WETMOD: A Generic Wetland Ecosystem Model for the Simulation of Floodplain Wetlands at the Lower River Murray (South Australia)

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Abstract: A generic wetland ecosystem model WETMOD has been developed based on the models Pat_GEM and SALMO. The current structure of WETMOD considers nutrient loadings, water temperature, turbidity, secchi depth and solar radiation as driving variables, and dissolved inorganic phosphorous and nitrogen, macrophytes, phytoplankton, and zooplankton as state variables. The model has been validated by means of data from one restored and four degraded wetlands which occur typically in the Lower Murray floodplains. In the context of a scenario analysis WETMOD realistically predicted the response of degraded wetlands to feasible restoration measures. Results have demonstrated that a generic wetland model can be developed for qualitatively different wetland ecosystems at the Lower River Murray and be used as a decision tool for wetland restoration.

***Key words*:** Wetland model WETMOD; Landscape model AQUALINK; Lower River Murray wetlands; Wetland restoration.

1. INTRODUCTION

In the past, wetlands were often thought of as wastelands but are now being acknowledged as important ecosystems providing the biosphere with invaluable service functions [Costanza et al., 1997]. The unique Lower River Murray wetlands in South Australia are seriously under threat by factors such as eutrophication, salinisation, invasion by exotic species or changed hydrology. Only an early implementation of appropriate restoration concepts promises recovery and survival of these wetlands [Middleton, 1999].

The aim of this study is to demonstrate how the use of dynamic wetland modelling contributes to the development of robust management strategies for the restoration of the Lower River Murray wetlands. The generic wetland ecosystem model WETMOD was constructed based on ecosystem interactions between macrophytes, phytoplankton, zooplankton, and dissolved inorganic nutrients in the open water. Processes between these ecological entities prove to be fundamental to wetland ecosystems and are prime targets in the restoration of degraded wetlands in the Lower River Murray region.

The model WETMOD has been calibrated and validated by means of data from Lower River Murray wetlands. Thus, data from the Pilby Creek wetland were used, which has been restored by annual temporary drying since 1996, as well as from the four degraded wetlands Lock 6, Sunnyside, Paiwalla and Reedy Creek. Each of these four wetlands is affected by permanent inundation as a result of the river flow regulation, but also by excess nutrients from agricultural drainage and high abundance of common carp (*Cyprinus carpio*). A scenario analysis was run by WETMOD to simulate restoration options for Reedy Creek and Lock 6 wetlands.

The suitability of WETMOD for conducting scenario analysis forms a prerequisite for its integration as a core unit model into the landscape model AQUALINK that is currently under construction. The simulation of habitat conditions for each single wetland before and after restoration scenarios will allow cumulative assessments of landscape-wide restoration policies for the Lower Murray floodplains.

2. METHODS

2.1 Data Sources

To run specific simulations the following input data were taken from wetland specific field data: water temperature, Secchi depth (measure of light penetration), turbidity and initial values for phytoplankton, nitrate and phosphate. Input data for solar radiation [Bowles et al., 1987] and water flow [Walker and Hillman, 1982] were not available from field data, so were taken from the literature.

The input data for Lock 6 and Pilby Creek wetlands were collected fortnightly in summer and monthly in winter in 1997 [Marsh, 1997]. The input data for Sunnyside and Paiwalla wetlands were collected fortnightly between January and September, 1997 [Bartsch, 1997]. While the input data for water temperature and turbidity of Reedy Creek wetland were collected fortnightly in summer and monthly in winter in 2000 [Wen, *unpbl data*], an estimated Secchi depth of 0.3m was applied to the simulations [Recknagel, *pers com*; Wen, *pers com*]. Simulation times corresponded with the time periods when samples were collected.

2.2 Model Design and Construction

WETMOD was built using the dynamic simulation software STELLA v.6 which has been widely applied in ecological modelling [Costanza and Gottlieb, 1998]. Mass balance models can be created through differential equations, which consider source and sink relationships typical of ecological systems.

WETMOD was developed based on the Patuxent Landscape Model (Pat_GEM) [Boumans et al., 2000] and the lake ecosystem model SALMO [Recknagel and Benndorf, 1982]. The current structure of WETMOD is diagrammatically represented in Figure 1. The model considers nutrient concentrations, light levels, turbidity and water temperatures as limiting factors for gross primary production of macrophytes and phytoplankton. Losses in biomass of the primary producers are driven by respiration and mortality where phytoplankton is additionally declined by sedimentation and zooplankton grazing. Growth of herbivorous zooplankton is driven by water temperature and phytoplankton biomass available for grazing. Zooplankton losses are simulated to occur through mortality and predation. Nutrient concentrations in the open water increase through loadings from surface runoff and the release of nutrients from bottom sediments. Nutrient losses from the open water are through nutrient uptake by macrophytes and phytoplankton, nutrient coprecipitation by soil particles during high turbidity events and nutrient transport by out fluxes from wetlands.

2.3 WETMOD Calibration and Validation

Calibration and validation of the wetland model was conducted for five wetlands, which are representative of typical wetlands occurring in the Lower River Murray region. Wetland specific data were applied to simulate outputs comparable with the measured data. While the generic model structure was maintained, only 6 site-specific constant parameters were calibrated to achieve a close fit to the measured data. A range for each calibrated parameter was obtained once the model was validated.

2.4 WETMOD Scenario Analysis

In order to test the suitability of the wetland model for decision support a scenario analysis was applied to the highly degraded Lock 6 and Reedy Creek wetlands, where data of the restored Pilby Creek wetland were used as a reference.

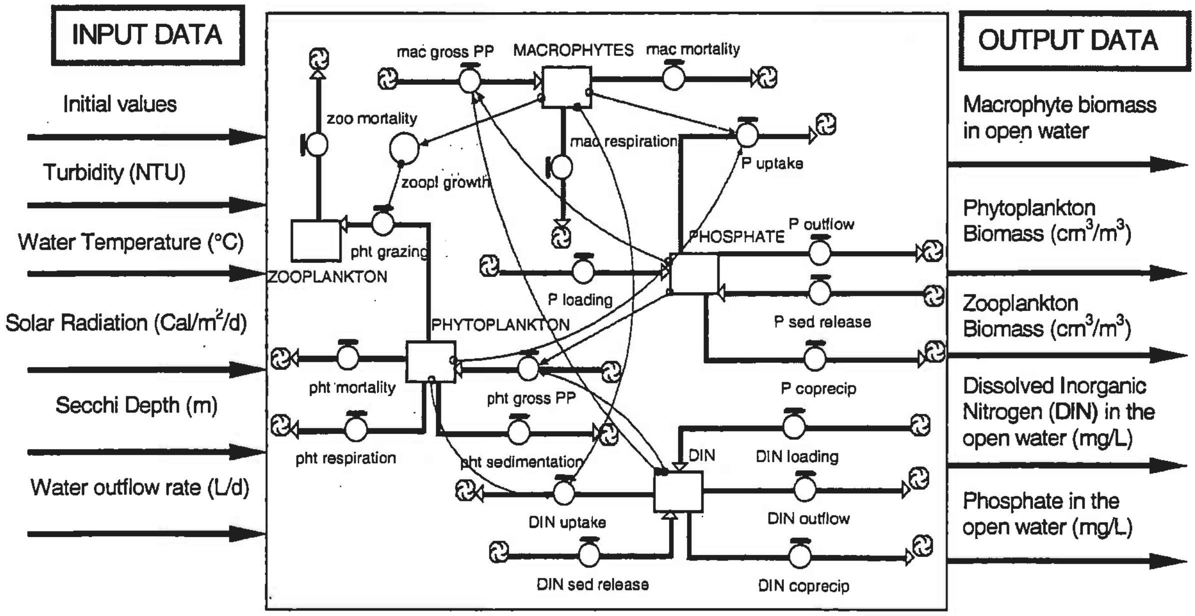


Figure 1. Structural diagram of WETMOD.

Scenarios for hypothetical restoration management included treatment of agricultural drainage water for nutrient reduction, carp barriers and drying-wetting cycles. Even though the simulated scenarios affected all state variables in the wetland model, only simulation results for macrophytes, phytoplankton, zooplankton and phosphate are presented in this paper.

Data in Table 1 summarise definitions of scenarios to be controlled by modified input data according to habitat conditions at Pilby Creek. Turbidity was altered as an indicator of carp activity, as WETMOD does not simulate carp population at this stage.

Table 1. Degrees of input changes controlling restoration scenarios for two degraded wetlands.

	Reedy Creek	Lock 6
Turbidity	- 25%	- 20%
Secchi depth	+ 25%	+ 30%
Phosphate loadings	- 19.3%	—
Nitrate loadings	- 19.3%	—

3. RESULTS

3.1 WETMOD Calibration Results

The wetland model was firstly calibrated based on data collected from the Pilby Creek wetland, used as a reference system, before it was applied and calibrated to the remaining 4 wetlands. Of the 26 constant parameters implemented within the wetland ecosystem model, 20 parameters were considered to be general and remained constant during the calibration and validation process. Only 6 parameters were shown to be wetland specific, which were subject to calibration for each wetland.

3.2 WETMOD Validation for Five Wetlands

The major focus of the model validations was to realistically achieve seasonality and a range of magnitudes for each state variable simulated by WETMOD. WETMOD predicted satisfactorily seasonal dynamics of phytoplankton and nutrients in the open water for all four wetlands. On average the magnitudes were simulated realistically over time, with observed trends in the decline and increase of phytoplankton biomass and nutrient concentrations clearly simulated (Figure 2).

3.2.1 Phosphate concentration

Phosphate concentrations were adequately simulated for each wetland by WETMOD. Timing and magnitudes of peaks in phosphate concentration were slightly compromised in most cases, with the timing delayed in simulations of the Paiwalla wetlands and the magnitude of the large peak in mid-July underestimated for the Sunnyside wetland (Figure 2a). Even though the phosphate peak as measured in the Reedy Creek wetland in March was simulated correctly, the large peak in mid-July was not predicted adequately. Simulation results for phosphate in the Lock 6 and Pilby Creek wetlands were disappointing, with large overestimations in September for the Lock 6 wetland. Also, the sharp decline in phosphate concentration observed in the Pilby Creek wetland was not simulated adequately by WETMOD, even though the declining trend in phosphate concentration was simulated correctly (Figure 2a).

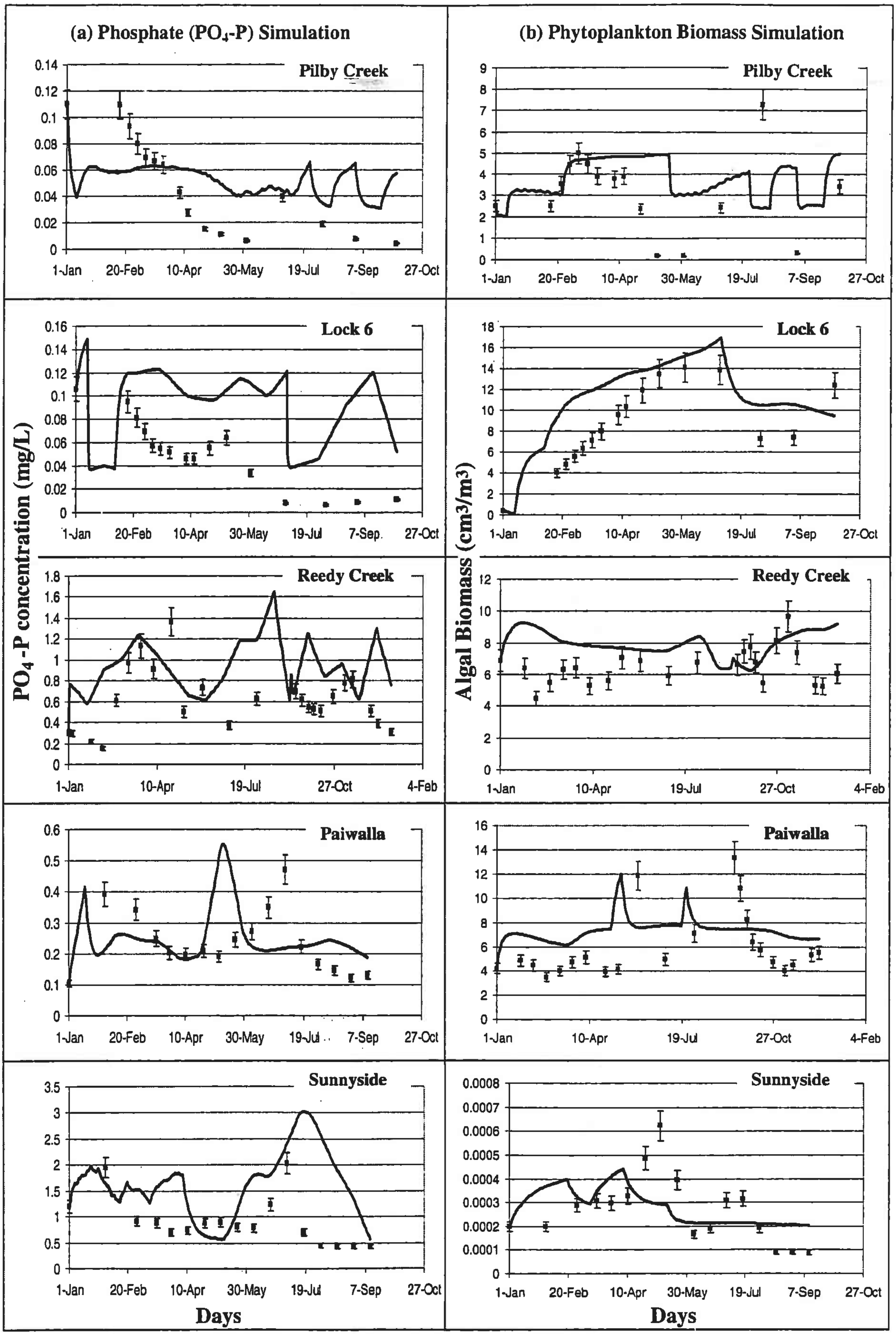
3.2.2 Phytoplankton biomass

WETMOD predictions of phytoplankton dynamics corresponded well with the measured data in most cases (Figure 2b), where best results were achieved for the Lock 6 wetland. Simulations of algal biomass for the Paiwalla and Sunnyside wetlands were slightly overestimated in both timing and magnitude. The measured phytoplankton biomass for Reedy Creek wetland was highly variable and a linear trend in seasonality was observed. Generally, WETMOD was able to simulate these conditions reasonably well, with the range in algal biomass magnitudes detected (Figure 2b). The measured data for Pilby Creek phytoplankton biomass was more difficult to simulate. The algal biomass trajectories for Pilby Creek wetland were closely predicted by WETMOD between January and April, but were overestimated for the remaining time period.

3.3 WETMOD Scenario Analysis Results

3.3.1 Scenario 1: Implementation of drying-wetting cycles and carp exclusion to Lock 6 wetland

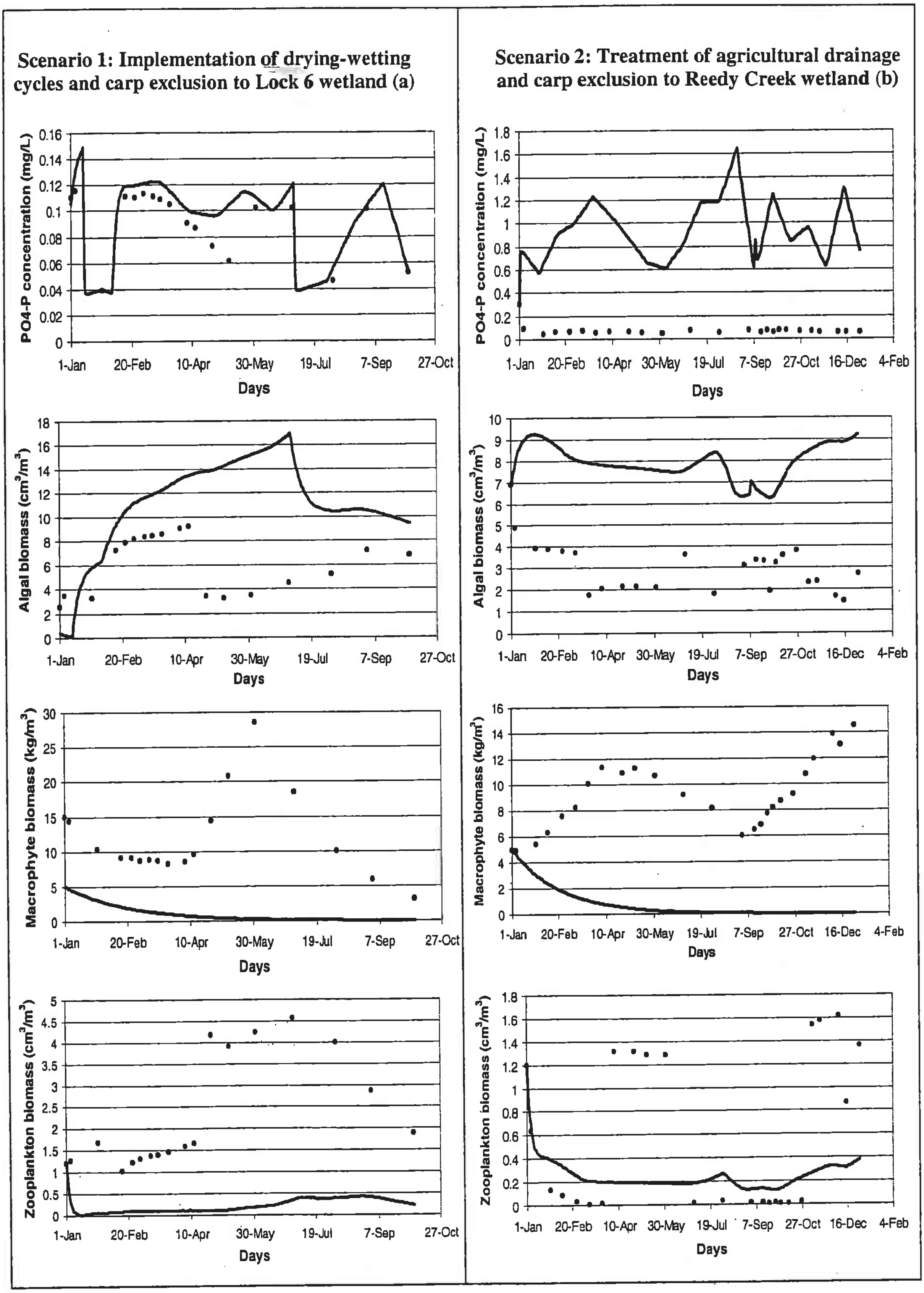
Improved water quality as simulated according to Table 1 has not greatly affected the phosphate concentrations, which is expected, however a sharp decline towards late May was predicted (Figure 3a). This temporary decline corresponds well with the increase in macrophyte biomass due to higher nutrient uptake and also a sharp decrease in phytoplankton biomass, suggesting increased macrophyte competition for nutrients. Zooplankton biomass increased to abundances greater than under degraded conditions, which increased the grazing pressure on phytoplankton. Scenario 1 demonstrates that an increase in the abundance of macrophytes and zooplankton may indicate the potential recovery of biodiversity for Lock 6 wetland. Water turbidity appeared to be the key driving variable for Scenario 1 in order to improve macrophyte and zooplankton abundances and inhibit phytoplankton growth.



(a) Phosphate (PO_4-P) Simulation

(b) Phytoplankton Biomass Simulation

Figure 2. Phosphate (a) and phytoplankton biomass (b) validation results for the five wetland data sets (1997 and 2000 for Reedy Creek). —— Simulated outputs; ▪ measured data. Bars indicate standard errors.



Scenario 1: Implementation of drying-wetting cycles and carp exclusion to Lock 6 wetland (a)

Scenario 2: Treatment of agricultural drainage and carp exclusion to Reedy Creek wetland (b)

Figure 3. Scenario analysis using WETMOD for the restoration of Lock 6 (a) and Reedy Creek (b) wetlands. — Degraded wetland simulations before implementation of management scenarios; • implementation of managed scenarios outcomes.

3.4.2 Scenario 2: Treatment of agricultural drainage and carp exclusion to Reedy Creek wetland

Phosphate concentrations in Reedy Creek wetland were lowered by approximately 50 % (Figure 3b) as a result of reductions in nutrient loadings by 20% and an improvement of light penetration by 25%. The reduction of turbidity stimulated the growth of macrophytes and consequently increased the abundance of zooplankton in the open water. As a result of both enhanced competition by plants and grazing by zooplankton, phytoplankton biomass decreased to approximately half of the magnitudes observed under degraded conditions (Figure 3b).

4. DISCUSSION

During this study a generic wetland ecosystem model was developed considering four ecological entities fundamental to wetland dynamics: macrophytes, phytoplankton, zooplankton, and nutrients. The validation of the current model version focused primarily on qualitative correctness of simulation results, before it will emphasise, in the next stage, on improvements of quantitative accuracy [Levins, 1966].

Validation results have shown that WETMOD realistically simulated trends of measured state trajectories of five qualitatively different wetlands. The improvements of quantitative accuracy of the model are essential for the next stage of model development.

Many ecosystem models are designed specifically to be used as decision making tools for ecosystem management [e.g. Recknagel et al., 1995; Hamilton and Schladow, 1997]. Such models allow scenario analysis for testing management options and predicting their effectiveness. The scenario analyses for Reedy Creek and Lock 6 wetlands, have demonstrated that WETMOD can accordingly be utilised as a decision making tool. As the scenario analysis results have indicated, external nutrient loadings and turbidity are key control variables to be explored for the restoration of the two wetlands.

WETMOD will be further developed towards a more complex wetland ecosystem model, simulating additional processes relevant to wetland dynamics such as interactions with bottom sediments and hydrology. In the future, WETMOD aims to become a core unit model for the Lower River Murray landscape model AQUALINK. It is designed to cumulatively assess restoration concepts for Lower Murray wetlands at landscape scale.

5. REFERENCES

Bartsch, D. L., Impact of irrigation drainage on Sunnyside Wetland: a comparative limnological study, Honours thesis, University of Adelaide, Adelaide, 1997.

Bowles, B. A., I. J. Powling, and B. F. Burns, Effects on Water Quality of Artificial Aeration and Desertification of Tarago Reservoir, Victoria, Murray-Darling Basin Ministerial Council. pp. 104, State Pollution Control Commission, Sydney, 1987.

Boumans, R. M., F. Villa, R. Costanza, A. Voinov, H. Voinov and T. Maxwell, Non Spatial Calibrations of a General Unit Model for Ecosystem Simulations, Special Issue for Ecological Modelling, to cover the International Conferences on Applications of Machine Learning. Adelaide, Australia, Nov 27 to Dec 1, 2001.

Costanza, R., and S. Gottlieb, Modelling ecological and economic systems with STELLA: Part II, *Ecological Modelling*, 112, 81-84, 1998.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, S. Naeem, K. Limburg, J. Paruelo, R. V. O'Neill, R. Raskin, P. Sutton and M. van der Belt, The value of the world's ecosystem services and natural capital, *Nature*, 387, 253-260, 1997.

Hamilton, D.P. and G.S. Schladow, Prediction of water quality in lakes and reservoirs. Part 2 - Model calibration, sensitivity analysis and applications, *Ecological Modelling*, 96, 91-110, 1997.

Levins, R., The strategy of model building in population ecology, *American Scientist*, 54, 421-431, 1966.

Marsh, F., A comparative study of the impacts of carp on phytoplankton and water quality in two Lower River Murray wetlands, Honours Thesis, University of Adelaide, Adelaide, 1997.

Middleton, B., *Wetland Restoration, Flood Pulsing and Disturbance Dynamics*, John Wiley & Sons, Inc., New York, 1999.

Recknagel, F. and J. Benndorf, Validation of the Ecological Simulation Model "SALMO", *International Revue of Hydrobiology*, 67, 113-125, 1982.

Recknagel, F., M. Hosomi, T. Fukushima and D.-S. Kong, Short- and long-term control of external and internal phosphorous loads in lakes: a scenario analysis, *Water Research*, 29, 7, 1767-1779, 1995.

Walker, K. F. and T. J. Hillman, Phosphorous and nitrogen loads in waters associated with the River Murray near Albury-Wodonga, and their effects on phytoplankton populations, *Australian Journal of Marine and Freshwater Research*, 33, 223-243, 1982.