Using wetland nutrient modelling to estimate River Murray and floodplain wetland water exchange

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Abstract: River water quality is substantially influenced by adjacent wetlands. The water exchange estimate is a step in the process of developing a model capable of simulating management strategies for wetlands of the Lower River Murray and their effect on nutrient load in the river. An expanded wetland process model was used to find the water exchange between wetlands, where there is a lack of channel morphology data and no measured wetland water turnover. This paper describes the development of the wetland ecosystem model WETMOD to include spatial driving variables of the floodplain landscape. The added spatial driving variables for WETMOD are used to account for local variations and inflow into a wetland, particularly to reflect bi-directional water and nutrient exchange between the River Murray and the wetlands. The spatial driving variables are derived from a database containing site-specific flow and nutrient data from the river and wetlands. In order to simulate the water exchange between individual wetlands and the River Murray an *ad hoc* flux estimation technique was developed. This was based on a combination of the river flow volume and the wetland specific budget of phosphorus (PO_4-P) simulated by WETMOD. We demonstrate that it is possible to obtain the turnover volume of water in a wetland using nutrient modelling output.

Keywords: *Landscape Modelling; Lower River Murray; Floodplain Wetland, nutrient modelling, flow exchange modelling.*

1. INTRODUCTION

The wetlands of the lower River Murray have become increasingly degraded over the last century, particularly since the introduction of the river locks in the 1920’s. The wetlands are permanently inundated, while they would previously have experienced natural drying cycles. Through the management of some experimental wetlands by introduced drying cycles, the recovery of aquatic flora and fauna has been reinstated. Studies by van der Wielen (2001) have shown that dry periods lead to sediment consolidation and therefore reduced sediment resuspension. These wetlands have shown an improvement in water clarity (Recknagel et al., 1998, Recknagel and van der Wielen, 2001, van der Wielen, 2001).

Dissolved and particular inorganic nutrients such as phosphorus, nitrogen, and silica are a natural part of the water content in the river. In excess, these substances become pollutants and contribute to growth of phytoplankton and other aquatic plants (Shafron et al., 1990). Wetland processes and functions can buffer water quality for adjacent rivers and tributaries, through accumulation of nutrient and trapping of sediment (Mitsch, 2000, Johnston, 1991, Boon, 1998).

Based on existing knowledge, Cetin et al. (2001) created the model WETMOD capable of simulation scenarios of management drying cycles for selected wetlands. The wetland model concentrates on internal wetland processes and the simulation of monitored data. The purpose of this model is to simulate macrophytes, phytoplankton, zooplankton and nutrients, in the open water of wetlands.

Many floodplain wetlands of the Lower River Murray (Figure 1) are highly degraded. In order to study the potential effect of wetland restoration through drying and wetting a modified version of the WETMOD model was developed.

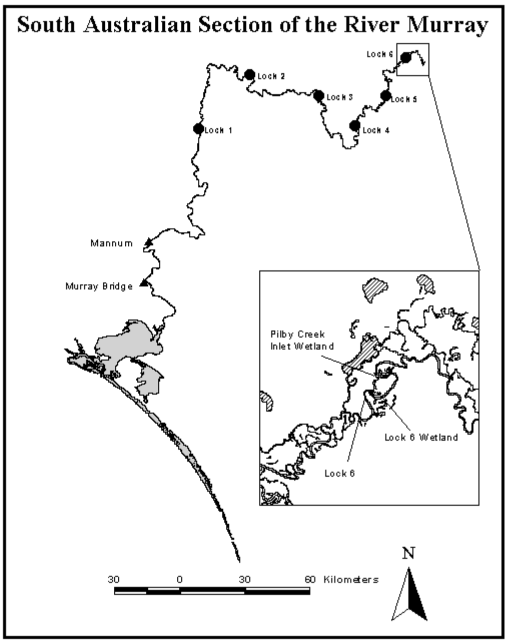

Figure 1. Study Area.

The transport of material, including nutrient, in and out of wetlands is primarily a function of water flow (Johnston, 1991). Since the regulation of the Lower River Murray through the creation of locks the river has lost its original seasonal fluctuation. The locks are maintained at constant levels effectively permanently inundating previously seasonally dry wetlands. As the considered wetlands are these permanently inundated wetlands, it is deemed justifiable to assume that as a result of lock management all wetlands included in potential management scenarios have a constant volume as well as a permanent connection with the River Murray. As a consequence there is a bi-directional and permanent exchange of water and nutrient with the river, the exchange volumes (in- and out-flow) being equal. We also assumed that the exchange volume was solely dependent on the river flow volume. We assumed the wetland nutrient data to be homogeneously mixed throughout the wetland for each modelling time step.

2. METHODOLOGY

2.1. Model Description

The WETMOD model (Cetin et al. 2001) is a generic wetland ecosystem model. WETMOD simulates internal wetland nutrient processes using water temperature, turbidity, secchi depth and solar radiation as driving variables. Phosphorus (PO_4-P), nitrogen (NO_3-N) macrophytes, phytoplankton and zooplankton are state variables.

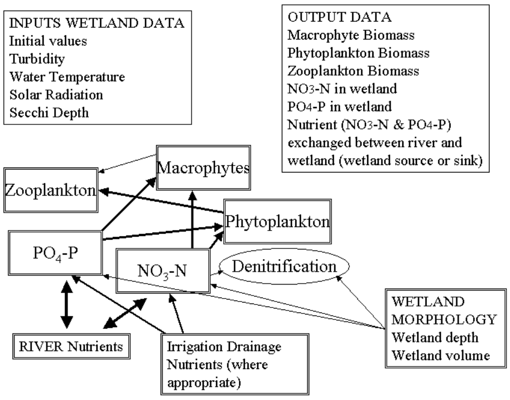

Figure 2. Model Structure of WETMOD

The model simulates the growth of macrophytes and phytoplankton. Nutrient contribution to the wetland occurs through sediment release, surface runoff, irrigation drainage and river inflow. Nutrient loss is simulated through uptake by macrophytes and phytoplankton as well as wetland outflow. A denitrification equation based on water temperature, wetland volume (derived from the depth * the volume) and wetland depth, adapted from Kallner and Wittgren (2001) and Arheimer and Wittgren (2002), was introduced into WETMOD to improve the estimation of nitrogen (paper in Preparation). The model structure is presented in Figure 2.

2.2. Exchange modelling

River concentrations of both NO_3-N and PO_4-P were generally higher than the concentration within the wetlands (Figure 3). Exceptions occurred where wetlands were influenced by irrigation drainage. This suggests that where there is an inflow of water from the river to the wetland, the river will act as a source of both NO_3-N and PO_4-P to the wetland, where wetlands are not directly influenced by irrigation drainage. If the wetland processes manage to take the nutrients up in macrophyte and phytoplankton growth, and these are retained within the wetland, the water outflow from the wetland into the river would contain lower nutrient concentrations. The wetland would therefore act as a nutrient sink. For wetlands with higher concentrations of nutrients than the river the wetlands may act as point sources of nutrients to the river

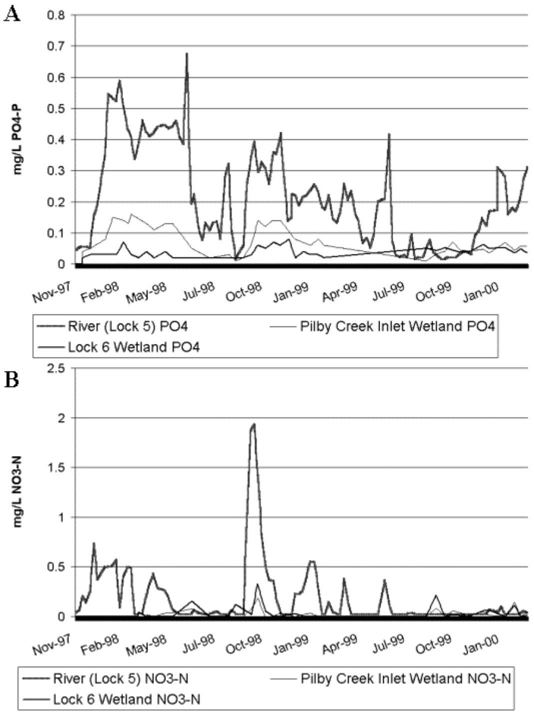

Figure 3. River V's Wetland, A: PO_4-P, B: NO_3-N

The bi-directional exchange between the wetland and the river $\frac{\Delta N_R}{\Delta t}$ [mg/day] is computed as

$$\frac{\Delta N_R}{\Delta t} = (C_R - C_W) \cdot f \cdot R \qquad (1)$$

with C_R and C_W denoting concentrations of nutrients in the River and wetland respectively and f being a fraction of river flow rate R [l/day]. Wetland water turnover rate τ [1/day] relates to the factor *f* as:

$$\tau = \frac{f \cdot R}{V_W} \qquad (2)$$

with *Vw* being the wetland volume.

The factor *f* quantifies in a simple way, how the wetland is connected to the river. It summarises the complex morphology of linkage of wetlands and the River through channels, topographic conditions and distance for example.

The factor f is varied and the model performance with respect to PO_4-P & NO_3-N is tested. As the evaluation criterion *D* (equation. 3) we used the average linear deviation from the measured values as a fraction of the average observed values. This avoids over-representation of errors at peaks as this would be the case by using squared error estimates.

The index *D* is derived as

$$D = \frac{\sum(ABS(M - E))}{\sum E} \qquad (3)$$

with *M* being the modelled and *E* measured or expected PO_4-P or NO3-N values at the monitoring dates, respectively.

The method used in assessing the NO_3-N concentration used was a colorimetric method (Cadmium Reduction Method). Colorimetric methods require an optically clear sample as the turbidity of a sample can conflict with the colorimetric measurement (Greenberg et al. 1992). After discussions with van der Wielen (van der Wielen pers. comm.), we considered it likely that the very turbid waters of the River Murray wetlands sampled compromised the monitored NO3-N values. Therefore we focused on PO_4-P for the estimation of water and nutrient exchange. We considered a *D* of less than 40% significant improvement to the modelling results. The best scenario below this 40% target is assumed to represent the best estimate of water and nutrient exchange volumes. Despite focusing on PO_4-P, results for both phosphorus and nitrogen are presented in the paper.

2.3. Data Sources

A number of sources have contributed monitoring data to this project. River flow data collected by the Murray Darling Basin Commission (MDBC) is collected at all locks. The River Murray nutrient data (Table 1) was provided by the Department of Environment and Heritage South Australia (DEH), being a collection of data obtained from the Environmental Protection Agency (EPA), the MDBC and South Australian Department of Water (SA Water).

Planning SA provided GIS data covering the wetlands, Locks and the River Murray. Wetland Care Australia provided the Wetlands Management Study report 1998 (Nichols, 1998).

Table 1. Data, Sources, Type & Monitoring Frequency

Source	Data Type	Monitoring Frequency	DATA Included
University of Adelaide	Wetland (water quality)	Fortnightly	NO_3, PO_4, Turbidity, Temperature, Chl-a & Secchi depth
Monitoring	Drainage inflow	Fortnightly	
	River	Fortnightly	
DEH	River Monitoring	Weekly	Temperature & Turbidity
		Fortnightly	Chl-a,
		Monthly	PO_4 & NO_3
MDBC	River Flow Volume	Daily	Water Flow

Wen (2002), Marsh (1997), Bartsch (1997) and van der Wielen (pers. comm.) have collected a substantial quantity of water quality data for some the wetlands of the Lower River Murray.

In this paper only two of the monitored wetlands are presented (Figure 1), neither of these being affected by direct irrigation drainage.

3. RESULTS

For the initial scenarios, it was assumed there was no exchange of water and nutrient between the wetlands and the river. The model output of PO_4-P and NO_3-N for Lock 6 wetland deviated from the monitored values, by 48% and 100% respectively. The model output of PO_4-P and NO_3-N for Pilby Creek Inlet wetland deviated from the monitored values, by 81% and 92% respectively. Seasonality was modelled for Lock 6 Wetland PO_4-P (Figure 4A) and NO_3-N (Figure 4B). At the zero water and nutrient flow exchange scenario there was not as an apparent PO_4-P seasonality modelled in Pilby Creek Inlet Wetland as was expected (Figure 5A). However, NO_3-N does show some seasonality (Figure 5B).

When scenarios using bi-directional water and nutrient exchange were implemented, D improved (Tables 2 &3). The Lock 6 Wetland obtained a 38% *D* for PO_4-P, at 0.03% river flow volume used as an exchange volume, which is equal to 1.26% of the wetland volume. The NO_3-N *D* at Lock 6 wetland was 103%. The Pilby Creek Inlet Wetland PO_4-P modelled values improved from 81% to a 37% deviation of modelled values from monitored data for PO_4-P at a bi-directional exchange volume of 0.09 of the river flow volume, equal to 6.9% of the wetland volume. The NO_3-N *D* showed a poorer modelling performance at 124%.

Table 2. Exchanged River Flow volume and resulting % deviation (*D*) of modelled values from measured values for Lock 6 Wetland.

f (%) (see eqn. 2, River Volume Exchanged)	*D* P % Deviation From Monitored Values	*D* N % Deviation From Monitored Values	τ (%/day) (see eqn 2, Wetland water turnover)
0	48.3	100.9	0.0
0.01	42.0	101.9	0.4
0.02	38.9	102.8	0.8
0.03	38.7	103.7	1.3
0.04	41.5	104.8	1.7
0.05	44.4	105.9	2.1
0.1	62.2	111.2	4.2
1	279.0	134.9	42.3

Table 3. Exchanged River Flow volume and resulting % deviation (*D*) of modelled values from measured values for Pilby Creek Inlet Wetland.

f (%) (see eqn. 2, River Volume Exchanged)	*D* P % Deviation From Monitored Values	*D* N % Deviation From Monitored Values	τ (%/day) (see eqn 2, Wetland water turnover)
0.00	81.8	92.4	0.0
0.03	56.4	89.8	2.3
0.05	44.9	93.9	3.9
0.07	38.3	109.0	5.4
0.08	37.4	116.6	6.2
0.09	37.1	124.0	6.9
0.10	37.4	131.1	7.7
0.11	37.9	138.1	8.5
0.20	49.0	191.6	15.4
0.30	64.5	204.9	23.1
1.00	120.0	109.4	77.1
2.00	134.8	134.8	154.2

Lock 6 wetland modelled PO_4-P output, which had a good seasonality even during no exchange simulation, improves to include some of the fluctuations noticed in the examination of monitored values (Figure 4A). Even the NO3-N shows a slight improvement (Nov 98, Figure 4B). The seasonality not evident in the original scenario for Pilby Creek Inlet Wetland PO4-P develops with the introduction of bi-directional water and nutrient exchange with the river (Figure 5A). The seasonality of NO3-N also improves (Figure 5B).

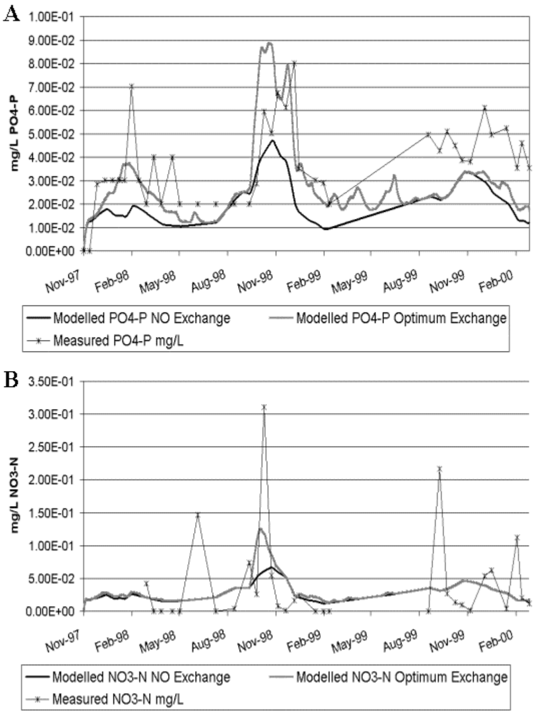

Figure 4. Measured v's Modelled Nutrient: Lock 6 Wetland.

The net uptake of nutrients during bi-directional water and nutrient exchange by the two wetlands is presented in Table 4. The net uptake of PO4-P by the Lock 6 Wetland is calculated at 312kg/annum, and NO4-N at 521kg/annum. Pilby Creek Inlet Wetland accounts for a PO4-P uptake of 454kg/annum and NO3-N uptake of 874kg/annum.

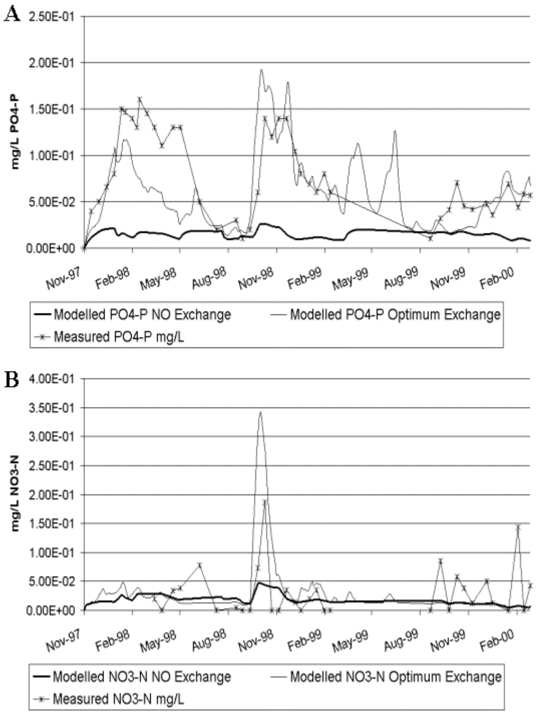

Figure 5. Measured v's Modelled Nutrient: Pilby Creek Inlet Wetland.

Table 4. Uptake of nutrients by wetlands (Nutrient Balance (NB)).

	Average net Loading kg			
	PO4-P to wetland per day	PO4-P to wetland per annum	NO3-N to wetland per day	NO3-N to wetland per annum
Lock 6 Wetland	0.37	312	0.62	521
Pilby Creek Inlet Wetland	0.54	454	1.03	874

4. DISCUSSION

The continued development of the wetland based process model WETMOD has produced a model capable of simulating the effects that wetland processes have on the nutrient content of bi-directional water exchange. Using this modelling capability, a simulation of the change in bi-directional nutrient exchange after the introduction of wetland management (restoration through drying cycles) was performed.

The introduction of river exchange to the model resulted in an improvement in modelled PO_4-P (Tables 2 & 3). However the NO_3-N modelling performance actually declined (Tables 2 & 3). As discussed the NO_3-N wetland monitored values are not as reliable as the PO_4-P. The NO_3-N modelling results were found to be consistently poorer that that of PO_4-P. Besides the described measurement error, another factor affecting the prediction of NO_3-N is the higher variability of NO_3-N than PO_4-P within a wetlands system, which cannot be accounted for in a simplistic model such as WETMOD. That said WETMOD however, fulfilled and improved on one of its objectives of modelling seasonal NO3-N nutrient load within a wetland, as can be seen in the comparison of modelled NO_3-N values for both scenarios, with no exchange as well as with bi-directional exchange, (Nov 98, Figure 4B & Nov 98, Figure 5B). Although the NO3-N modelling was not considered in deriving the bi-directional water exchange, it performed well enough to be considered in management scenario modelling.

Using the best scenarios obtained based on PO_4-P *D* an estimation of the bi-directional water exchange volume as well as the bi-directional nutrient volume exchange was obtained. The balance of nutrients exchanged between the river and wetland can be used to estimate the effects that a wetland (both prior to and post restoration) has on nutrient exchange with the River Murray. As seen in Table 4, both these wetlands act as a sink of nutrients during a bi-directional exchange of water and nutrients with the river. Future modelling, including on management options, will give an estimate of the change in nutrient balance between the river and the restored wetland.

The improvement in the modelling of PO_4-P at Pilby Creek Inlet Wetland, with the inclusion of bi-directional river water and nutrient exchange is 44%. This improvement suggests the significance that river transport of nutrients in and out of wetlands can have on wetland nutrient content. This is further supported by the improvement of PO_4-P at Lock 6 Wetland (48% to 38% *D*). The River Murray seems to be a significant contributor of PO_4-P to the two-modelled wetlands (Figures 4A & 5A), and to some degree also a contributor of NO_3-N (Figures 4B & 5B).

5. ACKNOWLEDGEMENTS

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