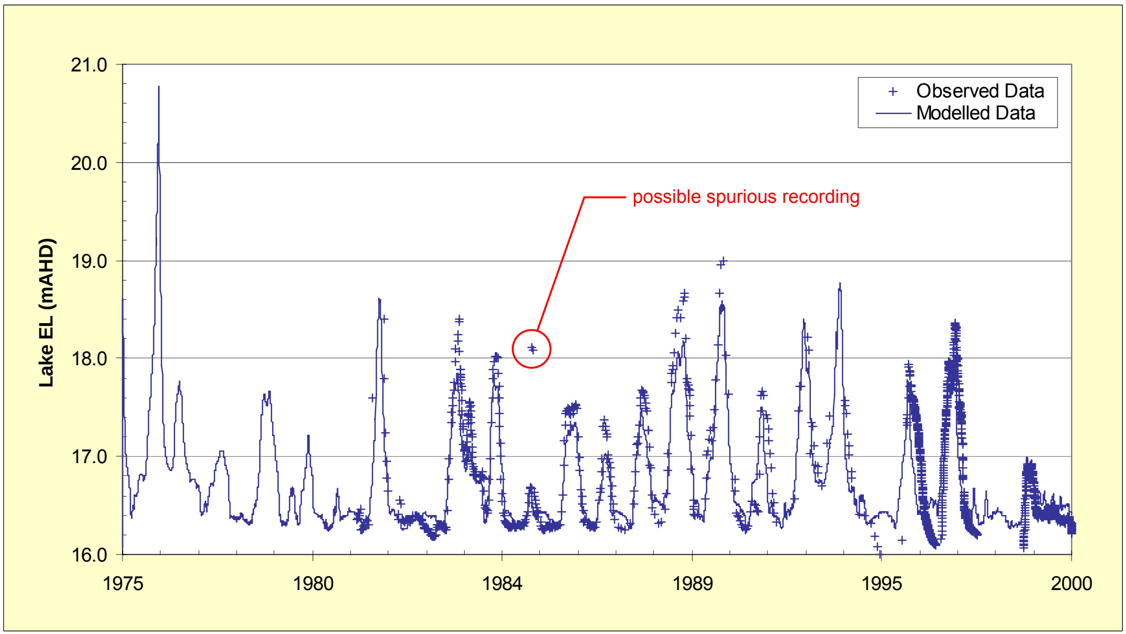


Figure 4.1: *WaterCress* calibration for Lake Merreti water level, 1975 to 2000.

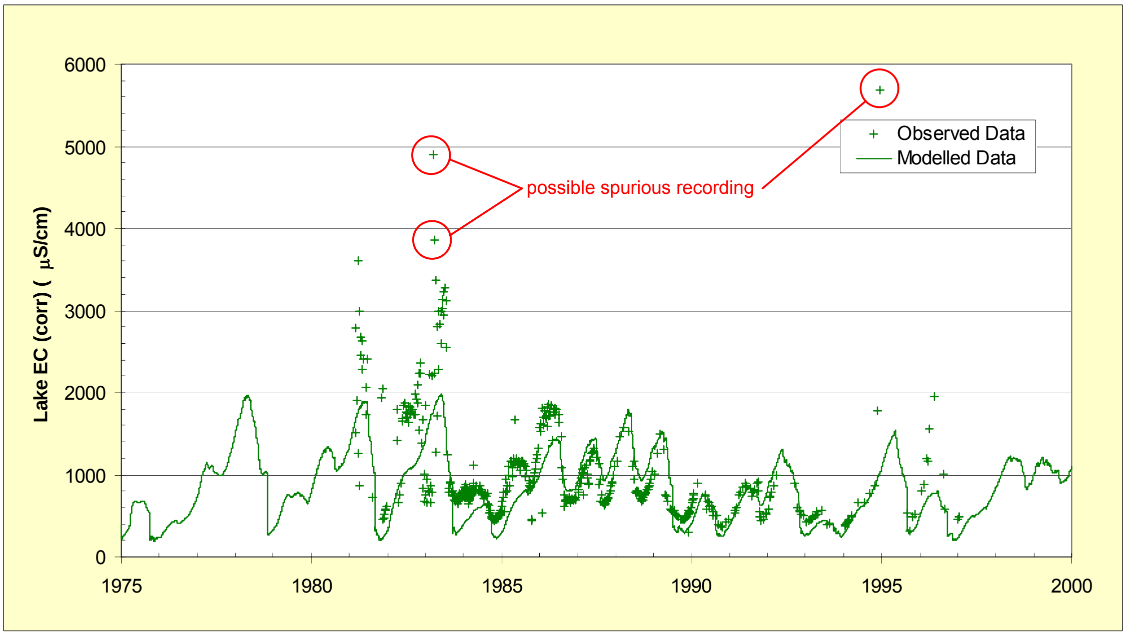


Figure 4.2: *WaterCress* calibration for Lake Merreti EC, 1975 to 2000.

It is worth noting that Murdoch et al. (2005) had reason to suspect a surveying error in observed water level data of some 150 mm, and adjusted observed data down by this amount. If a similar adjustment were applied here, then the apparent discrepancy between observed and modelled Lake levels would be less significant.

At lower Lake levels some departure is evident in the modelled data from the observed data. Since 1983, when the regulator was built on the main inlet, the Lake has been subject to regulation (Steggles and Tucker 2003). While Steggles and Tucker have summarised the history of management actions, the monitoring and recording of regulator operation have not been adequate to allow replication in the model, and this is almost certainly responsible for much of this apparent discrepancy.

The modelled EC data generally shows good agreement with observed data (Figure 4.2), although there are isolated clusters of high EC values in the observed data that the model does not adequately replicate, notably in the period 1981 to 1984 (Figure 4.3). These clusters of high EC values approximately correspond with or immediately follow periods of very low lake level. Since it is not known how this EC data was collected, it is possible that the operator was measuring brackish waters located in isolated pools.

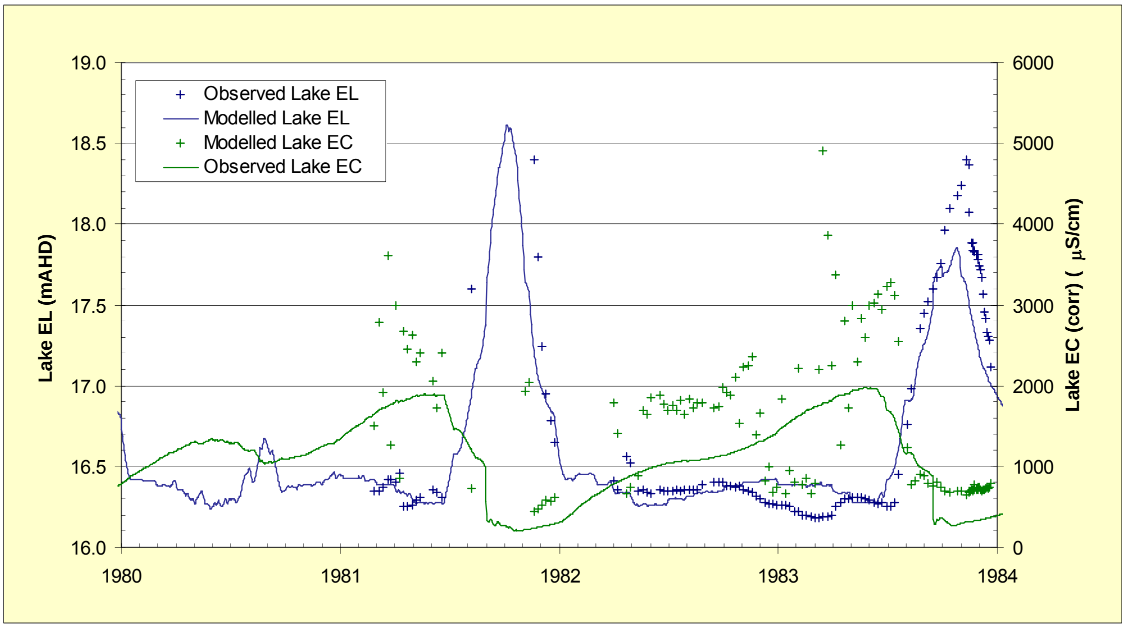


Figure 4.3: Comparison of Lake Merreti water level (modelled and observed) and EC (modelled and observed) for the period 1980 to 1984.

5. DISCUSSION

Comments made by Murdoch et al. (2005) concerning the dearth of appropriate hydrometric and bathymetric data, inconsistencies in the recording of operational management decisions, and complexities in modelling River Murray wetlands remain pertinent. These complexities make calibration difficult to achieve. If the model is not calibrated, then the results should only be used with clear qualification.

5.1 Model Strengths

While the model was written with application to the SA MDB in mind, it is sufficiently generic that a skilled modeller could adapt it to other river systems characterised by wetlands on broad, flat floodplains.

Unlike other models broadly used in the same context (see Section 2.1), the model operates in a transient mode and is location specific.

The *WaterCress* platform addresses many of the specific limitations of the SIWM model that were identified by Murdoch et al. (2005). These are discussed in the ensuing sections.

5.1.1 PLATFORM

WaterCress is coded in the C++ language and will run on any PC using a 32-bit Windows operating system (Microsoft Windows™ 95/98/Me/NT/2000/XP). *WaterCress* runs from a single executable file (ie it does not require a third-party platform). Twenty-five years of simulation can be rapidly executed in less than one minute, easily facilitating numerous model runs during calibration and scenario testing.

5.1.2 OVERBANK FLOWS

A specific weakness of SIWM was its inability to replicate wetland salinities during overbank flow events. This was in part due to its practice of 're-setting' wetland salinity to river salinity once over-bank flows occurred. That is, it assumed that wetland water was wholly ameliorated with river water through perfect and instantaneous mixing (Murdoch et al. 2005).

WaterCress overcomes this at least to some degree by allowing unregulated flows to the wetland through flood runners to gradually increase as river levels rise, prior to bank-full discharge and overtopping flows into the wetland.

5.1.3 BATHYMETRY

The coarse depth-volume and surface area-volume relationships of the SIWM model had insufficient resolution to accurately account for changes in water volume. *WaterCress* incorporates continuous functions to describe the depth-volume and surface area-volume relationships. The user has the flexibility to derive these functions using as much or as little information as may be available. Where detailed bathymetry exists, GIS techniques are particularly applicable.

5.1.4 REGULATING INFRASTRUCTURE

SIWM contained a number of hard-coded options for regulating structures in its input (weir, circular pipe and rectangular culvert) and the user selected the structure or structures that most closely resembled the actual inlet(s). While it is acknowledged that the intention was to make the model accessible to the non-technical user, in reality this has appeared to create confusion while still not adequately addressing the in-field reality of arrays of structures operated independently (Murdoch et al. 2005).

WaterCress uses a generic power function to describe flow through inlets. While inevitably this requires more skill on the part of the modeller, it is inherently more flexible and can be manipulated to account for in-field anomalies.

Preliminary testing has highlighted that estimating flows through regulating structures using hydraulic formulae leads to inaccuracies when assumptions implicit in their derivation do not hold (eg under drowned conditions). Inclusion of a ‘rating table’ option to describe inflows will allow observed behaviour to be accurately replicated in the model

5.1.5 WETLANDS BELOW LOCK 1

Rather than relying on backwater curves to convert river discharge to stage, *WaterCress* uses a flow-depth relationship. This method is able to make better use of measured water level data available at numerous sites below Lock 1 and indeed elsewhere along the length of the River, as the modeller has the flexibility to select water level data that best represents the subject reach.

5.1.6 GROUNDWATER INTERACTIONS

SIWM characterised the connectivity between the groundwater and wetland as good, low or nil. This necessarily simplistic approach failed to adequately address groundwater processes between the wetland and the river. Based on advice from the then KID Groundwater Group, *WaterCress* implements a traditional groundwater slice model which provides greater flexibility in modelling more complex groundwater processes.

5.1.7 CLIMATIC DATA

Climatic data used in the SIWM model consists of a single, regional data set. While the intention here was to limit the complexity of the model for the benefit of non-technical users, climatic data can vary significantly across the region, leading to substantial and avoidable inaccuracies.

WaterCress requires the modeller to input climatic data and therefore offers the flexibility to use the best available climatic data.

5.1.8 OPERATING RULES

SIWM was limited in its model input for wetland management (operation of control structures) to annual cyclic combinations (Murdoch et al. 2005). *WaterCress* allows up to six *management plans* to be defined. Each management plan has a recurrence interval and incorporates up to three stages. Actions available in each stage consist of: direct connection to the river; filling and releasing on falling river (post flood); filling and retaining on falling river (post flood); isolation from the river; pumping in or out of the wetland; or no action.

Although the management options were not used in this evaluation, due to a paucity of operational data (see Section 4.1), the combination of management plans, management stages and actions represents a potentially powerful means of reproducing actual or proposed management regimes.

5.2 Model Limitations

Models such as these require significant user knowledge to ensure that results generated are meaningful and are interpreted appropriately. SIWM attempted to simplify modelling inputs for the non-technical user by prescribing an array of inlet options, simplifying representation of physical processes, and specifying default values for many model parameters. *WaterCress* uses fewer and more generic functions which allow the modeller greater flexibility but consequently require a higher degree of technical knowledge to ensure results are beneficial.

5.3 Monitoring

The dynamics of salt and water movement within and across floodplains are complex and not easily quantified. Results from the *WaterCress* will not be able to be verified if no suitably accurate data exists and at no time will this or any other model negate the need for accurate monitoring.

Catchment Water Management Board baseline data collection programmes apparently are not targeted towards any specific assessment process. Adoption of a modelling approach such as *WaterCress* across a large system such as SA MDB wetlands will serve to inform and target monitoring.

5.3.1 CALIBRATION DATA

If outputs from the model are to be used with confidence then the model must be calibrated. Measuring discharges through inlets is difficult, and rating structures by manual gauging is resource intensive. Water levels (and salinities) on the other hand can be continuously monitored easily and cheaply. Data sets of wetland water level and salinity (from a representative location) provide excellent calibration data sets with which to calibrate a *River/Floodplain node.*

5.3.2 INPUT DATA

The input data sets required by the model are described in Section 3.3. In terms of input data, the model would benefit most from improvements in river discharge and river stage data sets. Despite questions concerning the accuracy of A4261001 ‘Calculated Flow to SA’ (Stace and Greenwood 2004, pp. 10-13), A4261001 probably represents the most consistent discharge data set for hydrological monitoring. Operational recordings of river discharge at Locks often lack the veracity required for hydrological assessment. Lock rating reviews and operational methodologies for recording discharge need to be clarified with SA Water Corporation.

Monitoring at a greater number of sites adjacent to the wetlands of interest could improve records of river stage and salinity. While numerous new continuous water level and monitoring sites have been installed in recent years as part of project funded initiatives, these sites lack the long-term period of record required for longer model runs. This situation will continue to improve as periods of record grow.

6. CONCLUSIONS & RECOMMENDATIONS

This evaluation has described the groundwater slice model that has been incorporated in the *WaterCress* platform. Salt and water movement through and across a floodplain is an inherently complex process. While the model is underpinned by robust and widely accepted science, it must be remembered that the model *is simple* and limitations do inevitably arise in using a simple water balance to model a complex system. The model does differ from others broadly used in the same context in that it represents physical processes in one location, rather than across a region, and handles transient rather than steady-state fluxes.

Like any hydrologic model, the quality of model outputs is intimately related to the quality of model inputs. If the outputs from the model are to be relied upon, the model must be calibrated against accurate and reliable data.

This evaluation, although limited to one wetland system, has demonstrated that the model is able to replicate fluxes and salinities reasonably well. Nevertheless the model should continue to be developed and improved as new information becomes available, and as experience highlights model deficiencies. Experience gained from this evaluation has identified the need for a 'rating table' type inlet/outlet, and an option for 'table' type entry of wetland bathymetry data (in contrast to 'function' type entry).

Recommendation 1

Changes should be made to the model to incorporate:

1.1) a 'rating table' type inlet/outlet;

1.2) 'table' type entry of bathymetric data.

This evaluation and others (eg Murdoch et. al 2005) have highlighted the difficulties of replicating operating rules in models. Operating rules need to be elucidated and clearly articulated. This should occur as part of the Wetland Management Planning (WMP) process being managed in partnership with SPD. If operating rules are altered, or an alternative management regime undertaken, then this should be documented accordingly.

Recommendation 2

Wetland operating rules need to be elucidated and articulated so they can be appropriately replicated in the model. Operational decisions and exceptions to operating rules need to be accurately documented.

In order to ensure reliability of model outputs, the model needs to be calibrated. The majority of wetlands scheduled for interventionist management are devoid of any form of monitoring and recording of operational decisions. Adoption of a modelling approach such as this one should be used as an opportunity to inform and target monitoring programmes.

Recommendation 3

When devising monitoring programmes, wetland managers should give consideration to the need for monitoring programmes to inform modelling processes, and vice-versa.

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