Use Of Sednet Model To Establish Sediment Export Targets For Catchments Of The Wet Tropics Draining To The Great Barrier Reef

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EXTENDED ABSTRACT

Some of the inshore reefs of the Great Barrier Reef are showing impacts consistent with a decline in water quality as a result of increased sediments and nutrients. The Wet Tropics covers approximately 2.2 million hectares and includes 91 percent of the Wet Tropics World Heritage area. The climate and geomorphologic conditions of the region are unique in Australia and generally result in fast flowing streams with high discharge rates into the GBR. The exception is the drier Herbert River.

SedNet is a regional scale model for estimating long-term annual sediment budgets. It identifies patterns in erosion processes and the delivery and movement of sediment in surface water. SedNet can assess management actions and priority areas to maintain or improve water quality. This paper focuses on 8 northern catchments, from the Daintree to the Herbert. Modelling of sediment generation and transport with SedNet has previously been completed in catchments from the Daintree in north Queensland to the Burnett-Mary 1300 km south. The aim of the study was to update previous SedNet modelling, improve local modelling expertise and assist the Far North Queensland Natural Resource Management board to;

- Establish water quality targets to meet requirements of the Reef Water Quality Protection plan

- Predict if management actions will reduce sediment generation and delivery to the GBR.

Improved data layers such as finer scale digital elevation model, land cover and land use are being used, building on previous modelling.

The modelling indicated that hillslope erosion was the dominant source of sediment in the Wet Tropics catchments. It contributed 1160 kt/yr or 59% of the sediment supply. A total of 1610 kt/yr or 82% of the suspended and bed load sediment that was generated in sub-catchments was exported to the coast. The Herbert River had the largest catchment and contributed 35% of the total sediment load to the end of catchment (490 kt/yr). The export of sediment to the coast per unit of land area was highest for Mossman and Russell-Mulgrave catchments; 120-125 t/km^2. The sub-catchments that delivered the highest loads to the coast were found in the Russell-Mulgrave and Johnstone catchments (120 and 100 t/km^2, respectively). The 10 sub-catchments that contributed the highest suspended and sediment loads to the coast occupied only 5% of the catchment area but contributed 11% of the sediment to the coast.

Simulations of improved management of sugarcane and bananas resulted in a reduction of 10% (144 kt/yr) in suspended sediment export to the coast and 14% in hillslope erosion. The conversion of sugarcane to grazing and of dairy to beef cattle also resulted in a total reduction of suspended sediment to the coast of 10% (138 kt/yr) and reduced hillslope erosion by 13%. Restoration of riparian vegetation in 30% of river links (49 km) resulted in a 5% (73 kt/yr) reduction in suspended sediment to the coast.

The regional scale conclusions of this study have generally been accepted by the Board. However, some concerns have been raised about the accuracy of hillslope and bank erosion at some local scales. Model validation in the near future may resolve this issue.

The Board will consider these SedNet modelling results along with other data and information when meeting the requirements of the Reef Water Quality Protection.

1. INTRODUCTION

Some of the inshore reefs of the Great Barrier Reef (GBR) are showing impacts consistent with a decline in water quality as a result of increased sediments and nutrients (Furnas 2003). The Wet Tropics covers approximately 2.2 million hectares and includes 91 percent of the Wet Tropics World Heritage area. The climate and geomorphologic conditions of the region are unique in Australia and generally result in fast flowing streams with high discharge rates into the GBR, the exception is the drier Herbert catchment.

The Sediment and River Network (SedNet) Model was developed for the National Land and Water Resources Audit (NLWRA, 2001), to calculate sediment and nutrient budgets for much of Australia, including catchments draining to the GBR. This work was has been refined in the Wet Tropics by Brodie *et al.* (2003), Bartley *et al.* (2003) and Bartley *et al.* (2004). SedNet is a regional scale model for estimating long-term annual sediment budgets. It identifies patterns in erosion processes and the delivery and movement of sediment in surface water. SedNet can assess management actions and priority areas to sustain or improve water quality.

A short-term catchment modelling project was developed to assist regional bodies in the GBR catchment region with target setting under the Reef Water Quality Protection Plan (RWQP 2003) (Action H1). Objectives of this project include the development and improvement of regional sediment and nutrient budgets with the SedNet and ANNEX (Annual Network Nutrient Export module) models. A major communication component delivered modelling results and raised awareness on the strengths and limitations of modelling.

This paper focuses on 8 northern catchments, from the Daintree to the Herbert. The aim of the study was to update previous SedNet modelling, improve local modelling expertise and assist the Far North Queensland Natural Resource Management (FNQNRM) board to;

(a) Establish water quality targets to meet requirements of the RWQP plan; and

(b) Predict if management action targets will achieve significant reductions in sediment generation and delivery to the GBR.

A current condition sediment budget was initially completed and then various scenarios of changes in land use management and riparian vegetation targeted to reduce hillslope and bank erosion were developed. Scenarios were developed in consultation with FNQNRM and experienced industry representatives to reflect realistic changes to land management. This paper focuses on results from the sediment budget, in particular the contribution of suspended sediment to the coast. For the purpose of this paper, 'to the coast' means to where the river meets the estuary.

2. METHODS

The SedNet User Guide provides an overview of the model, which is based on a river network defined from a digital elevation model (DEM) (Wilkinson *et al.* 2004). SedNet divides up the river network into links, which form the basic unit of calculation for sediment and nutrient budgets. The floodplain extent is calculated from a floodplain grid. Each river link has a start and a finish node and its own defined sub-catchment. Sediment budget calculations are attached to each link in the river and stored in a database. For each link, SedNet calculates mass balance budgets for suspended sediment, bed load sediment, nitrogen and phosphorus. Once this configuration is set up, the user can create a scenario, which contains datasets, parameters and results associated with a catchment condition.

The flow component requires long-term flow records, grids of rainfall and potential evapotranspiration. The flow module calculates several flow attributes such as mean annual flow, bankfull flow and a runoff coefficient. Sedmodel computes the remainder of the budget, incorporating the stream network, spatial data and flow and essentially moves the sediment across the landscape and through the channels onto the floodplain or exports the sediment and nutrients to end of catchment.

Windows-based SedNet version 1.4.1 was used in this project. More detailed information on the methods and algorithms used in SedNet can be found in Prosser *et al.* (2001). This project was designed to update and improve the work of Brodie *et al.* (2003). Input datasets and parameter values that are different to Brodie *et al.* (2003) for the Wet Tropics region are outlined.

A 100x100m horizontal grid DEM was used to derive topographic attributes including the stream network, sub-catchments and the slope of each river link. The low variation in topography for much of the coastal floodplain resulted in parts of the SedNet river network not spatially corresponding with 1:100,000 topographic drainage patterns. To overcome this problem, coastal streams from the 1:100,000 drainage data were "burned" into the DEM to more accurately represent floodplain drainage.

Applying a minimum drainage area threshold of $30km^2$ with a minimum first order link length of 1km, resulted in a total of 436 sub-catchments averaging at $47km^2$. Many of the small coastal streams draining directly to the coast were not defined in the river network and therefore not modelled. The proportions of each land use category not modelled (a total of $1160km^2$, or 6% of the total area) include, marsh/wetland & coastal mosaic (43%), urban (13%), and other (12%) land uses (other includes rural residential and intensive animal production).

Table 1. Land use, C factors and land use as % of total area

Land use	C factor	% of total area
Mining	0.070	0.1
Perennial horticulture	0.056	1
Sugarcane	0.056	9
Other agriculture	0.056	1
Grazing (upper Herbert)	0.030	26
Cleared	0.025	2
Grazing (Wet Tropics)	0.016	15
Dairy	0.010	2
Dry sclerophyll	0.010	11
Wet sclerophyll	0.008	0.5
Rainforest	0.006	29
Urban	0.003	1
Other	0.003	0.5
Coastal mosaic	0.001	1
Marsh/wetland	0.000	1
Water	0.000	1

Hillslope erosion was estimated using the Revised Universal Soil Loss Equation (RUSLE) Renard *et al.* (1997). The RUSLE calculates mean annual soil loss (HE_x, t/ha/yr) derived from 6 factors, rainfall erosivity (R), soil erodibility (K), slope gradient (S), slope length (L), ground cover (C), and land use practice (P) [Equation 1].

$HE_x = RKLSCP$ Equation 1

S and L factors were derived from the 100m DEM, calculated using methods developed by Lu *et al.* (2001). The L factor was applied to cropping and set to 1 for all other landuses.

Land use data used to attribute C factors as part of the RUSLE grid was derived from the Queensland Land Use Mapping Program (QLUMP) (QNR&M, 2005), EPA Regional Ecosystems (versions 4.0 & 4.1) and Tracey and Webb (1975) vegetation mapping (Table 1).

The R factor was derived from daily rainfall surfaces (1915-2001) Brough *et al.* (2004). C factors estimated in previous studies Bartley *et al.* (2004) and Brodie *et al.* (2003) were used and attributed to the modified QLUMP land use data (see Table 1).

Riparian vegetation is one factor in SedNet that controls the rate of bank erosion. The proportion of riparian vegetation along each link is calculated by averaging the riparian condition over the link. Riparian vegetation condition was derived from the Statewide Landcover and Trees Study (SLATS) Derived 2001 Landcover Version 08.

Land cover was reclassified as a value of either zero or one. Zero represented degraded riparian vegetation and one represented healthy riparian vegetation. Woody vegetation, regrowth and orchards was classified as one and pasture (<12% foliage percentage cover) crops, settlements, or bare areas were classified as zero. The bankfull recurrence interval is also used to estimate bank erosion and was set to 1 in 4 years.

SedNet incorporates a number of hydrological parameters for the calculation of the sediment budget. SedNet derives these flow parameters from 39 unregulated gauges within the study region, all having a minimum of 12 years flow record. Coefficient of efficiency (E*) is an indication of the uncertainty in the fit for flow parameters and for this study range from 0.62-0.69. These flow parameters are then applied to each river link for the calculation of sediment erosion transport and deposition.

SedNet modifies the flow downstream of regulated dams, which were the Tinaroo Falls and Copperlode dams in the Barron catchment and Koombooloomba dam in the Tully catchment.

2.1 Scenarios

The scenarios generated were modifications to the input datasets. Scenario 1 simulated improving land management practice by increasing ground cover for sugarcane and bananas, by incorporating zero tillage for sugarcane and grassed interows for bananas. The C factor (part of the RUSLE grid) was changed from 0.056 for sugarcane and bananas (perennial horticulture) to 0.02. For this scenario, it is assumed that all perennial horticulture from land use data is bananas.

Scenario 2 simulated land use change by converting all sugarcane and dairy to beef grazing. Again this involved changing the C factor for sugarcane from 0.056 and the dairy C factor 0.01 to the C factor for grazing 0.016. Some dairy farms occur in the upper Herbert catchment and the C factor for grazing in this region is 0.05, to reflect drier climatic conditions. For Scenario 6, 20% of sugarcane from those sub-catchments with the highest hillslope contribution (t/km^2/yr) was converted to grazing.

Scenarios 3, 4 and 5 simulated riparian vegetation restoration to reduce bank erosion. Scenario 3 increased the proportion of riparian vegetation to 100% in the links that contributed the highest 30% of bank erosion to the coast. Scenario 4 was similar to scenario 3 and increased the proportion of riparian vegetation to 100% in the highest 50% of links while in Scenario 5 riparian vegetation increased the proportion to 100% for all links.

Scenario 7 simulated converting sub-catchments that contributed the highest 3% of hillslope erosion to the dominant natural vegetation state. The dominant vegetation type for the 13 sub-catchments was either rainforest or dry sclerophyll.

3. RESULTS

It is important to point out some uncertainties and guidelines for interpreting the results. SedNet aims to represent complex landscape processes through simple conceptual and empirical equations. The results are long-term annual averages and may not reflect sediment movement within a particular year. The relatively short flow record used (minimum 10 years) may not represent climate variability over a longer period. Moreover, the model reflects the quality of the input datasets and parameter values.

SedNet is a regional-scale planning tool, which can help to identify patterns in erosion rates, sediment fluxes and deposition. Therefore the results should be interpreted at a regional scale, not at the sub-catchment or individual link level. Using the RUSLE to estimate hillslope erosion as an example, because it is averaged over the sub-catchment, it is likely to be within 50-100% of the actual value depending on input data used (Wilkinson *et al.* 2004). Considerable uncertainty lies with using the RUSLE on forested areas and results should be treated with caution. Site inspections and comparisons with long-term water quality monitoring are essential to validate modelled results.

Base condition

Hillslope erosion was the dominant source of sediment in the Wet Tropics catchments. It contributed 1160 kt/yr which was 59% of the sediment supply (range 46-76% for individual catchments). Contributions from bank erosion and gully erosion were 575 kt/yr (29%) and 240 kt/yr (12%), respectively. A total of 1610 kt/yr or 82% of the suspended and bed load sediment that was generated in sub-catchments was exported to the coast after the deposition of 360 kt/yr. Most of the exported sediment was suspended sediment, as bedload was only 210 kt/yr. Of the sediment deposition, most occurred in the river network (190 kt/yr, 53%) and smaller amounts on the floodplain (130 kt/yr, 36%) and in dams (40 kt/yr, 11%).

The Herbert River had the largest catchment (9580 km^2 or 50% of the total area modelled) and contributed 35% of the total sediment load to the end of catchment (490 kt/yr). The Daintree, Johnstone and Russell-Mulgrave catchments contributed similar loads (175-230 kt/yr, 12-16% of total) while loads from Barron, Mossman, Murray and Tully catchments were 3-9% of the total (40-120 kt/yr).

There was a wide range in the export of sediment per unit of land area to the coast. It varied from 43 t/km^2 for the Barron to 120-125 t/km^2 in the Mossman and Russell-Mulgrave catchments. There were large differences in the S and R factors (RUSLE) for these catchments with extremes of sediment export per unit of land area. For the Barron and Mossman catchments, the mean S factors were 1.14 and 2.4, and R factors were 8,123 and 11,914, respectively. The RUSLE value for hillslope erosion was 4.6 t/ha in the Barron and 10.1 t/ha in the Mossman. Floodplain deposition was 40,000 t/yr in the Barron and 1190 t/yr in the Mossman, due to the influence of Tinaroo Falls and Copperlode dams in the Barron.

Figure 2 highlights the spatial patterns of the amount of fine sediment (kt/yr) contributed by each sub-catchment to the coast. The highest contributors tend to be focused in the Russell-Mulgrave and Johnstone catchments, with two also located inland in the Herbert catchment and one each on the Daintree and Tully catchments.

The 10 sub-catchments that contributed the highest suspended sediment loads to the coast occupied only 5% of the catchment area but contributed 11% of the sediment to the coast.

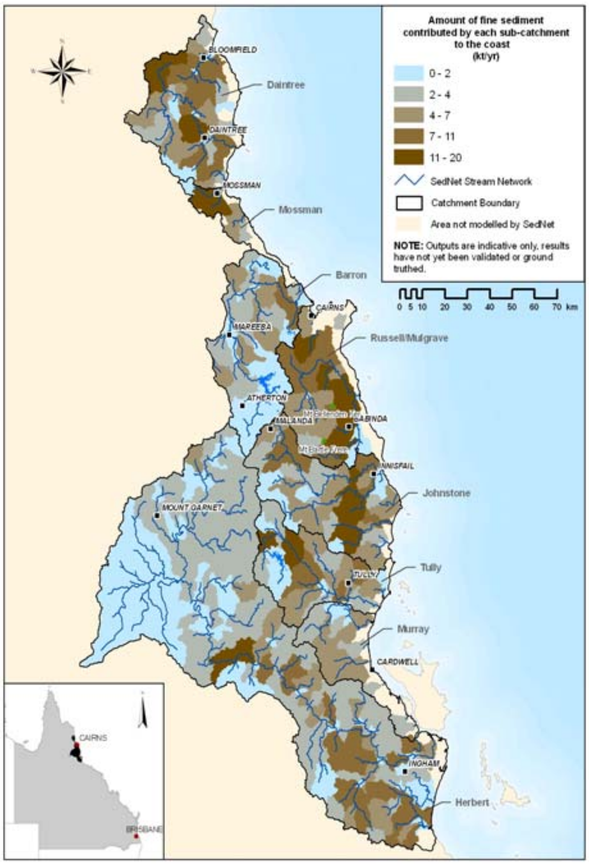

Figure 2. Contribution of total suspended sediment to the coast

Approximately 35% of the land use in these catchments was rainforest, with grazing, sugarcane and dry sclerophyll occupying 17% each.

For contribution of hillslope erosion to sediment export to the coast, some of the highest contributing sub-catchments occurred close to the coast in the Russell-Mulgrave catchment (10-17 kt/yr) (around Babinda). Other high contributing sub-catchments were located more inland in the Daintree (10-13 kt/yr) and Johnstone catchments (11-13kt/yr) and one in the Mossman catchment (11kt/yr).

Similarly, for the contribution of bank erosion to the end of catchment, some of the highest contributing sub-catchments occurred in the Herbert (7-15 kt/yr) and Russell-Mulgrave catchments (6-15 kt/yr). Other high contributing sub-catchments occurred in the Johnstone and Tully (7-9 kt/yr) and Mossman 7 (kt/yr).

Scenarios

Scenarios 1-2, 6 and 8 targeted reducing hillslope erosion, by decreasing the C factor in the RUSLE. Scenario 1, which simulated improved land management for sugarcane and bananas, resulted in an overall reduction of 10% (144 kt/yr) to suspended sediment export to the coast and reduced hillslope erosion by 14%. Greater reductions were seen in individual catchments with the highest reductions of suspended sediment in the Johnstone (19%) and Mossman (15%). Scenario 2 simulated land use change by converting sugarcane and dairy to beef grazing also reduced suspended sediment to the coast by 10% (138 kt/yr) and reduced hillslope erosion by 13%. Some catchments such as Mossman improved the most (17%) followed by Johnstone (14%) & Russell-Mulgrave (13%).

Scenarios 3-5 aimed to reduce bank erosion by increasing the proportion of good riparian vegetation. Scenario 3 increased the proportion of riparian vegetation to one for 30% of river links (49km), resulting in a 5% (73 kt/yr) reduction in suspended sediment to the coast. Individual catchments performed better with the Tully 12%, followed by the Mossman 10%, Johnstone 9% and Russell-Mulgrave 8%. Scenario 4 increased the proportion of riparian vegetation to one for 50% of river links (160 km), resulting in a 9% (125 kt/yr) reduction in suspended sediment to the coast. The reduction was highest in the Johnstone and Tully (19%), Russell-Mulgrave (15%) and the Mossman (10%) catchments.

In Scenario 5, the proportion of riparian vegetation was increased to 1 for all river links (3,200 km) and resulted in a 13% (183 kt/yr) reduction in suspended sediment to the coast. The reduction was highest in the Tully (24%), Johnstone (22%) and Mossman and Russell-Mulgrave (18%) catchments.

Scenario 6 also simulated land use change but to a targeted 20% of sugarcane to grazing. This scenario resulted in a reduction of 4% (53 kt/yr) to suspended sediment export to the coast, with an individual catchment improvement of 15% for the Mossman, Johnstone 8% and Russell-Mulgrave 7%. Scenario 8 also took on a targeted approach and converted <3% of disturbed land use back to the dominant natural vegetation state, resulting in a 4% (49 kt/yr) reduced load of suspended sediment to the coast.

4. DISCUSSION

A major objective was to assist regional NRM bodies to identify sub-catchments that deliver disproportionate quantities of sediment and nutrient to the Great Barrier Reef.

Table 3. SedNet sediment budget for the Wet Tropics catchments.

SedNet Sediment Budget	Catchment								
	Barron	Daintree	Herbert	Johnstone	Mossman	Russell-Mulgrave	Murray	Tully	Total
Total sediment supply (kt/yr)	160	205	740	320	50	260	70	180	**1,975**
Hillslope erosion (% of supply)	63	76	58	46	61	62	72	50	**59**
Bank erosion (% of supply)	21	23	18	46	39	36	22	47	**29**
Gully erosion (% of supply)	15	0	24	7	1	2	6	3	**12**
Suspended sediment export (kt/yr)	90	175	490	230	40	200	50	120	**1,405**
Suspended sediment export (% of total)	7	12	35	16	3	14	4	9	**100**
Catchment area (km^2)	2,160	1,980	9,580	2,260	320	1,670	890	1,640	**20,500**
Suspended sediment export (t/km^2)	43	88	51	101	125	120	59	75	**69**

There are many ways to use SedNet model outputs to allocate priority for on-ground control of sediment movement to rivers. On a total catchment area basis, the Herbert River is the largest and exports the most suspended sediment and bedload. For source of sediment, hillslope dominates with 59% of the total sediment generation, and as much as 74% of the load to the coast. Gully and bank erosion could be considered to be a low priority because they only contribute 7 and 19%, respectively, of the sediment delivered to the coast. However, there are biodiversity and recreation benefits from rehabilitation of such areas. Three catchments, Mossman, Russell-Mulgrave and Johnstone, had the highest sediment export per area when averaged across the entire catchment.

The highest sediment generation was produced by sugarcane and perennial horticulture (110 t/km^2). The sugarcane industry has adopted practices that have considerably reduced sediment generation, such as the use of green cane trash blanket harvesting by 98% of farms in the Wet Tropics. Further improvements in management are likely to have only a small impact on sediment generation rates. The main options are retention of trash and stool at the end of the last ratoon crop to provide protection to the soil surface over the wet season, and zonal tillage that disturbs only about 1/3 of the paddock for planting (which occurs only every 4-5 years) (D. Calcino, BSES, pers. com.). Beef and dairy pastures produced the lowest sediment (50 t/km^2) of disturbed land use. Rainforest sediment generation rates (80 t/km^2) reflect its location; that is generally in the steepest and wettest areas of catchments. In addition, the RUSLE factors are unlikely to be well calibrated for rainforest soils that are characterised by high organic matter, thick litter layer and very high infiltration rates, which correspond to low rates of runoff except in very intense rainfall.

For the scenarios examined, reductions in suspended sediment loads occurred only in catchments where sugarcane and bananas were located coupled with high unit per area ($t/km^2/yr$) estimates of suspended sediment export to the coast. For these reasons, the Johnstone followed by the Mossman and Russell-Mulgrave catchments performed the best.

The condition of riparian vegetation is only one component affecting bank erosion. For example, bank erosion rates were as high as 450 (t/km/yr) in the Herbert catchment where the riparian vegetation condition is also high (88% of links having a score of one). This is one reason why improving riparian vegetation in the model yields only a small improvement. The other reason is that bank erosion contributes only 29% of the total sediment exported.

The next phase of this project will be verification of SedNet output. This will use measured water quality data from the catchments including extrapolation of event data to annual load, alternative modelling outputs and the local expert knowledge of land managers.

The annual export of sediment from rainforest (110 t/km^2 across all catchments) is similar to that derived from modelling with HSPF in the Johnstone River (120 t/km^2, Hunter *et al.* 2001). However, loads for sugarcane and bananas in this study are approximately 25% of those calculated by Hunter *et al.* (2001). In comparison to earlier SedNet modelling by Brodie *et al.* (2003) in the Barron, Russell-Mulgrave, Johnstone, Tully and Murray catchments, these results are approximately 80% lower for both sediment generation and export. The mean RUSLE-derived hillslope erosion was 8.1 t/ha in the earlier work compared to 5.6 t/ha here. A major component of this difference is the S factor which reduced from 1.8 to 1.4. Initial investigation shows that slope from 100 m DEM picks up break in S better than the 250 m DEM (used in the previous work), especially in steeper country.

Improvements in the model outputs may be achieved by improvement of datasets, particularly USLE and measurement of the impact of riparian vegetation on bank erosion, and parameter values e.g. hillslope delivery ratio and bankfull discharge.

The regional scale conclusions of this study have generally been accepted by the Board. However some concerns have been raised about the accuracy of hillslope and bank erosion estimates at more local scales. Validation of modelled results and input datasets in the future will assist to resolve this issue. The Board will consider these SedNet modelling results along with other data and information when meeting the requirements of the RWQP.

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