Testing Output Quantities and Spatial Patterns of a Catchment-Scale Stream Pollutant Model Against Collateral Studies

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Abstract: This paper describes the methods used to test the outputs of the catchment-scale stream pollutant model, SedNet, in the upper Murrumbidgee River catchment. Results from the SedNet model were compared with collateral studies to assess the performance of the model for predicting both the spatial patterns and quantities of sediment yield. The quantities of sediment export were assessed at various scales through comparisons with: a compilation of published sediment yield data, a detailed subcatchment sediment budget based on farm dam sedimentation and valley floor stratigraphy studies, a reservoir sedimentation study and suspended sediment loads estimated from observed sediment concentration and streamflow data modelled using the rainfall-runoff model IHACRES. The patterns of sediment predicted using SedNet were assessed through comparison with radionuclide and magnetic sediment tracing techniques. There was reasonable agreement between the outputs of the SedNet model with collateral studies, both in terms of the quantities and patterns of sediment source and transport estimated. Further testing is required before more definitive conclusions can be reached.

Keywords: *Water quality; Sediment modelling; Model testing.*

1. INTRODUCTION

Appropriately constructed pollutant export models can help set management priorities for catchments, identify critical pollutant source areas, and are important tools for developing and evaluating economically viable ways of minimising surface water pollution. This paper describes the methods used to test the outputs of the catchment-scale stream pollutant model SedNet, in the upper Murrumbidgee River catchment. Results from the SedNet model are compared with collateral studies to assess the performance of the model for predicting both the spatial patterns and quantities of sediment yield.

Two important components of evaluating and improving pollutant load modelling are to compare and assess accuracy through comparison with collateral knowledge; and to assess sensitivity of changes in model inputs and components on a model's output. In the case of the SedNet model, accuracy assessment is required to assess confidence in both the predicted total sediment loads and also in the patterns of sediment transport. Comparison with collateral knowledge can also assist sensitivity analysis by enabling realistic bounds to be attached to model outputs needed for identification of uncertainties in model inputs and parameters. Newham et al. (in press) describes sensitivity analysis on the SedNet model.

According to Wasson (1994) the construction of sediment budgets from observed data for large basins is an ideal against which to assess the success of models of basin wide sediment transport. Potential sources on which to base the comparison include but are not limited to:

- loads modelled using in-stream pollutant concentration and streamflow data;
- sediment budgets constructed using a variety of reconnaissance techniques, for example: aerial photo interpretation, assessing historic change in stream cross sections, strategic establishment of erosion pins etc., for example Reid and Dunne (1996);

- reservoir sedimentation studies, for example United States Army Corps of Engineers (1994); and
- magnetic and radionuclide sediment tracing techniques, for example Wallbrink et al. (1998).

2. SEDNET MODEL

SedNet, the Sediment River Network Model, is a steady state model used to estimate the propagation and deposition of sediment from riverbanks, gully and hillslope sources in a river network. Outputs from SedNet are intended to address catchment-scale resource management questions such as determining which subcatchments dominate sediment supply, where sediment is stored (deposited), the proportion of sediment supplied by each of the erosion processes and, importantly, how management change may alter downstream sediment yields (Newham et al. in press). SedNet is fully described by Prosser et al. (2001).

The basic unit of calculation of SedNet is a river link each of which has an internal catchment from which sediment may be delivered by hillslope and gully erosion submodels. Using physical attributes associated with the link, streambank erosion, floodplain deposition and sediment transport capacity submodels are used to estimate the propagation of sediment through the river network.

2.1. Upper Murrumbidgee Application

SedNet has been applied to the upper Murrumbidgee River catchment as a tool for improving land and water management and for investigating further development of the model. The upper Murrumbidgee application is described in Newham et al. (in press). First order streams typically had contributing areas of 25-50km^2 and stream reach lengths of approximately 10km.

3. SEDIMENT LOAD COMPARISONS

Five separate comparisons are presented in this paper. The first is a comparison between the outputs of SedNet with load estimates from a variety of sources compiled in the publication of Wasson (1994). The second comparison evaluates the pattern of sediment transport predicted by SedNet against data from the sediment tracing study of Wallbrink and Fogarty (1998). The third compares a detailed small-scale sediment budget with outputs from the SedNet model. The reservoir sedimentation study of Wasson et al. (1999) is then compared with the outputs of SedNet in the fourth comparison. The final comparison is between modelled suspended sediment load estimates from Burra and Jerrabomberra Creeks with corresponding estimates from SedNet.

3.1. Southern Upland Sediment Yield Comparison

Wasson (1994) has collated sediment yield data from a variety of sources for the southern uplands of Australia in order to build on previous compilations of sediment load made by Olive and Walker (1982) and Olive and Rieger (1986). Additional data includes published and unpublished load estimates from sedimentation studies of farm dams and reservoirs, mining sites and tracer-based studies. The data used in the analysis of Wasson (1994) are primarily sourced from suspended load estimates but combine bedload estimates in some instances. It is argued by Wasson (1994) that the exclusion of the bedload fraction introduces uncertainty that is small relative to other uncertainties. Excluding the bedload component leads to an underestimate of the total stream sediment load and may result in a comparison showing poor agreement.

Figure 1 shows a plot of the data on which Wasson (1994) based his analysis and the associated regression line. Approximately 40% of the reported sediment yield data of Wasson (1994) are sourced from the upper Murrumbidgee catchment. The bulk of these are the yields from small-scale farm dam sedimentation studies. The cluster of the dam sedimentation data can be seen in the region of the graph corresponding to catchment areas of 0.01 - 1 km^2. Comparatively few of Wasson's data points are from studies at scales similar to those in the application of the SedNet model. Also shown on the same figure are the simulated total sediment outputs from each reach of the SedNet application in the upper Murrumbidgee catchment under current management conditions.

The outputs from SedNet for the upper Murrumbidgee system show similar trends to the results compiled by Wasson (1994). However, it can be observed in the plot that the majority of the predicted outputs from reaches of SedNet lie above the regression line fitted to the Wasson (1994) data. This is because either the SedNet estimates are on average too high, or more likely, neglecting the bedload component of the sediment budget has led to an underestimate by Wasson (1994).

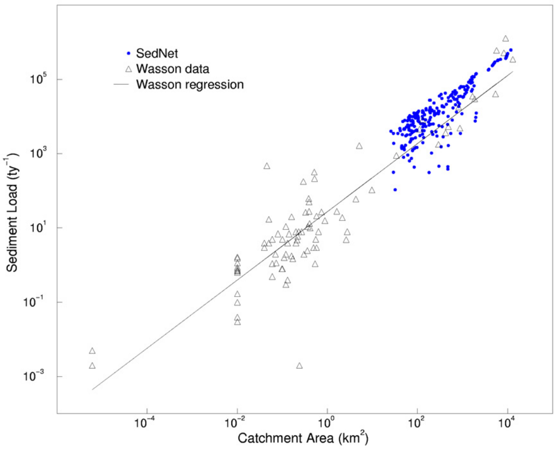

Figure 1. Mean annual sediment yield versus catchment area for the southern upland areas of Australia and SedNet load estimates for reaches of the upper Murrumbidgee catchment.

3.2. Radionuclide and Magnetic Sediment Tracing Comparison

Wallbrink and Fogarty (1998) have undertaken sediment tracing work in the Molonglo River subcatchment of the upper Murrumbidgee. Their research applied both magnetic and radionuclide tracing techniques at stream confluences to determine the relative contribution of sediment from each tributary.

Caution must be exercised when comparing the results of sediment tracing and the SedNet modelling. As with modelling, sediment tracing techniques are based on assumptions and are influenced by errors in measurement. Tracing results can be strongly influenced by individual sediment transport events that do not reflect the relative tributary supply over long time periods. In contrast, the steady state SedNet model attempts to effectively aggregate the influence of such events.

Tracing results from three common stream confluences are available for comparison with the results of SedNet. Wallbrink and Fogarty (1998) analysed two sediment size fractions. For the purposes of assessing the SedNet model, the Wallbrink and Fogarty (1998) <63µm fraction was compared with the SedNet suspended load, and the 125-250µm fraction with the bedload. Results of the comparison are presented in Table 1. The relative contributions from each of the stream confluences are presented.

Table 1. Comparison of relative contribution of stream confluences: Wallbrink and Fogarty (1998) tracing and SedNet modelling comparison.

Confluence	Suspended Load		Bedload	
	Tracing (%)	SedNet (%)	Tracing (%)	SedNet (%)
Ballalaba Creek	100±60	44	34±12	42
Yandygunula Creek	40±17	31	-	31
Hoskinstown Creek	38±21	41	0±10	41

The comparison presented in Table 1 shows general agreement between modelled results and sediment tracing estimates. With the exception of the bedload estimate for Hoskinstown Creek, all SedNet relative contributions are within the uncertainty estimated for the sediment tracing. These results give confidence that the SedNet model is reproducing the pattern of sediment transport, at least within the range of uncertainty of the sediment tracing at these sites. The results of the tracing comparison reveal nothing of the quantities of sediment transported by any of the tributaries.

3.3. Detailed Small-Scale Sediment Budget Comparison

A detailed sediment budget for the Jerrabomberra Creek subcatchment of the upper Murrumbidgee River has been published by Wasson et al. (1998). Data sourced from farm dam sedimentation surveys were used as the basis of calculating sediment yields for subcatchments of the Jerrabomberra Creek.

In constructing the sediment budget, Wasson et al. (1998) considered hillslope areas separately from channels and associated floodplains. For the analysis, the Jerrabomberra Creek catchment was subdivided on the basis of its stream network into subcatchments using a similar method to what is automated in SedNet. Data from sedimentation rate surveys of 50 farm dams (sourced from the publication of Neil and Galloway, 1989) were extrapolated using regression analysis across each of the subcatchments. The contribution of channel incision to the sediment budget was considered separately. These channel incision components of the sediment budget were estimated based on the stratigraphy of the valley floors and hillslope valleys (Wasson et al. 1998).

The post European settlement sediment budget of Wasson et al. (1998) was directly compared with the outputs of the SedNet model the for

Jerrabomberra Creek catchment. Meaningful comparison can only be made between the total hillslope erosion estimate, the sum of streambank and gully erosion and the total catchment load. Table 2 shows the comparison between the results of the SedNet application and the sediment budget. It was necessary to multiply the annual average outputs from the SedNet model to allow direct comparison with the work of Wasson et al. (1998). Annual average outputs were multiplied by the SedNet gully age parameter τ (100 years).

The data presented in Table 2 show that sediment inputs from gully and streambank sources are estimated within one order of magnitude for both approaches (1.1×10^6 and 7.2×10^6 for SedNet and Wasson et al. 1998, respectively). Hillslope erosion estimates for SedNet are higher, but again less than one order of magnitude than the corresponding estimate made by Wasson et al. (1998). Hillslope erosion data for the application of the SedNet model was sourced from continental scale mapping of Lu et al. (2001). Increasing the spatial resolution of the hillslope erosion modelling used in SedNet may result in better agreement with the estimate of Wasson et al. (1998).

Table 2. Comparison of SedNet and Wasson et al. (1998) sediment budgeting for the Jerrabomberra Creek catchment. All measurements are in tonnes.

Budget Element	SedNet	Wasson et al. (1998)
Gully erosion input	1.1×10^6	7.25×10^6
Streambank erosion input	2.9×10^4	
Total hillslope erosion	1.3×10^7	-
Hillslope erosion input	6.6×10^5	3.38×10^5
Total sediment input	1.8×10^6	-
In-channel and floodplain deposition	3.7×10^5	-
Suspended sediment yield	8.6×10^5	-
Bedload sediment yield	5.6×10^5	-
Total sediment yield	1.4×10^6	3.42×10^6

The total sediment yield predicted by Wasson et al. (1998) is approximately 2.5 times higher than the yield predicted using the SedNet model. More careful consideration of the time periods of each approach would result in closer agreement.

In the upper Murrumbidgee application of the SedNet model the Jerrabomberra Creek catchment was modelled as only two links in the stream network. A comparison at this scale is at the lower limit of the SedNet model in terms of spatial resolution. On the other hand, the scale of the detailed sediment budgeting of Wasson et al. (1998) is approaching its upper limits. Without substantial investment, construction of a similarly detailed sediment budget would be impractical at the scale of the upper Murrumbidgee catchment. Certainly such detailed studies would be not be possible at continental scales.

Caution needs to be exercised when drawing conclusions from this particular comparison. The scale of the comparison is very small for the SedNet model and potentially influenced greatly by data inputs such as gully erosion mapping and hillslope erosion modelling. A second, potentially significant factor influencing the results is the use of the gully age parameter to sum the results of the SedNet modelling. Summing the SedNet modelling over a longer period would result in the outputs showing closer agreement.

3.4. Dam Sedimentation Comparison

Reservoir sedimentation data are often useful for checking modelled estimates of sediment yield (Reid and Dunne, 1996). Wasson et al. (1999) have compiled an estimate of the total sediment input to the Burrinjuck Reservoir since its construction in 1912. Their budget is based on analysis of the distribution of sediments on the bottom of the reservoir. The approach of the study was to combine information captured from aerial photography (taken at low water levels) with field measurements of sediment thickness (also collected at low water levels) and data collected remotely in submerged areas using an adapted oceanographic seismic profiler. These data sets were used to produce both a map of the distribution of accumulated sediment in the reservoir and to estimate the total volume of sediment delivered since construction. Wasson et al. (1999) estimate that 2.26×10^7 m^3 of sediment have been deposited in the reservoir since construction. Using a sediment bulk density of 1.5 tm^{-3} this equates to a total deposition of 3.39×10^7 t. As the bulk of the data on which Wasson et al. (1999) based their calculations were collected in 1985, the deposition has occurred over approximately 73 years. Assuming a sediment trap efficiency of 100% as Wasson et al. (1999) have, the annual average sediment delivery over that period is 4.6×10^5 ty^{-1}.

The total SedNet estimate for sediment delivery to Burrinjuck Dam from its catchment is 2.15×10^5 ty^{-1} and 4.13×10^5 ty^{-1} for the bedload and suspended loads respectively. This represents a total of sediment supply of 6.3×10^5 ty^{-1}.

The results from SedNet and from the Wasson et al. (1999) study show reasonably close agreement. The result is encouraging and shows that at large scales the SedNet estimates of sediment export are reliable.

3.5. Suspended Load Estimates

The final comparison presented in this paper is between outputs of the SedNet model and suspended sediment exports estimated for two upper Murrumbidgee subcatchments (Burra and Jerrabomberra Creeks). The Burra and Jerrabomberra Creek subcatchments have areas of approximately $68km^2$ and $121km^2$ respectively. Both catchments are used for extensive grazing and limited horticultural production.

Suspended sediment export was estimated through use of a linear regression method to relate suspended sediment concentration to streamflow. A regression-based method was selected for use because of the limited number of samples on which the analysis was based and the need to extrapolate beyond the period of data collection. Event-based water quality data from several separate flow events across a range of hydrologic conditions was used to develop the relationship with streamflow. The IHACRES rainfall-runoff model (Jakeman et al. 1990; Evans and Jakeman 1997) was used to simulate daily streamflow for both catchments over a ten year period beginning at the start of 1988. The IHACRES models were fully calibrated against observed streamflow data at both sites. A full description of the techniques used to estimate suspended sediment loads is made in Newham (2002).

The suspended sediment loads calculated for the Burra and Jerrabomberra Creek subcatchments were 3.0×10^3 ty^{-1} and 3.1×10^3 ty^{-1} respectively.

The corresponding estimate of the suspended sediment fraction at these two sites from the SedNet model is 7.4×10^3 ty^{-1} and 8.6×10^3 ty^{-1}. In relative terms the suspended sediment load calculated for Burra Creek was 97% of the load for Jerrabomberra Creek over the same time interval. For the SedNet model the sediment load of Burra Creek was estimated to be 86% of the load of the Jerrabomberra Creek subcatchment.

Results show general agreement between the SedNet model and the load estimates in terms of the relative contribution from each subcatchment. The total loads predicted are however lower than the load predicted by SedNet. An explanation to account for the variation is that the comparison is influenced by the time periods of the load estimation. In the case of the SedNet estimates, the modelling time period is 100 years whereas for the load calculations, the period was only 10 years. The loads calculated are based on recently sampled concentration data (mid 1990's) and thus have declined from the peak of sediment yields that followed European settlement as described by Wasson et al. (2000). Loads are also influenced by the prevailing climatic and hydrologic conditions at the time of sampling.

4. DISCUSSION AND CONCLUSIONS

Accuracy assessment is an important component of evaluating pollutant load modelling techniques. This paper has presented a comparison between outputs of the SedNet model with collateral knowledge from five separate pollutant load studies. In each case, careful consideration was made of the inherent limitations in comparing modelling techniques.

The comparison presented in Section 3.1 shows that there is reasonable agreement between outputs of the SedNet model with the Wasson (1994) compilation of sediment yield data from the southern uplands region of Australia. In Section 3.2, it was seen that the patterns of sediment loads estimated using the SedNet model show agreement (within the uncertainties of sediment tracing techniques), for a limited number of sites in the Molonglo River subcatchment. The third comparison, described in Section 3.3, showed that at very small scales relative to the overall application of the SedNet model, outputs do not show close agreement with a detailed sediment budget constructed by Wasson et al. (1998). However, problems with the time periods used for the comparison and the different scale of each of the applications are thought to have influenced the result. At large scales relative to the described SedNet application, the model shows close agreement with an estimate of reservoir sedimentation made by Wasson et al. (1999) (see Section 3.4). The final comparison of the SedNet model with the results of the load calculations (Section 3.5) shows that SedNet predicts the relative source strength of the catchments well. The total loads may be underestimated because of the use of daily data and different time periods used for the comparison.

From the comparisons it can be cautiously concluded that the SedNet model is generally performing well at predicting both the patterns and quantities of sediment source and transport at catchment scales. Further testing is required before more definitive conclusions can be reached.

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