Sensitivity Analysis Of A Catchment Scale Sediment Generation And Transport Model

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EXTENDED ABSTRACT

A catchment-scale sediment generation and transport model called SedNet (**Sed**iment River **Net**work) is being used in a number of national and statewide water quality projects in Australia. In order to increase confidence in the use of SedNet we need to quantify the likely errors in prediction associated with uncertainties in parameter values.

This paper presents results of a simple one-at-a-time sensitivity analysis of the SedNet model. All together 23 parameters were varied by -10%, -5%, +5%, and +10% from their baseline values.

The Burnett catchment in Queensland, Australia, has been chosen for this study as it is one of the priority catchments in the National Action Plan for Salinity and Water Quality (NAPSWQ) and in the Great Barrier Reef Water Quality Protection Plan. The size of the catchment also makes it suitable for the analysis undertaken.

There are a number of different outputs from the SedNet model. Due to space limitations, only results of the sensitivity to total sediment export is presented as it is likely to be an output of greatest interest to many users of model outputs. As shown in Figure 1, total sediment export was found to be sensitive to changes in some of the parameters although the degree of sensitivity varied from parameter to parameter. It was found that total sediment export was more sensitive to changes in parameters such as gully age, hillslope delivery ratio, and bankfull discharge recurrence interval and less sensitive or not sensitive to other parameters.

The simple sensitivity analysis reported here has been valuable in determining which model parameters exert significant influence on model outputs and which are inconsequential. However, being a local one-at-a-time sensitivity analysis, it (a) did not include parameter interactions, (b) did not include model output uncertainty due to uncertainty in spatial input datasets, (c) only investigated four changes in each parameter value out of many possible values, and (d) is likely to be catchment specific.

These constraints were brought about by the fact that it is not computationally feasible to do a global sensitivity analysis in the current structure of the model. Future research is required to address these issues.

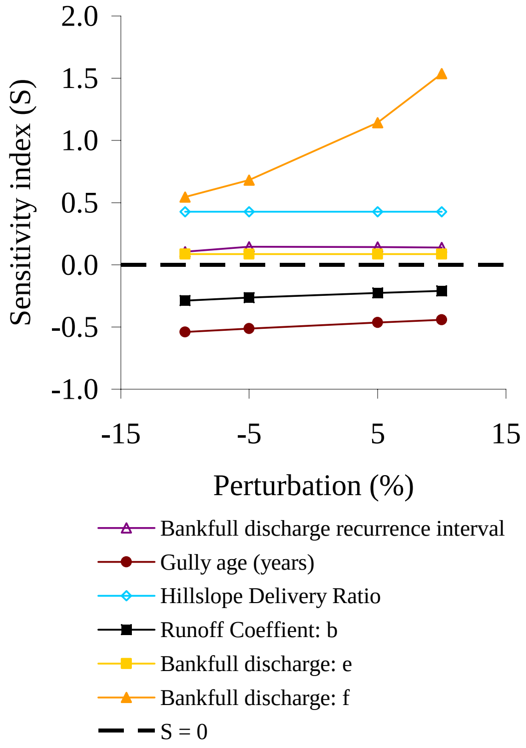

Figure 1. Plot of sensitivity indices as a function of % change in parameter values. Note that, for the purpose of readability, only parameters to which total sediment export is sensitive are included in this plot. Other parameters included in this study have a sensitivity index of zero (or close to zero) and overlap on top of the S = 0 line.

1. INTRODUCTION

The SedNet model has been previously used to estimate sediment and nutrient generation and transport in the Great Barrier Reef catchments (Brodie *et al.*, 2003). The Burnett catchment used in this study is one of these catchments. However, the above study did not include sensitivity analysis of model outputs to changes in parameter values, which is an essential step to increase the level of confidence in the use of the model. In order to evaluate the confidence levels in the SedNet model, Fentie *et al.* (2005) compared SedNet-estimated total suspended sediment from sub-catchments in the Fitzroy basin with those estimated by Joo *et al.* (2005) using rating curves. However, sensitivity analysis of the model has not been carried out in Queensland catchments. In the only sensitivity analysis of the SedNet model to-date, Newham *et al,* (2003) investigated the sensitivity of outputs of the model to changes in a subset of model parameters in the Upper Murrumbidgee catchment, New South Wales. This study reports on a simple sensitivity analysis of SedNet in the Burnett catchment, Queensland, Australia.

Sensitivity analysis (SA) can be defined as the process of determining the effect of changing the value of an input variable on model output. It is a valuable tool for developing, modifying, calibrating, and testing the model (Sieber and Uhlenbrook, 2005). According to Sieber and Uhlenbrook (2005), a sensitivity analysis is a useful tool to:

> "*(i) identify parameters the model reacts most sensitively to and thus simplify and accelerate the calibration of the model or enable a more focussed planning of future research and field measurement, (ii) show whether the model's response to representative variations of parameter values and boundary conditions is realistic, (iii) prove the model concept to be sufficiently sensitive to represent the natural system's behaviour, and (iv) reduce a model to its essential structures*".

According to Campolongo *et al*. (2000), Sensitivity analysis (SA) can be applied in three main areas, which are (i) identifying influential factors in a system with many factors (factor screening); (ii*)* employing partial derivatives to quantify the influence of model parameters, inputs and structural features for a limited range of variations about specific operating points (local SA), and (iii) apportioning the output sensitivity to its causes, over the whole realistic operating range (global SA). The analysis in this study used the local SA setting.

The Burnett catchment (Figure 2) was chosen for this study as it is one of the priority catchments in the National Action Plan for Salinity and Water Quality (NAPSWQ) and is included in the Great Barrier Reef Water Quality Protection Plan.

2. THE BURNETT 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.

Table 1. Climatic data of the Burnett catchment. Source: Van Manen (1999).

Location	Mean annual rainfall (mm)	Mean annual evaporation (mm)	Mean temperature Min-Max (°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

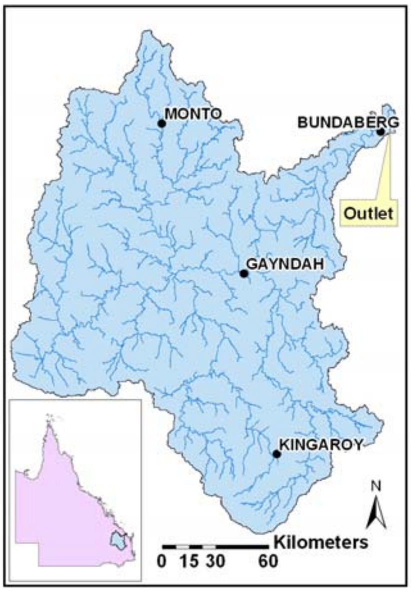

Figure 2. Location map of the Burnett catchment.

Grazing is the dominant land use within the catchment covering about 26500 km^2 (67%) of the 39500 km^2 catchment.

3. THE SEDNET MODEL

The SedNet model is based on a node-link configuration (Figure 3) defined from a pit-filled digital elevation model (DEM). The model produces outputs for each link.

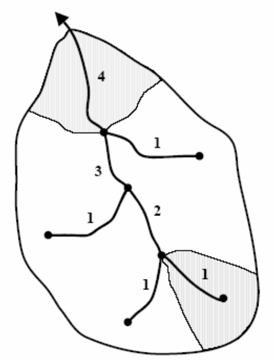

Figure 3. A river network showing links, nodes, and the Shreve order of each link. Source: (Wilkinson *et al.*, 2004).

Hillslope, gully, and bank erosion are the three sediment generation processes considered in SedNet. Amounts of suspended sediment deposition on floodplains and reservoirs are calculated and subtracted from the amount of suspended sediment supplied to a link.

Components of the sediment budget are grouped into two as inputs and outputs. The inputs category includes hillslope erosion, gully erosion, and bank erosion supply to the stream network. The outputs category includes deposition in reservoirs (both bed and suspended sediment), deposition on floodplains (suspended sediment), deposition in the channel (bed load) and export (both and suspended sediment). The sediment budget calculation ensures that the sum of the input components is equal to the sum of the output components.

Figure 4 shows components of the sediment budget for both bed and suspended loads. In the case of bed load budget, tributary supply, riverbank erosion, and gully erosion are the sources of sediment into the link while deposition on the bed is a sink, the difference being exported to the link downstream. In the case of suspended load budget, hillslope erosion is another source of sediment in addition to the sources in the bed load budget listed above while floodplain deposition is the sink while the difference is exported to the link downstream.

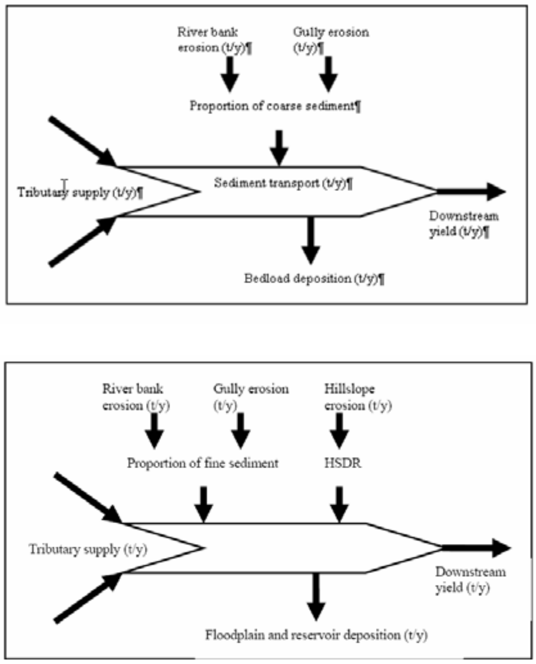

Figure 4. The SedNet sediment budget (top: bed load and bottom: suspended load). Source: (Wilkinson *et al*., 2004).

4. THE SENSITIVITY INDEX AND PARAMETERS USED

As mentioned in the introduction section, the type of sensitivity analysis used in this paper is local SA. As suggested by Newham *et al.* (2003), there are two reasons for the selection of local SA for the SedNet. First, SedNet has a modest number of parameters (23 included in this study) that have generally well known values and it is not difficult to select representative operating conditions for the model. Secondly, local SA makes relatively modest computational demands and produces readily understandable results.

The local one-at-a-time sensitivity analysis method adopted in this study uses a dimensionless sensitivity index (S) defined as the derivative

$$S = \frac{\partial Y}{\partial X} \tag{1}$$

where ∂X is relative change in parameter from the baseline value and ∂Y is the corresponding relative change in output of interest. The SedNet model produces various outputs for each link within the model. In this study, the output of interest was only considered at the catchment outlet. The output being considered in this analysis is annual average total suspended sediment load.

Table 2. Parameters of the SedNet model with baseline values and percent changes used in the sensitivity analysis.

Parameters	-10%	-5%	Baseline	+5%	+10%
Configuration parameters					
Drainage area threshold (km^2)	45	47.5	50	52.5	55
Minimum first order link length (km)	0.9	0.95	1	1.05	1.1
Channel width coefficient	5.436	5.738	6.04	6.342	6.644
Channel width area exponent	0.2331	0.24605	0.259	0.27195	0.2849
Scenario parameters					
Bankfull discharge recurrence interval	2.25	2.375	2.5	2.625	2.75
Gully age (years)	90	95	100	105	110
Maximum bedload depth (m)	1.35	1.425	1.5	1.575	1.65
Uniform bank height (m)	1.8	1.9	2	2.1	2.2
Hillslope Delivery Ratio	0.045	0.0475	0.05	0.0525	0.055
Sediment bulk density (t/m^3)	1.35	1.425	1.5	1.575	1.65
Floodplain settling velocity (m/s)	9.0E-07	9.5E-07	1.0E-06	1.05E-06	1.1E-06
Bank erosion coefficient	1.8E-05	1.9E-05	2.00E-05	2.1E-05	2.2E-05
Sediment transport capacity coefficient (k1)	504	532	560	588	616
Minimum link length (m)	1800	1900	2000	2100	2200
Proportion of suspended sediment	0.45	0.475	0.5	0.525	0.55
Hydrologic parameters					
Runoff Coefficient: a	0.9216	0.9728	1.024	1.0752	1.1264
Runoff Coefficient: b	0.585	0.6175	0.65	0.6825	0.715
Sigma daily: c	0.3609	0.38095	0.401	0.42105	0.4411
Sigma daily: d	0.7776	0.8208	0.864	0.9072	0.9504
Bankfull discharge: e	5.4	5.7	6	6.3	6.6
Bankfull discharge: f	0.0018	0.0019	0.002	0.0021	0.0022
Median overbank flow: g	0.7812	0.8246	0.868	0.9114	0.9548
Median overbank flow: h	0.6939	0.73245	0.771	0.80955	0.8481

Table 2 shows the parameters of the SedNet model included in the sensitivity analysis carried out in this study. The parameters have been grouped into three categories, these being “configuration” (4 parameters), “scenario” (11 parameters) and “hydrologic” (8 parameters) in accordance with the model structure and processing steps involved in running it. Baseline values of each parameter and -10%, -5%, +5%, and +10% changes from the baseline values are also given. For detail description of the parameters, the reader is referred to Wilkinson *et al*. (2004).

The interpretation of the sensitivity index determined from Equation (1) is as follows:

- a value of zero indicates that the model is not sensitive to changes in the parameter;
- a negative value indicates that the model output decreases as the parameter increases;
- a positive value indicates that the model output increases as the parameter increases; and
- the model is the most sensitive to parameters with high absolute value sensitivity indices.

It is expected that results of the local sensitivity analysis of the SedNet model may vary from catchment to catchment and from scenario to scenario within the same catchment. Therefore, it needs to be carried out for each specific catchment and scenario of interest.

5. RESULTS AND DISCUSSION

Figure 5 shows sensitivity indices plotted as a function of percentage change in parameter values. As can be seen from Figure 5, total suspended sediment is only sensitive to six of the 23 parameters included in the sensitivity analysis. All other parameters were found to have zero or close to zero sensitivity index values which resulted in corresponding lines in Figure 5 overlapping with the S = 0 line (the broken line), and were subsequently removed from the plot in this figure. Sediment load increases as four of the parameters increase. These are bankfull discharge parameter (f), hillslope sediment delivery ratio (HSDR), bankfull discharge recurrence interval, and bankfull discharge parameter (e). On the other hand, increase in runoff coefficient

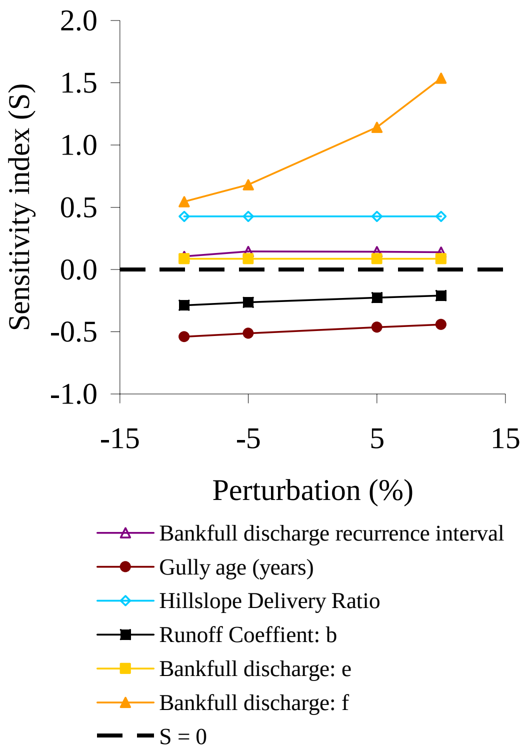

Figure 5. Plot of sensitivity indices as a function of % change in parameter values. Note that, for the purpose of readability, only parameters to which total sediment export is sensitive are included in this plot. Other parameters included in this sensitivity analysis have a sensitivity index of zero (or close to zero) and overlap with the S = 0 line.

parameter (b) and gully age result in reduction in total sediment.

When assessed against the four functions of sensitivity analysis listed in the introduction section, the results indicate that (i) model calibration can be accelerated and planning of future search and field work be focused by targeting only those parameters to which the model is the most sensitive, (ii) the model's response to representative variations of parameter values and boundary conditions is realistic, (iii) the model concept is sufficiently sensitive to represent the natural system's behaviour, and (iv) the model could be reduced to its essential structures by fixing parameters to which it is not sensitive.

It follows from the interpretation of the sensitivity indices as defined in Section 4, that total sediment export is hardly sensitive to all configuration, five scenario, and four hydrologic parameters. This implies that ±10% and ±5% changes in these parameters do not change total sediment export estimated by SedNet. On the other hand, total sediment export is relatively highly sensitive to bankfull discharge exponent (f), gully age, hillslope sediment delivery ratio, runoff coefficient parameter (b), and bankfull recurrence interval. Therefore, effort in obtaining realistic parameters should be directed towards these six parameters rather than those to which the output of interest is not sensitive.

As shown in Table 2, the current model assumes baseline values of 0.002 and 0.65 for bankfull discharge exponent (f) and runoff coefficient (b), respectively. However, these values can be determined by calibration against monitored stream flow data. Given the importance of these parameters, effort should be directed towards the collection and collation of quality stream flow data.

With regard to gully age, a baseline value of 100 years (Wilkinson *et al*., 2004) has been assumed. However, it is likely that this value is spatially variable depending on such factors as land use, soils, climate, and cover. Hence, it is important to determine a more plausible value for this parameter for each catchment, or a spatially variable input for a catchment, which would involve change in the algorithm of the model.

Hillslope sediment delivery ration (HSDR) is another important parameter that needs attention. The current default value of HSDR in SedNet of 0.05 (Wilkinson *et al*., 2004) has been used as the baseline value in the sensitivity analysis. However, it is recognized that HSDR is spatially variable (Lu *et al*., 2003). Therefore, future research should be directed towards developing a methodology that accounts for this spatial variability.

Bankfull recurrence interval is another parameter that has been found to be important in terms of its effect on total sediment export estimate from the SedNet model. The SedNet default value of bankfull recurrence interval of 2.5 years (Wilkinson *et al*., 2004) used as a baseline value in this study is not considered to be suitable for all climatic and catchment conditions. Therefore, more appropriate value of this parameter needs to be determined using historical data and appropriate statistical tools for each catchment.

Figure 6 shows the spatial pattern of suspended sediment load exported to the catchment outlet. Although total sediment export (bed load plus suspended load) has been used for the sensitivity analysis conducted, SedNet only produces a map of suspended sediment contribution to a point of interest. However, it has been found in this study (result not shown because of space limitation) that about 90% of the total sediment from the Burnett catchment is exported as suspended sediment. Therefore, Figure 6 can be used to highlight some of the spatial issues associated with the sensitivity analysis.

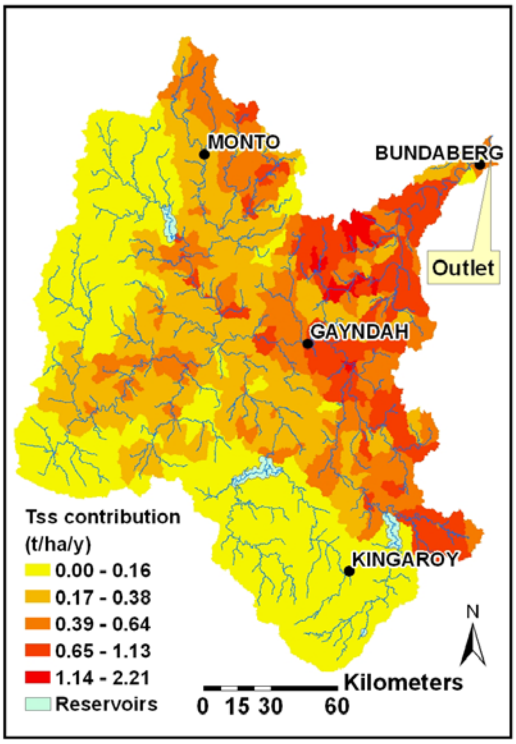

Figure 6. Map of total suspended load contribution of the Burnett catchment to the coast

It is clear from Figure 6 that only some parts of the catchment contribute to the majority of the suspended load export to the coast. It is likely that the sensitivity of the model to parameter perturbations may vary depending on the spatial scale at which the model output is captured.

The spatial issues highlighted here are consistent with the findings of Newham *et al.* (2003) who showed that the model is more sensitive at larger spatial scales than at smaller spatial scales. It is also to be noted that parts of the catchment upstream of reservoirs have little contribution to sediment at the catchment outlet due to sediment entrapment in these structures.

6. CONCLUSIONS

The results of this simple local sensitivity analysis have been useful in identifying parameters to which the SedNet model output of interest (total sediment export) is the most sensitive and those that have negligible or no influence at all. This information is vital in focusing our attention on those parameters to which the model is the most sensitive. Out of the 23 model parameters included in the sensitivity analysis, only changes in six have been found to significantly influence total sediment export at the outlet of the Burnett catchment.

The local one-at-a-time sensitivity analysis, adopted here (a) did not include parameter interactions, (b) did not include model output uncertainty due to uncertainty in spatial input datasets, and (c) only investigated four changes in each parameter value out of thousands of possibilities. These constraints were brought about by the fact that it is not computationally feasible to do a global sensitivity analysis in the current structure of the model. A structural change in the model and better computing resources would allow future research to address the above constraints by using a more robust sensitivity analysis.

Despite its limitations outlined above, the local sensitivity analysis adopted in this study has been valuable in quickly identifying parameters the SedNet model is most sensitive to, and therefore, direct monitoring efforts towards obtaining realistic values for these parameters. As the results of the sensitivity analysis may vary from catchment to catchment and from scenario to scenario within the same catchment, we recommend that it be included as an optional tool in SedNet.

7. ACKNOWLEDGMENTS

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