Estimating Sediment and Nutrient Loads in Gippsland Lakes Catchments Using E2 Modelling Framework

[1,2]Kandel, D.D. and [2]R. M. Argent

[1]Murray-Darling Basin Commission, [2]The University of Melbourne, E-Mail: durga.kandel@mdbc.gov.au

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EXTENDED ABSTRACT

The deterioration of water quality in Gippsland Lakes, indicated by severe algal blooms, and influenced by the flow of nutrients from the Lakes catchments, has received increasing attention. For priority setting on appropriate management actions, a clear understanding is needed of spatial and temporal dynamics of sediment and nutrient fluxes in the catchments of Gippsland Lakes. A number of studies have been performed over recent years to investigate the sources and amounts of nutrient and sediment load entering the Gippsland Lakes (e.g. Grayson *et al.*, 2001; Grayson and Argent, 2002). Following the establishment of various targets for load reductions to the Gippsland Lakes, attention has now turned to assessment of amelioration and load reduction options. The work reported here is a part of a larger undertaking of DPI Victoria to quantify the impacts of selected 'Best Management Practices' on water quality in the Gippsland Lakes catchments, which uses Bayesian techniques to investigate the impact of grazing and fertiliser management on loads generated from irrigated and non-irrigated farmland.

This work builds upon an investigation using the CSS modelling system (Grayson and Argent, 2002) on flow and loads into Gippsland Lakes, and aimed to provide the capability required to support the catchment-scale assessment of the impacts of farm-scale management actions. To achieve this, the model structure and code base were updated using a new modelling system and two new component models, created for the Gippsland Lakes application, were developed. Flow and constituent loads (Total Suspended Solids (TSS), Total Phosphorous (TP) and Total Nitrogen (TN)) were simulated for the catchments of Gippsland Lakes using the E2 software, from the Catchment Modelling Toolkit (www.toolkit.net.au). E2 is a flexible catchment modelling software that supports construction of a range of models of different complexity using an approach built around selection and/or creation of particular component models.

In this case, the Gippsland Lakes E2 model runs on a monthly time-step using twenty years of data covering high, medium and low flow years. Stream discharge and water quality loads are simulated using historic climate data, land use, and management information. The sources of sediment and nutrient loads are identified. E2 provides the capability to have different component models for flow, constituent generation and filtering for each functional unit (FU). The FUs within each sub-catchment are identified according to land use, and monthly flow and constituent loads are calculated for each FU. The loads from FUs within each sub-catchment are lumped to form sub-catchment loads, which are then transferred downstream through a node-link structure.

Following Grayson and Argent (2002), model outputs are available for major catchments (Latrobe, Thomson/Macalister, Avon, Mitchell, Nicholson and Tambo), for Western catchments, for Eastern catchments, and for the "whole of Gippsland Lakes". As part of model testing, evaluation of results for specific sub-catchments as well as "whole of catchment" were undertaken. These results for major catchments of the Gippsland Lakes were compared with those of the CSS modelling system. Compared to the CSS model, E2 was generally found to be at least as robust or better. Long-term average annual loads were well predicted but there were many inconsistencies for months. Overall, the modelling results provide confidence that the model does capture the basic temporal and spatial variability of the system well. Point source data were not included in the E2 modelling reported here, as point source loads have changed significantly over recent years. Apart from this difference, the E2 system used similar data, timesteps and complexity and so has a similar level of certainty to the results of Grayson and Argent (2002). Their caution therefore continues to hold, i.e. the model should (therefore) be used for making *relative assessments* of the impact of various management actions to reduce *long-term average* nutrient and suspended loads.

1. INTRODUCTION

Water quality in Gippsland Lakes is being degraded by the influx of nutrient loads from its catchments. This has drawn increasing attention of the State government agencies and other stakeholders. For priority setting on appropriate management actions for optimal reduction of the severity and frequency of algal bloom in the Gippsland Lakes, a clear understanding of the sediment and nutrient dynamics within the Gippsland Lakes catchments is needed. Following the establishment of various targets for load reductions to the Gippsland Lakes, attention has now turned to assessment of amelioration and load reduction options. This requires a versatile tool to assess from where the sediment and nutrient loads to the Gippsland Lakes are coming, and the effectiveness of the paddock-scale management actions in altering the sediment and nutrient loads to the Gippsland Lakes. Provision of such modelling capability can be crucial for planning management interventions.

This study follows on from earlier Gippsland Lakes catchment modelling using the Catchment Simulation Shell (CSS) by Grayson and Argent (2002), which was primarily an expansion of the Latrobe River AEAM system model developed by Grayson et al. (1994). The work presented here is part of a broader project that uses Bayesian techniques to analyse the paddock-farm scale effects of adoption of best management practices for fertiliser application and animal management on dryland and irrigated farmland in the Gippsland Lakes catchments, focussing primarily on the Macalister Irrigation District.

This paper summarises the development of an E2 version of the CSS catchment model for the Gippsland Lakes, using the E2 modelling software, from the Catchment Modelling Toolkit (www.toolkit.net.au). E2 Modelling includes more spatial lumping than in the CSS model, greater flexibility in model choice and output visualisation. E2 is a node-link style modelling system, while CSS is a grid-based system. In E2, flow and constituents generated in sub-catchments are passed to a node before being routed and processed through a node-link system to the catchment outlet. The major components of the model in each sub-catchment are based on common response areas (called Functional Units), each of which has options related to the processes of runoff and constituent generation, and filtering. This provides a menu of different algorithms for each process in each sub-catchment, delivering the resulting flows and loads to the sub-catchment node.

The model is intended to get a "big-picture" view of major sources and to assist in providing relative estimates of the overall influence of possible management actions within the catchments, and does not involve any analysis of potential management scenarios. This paper describes the development and preliminary testing of the model, and summarises the current sources of loads on a catchment-by-catchment basis, including the relative contribution by each catchment to overall loads to the Gippsland Lakes. The model is limited to water quality (TSS, TP, TN) and river flows, and does not deal with ecohydrological response in either streams or lakes. The model uses historic climatic data, land use and management information to simulate stream discharge and water quality loads.

2. GIPPSLAND LAKES E2 MODEL

The Gippsland lakes E2 model divides the catchment into 24 sub-catchments (Figure 1), mainly based on the location of dams, reservoirs and gauging stations.

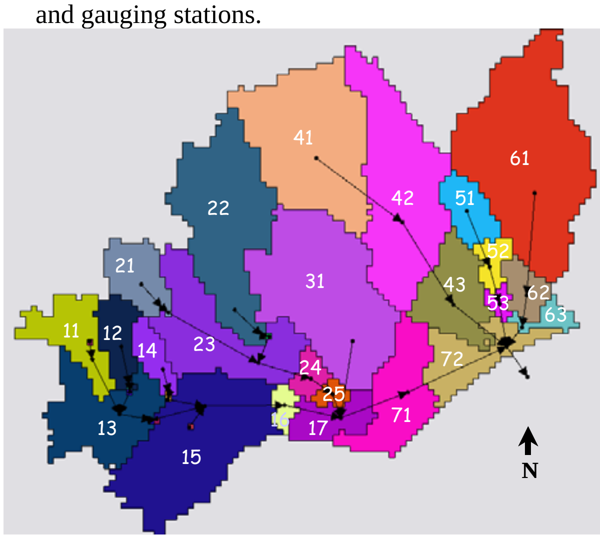


Figure 1. Node-link network and catchments of Gippsland Lakes in E2: Latrobe (subcatchments 11 to 17), Thomson/Macalister (21 to 25), Avon (31), Mitchell (41 to 43), Nicholson (51 to 53), and Tambo (61 to 63).

Spatially averaged monthly rainfall was calculated for each sub-catchment. Sub-catchments having similar rainfall patterns were combined into rainfall regions, with a total of 15 regions being used. Mean monthly raster maps of spatially distributed rainfall and monthly timeseries (Jan 1980 - Dec 1999) of point measurements from three base stations (Dargo, East Sale and Hotham) were used to calculate monthly timeseries of rainfall for each rainfall region. Monthly patterns of rainfall for eastern catchments (Tambo, Nicholson, Mitchell) were based on measurements at Dargo and those for western catchments (Latrobe, Thomson, Avon) were based on rainfall records from East Sale. Elevation effect on rain of high altitude areas was also considered. Rainfall for areas with elevation > 400 m and > 600 m was also weighted based on Hotham rainfall measurements. Similarly, five potential evapotranspiration (PET) regions were identified based on the dominant PET patterns in the monthly PET raster maps and spatially averaged monthly PET values were then calculated for each PET-region.

3. MODEL COMPONENTS

Simbuck model and constituent model are the two major components in E2 that were developed as part of the process of transferring the CSS Gippsland Lakes model structure into E2, and enhancing the model capability to support assessment of the whole of catchment impact of the outputs of the Bayesian modelling.

3.1. Simbuck Hydrology Model

SimBuck is a "simple bucket" conceptual rainfall-runoff model (Figure 2) derived from the earlier CSS model, described as follows:

$$Qflow = \begin{cases} SMS - SMSC & \\ 0 & SMS \le SMSC \end{cases} \tag{1}$$

$$Sflow = \beta \times SMS^{m} \tag{2}$$

$$ET = \begin{cases} Min(mxET, PET) & SMS > 0.7SMSC \\ mxET \dfrac{SMS}{0.7SMSC} & SMS \le 0.7SMSC \end{cases} \tag{3}$$

$$SMS_n = \begin{cases} SMS_{n-1} + Rain - ET - Qflow - SFlow \\ 0 \end{cases} \tag{4}$$

Where *Qflow/Sflow* = quick/slow flow, *SMS* = soil moisture store, *SMSC* = soil moisture store capacity, β = slow flow coefficient, *m* = non-linearity of slow flow component, *ET* = actual evapotranspiration, *mxET* = maximum vegetation ET, and *PET* = potential evapotranspiration. The quick and slow flows together give total runoff.

3.2. Gippsland Lakes Constituents Model

Constituent load was calculated based on mean concentration (MC), separately for slow flow and quick flow components as given below.

$$QflowConstituent = quickMC \times Qflow \tag{5}$$

$$SflowConstituent = slowMC \times Sflow \tag{6}$$

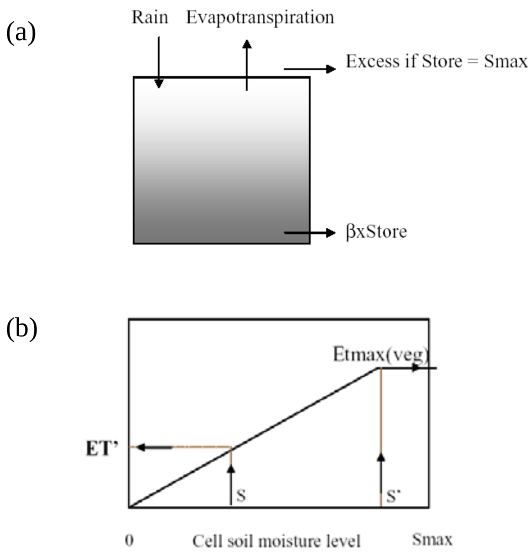


Figure 2. Water balance relationships: a. Simbuck hydrology model, b. Evapotranspiration model

A constant value of 3 mg/L for TSS, 0.3 mg/L for TN and 0.03 mg/L for TP were used in this preliminary development for *slowMC* (slow mean concentration). Quick mean concentration (*quickMC)* was calculated using a generalised constituent equation, given in Equation 7,

$$quickMC = TSS_{coef} \times quickTSSmc + TP_{coef} \times quickTPmc + TN_{coef} \times quickTNmc \tag{7}$$

where TSS_{coef}, TP_{coef} and TN_{coef} are the dummy variables to flag a particular constituent being calculated. For example, TSS_{coef} =1, TP_{coef} =0, TN_{coef} =0 gives quick mean concentration for TSS. TSS *quickMC* (*quickTSSmc*) was calculated as a power function of quick flow (Equation 8).

$$quickTSSmc = const1 + coef1 \times Qflow^{expo1} \tag{8}$$

Equation 8 can be generalised to directly use observed mean concentration by assigning *const1*=observed mean concentration and setting *coef1*=0. The quick mean concentration for TP (*quickTPmc*) was calculated as

$$quickTPmc = qMCbase + qMCgrazing + qMCfertilizer + coef2 \times quickTSSmc \tag{9}$$

where *qMCbase* = base mean concentration, *qMCgrazing* = contribution to mean concentration due to grazing, qMCfertilizer = contribution to mean concentration as a result of fertilizer application, and the last term with *coef2* is an additional concentration contributed by sediments, presented here as a proportion of TSS. To calculate the quick mean concentration for TN (*quickTNmc*), algorithm similar to Equation 9 was used but without the last term.

4. FLOW MODELLING

The hydrology and water quality components of the Gippsland Lakes catchments model were tested by comparing simulated flows and constituents with gauged data at various points in the Latrobe, Thomson, Avon, Mitchell, Nicholson and Tambo rivers, as well as with previously estimated total major catchment outflows. The main focus was on getting realistic 'whole of catchment' simulations, comparing the results of the CSS modelling study by Grayson and Argent (2002). Calibration was done by manually adjusting model parameter values to match the observed flows at sub-catchment level where possible. Model parameters were selected with the aim of capturing the basic variability and magnitude of flows and loads as well as ensuring similar or better long-term average flows and loads to those by Grayson and Argent (2002).

Note that the modelling approach used here is not overly complex, being at a scale to suit the problem and available resources, and model testing was done with limited information at large spatial scale. Thus absolute errors in flow estimates are likely to be significant - in the order of 20% in the long term annual mean values (Grayson *et al.*, 2001). It is recognised that there were difficulties and deficiencies in accurately accounting for regulated flows and loads, especially in Western catchments (mainly the Latrobe and Thomson), in which the model performed relatively poorly compared to Eastern catchments. It should be noted, however, that the E2 software system has an in-built flexible structure and the model sophistication can be improved if better information becomes available.

The flow modelling results are shown in Tables 1 and 2 for each major river separately and for Eastern and Western catchments as a whole. Table 1 shows the observed and predicted mean annual flows and percent contribution of Eastern and Western catchments to overall flow including their respective anomalies. Western catchments cover more than half of total area and contribute proportionately to the overall flow. The predicted mean annual flows for Western and Eastern catchments are consistent with the observed values but the predicted flows have slightly more annual variability than the observed flows.

The ratio of observed to simulated average annual flows for the Western and Eastern catchments as well as for individual rivers were within 5% of those recorded, except for the Thomson River, which is within 10% (see Table 2). These results are significant improvements over those of CSS modelling study of Grayson and Argent (2002), particularly for Eastern catchments.

Table 2. Ratio of observed to predicted average annual flow (ratio > 1 indicates underprediction)

Catchments	Area (km^2)	E2 model	CSS model
West	11000	1.04	1.01
East	8700	1.01	1.03
All	20000	1.03	1.02
Latrobe	4800	0.96	0.90
Thomson	3700	0.94	1.15
Avon	2400	1.02	1.03
Mitchell	5000	1.01	1.02
Nicholson	630	1.02	0.95
Tambo	3100	1.01	1.10

Scatter plots of annual observed versus measured flows and monthly time series of observed and predicted flows for the 20-year period are provided in Figure 3 and Figures 4-6 respectively for the Western, Eastern and All. Rainfall forcing in the rainfall-runoff model was obtained using three base stations (Dargo, East Sale & Hotham) spatially distributed from mean monthly patterns. Given the way in which rainfall is applied in the model, the annual flow results as shown in Figure 3 can be considered very good and indicate that the modelled flows are appropriate for the long-term average comparisons intended with the E2 modelling framework in this study.

Table 1. Observed and predicted mean annual flows, percent contribution of Eastern and Western catchments to overall flow and their respective anomalies (SD = Standard Deviation)

Catchments	Modelled flow, GL		Observed flow, GL	
	Mean ± SD	% Contribution	Mean ± SD	% Contribution
West (55 % of total area)	1400 ± 670	57 ± 12	1460 ± 660	58 ± 7
East (43.5 % of total area)	1030 ± 550	43 ± 12	1040 ± 480	42 ± 7
All (total area = 20,000 km^2)	2430 ± 1150	100	2500 ± 1100	100

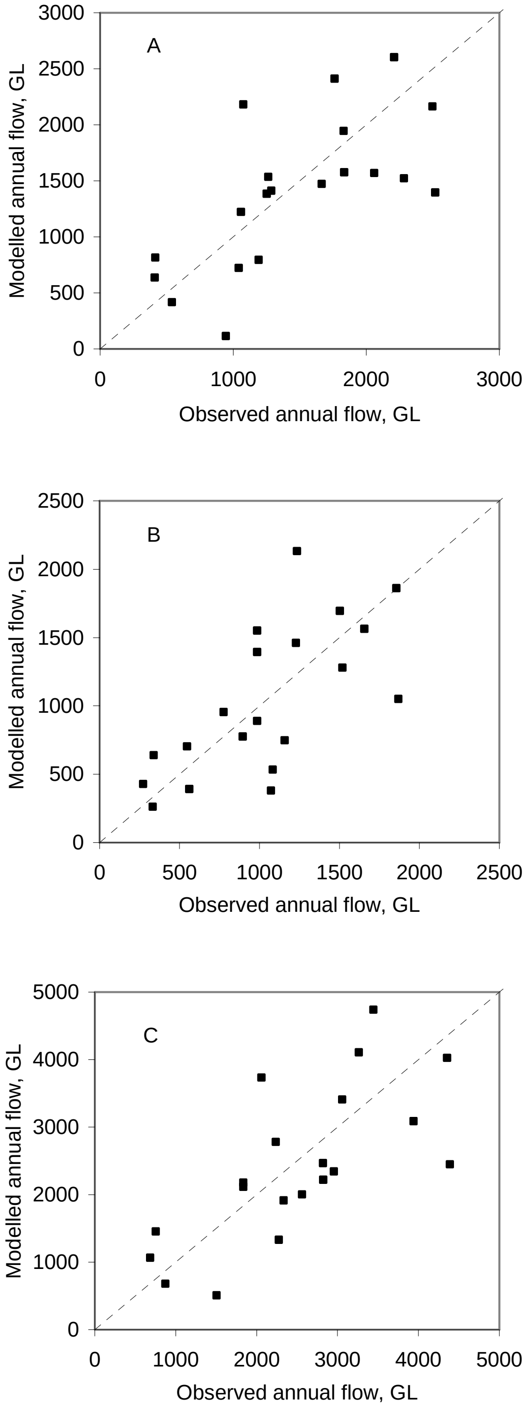


Figure 3. Annual observed versus predicted flows: A. *Western*, B. *Eastern*, C. *All* catchments.

In examining the monthly time series in Figures 4-6, the general magnitude and frequency of base and peak flows are captured well, however there are clearly some problems with peak flows in some months, particularly during the early months of simulation period. The monthly flow simulation in western catchments (Figure 4) is not as good as that in the eastern catchments (Figure 5). This is mainly due to higher levels of management intervention and regulation of flows in the west and the lack of accuracy in representation of diversions, extractions and storages in the model.

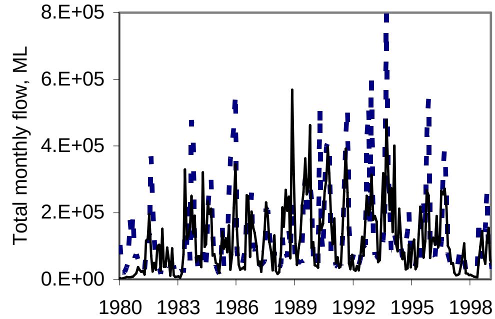


Figure 4. Observed (dashed) and predicted (solid) monthly flow – *Western catchments*

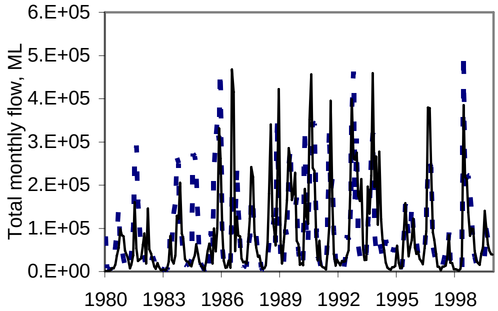


Figure 5. Observed (dashed) and predicted (solid) monthly flow – *Eastern catchments*

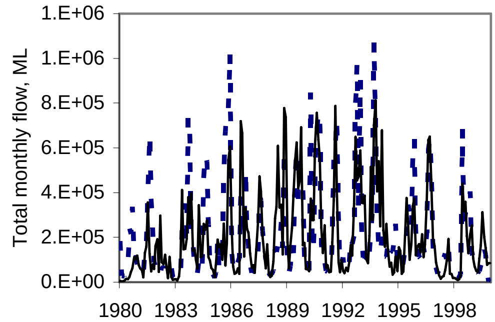


Figure 6. Observed (dashed) and predicted (solid) monthly flow – *All*

Therefore, the model should not be used for assessing behaviour in particular years or particular months at particular locations. Obviously, the rainfall data and runoff process are not representative for some particular months, where insufficient rain appears to fall on the catchments to produce the observed runoff (or vice versa).

5. CATCHMENT LOADS MODELLING

Load prediction was undertaken for the same sub-catchments as used for flow prediction. Model calibration was done by manually adjusting concentration values to match the observed loads at sub-catchment level where possible. Note the 'observed' values are those used by Grayson and Argent (2002), arising from the CSIRO study (Grayson *et al.*, 2001). Tables 3 and 4 provide the results of these estimations for the western, eastern, all areas, as well as for individual river basins. Point source data were not included in the E2 modelling reported here, as point source loads have changed significantly over recent years. However, this will not detract from use of the E2 model for comparative purposes.

Table 3. Ratio of observed to predicted average annual load: *E2 model* (ratio > 1 indicates underprediction and vice-versa)

Catchments	TSS	TP	TN
Western	0.94	1.07	1.19
Eastern	0.95	1.06	0.97
All	0.94	1.07	1.13
Latrobe	1.20	1.17	1.25
Thomson	1.27	0.93	1.10
Avon	1.30	1.06	1.02
Mitchell	0.91	1.08	0.99
Nicholson	1.03	1.01	0.99
Tambo	1.05	1.01	0.92

Table 4. Percent contribution of Eastern and Western catchments to total load (annual mean ± standard deviation)

Catchments	**West** (55 % of total area)	**East** (43.5 % of total area)
TSS – Observed	80 ± 11	20 ± 11
TSS – E2	70 ± 10	30 ± 10
TN – Observed	75 ± 10	25 ± 10
TN - E2	66 ± 14	34 ± 14
TP – Observed	74 ± 15	26 ± 15
TP - E2	61 ± 11	39 ± 11

Overall long-term loads are within 10% for TSS and TP, and within 15% for TN of the observed values (Table 3). These estimates are an improvement to those of the CSS modelling system. TSS is over predicted while TP and TN are under predicted. There are relatively higher prediction errors in the Western catchments (up to 30%) than in the Eastern catchments (<10%). Therefore, all catchments together in the East have less overall errors than those in the West (<6% against <20%). Most of the discrepancies in overall prediction errors come from the under prediction of one big event or two in different catchments (e.g. under predictions of TSS, TP and TN in April 1990 for Mitchell and Avon rivers, and in November 1995 for Latrobe river).

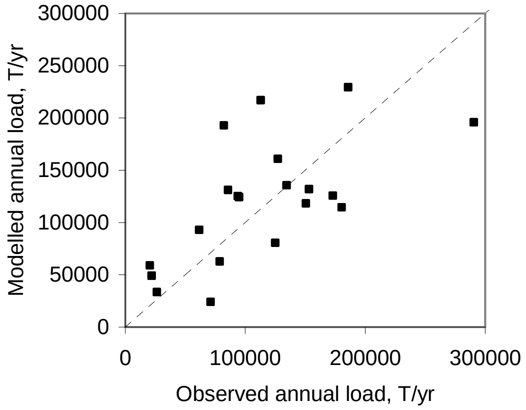
The overall annual loads for TSS, TN, and TP are shown in Figure 7. Generally, the modelled loads are consistent with other studies. Qualitative comparisons of monthly values between the simulated and the observed loads showed that the basic dynamics of load behaviour were generally captured but most of the peaks were under predicted. The mean concentrations used in this computation falls within the range of other published values (see Chiew and Scanlon, 2002; Grayson and Argent, 2002) but the model was not rigorously calibrated for constituent loads (same concentrations used for all FUs in a sub-catchment and point sources unaccounted), and the model prediction is likely to be improved after a rigorous model calibration.

The purpose of this modelling being to get a *big picture* for whole-of-system of major sources of constituents loads and long-term overall mean values for the Gippsland Lakes, the model results are not reliable for more detailed analysis and interpretation at fine time scales due to the large degree of uncertainty that would be involved with the absolute values. Nevertheless, the model results provide an indication of the relative importance of different sources and sub-catchments to the Gippsland Lakes. In this respect, Table 4 provides some insights on how much constituent loads come from the Western and Eastern catchments, and which catchments are critical in terms of management actions in reducing the generation of constituent loads. The percent contributions of various catchments respectively to their Western or Eastern region are consistent with the observation. Western catchments together provide 80 % of the overall load. Mitchell and Latrobe rivers are critical in the Eastern and Western region respectively.

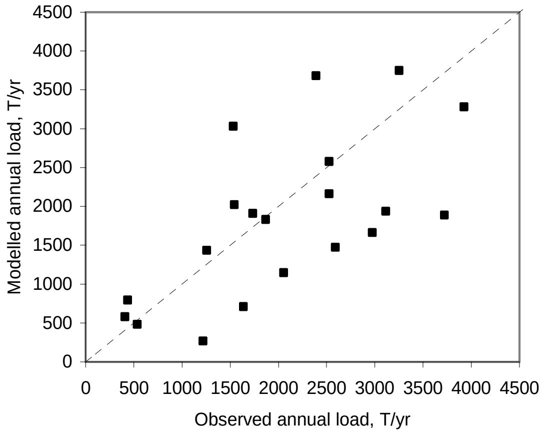
6. CONCLUSIONS

Flow and constituent loads (TSS, TP and TN) were simulated at monthly timesteps for the catchments of Gippsland Lakes using E2 modelling framework. The E2 model operates on a series of node-link network and monthly flow and constituent loads were calculated for each of the sub-catchments, nodes and links. These results for major catchments of the Gippsland Lakes (Latrobe, Thomson, Avon, Mitchell, Nicholson and Tambo) were compared with those of the CSS modelling system by Grayson and Argent (2002).

a. TSS



b. TN



c. TP

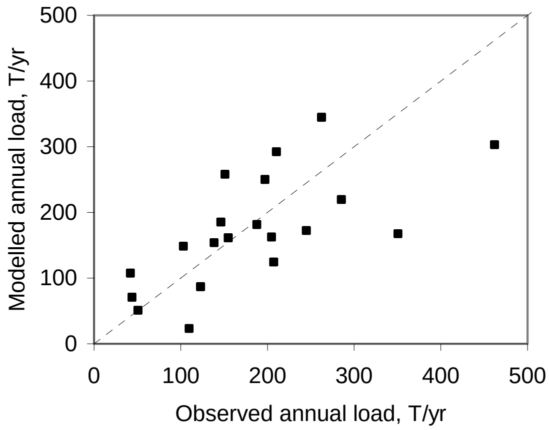


Figure 7. Annual observed versus predicted loads for All catchments: a. TSS, b. TN, c. TP

The modelling undertaken here included more spatial lumping than in the CSS model, greater detail in modelling and routing catchment flows, a similar level of model parameterisation, and was calibrated against the same data as the CSS.

Note that there is significant uncertainty associated with “observed” estimates of load and the E2 modelling has a similar level of certainty to the CSS modelling and the caution of Grayson and Argent (2002) continues to hold, i.e.

> "the model should be used for making **relative assessments** of the impact of various management actions to reduce **long-term average** nutrient and suspended loads."

The E2 modelling system performed as well or better than the CSS modelling system. The long-term average annual loads were well predicted but there were many inconsistencies for particular year or month. If the results of individual months or years were to be analysed in detail, complete monthly spatial data as well as daily temporal forcing would be needed. The model results provide confidence that the model does capture the basic temporal and spatial variability of the system well. These results are encouraging, given the data availability, scale and purpose of this modelling that focuses on long-term behaviour. In summary, the spatial lumping in E2 did not alter model outputs adversely and the E2 modelling system was considered at least as robust, and more flexible, than the CSS modelling system.

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