The Application of the E2 Water Quality Model for Regional NRM Planning

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EXTENDED ABSTRACT

The introduction of the National Action Plan for Salinity and Water Quality in Queensland (NAPS WQ) has resulted in greater responsibility for the delivery of Natural Resource Management (NRM) planning being given to the community through State and Federally approved NRM Regional bodies. These Regional Bodies are required to regularly report to the State and Federal governments on progress towards meeting resource condition targets. Quantifying any change in resource condition, such as water quality, as a result of implementing on-ground works is a difficult task for Regional Bodies. Identification of condition and trend may take decades and is costly. Computer simulation (models) may provide an alternative means of assessing the long term impacts of on-ground works on water quality.

The NAPSWQ team in collaboration with the Regional NRM Body, Queensland Murray Darling Committee (QMDC) used the E2 catchment modelling software to evaluate the likely changes in sediment and nutrient loads as a result of implementing on-ground works. The area modelled was the Condamine, Balonne and Maranoa Catchments at the headwaters of the Murray Darling Basin in Queensland (80,000 km^2) (Figure1).

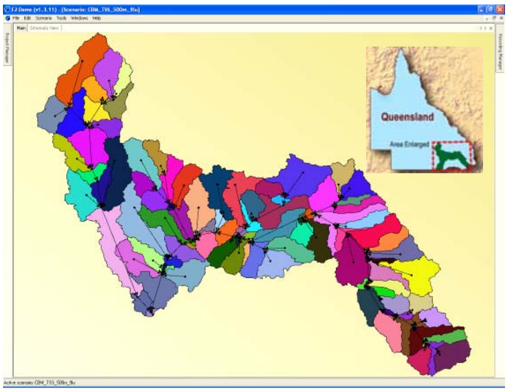

Figure 1: Condamine-Balonne-Maranoa subcatchments generated in E2.

Model output showed good agreement with observed data. Modelled runoff was within 10% of observed runoff for the majority of sites at the monthly timestep. Modelled runoff was within 20% of observed runoff events less than a month in duration. The majority of modelled sediment and nutrient loads were within 30% of observed loads.

The model was then applied by QMDC to estimate the relative change in sediment and nutrient loads exported from the catchment as a result of implementing 100,000ha of on-ground works. The on-ground works implemented by the landholders and subsidised by the Regional Body were: conversion from conventional to no tillage cropping, addition of contour banks in steep cropping lands, improved grazing management, installation of additional watering points and fencing off riparian areas.

Estimated catchment average annual reduction in sediment and nutrient loads in tonnes per annum (t/a) as a result of the funded on-ground works were 3,500 t/a (3%) of Total Suspended Sediment (TSS), 8 t/a (2%) of Total Phosphorus (TP), 3 t/a (2%) of Total Nitrogen (TN).

An unexpected benefit of the modelling exercise was that QMDC staff were able to independently run the model and test scenarios. QMDC staff now have a much greater awareness of how such models operate and some of the limitations of water quality modelling. A future application for the model will include prioritisation of on-ground works to determine where the most appropriate areas are for investment. QMDC staff are also collecting further event data to enhance model calibration. This work demonstrates that models can play a beneficial and useful role for Regional NRM Bodies as an assessment and/or prioritisation tool.

1. INTRODUCTION

Under the National Action Plan for Salinity and Water Quality (NAPSWQ), increased responsibility for delivery of NRM planning has been given to the community through Regional NRM bodies such as the Queensland Murray Darling Committee Inc. (QMDC). A component of the funding provided to Regional NRM Bodies is used to implement on-ground works as part of the their NRM planning process. Regular reporting to the State and Federal governments on progress towards meeting their resource condition targets (outlined in their NRM plans) for their catchments is a prerequisite.

One assumption is that on-ground works will result in improved water quality. Quantifying water quality improvement is a challenging task due to climatic influences overriding improvements attributed to on-ground works. Secondly, significant lag times are often required before impacts may be detected in downstream water quality. Thirdly, the area of on-ground works undertaken may be to small to reflect a change in water quality at the larger catchment scale.

Given the difficulties in using direct measurement, computer simulation modelling was an alternative means of assessing the impacts of works. QMDC were interested in evaluating the role of models as a means of assessing the water quality effects resulting from subcatchment land management changes and using this approach as part of their reporting process. The Queensland NAP Water Quality State Investment Program (WQSIP) team worked in partnership with QMDC to use and test a water quality model for the Condamine, Balonne and Maranoa Catchments for this purpose.

The E2 catchment water quality modelling software was chosen as an appropriate model for the application. The E2 modelling software is available at http://www.toolkit.net.au and a detailed description of the model can be found in Argent *et al.*, (2005). This model was chosen because it was developed in Australia and is locally supported. Secondly the model can simulate a range of catchment process that changes to land use and land management affect. Thirdly, the model operates at a daily timestep providing a means of reporting at event, monthly or annual timescales.

E2 operates at a subcatchment scale and output includes daily runoff (Q), and daily loads of total suspended sediment (TSS), total phosphorous (TP) and total nitrogen (TN). Sediment and nutrient generation is based on the application of event mean concentrations (EMC) and dry weather concentrations (DWC) to runoff. Point sources, dams and water storages are all represented in the model.

The features of E2 that were appealing to QMDC were its ease of use, its ability to represent the range of land use or land management changes they had funded and the ability to produce model outputs in a form useful for communicating with landholders.

2. CATCHMENT DESCRIPTION

The Queensland section of the Murray Darling Basin contains the Condamine, Balonne and Maranoa catchments. It drains 96,720 km^2 west and south of the Great Dividing Range. The Condamine River is a tributary system draining the steep slopes to the west of the Great Dividing Range. The Condamine River becomes the Balonne River which meanders southwest and joins the Maranoa River upstream of St George (Figure 2). Downstream of St George, the river becomes a complex distributary system in an alluvial fan known as the lower Balonne floodplain. The model can not route hydrology through a distributed network and the modelled area was therefore contained upstream of the floodplain at St George (80,000km^2) (Figure 2).

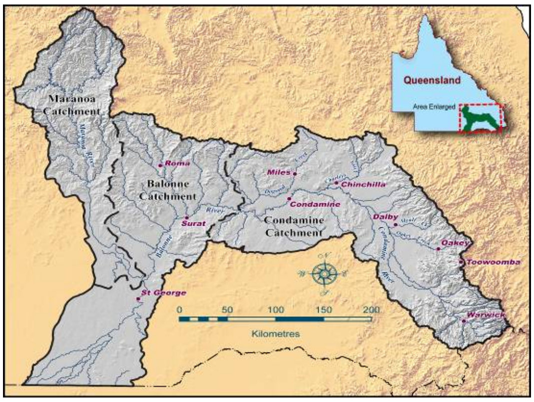

Figure 2: Condamine, Balonne and Maranoa catchment boundaries.

The catchments have a summer dominant but highly variable rainfall pattern. The mean annual rainfall decreases from 1000 mm in the east to less than 400 mm to the west.

The majority of the Condamine, Balonne and Maranoa streams are ephemeral. Flow is highly variable with the mean annual flow at St George being 1.3 million ML and having a standard deviation of 616,000 ML. Long term records show that the upper reaches flow 90% of the time, middle reaches 75% of the time with the western catchments flowing 40% of the time.

Land use (as a percentage of catchment area) is dominated by grazing (71%), dryland cropping (14%), State forest (8%) and irrigated cropping (3%) with the remainder made up of urban, rural residential and industry. Dominant point sources include sewage treatment plants and intensive animal industries, which combined make up 2% of the catchment area.

3. METHOD

A detailed description of the methodology used to develop the QMDC E2 model is outlined in Waters (2006).

There were 110 subcatchments generated within E2 from the DEM. Runoff generation was modelled on a daily timestep. Sediment and nutrient generation was via an EMC/DWC approach where daily pollutant load was the sum of surface runoff x EMC and subsurface runoff x DWC. EMC/DWC values were spatially varied via the method described below. A 30 year modelling period was chosen (1973-2003) to ensure that a range of wet and dry years were included.

3.1. Input Data layers

The following spatial data sets were used as the input layers to E2:

- A 25m DEM (Smith and Brough, 2006), re-sampled at 200m grid cell size and pit filled, was used for subcatchment generation.
- From the DEM, a subcatchment map was generated in E2. A minimum subcatchment threshold of 500 km^2 was chosen as being appropriate for QMDC reporting purposes. A total of 110 subcatchments were automatically generated (Figure 3).
- Eighteen NRW gauging station locations were added to the stream network as nodes for the purpose of either model calibration or validation.
- Daily rainfall and Potential Evapotranspiration (PET) files were generated for each subcatchment from the NRW Silo Data Drill database (Silo, 2004).
- Land use classifications from the Queensland Land-use Mapping Program (QLUMP 2004) were aggregated into 12 appropriate land use categories or functional units (FU).

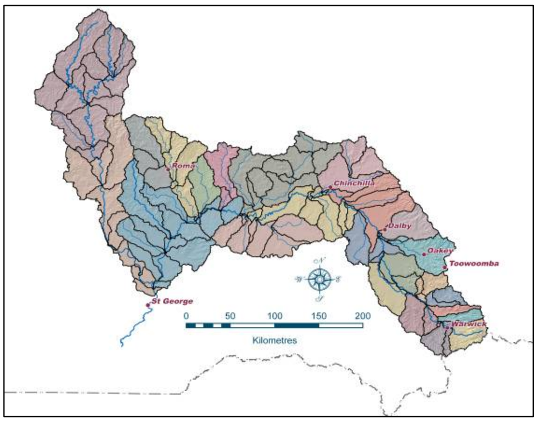

Figure 3: E2 generated 110 subcatchments for the modelled area with a threshold catchment area of 500 km^2.

- The three largest storages in the catchment greater than 10,000 ML capacity (Cooby Creek, Leslie and Beardmore Dams) were included in the model. Storages below this capacity were excluded as they were deemed to have minimal influence on event pollutant loads
- 25 sewage treatment plants were incorporated in the model with estimated TN and TP loads obtained from CBWC (2001)
- The event mean concentration (EMC) and dry weather concentration (DWC) parameter values for each functional unit (FU) were obtained from local literature see Waters (2006) for full list of reference material
- A universal soil loss equation (USLE) (Wischmeier and Smith 1978) was used to derive an average annual hillslope soil loss layer for the catchment. This layer was then used in E2 to spatially scale EMC and DWC values across the catchment
- Nine unique hydrologic regions were determined for the catchment. The hydrologic regions were derived through the analysis of annual rainfall, soil permeability, elevation and an index of flatness.
- E2 has a number of runoff generation models available. SIMHYD (Peel *et al.*, 2001) was chosen for this application. SIMHYD parameters were derived for each hydrologic region external to E2 using The Rainfall Runoff Library (RRL) software available at http://www.toolkit.net.au. A description of RRL and SIMHYD can be found in

Podger *et al*., (2004). RRL uses daily time series rainfall, evapotranspiration and observed runoff data to generate daily catchment runoff and to derive optimised runoff parameters calibrated against observed gauging station runoff data.

3.2. Hydrology and water quality validation

To assess the model performance, runoff data from six gauging stations on the main stream network were omitted from the RRL calibration exercise. Daily and monthly observed and predicted runoff were then compared to assess how well the modelled runoff matched observed runoff at gauges not included in the calibration. Warwick, Brigalow, Mitchell and Cashmere gauging stations listed in Table 1 were four of these gauging stations omitted from the calibration.

For the water quality validation, predicted TSS, TP and TN event loads were compared to observed loads measured in previous catchment studies (CBWC 2002; Horn *et al.*, 1988).

3.3. Model application to assess the impacts of on-ground works on water quality

The calibrated E2 model was then used to evaluate the impact on water quality resulting from the on-ground works implemented over the three years (2003-2005). The spatial location and extent of works were gathered and assigned to the appropriate subcatchment FU's. The underlying assumption in the exercise was that the on-ground works would result in increased ground cover and a reduction in TSS, TP and TN. Based on empirical models and data from local research, models of the form shown in Figure 4 were used to estimate this reduction in sediment and nutrients generated in runoff resulting from the increased ground cover on hillslopes. For riparian works, local and Australian literature were used to estimate the model parameters.

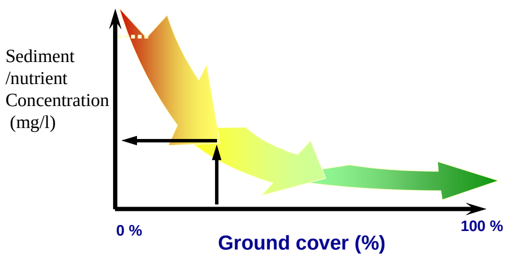

Figure 4: Empirical models of this form and local research were used to determine the reduction in sediment and nutrients in runoff as a result of implemented on-ground works.

The implemented on-ground works were grouped into 3 categories:

- **Improved grazing management** (106,000 Ha). Fencing land by soil type or landscape position and installing additional watering points to enable more uniform grazing pressure and planting new pasture species
- **Improved cropping practices** (2,300 Ha). Conversion of conventionally cropped areas to minimum tillage or no-tillage cropping and construction of contour banks on steep sloping areas
- **Fencing off riparian areas** (53 km). This involved fencing off one or both sides of creeks/rivers to allow either total stock exclusion or periodic grazing of the area. The streams fenced ranged from 1st – 6th order and the reduction in sediment and nutrients due to fencing was scaled according to stream order.

In each of the 15 subcatchments where works had been undertaken (Figure 5) a new "modified" land use category was added to the model with a reduced EMC and DWC value assigned to the modified land use (refer Waters 2006). Where riparian fencing was applied, a percentage removal approach was used for filtering of sediment and nutrients. Percentage removals were estimated from literature and scaled according to stream order.

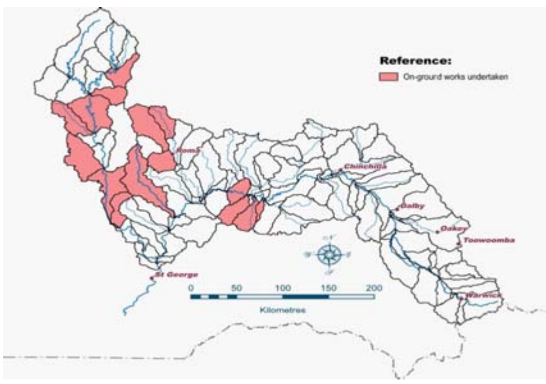

Figure 5: Shaded areas indicate subcatchments where on-ground works were implemented.

4. RESULTS

4.1. Hydrology output

Table 1 provides examples of predicted and observed output for catchment areas ranging from 500-50,000 km^2. Total predicted runoff volume was within 10% of the total observed runoff volume over the 30 year modelling period for the majority of gauging stations. Daily coefficient of efficiency values (E_{daily}) were between 0.5-0.8 for all gauges. Monthly values ($E_{monthly}$) ranged from 0.69 – 0.94. Chiew and McMahon, (1993) indicated that calibrations could be regarded as “good” where $E_{monthly}$ values were greater than 0.8.

Table 1: Example of model performance for total volume and daily and monthly totals at a range of scales.

Gauge	Area (km^2)	Pred/ Obs@	E_{daily}#	E_{month}#
Hodgson Ck Balgownie	560	0.95	0.76	0.94
Condamine R Warwick	1,360	0.97	0.62	0.85
Dogwood Ck Gilweir	3,010	1.08	0.53	0.69
Condamine R Brigalow	18,000	1.07	0.54	0.82
Maranoa R Cashmere	19,490	1.09	0.62	0.75
Balonne R Weribone	51,540	1.19	0.53	0.88

@ Ratio of total predicted runoff volume and observed runoff volume for 30 year modelled period
# (E) is the Coefficient of Efficiency for daily and monthly runoff (Nash and Sutcliffe, 1970) where E=1 is optimum

Modelled runoff volumes were within 20% of observed runoff for events ranging from 3 – 30 days duration. Event runoff peaks were of the correct order of magnitude.

4.2. Water quality output

A summary of both annual and event load comparisons for TSS, TP and TN is given in Waters (2006). TSS results are only presented in this paper due to document size restrictions. Figures 6 and 7 give examples of a number of events where predicted and observed load data were available for comparison. Theses events cover a range of return periods (3- 10 year ARI). Predicted TSS, TP and TN loads were within 30% of observed loads for the majority of events and showed reasonable agreement across the range of spatial scales.

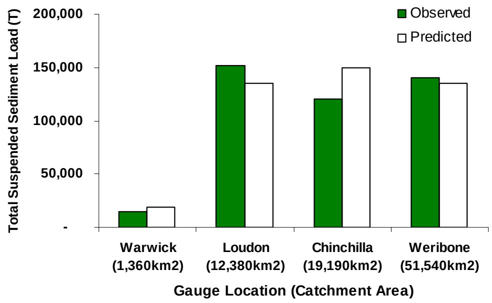

Figure 6: Observed and predicted event loads for four gauging stations for a runoff event in March 1999 (3 year ARI).

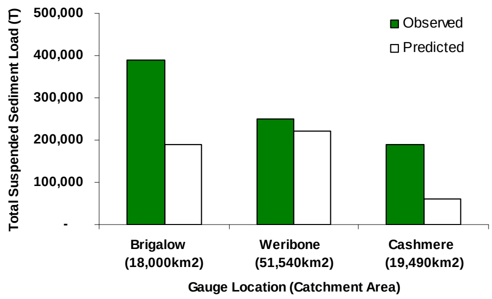

Figure 7: Observed and predicted event loads for three gauging stations for events sampled between 1995 and 1997.

4.3. On-ground works assessment

The 15 subcatchments where works occurred had a total area of 13,000 km^2 with on-ground works on 1,100 km^2. The E2 annual export loads prior to on-ground works implementation were estimated at 148,234 t/a of TSS, 106 t/a of TP and 374 t/a of TN at the whole of catchment outlet. Post on-ground works, predicted loads were reduced by 3,524 t/a (3%) for TSS, TN 8 t/a (2%) and TP 3 t/a (2%). The largest estimated reduction in pollutant load for a single subcatchment was 8% where approximately 70% (1,500km^2) of the catchment had on-ground works implemented.

5. DISCUSSION

The E2 runoff estimates for this catchment could be regarded as quite acceptable with the coefficient of efficiency values ($E_{monthly}$) greater than 0.8 for the majority of sites. Low flows were generally overestimated, particularly in the mid section of the catchment where major irrigation extractions and overland flow capture have occurred over the modelling period.

Despite the SIMHYD runoff generation model being more appropriate for comparison of runoff at a monthly timestep. E2 runoff volumes were quite acceptable when runoff events were for smaller time periods. Given the size (80,000km2) and complexity of such a large catchment, the results indicate that once calibrated, SIMHYD can estimate event runoff well for this catchment.

It is encouraging that the E2 modelled loads were of a similar order of magnitude to observed loads (within 30%). Predicted TSS loads for one event at four locations (Figure 6) were within 30% of observed loads across a range of spatial scales. This result was considered acceptable given the uncertainty in both measured and modelled loads. This particular event was generated from heavy rain in the headwaters followed by widespread rainfall across the catchment where runoff generated in the headwaters travelled the length of the catchment over 40 days.

All event loads presented in Figure 7 were underestimated by E2. In contrast to the event in Figure 6, the events presented in Figure 7 were generated from localised runoff. The two examples suggest that the E2 may predict event loads better where runoff is from significant areas of a catchment as opposed to localised areas.

Whilst the on-ground works activities were implemented across 15 subcatchments, the extent of on-ground works was only 3% of the total catchment area. As a result the predicted reduction in sediment and nutrient loads at the larger catchment scale were small. At the subcatchment scale, predicted sediment and nutrient reductions of up to 10% were found. Therefore, the scale at which results are reported is an important consideration for Regional Bodies. For landholders and the local community, subcatchment scale reporting may be more relevant.

When developing a model for such a large catchment, a lack of data is always a major limitation. A poor distribution of gauging stations was one issue encountered with 70% of the gauging stations located in the top 25% of the catchment. Availability of EMC data at the appropriate scale was also limited. As a result of this modelling exercise, additional EMC data is now being collected by Regional Body and agency staff to improve model parameterisation, calibration and validation.

The calibrated model now provides QMDC with the opportunity to explore the extent of works that may be required to see a significant change in sediment and nutrient loads at both the subcatchment and catchment scale.

The E2 model has proven to be a useful tool for QMDC to demonstrate to government, community and land holders the effectiveness of their on-ground works investment. A secondary benefit of the modelling exercise was its effectiveness as an extension tool in engaging Regional Body staff and landholders. QMDC staff can now independently run the model and test scenarios.

Some improvements to the model interface such as graphical presentation of subcatchment land uses and the ability to overlay spatial layers such as towns and satellite imagery would enhance the models useability as an extension tool to landholders and catchment groups.

6. CONCLUSION

An E2 model was developed for the Condamine, Balonne and Maranoa catchments. Modelled hydrology and water quality could be regarded as acceptable. Modelled event runoff was within 20% of observed runoff. The majority of modelled sediment and nutrient loads were within 30% of observed loads. The good agreement between observed and E2 event loads suggest that E2 runoff generation and pollutant generation parameters were appropriate to predict runoff and pollutant loads. E2 was able to estimate sediment and nutrient loads well for events ranging from 3 to 30 days in duration and across a range of spatial scales from 500 – 50,000 km^2.

The model was successfully applied by QMDC to estimate the long term changes in water quality as a result of implementing 1,100 km^2 of on-ground works. QMDC staff have a greater awareness of how models operate, their limitations and some indication of the extent of on-ground works required to achieve improvements in water quality at the catchment scale. Future applications of the model may also include prioritisation of on-ground works in the catchment.

This work demonstrates that the E2 model can be a useful tool for Regional Bodies to assess the benefits of on-ground works and to target remedial action.

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