18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

# Visual comparison of spatial patterns of annual suspended sediment loads estimated by two water quality modelling approaches

**Fentie, B.**[1], **D. Pagendam**[2] **and D. Roberts**[1]

[1] *Queensland Department of Environment and Resource Management*
[2] *The University of Queensland, St Lucia, Queensland*
*Email:* banti.fentie@derm.qld.gov.au

**Abstract:** The Queensland Department of Environment and Resource Management is using the SedNet and E2 water quality modelling approaches to support government policy and natural resource managers in improving water quality. SedNet is designed to determine the long-term average annual sediment load, and does not deal with temporal variability. It includes hillslope erosion, gully erosion, and riverbank erosion, which enables land managers to undertake on ground works in areas of the landscape that generate disproportionate quantities of sediment. E2 is a daily time step model capable of modelling temporal variability in water quality as a result of management and/or climate changes. However, hillslope erosion, gully erosion, and riverbank erosion are not currently explicitly represented in E2 in which sediment generation is based on the concept of Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) with user assigned values depending on factors such as land use, soil type, and topography. As a modelling framework, E2 is capable of housing alternative models for the same process. Both SedNet and E2 modelling approaches are based on node-link configuration of the stream network generated from pit-filled digital elevation models. This configuration allows the user to determine outputs from either model at any point of interest within the catchment.

The objective of this study was to visually compare the spatial patterns of annual average sediment loads estimated by SedNet and E2 in relative terms. To our knowledge, a similar comparison of the two modelling approaches has not previously been done, and we believe that this work is a useful contribution in guiding model choice. The Burnett catchment, located in Southeast Queensland, Australia, has been chosen as the case study catchment for this work. In order to undertake a sub-catchment by sub-catchment comparison of model outputs, we intended to generate the same number of sub-catchments in E2 as those already generated in SedNet for a previous project. However, the version of E2 used for this study was unable to support as many sub-catchments as those in SedNet due to insufficient system memory. This issue has been addressed in the current version of E2 referred to as WaterCAST, which unfortunately was not available for this study.

Despite the discrepancy in the number of sub-catchments generated, the similarity in the spatial patterns of average long-term suspended sediment loads shown in Figure 1 indicates that both modelling approaches generally identified the same generation hotspots within the Burnett catchment. Where there are differences (as shown in the highlighted areas), these could be explained by the difference in the structure and process representation of the two models. Given the fact that the two models are independent; the similarity in the spatial pattern of the resulting sediment generation is quite encouraging in terms of building confidence in the use of both modelling approaches.

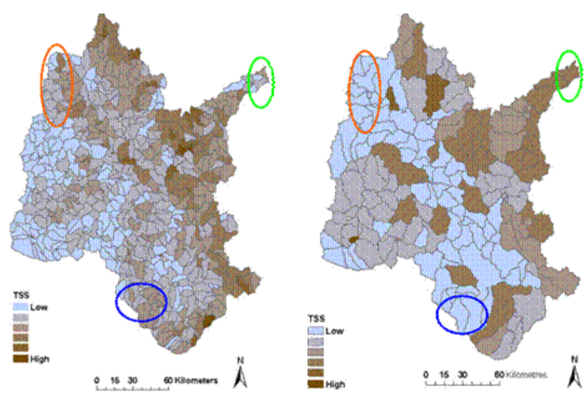


**Figure 1**. Annual suspended sediment load as estimated by SedNet (left) and by E2 (right)

***Keywords:*** *Burnett catchment, Dry Weather Concentration, Event Mean Concentration, E2, SedNet, TSS*

## 1. INTRODUCTION

The Queensland Department of Environment and Resource Management (DERM) is using water quality models in order to support policy and decision making in the management of water and related natural resources. This is being achieved through a number of initiatives such as the Reef Water Quality Protection Plan, which is being undertaken in collaboration with the Federal government of Australia. An example of these modelling activities is the recently completed water quality modelling project conducted in the Great Barrier Reef catchments (Cogle et al. 2006) using the SedNet model (Wilkinson et al. 2004).

The SedNet model is a long-term annual average water quality model that has been used both at the continental level through the National Land and Water Resources Audit (Prosser et al. 2001), at the regional level in catchments draining to the GBR lagoon (Brodie et al. 2003) and at the catchment scale (Prosser et al. 2002; DeRose et al. 2002; Bartley et al. 2004).

The E2 model (Argent et al. 2007) is a daily time-step water quality model developed to estimate water quality (e.g., suspended sediment, nitrogen and phosphorous). The current version of the model does not have a constituent generation module to represent the three erosion processes included in SedNet (i.e. hillslope erosion, gully erosion, and riverbank erosion). Land use related Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) values are determined from the land use grid and associated look up tables. These concentrations are multiplied by quick flow and base flow respectively and added together to result in the total suspended load from a sub-catchment.

Whilst both models are built around a node-link configuration of catchments, the E2 model is encapsulated around spatial entities called functional units (FUs) which are usually defined on the basis of land use, as was the case in this study. Outputs of both SedNet and E2 are summarised at the sub-catchment level. Daily outputs from E2 have been summarised to determine long-term annual average values.

In his “Scoping Report For Data Analysis and Modelling Requirements to meet the Objectives of the GBR Loads Monitoring Project (Reef Water Quality Protection Plan, Action I5)”, Grayson (2006) recommended E2 as the modelling framework to be used, and suggested areas of improvement to enhance its capabilities. The Burnett catchment in Southeast Queensland, Australia, used as a case study catchment in this work is one of a few catchments in which both the SedNet model and E2 are applied.

CRC for Catchment Hydrology (2005) lists the following four basic considerations in choosing the right model for a particular job:

1. objectives of the overall exercise,
2. access to data,
3. access to expertise, and
4. availability of resources (i.e., time and money).

One of the challenges facing catchment modellers is the lack of data that meets both spatial and temporal scales at which models are run in order to calibrate and validate them. In the absence of observed data, modellers often consider the comparison of model results with the results of two or more other models as a qualitative method of model validation.

The objective of this study is to compare the relative magnitudes of long-term annual average suspended sediment load estimates in the Burnett catchment from both SedNet (Fentie et al. 2006) and E2 (unpublished results) using visual inspection of spatial patterns of suspended sediment loads. Since the two models are developed on radically different conceptualisations and operate at different time-steps, it is not expected that the absolute values of loads estimated by the two methods will be comparable. Therefore, comparison in this study is limited to visual relative inspection. However, it is assumed that the spatial pattern of the estimations (i.e. the relative magnitudes) in terms of the spatial distribution of loads will be comparable. It is on this basis of this assumption that this study is comparing the results from the two models in the Burnett catchment.

Since hydrology is the driver of sediment generation and is multiplied by concentration to determine the total load, the hydrological components of the two models will also be compared and the effect of this on the comparison of suspended sediment load estimates from the two models will be discussed.

## 2. METHOD

### 2.1. The Case Study Catchment

The Burnett catchment is the third largest river basin draining to the Queensland coast, Australia, and is located south of the Tropic of Capricorn. The climate of the catchment is characterized by variable distribution of rainfall and subtropical weather patterns. Table 1 shows climatic data of the Burnett catchment.

As shown in Figure 2, grazing is the dominant land use within the catchment covering about 26500 $km^2$ (67%) of the 39500 $km^2$ catchment.

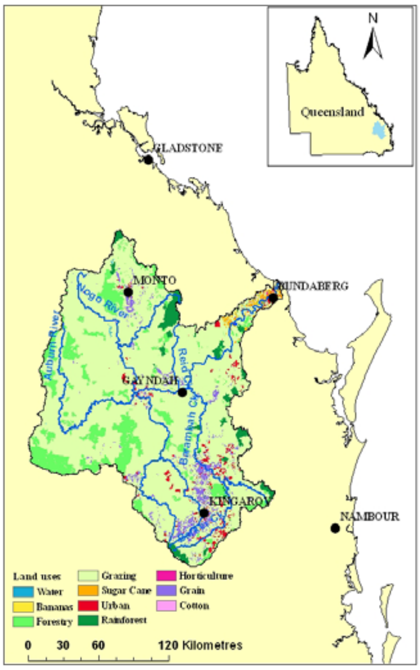


**Figure 2.** Location and land use of the Burnett catchment

**Table 1.** Climatic data of the Burnett catchment (Pa = Mean annual rainfall, Ea = Mean annual evapotranspiration, and Ta = Annual average min and max temperature). Source: (Van Manen 1999)

| Location | Pa (mm) | Ea (mm) | Ta (°C) |
|---|---|---|---|
| Bundaberg | 1123 | 1823 | 16.8-26.6 |
| Gayndah | 774 | 2020 | 14.2-28 |
| Monto | 723 | 1866 | 12.8-27.2 |
| Kingaroy | 778 | 1601 | 11.4-24.7 |

### 2.2. The SedNet Model

The SedNet model is a sediment generation and transport model for predicting long-term annual average end-of-valley and in stream pollutant loads. The model has been initially developed to be used in the National Land and Water Resource Audit to estimate the generation of sediment, nitrogen and phosphorus at the continental scale (Prosser et al., 2001). It has since been used in a number of catchment specific studies including the Burdekin catchment (Prosser et al., 2002), Murray-Darling basin (DeRose et al., 2003), Mary catchment (DeRose et al. 2002), Herbert (Bartley et al. 2003), and Douglas Shire catchments (Bartley et al. 2004).

The SedNet model is based on a node-link configuration generated from a digital elevation model (DEM) of a catchment. For this study, a total of 712 sub-catchments and associated links were generated. The suspended load budget for a link is computed as a mass balance of inputs and outputs as shown in the conceptual model depicted in Figure 3.

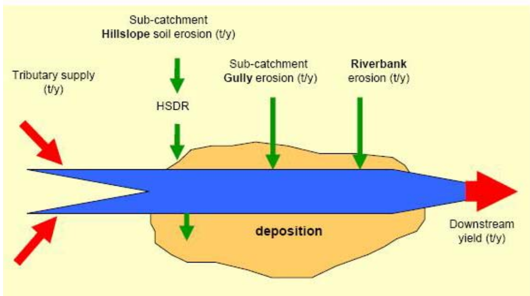


**Figure 3.** Components of the river link suspended load budget. After (Wilkinson et al. 2004).

SedNet includes the contribution of hillslope erosion, gully erosion and bank erosion to the total suspended sediment budget and accounts for sediment trapping in the floodplain and reservoirs. Hillslope erosion is determined using the Revised Universal Soil Loss Equation (RUSLE). Gully erosion is estimated using the distribution of gullies (i.e., a map of gully density), gully age and an average gully dimension. Riverbank erosion is calculated as a function of stream power and the proportion of the bank that is not protected by riparian vegetation. Mean annual flow is determined as a function of runoff coefficient, annual average rainfall, and catchment area.

Mean Annual Flow (MAF) in SedNet is calculated from:

$$MAF = R_c \times A \times P \tag{1}$$

Where the runoff coefficient, $R_c$, is calculated as function of the "dryness index", or ratio of potential evapotranspiration to mean-annual precipitation (P) and A is catchment area (Wilkinson et al., 2004).

### 2.3. The E2 Modelling Framework

E2 is a successor of EMSS which was developed and applied for water quality modelling in Southeast Queensland catchments (Chiew et al. 2002). EMSS has been used in a number of other catchments in Queensland (e.g., Searle 2005; Chiew et al. 2002, Waters 2006). E2 is not a model with fixed component models, but rather a flexible framework that allows alternative model components to be chosen when and where deemed suitable. Whilst there is capacity to build process-based sediment generation model components in the future, these are not available in the current version of the model. Therefore, Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) values derived as a function of land use for the Maroochy catchment in Southeast Queensland (Searle 2005) were used in this study due to the absence of these values for the Burnett catchment. Although recent work by Waters and Packett (2007) has shown that these suspended sediment EMC values could have been underestimated, the values used are considered to be adequate for the purpose of this study, which is only looking at relative magnitudes and not absolute values. Sub-catchments in E2 are further divided into areas of similar response or behaviour called Functional Units (represented as F1-F3 in Figure 4) which can be based on land use/land cover, management, or position in the landscape (topography). In this study functional units have been defined on the basis of land use.

E2 is also based on node-link stream network generated from a pit-filled DEM. The number of sub-catchments created as the result of the stream network generation process is dependent on the user provided minimum threshold area parameter. The intention in this study was to create the same node-link configuration (and hence the same number of sub-catchments) for both models. However, E2 version 1.3.2 used in this study could not support the generation of the same density of stream network used in the SedNet modelling, which was carried out previously and used here, and produced a "system out of memory" error. This issue has been addressed in the current version of E2 referred to as Water and Constituent Analysis and Simulation Tool (WaterCAST), which unfortunately was not available for this study. Consequently, only 189 sub-catchments were generated for the E2 model in this study compared to 712 sub-catchments in the SedNet model. In an attempt to quantify the difference between the estimates from the two modelling approaches, SedNet outputs were aggregated to the sub-catchments from E2 by taking the average of SedNet sub-catchments that fall within a sub-catchment from E2.

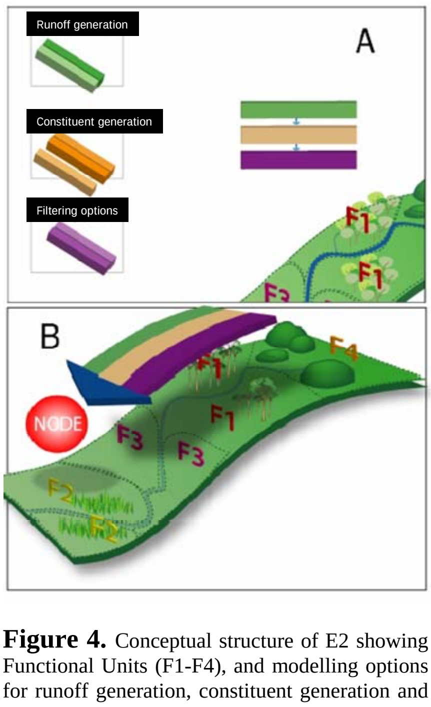


**Figure 4.** Conceptual structure of E2 showing Functional Units (F1-F4), and modelling options for runoff generation, constituent generation and filtering. After (Argent et al. 2007)

E2 has models for runoff generation, constituent (contaminant) generation and filtering. Hydrology in E2 is modelled by choosing one of a group of rainfall-runoff models for each functional unit, sub-catchment or whole catchment as appropriate. In this study the SIMHYD (Chiew et al. 2002) model has been chosen as it has been widely used in Queensland for previous water quality modelling projects.

The E2 modelling framework is expected to be further developed and populated with additional model components to cater for the needs of stakeholders in eWater CRC through the further development of WaterCAST.

## 3. RESULTS

Figure 5 shows mean annual flow modelled by SedNet (left) and E2 (right) while Figure 6 shows maps of suspended sediment load supplied to the stream network by each sub-catchment as estimated by SedNet (left) and E2 (right) models. Figure 7 shows the frequency distribution of the difference between E2 and SedNet estimated TSS values.

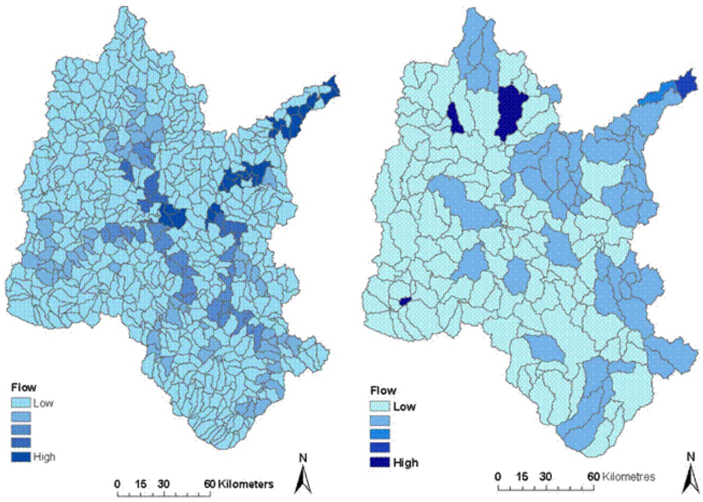


**Figure 5.** Mean annual flow as estimated by SedNet (left) and by E2 (right)

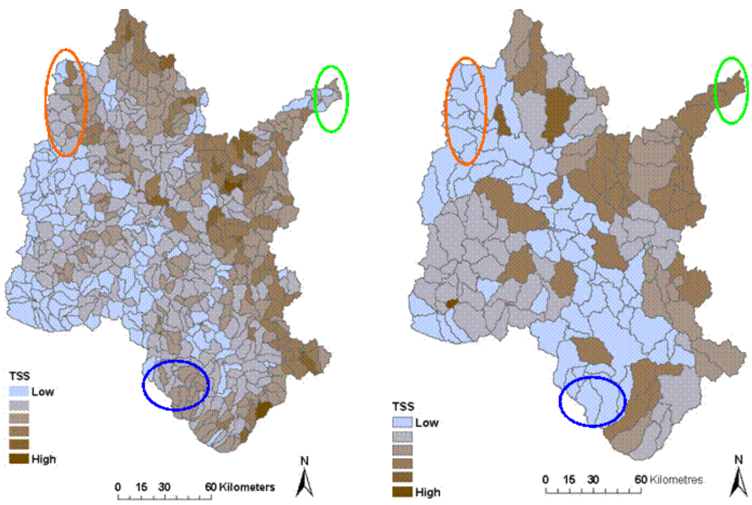


**Figure 7.** Annual suspended sediment load as estimated by SedNet (left) and E2 (right). Areas enclosed by the same color rings show sub-catchments with substantial differences between the two model estimates

Whilst the purpose of this study is only to visually compare the annual average suspended sediment load estimated by the two modelling approaches, the spatial pattern in mean annual flows estimated by the models are also presented in Figure 5 in order to assess if the spatial patterns in suspended sediment load are reflected in the flow patterns.

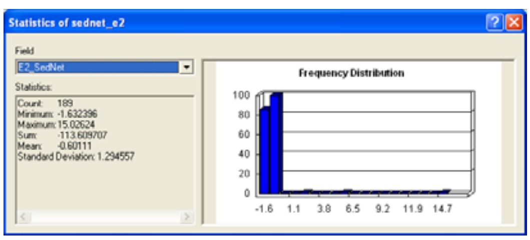


**Figure 6.** Frequency distribution of the difference in suspended sediment loads (t/ha/y) estimated by E2 and SedNet.

Although proper quantitative comparison of the TSS values estimated by the two modelling approaches is beyond the scope of this study, we aggregated SedNet sub-catchments into E2 sub-catchments and calculated the difference in TSS values resulting in the frequency distribution depicted in Figure 7. However, TSS estimated as the result of the aggregation described above is only an approximation and, therefore, the quantitative comparison presented in Figure 7 should be interpreted with caution.

## 4. DISCUSSION

As shown on the right hand side maps in Figures 5 and 6, there is a clear similarity between the flow and suspended sediment load spatial patterns estimated by E2. This reflects that suspended load in E2 is predominantly determined by the magnitude of runoff generation. This is not surprising since, without scaling EMC values to account for spatial variability as the result of factors other than land use, loads will just be a product of the EMC value and flow for a sub-catchment, given the majority of the catchment has the same land use. On the other hand, the relationship between the spatial patterns of flow and sediment load estimated by the SedNet model is not as strong as those estimated from E2. This is expected as sediment load in SedNet is contributed from hillslope, gully, and bank erosion in which sediment load and discharge are nonlinearly related while constituents and flow are linearly related in the EMC/DWC based approach of constituent generation in E2 as applied in this study.

The frequency distribution of the two model estimates in Figure 7 shows that most of the difference is in the -1.6 – 1.0 (t/ha/y) range. It is expected that the differences in process representations of SedNet and E2 will explain most of the difference in the spatial pattern of suspended sediment load. For example, E2 uses a single EMC value for a land use type regardless of other factors such as soils, topography, variable ground cover and the existence and severity of rills/gullies which are all expected to contribute to the difference in the spatial patterns produced by the two modelling approaches. Some of the discrepancies can also be explained by the fact mean annual average sediment load from SedNet is determined using long-term annual input parameters while that from E2 is determined by aggregating daily model outputs. The use of EMC and DWC values derived for the Maroochy catchment, due to lack of local data for the Burnett catchment, is expected to be a possible source of uncertainty in the TSS estimates from E2. However, we feel that this would not affect the spatial pattern in TSS estimated by E2 and hence the visual comparison of the spatial pattern of TSS estimated by the two modeling approaches.

Given the possible sources of difference, there is still a reasonable agreement between the spatial patterns of suspended sediment load estimated by the two models, as shown in Figure 6. However, due to the limited scope of this study, this similarity should not be used as a justification for the use of EMC/DWC values in E2 for sediment generation. To account for factors other than land use that affect EMC/DWC values, there is a capacity in E2 to scale these values by weighting them against indices determined using hillslope and gully erosion hazard maps used in the SedNet model. It is expected that this would result in greater agreement between the suspended sediment load maps estimated by the two models. However, this was not carried out in this study. Moreover, it is anticipated that constituent generation models will be developed and implemented in E2 resulting in even closer agreement in the spatial pattern of TSS estimated by the two modeling approaches.

E2 currently does not model the contributions of hillslope erosion, gully erosion and riverbank erosion explicitly. Therefore, if the purpose of the modelling is to identify which process is the most important source of suspended sediment and to identify priority sub-catchments in terms of their long-term total contribution of suspended sediment and guide the planning of management actions, the long-term mean annual model SedNet may be satisfactory. On the other hand, E2 should be the model of choice if temporal variation is of importance, provided that appropriate input data are available.

## 5. CONCLUSION

SedNet and E2 are two independent catchment-scale water quality modelling approaches designed to operate at long-term (annual average) and daily time steps, respectively. Given the difference in the time-step at which the two modelling approaches operate and the conceptual difference between them, there is a reasonable similarity in the suspended load spatial patterns estimated by the two models. This similarity indicates that either model may suffice to identify hotspots to address issues related to water quality associated with soil erosion. In the absence of data to do standard model validation, agreement in outputs of different independent models may also be used as a qualitative way of increasing our confidence in the use of these models. In this regard, the general agreement in the spatial pattern of suspended sediment loads estimated by the SedNet and E2 models is considered to be a good outcome. It is expected that when process based constituent generation models are developed and implemented in E2, the similarity between the spatial patterns of TSS estimated by the two modeling approaches might become even closer.

## REFERENCES

Argent, R.M., Podger, G.M., Grayson, R.B., Fowler, K. and Murray, N. (2007), E2 Catchment Modelling Software: User Guide.

Bartley, R., Henderson, A., Hotham, H., Hartcher, M. and Wilkinson, S. (2004), Using the SedNet model for scenario analysis within the Douglas Shire Catchment: final results and evaluation of the model.

Bartley, R., Henderson, A., Prosser, I.P., Hughes, A.O., McKergow, L., Lu, H., Brodie, J., Bainbridge, Z. and Roth, C.H. (2003), Patterns of Erosion and Sediment andNutrient Transport in the Herbert RiverCatchment, Queensland.

Brodie, J., Mckergow, L.A., Prosser, I.P., Furnas, M., Hughes, A.O. and Hunter, H. (2003), Sources of Sediment and Nutrient Exports to the Great Barrier Reef World Heritage Area. Technical Report 03/11, CSIRO Land and Water, Canberra, Australia.

Chiew, F., Scanlon, F., Vertessy, R. and Watson, F. (2002), Catchment scale modelling of runoff, sediment and nutrient loads for the Southeast Queensland EMSS. Technical Report 02/1, Cooperative Research Centre for Catchment Hydrology.

Cogle, A.L., Carroll, C. and Sherman, B.S. (2006), The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting. QNRM06138, Department of Natural Resources, Mines and Water, Brisbane.

CRC for Catchment Hydrology (2005), Series on Model Choice: General approaches to modelling and practical issues of model choice. CRC for Catchment Hydrology.

DeRose, R.C., Prosser, I.P., Weisse, M. and Hughes, A.O. (2003), Summary of sediment and nutrient budgets for the Murray-Darling Basin. Technical Report K, Murray-Darling Basin Commission.

DeRose, R.C., Prosser, I.P., Wilkinson, L.J., Hughes, A.O. and Young, W.J. (2002), Regional Patterns of Erosion and Sediment and Nutrient Transport in the Mary River Catchment, Queensland. 37/02, CSIRO Land and Water, Canberra, Australia.

Fentie, B., Searle, R., Esslemont, G. and Sherman, B. (2006), Sediment and nutrient modelling in the Burnett-Mary NRM Region. *In* "The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting" (Cogle, L., Carrol, C. and Sherman, B., eds).

Grayson, R. (2006), Scoping Report for Data Analysis and Modelling Requirements to meet the Objectives of the GBR Loads Monitoring Project: (Reef Water Quality Protection Plan, Action I5), Catchment to Sea Pty. Ltd.

Prosser, I.P., Moran, C.J., Scott, A., Rustomji, P., Stevenson, J., Priestly, G., Roth, C.H. and Post, D. (2002), Regional Patterns of Erosion and Sediment Transport in the Burdekin River Catchment. Technical Report 05/02, CSIRO Land and Water, Canberra, Australia.

Prosser, I.P., Rustomji, P., Young, W.J., Moran, C.J. and Hughes, A.O. (2001), Constructing river basin sediment budgets for the National Land and Water Resources Audit. Technical Report 15/01, CSIRO Land and Water, Canberra, Australia., Canberra, Australia.

Searle, R. (2005), Modelling of runoff, sediment and nutrient loads for the Maroochy River catchment using EMSS. 05/08, CRC for Catchment Hydrology, Brisbane.

Van Manen, N. (1999), State of the Rivers: Burnett river and major tributaries. Queensland Department of Natural Resources and Mines, Brisbane.

Waters, D. and Packett, R. (2007), Sediment and nutrient generation rates for Queensland rural catchments – an event monitoring program to improve water quality modelling. "Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference." (Wilson, A.L., Dehaan, R.L., Watts, R.J., Page, K.J., Bowmer, K.H. and Curtis, A., eds), Edition Charles Sturt University, Thurgoona, New South Wales.

Waters, D. (2006), Application of the EMSS water quality model for the Queensland Murray Darling catchment - Assessing the impacts of on-ground works. Technical Report of the Water Quality State-level Investment Project.

Wilkinson, S., Henderson, A. and Chen, Y. (2004), SedNet: User Guide, Client Report. CSIRO, Canberra.

## ACKNOWLEDGMENTS

The SedNet modelling was funded by NHT and NAPSWQ using Australian and Queensland Government financial support including that of the Coastal Catchments initiative, an NHT program. The E2 modelling was carried out under the first round of eWater CRC Application Projects.