Patterns of Erosion and Sediment and Nutrient Transport in the Douglas Shire Catchments (Daintree, Saltwater, Mossman and Mowbray), Queensland

A Report to Douglas Shire Council and the Department of the Environment and Heritage


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Executive Summary

One of the main aims of the Douglas Shire Water Quality Project (DSWQP) is to measure and monitor the sediment and nutrient loads for each of the four main catchments within the Shire (Daintree, Saltwater, Mossman and Mowbray). It is acknowledged, however, that the data obtained from the load monitoring program will not provide a reliable estimate of loads for at least 5-10 years. Therefore, the only practical framework to assess the patterns of sediment and nutrient transport across a complex area such as the Douglas Shire by September 2004 is to use a spatial modelling framework.

This report represents the results of SedNet modelling in the Douglas Shire Catchments. With support from the Australian Government’s Natural Heritage Trust (NHT) and Douglas Shire Council (DSC), this project was carried out to:

1. identify the major sources from which sediment and nutrients in rivers and streams of the Douglas Shire Catchments were generated;
2. determine the total sediment and nutrient loads for the Douglas Shire Catchments; and,
3. provide base-line data for use in the Douglas Shire Decision Support System which will allow the evaluation of best management practices (BMP's) for the shire and their impact on sediment and nutrient loads to the estuary.

The loss of sediment and nutrients from the land can degrade freshwater and marine ecosystems by reducing water quality and degrading aquatic habitat. It is also acknowledged that a loss of sediment and nutrients from agricultural landscapes can lead to a decline in the productivity of local farming systems. For individual catchments, a spatially-explicit understanding of both the magnitude of these sediment and nutrient losses from different parts of the landscape, and the erosional and hydrological processes controlling them, is essential to plan, implement and monitor improved land management practices with reduced impacts.

The Douglas Shire Catchments cover an area of approximately 1,850 km² and are characterised by complex patterns of geology, terrain, soils, vegetation type and land use, together with steep climatic gradients (especially for rainfall). There have been a number of studies investigating the ambient water quality within the Douglas Shire Catchments, and a review of the relevant aspects of this previous work is presented in this report. However, only a limited number of these studies have examined the major sources of sediment and nutrients, and fewer still have assessed these from a ‘whole of catchment’ perspective.

We used spatial modelling of the erosion, deposition, and transport processes that move sediment and nutrients within landscapes and streams to produce regional budgets for the Douglas Shire Catchments. These budgets map the main sediment and nutrient sources, as well as the patterns of deposition within the catchment. The resultant mean annual loads are calculated for streams across the catchment. The river budgets are modelled using a set of GIS-based programs known as SedNet. The sources of sediment considered are soil erosion by surface (hillslope) processes, riverbank erosion and cane drain erosion. Gully erosion was not considered in this project as it was pre-determined to be a negligible source of both sediments and nutrients. Hillslope, bank and constructed drain erosion processes, together with dissolved sources in diffuse run-off (e.g. fertiliser), are also the sources of phosphorus and nitrogen in the modelling. The model outputs are averages only, and are considered to represent the range of conditions experienced over a 100-year climate record. The use of averages constrains the relevance of the modelling to larger spatial scales (e.g. sub-catchments) and means that the results should not be used to extrapolate to sediment and nutrient loads at the individual property or farm scale. It is also important to note that the use of average figures for variables such as (ground) cover, means that the management practices of
individual landholders are not taken into consideration. In addition, suitable spatial and temporal data describing the level of cover on individual properties or sub-catchments does not currently exist; therefore average values were used. Subsequently, the results of this work must be applied with these limitations in mind.

The results of the modelling in the Douglas Shire Catchments demonstrate that hillslope (or sheet) erosion is the dominant source of sediment, contributing 65% of the total sediment load at the river mouth. Drain and stream bank erosion contribute 23% and 12%, respectively. The predominant sources of nitrogen (N) are in particulate form in the Daintree Catchment, and in dissolved form in the Saltwater, Mossman and Mowbray Catchments, as these last three catchments have higher areas under sugar cane relative to the size of the catchment. The predominant source of phosphorus (P) is the particulate form in all catchments. Both the N and P budgets are dominated by losses from forested areas that contribute large amounts of organic matter to the system, followed by cultivated cane lands and tree crop areas on the floodplain.

Sediment sources from the different land uses were estimated for the Douglas Shire. The main landuse contributing to the hillslope erosion budget are the rainforest and sclerophyll forest areas, as these areas make up 87% of the catchment landuse. However, on a per area basis fruit trees, sclerophyll forest, grazing and rural/residential are the highest contributors. However, the area occupied by some of these landuses need to be taken into consideration. For example, although fruit trees are the highest per unit contributor, they occupy less than 1% of the catchment. It is also worth noting that some of the landuse types that currently occupy the floodplain are, in pre-European terms, in a landscape ‘sink’ zone. That is, the floodplain would have been a major storage zone for sediments and nutrients that were transported from the upper catchment areas. The various activities related to some landuse types i.e. constructed drains and cleared areas now mean that the floodplain is serving as a sediment source.

Due to the lack of existing event based water quality data it was not possible to validate the reliability of the modelled results (as done for other catchments such as the Herbert River). It is anticipated, however, that as more data is collected from the water quality monitoring stations installed within the catchments in 2003, it will be possible to assess the modelled outputs.

*****Important notes for readers******

- The authors have made every attempt to use the best available data to estimate the sediment and nutrient loads for the Douglas Shire Catchments. However, it will not be possible to undertake a rigorous evaluation of the model results without long term measured load data from a range of sites and landuses within the catchments. Much of the data required to validate these models will need to be collected over the long term (> 3 years), and most of the data requirements are well beyond the life of this project. Therefore, until there are measured data from the various catchments and landuses within the Douglas Shire, the results from this report will remain as a first estimate of loads from these catchments only.

- An important distinction must be made between landuse and land practice. Landuse refers to the type of agriculture being used on a particular area of the catchment (e.g. sugar cane) and land practice refers to the type of management actions imposed on a particular landuse (e.g. trash blanketing). Land practice is NOT taken into consideration in this report, as data regarding the various land practices are not available. Also assessing land practice is currently beyond the scope of this model. Only ‘average’ conditions for any one landuse are incorporated.

- ‘Hillslope erosion’ actually encompasses all erosion from ‘surfaces’ whether they are on hills or on flat land. The term hillslope erosion is a global standard and is therefore used in this report, however, it represents all erosion that is not from gully, bank or drain erosion, i.e. flat land on the
floodplain will also be subject to hillslope erosion in that sediment and nutrients can move from the surface. In this context it is probably best to refer to this type of erosion as ‘sheet erosion’, however, we have left it as ‘hillslope erosion’ for consistency.

- This model is just one tool that can be used to assess land management change and needs to be taken into context with local knowledge and field data collected as well as other reports that have been produced in the area.

- *Sediments coming from the rainforest – can our current predictions be relied upon?*

The following notes explain why the current (March 2004) predictions of sediment movement from the forested portion of the Douglas Shire made by the SedNet model cannot be relied upon. Comparison of erosion rates and sediment yield between rainforest and other land uses (e.g. cane, grazing) using this model are therefore not appropriate. We are currently addressing this issue in SedNet using analysis of data from similar environments and from the monitoring program within the Douglas Shire.

The methods used to estimate hillslope erosion in the SedNet model are based on the RUSLE (Revised Universal Soil Loss Equation). The RUSLE is an empirical model developed using statistical techniques derived from analysis of runoff plot data from the American mid-west by Wischemeyer and Smith (1978) and are supported by Australian data compiled by Rosewell (1992). There are a number of problems with applying the RUSLE to the Douglas Shire conditions, and in particular, to non cultivated land surfaces such as forests. Some of the problems are listed below.

RUSLE assumes Hortonian overland flow. Hortonian overland flow is when the rainfall rate is higher than the infiltration rate of the soil, resulting in runoff. It assumes a non-saturated soil profile. There are two reasons that forest systems do not necessarily match the Hortonian overland flow model implicit in RUSLE:

1. Due to the porous nature and, hence, high infiltration capacity of many forest soils it is expected that the majority of the rainfall moves through the landscape as sub-surface flow;
2. In forest areas with shallow water tables, overland flow normally occurs as a result of soil saturation.

Based on the above points, the application of RUSLE to forest systems may not be appropriate for estimating soil loss.

A sediment delivery ratio (SDR) is often applied in situations where we have plot data that suggests that only a proportion of the sediments that are eroded from the landscape actually make it to the stream network. In this study we assumed a 10% sediment delivery ratio for all landuse types. However, it is possible that the SDR for rainforest systems is less than 1%.

The model assumes that soil erodibility is a constant;

In conclusion, our process understanding of how water and soil moves in forest systems is very poor, and subsequently *we may have grossly overestimated the amount of sediment moving from these systems*. Therefore, the results from this report, and from the forest systems in particular, should be used with great caution.

References:


Acknowledgments

This study was commissioned by the Douglas Shire Council using funds obtained from the Coastal Catchments Initiative Program within the Australian Government’s Natural Heritage Trust (NHT). This study further tests the application of sediment modeling approaches through the use of regional data sources. We acknowledge the hydrological data supplied by Neale Searle and Darren Alston (Mareeba) and Alan Hooper and Morgain Sinclair (South Johnstone) of the Queensland Department of Natural Resources and Mines hydrological section. Data was also supplied from John Russell (Queensland Department of Primary Industries), Allan Stafford (Mossman Agricultural Services), Brynn Mathews and Terry Webb (Queensland Environment and Protection Agency) and Peter Bradley (Douglas Shire Council).

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1. Introduction

This report presents a summary of the SedNet modelling work that was conducted to look at the major sediment and nutrient sources in the Douglas Shire Catchments (Daintree, Saltwater, Mossman and Mowbray). The loss of sediments and nutrients from a catchment can have impacts on the industries that use the land for farming and grazing (in terms of loss of productive nutrient rich soil), as well as impacts on downstream freshwater and marine ecosystems, such as the Great Barrier Reef World Heritage Area (GBRWHA). Sediment delivered to streams has several potential downstream impacts. High loads of suspended sediment, and the silts and clays that are carried in the flow, degrade water quality in streams, reservoirs and estuaries. This is a result of both the sediment itself and the nutrients that the sediment carries. High concentrations of suspended sediment reduce stream clarity; inhibit respiration and feeding of stream biota; diminish light needed for plant photosynthesis; make water unsuitable for irrigation and require treatment of water for human use. The export of high suspended sediment volumes to coastal areas and fragile marine environments such as in-shore reefs, and tidal flats can cause accelerated deposition, smothering aquatic habitats and increasing turbidity through re-suspension of the sediment. The general impacts of increased sediment and nutrients on stream systems have been well documented (e.g. Alexander and Hansen, 1986; ASCE, 1992) as well as on nearshore environments such as the Great Barrier Reef (e.g. Williams, 2001; McCulloch et al., 2003; Baker, 2003). It is also important to note that the suspended sediment loads of Australian rivers, and rivers in general, are supply limited (Olive and Walker, 1982). That is, rivers have a very high capacity to transport suspended sediment, and sediment yields are limited only by the amount of sediment delivered to the streams, not discharge of the river itself. Consequently, if sediment delivery increases, sediment yield increases proportionally. Therefore understanding where the major sediment and nutrient sources are within a catchment is a crucial step to understanding how to manage these pollutants in the future.

2. Background to project and aims of report

One of the main aims of the Douglas Shire Water Quality Project (DSWQP) is to determine the sediment and nutrient loads at the mouths of the four main catchments within the Douglas Shire (Daintree, Saltwater, Mossman and Mowbray). The most appropriate and rigorous way to estimate loads is to measure and monitor the sediment and nutrient loads over time. Monitoring of sediment and nutrient levels in each of the rivers is currently being carried out using a combination of automatic and manual sampling, however, it is acknowledged the data obtained from the monitoring will not provide a reliable estimate of loads for at least 5-10 years. Therefore, the only practical framework for determining the total loads, and for assessing the patterns of sediment and nutrient transport across a large complex area such as the Douglas Shire by September 2004, is to use a spatial modelling framework. In this report we present the results of SedNet modelling in the Douglas Shire to obtain load estimates for the Daintree, Saltwater, Mossman and Mowbray Catchments. The SedNet modelling will also provide the baseline data for underpinning the Douglas Shire Decision Support System which will allow the evaluation of best management practices (BMP’s) for the shire and their impact on sediment and nutrient loads to the estuary.

In this document we have:

(a) provided a brief description of the catchments of the Douglas Shire (Section 3);
(b) summarised previous research that has been conducted in the Shire related to sediments, nutrients and water quality (Section 4);
(c) described the theoretical background to the SedNet model and how it was used to evaluate the sediment and nutrient loads (Sections 5.1 and 5.2);
(d) described the specific data sets that have been used for the modelling (Section 5.4);
(e) described the results of the modelling work with respect to sediment and nutrient movement and delivery for the four major Douglas Shire catchments (Section 6);

(f) provided a discussion as how the results should be used and interpreted and where there is a need for further research (Section 6.5).

3. Description of Catchments

The Douglas Shire in Queensland's far north is made up of a number of sub-catchments including the Daintree River, Saltwater Creek, Mossman River and Mowbray River (Figure 1). The total catchment area for the four catchments sums to ~ 1850 km². The Daintree River Catchment is the largest catchment with an area of ~1332 km². Ninety-five percent of the catchment is undeveloped forest or wetland, 87% of which is within the World Heritage Area. Saltwater Creek has a catchment area of ~136km², of which 70% is forested, and 30% is under intensive farming on the coastal plain. Sugar cane and small-scale horticulture are the predominant land uses. Saltwater Creek is characterised by some of the largest rainfall quantities and intensities in the Shire, leading to an average annual rainfall of 2,591mm. Mossman River catchment, with an area of ~208km², includes the largest area of sugar cane in the Shire (4000 hectares), encompassing 20% of the catchment while another 78% is forested. Mossman township and the sugar mill are located within the catchment. Mowbray River catchment, with an area of 174km², is the driest catchment in the Shire, and much of the water flowing in this catchment moves within small coastal streams rather than in the Mowbray River itself. Port Douglas is the largest urban centre and is located within the Mowbray River Catchment. Most of the Mowbray catchment is forested (72%) with only small areas allocated for sugar cane and grazing. Overall, 78% of the Shire is included within the internationally significant Wet Tropics World Heritage.
4. Summary of previous research relating to water quality in the Douglas Shire Catchments

To date, most of the work related to the Douglas Shire Catchments has been confined to the two larger catchments, Daintree and Mossman. The Daintree Catchment, being at almost 10 times the size of the other catchments, has by far received the most attention in terms of water quality research and modelling of sediment and nutrient loads. The following section will summarise previous work in the shire that is relevant to understanding the major sediment and nutrient sources.
This is not meant as an exhaustive literature review, but to provide a general background to the major sediment and nutrient sources in the Douglas Shire Catchments.

A detailed study describing the condition of the streams, riparian and wetland habitats in the area is given in Russell et al., (1998). The main aim of this report was to provide baseline data to assist in the development of fisheries and fish habitat management strategies and to aid in the development of integrated catchment management plans. Results and data inputs from this study, in particular base line data on riparian condition, will be used in the sediment and nutrient modelling.

A study commissioned by the Douglas Shire River Improvement Trust, and carried out by GHD (1994), provides a good description of the general geomorphology, soils, climate, hydrology, landuse, vegetation and land degradation issues (amongst other things) within the Douglas Shire Catchments. It also provides a general description of the major sediment sources within the catchment, however, this information is qualitative in format and therefore is not particularly useful for the SedNet model. However, the descriptions provided by GHD (1994) will provide a useful cross check against the final model results. A more detailed description of the geology, soils and agricultural land suitability can be found in reports such as Murtha and Smith (1994) and Wilson (1991).

A number of existing reports also describe the major inputs from point source pollution (e.g. O’Brien, 2003; GHD, 1994). O’Brien (2003) provides a good summary of the major point sources pollution points including licensed discharges, industrial discharges, sewerage discharges, aquaculture discharges, water treatment discharges and urban stormwater runoff. However, without specific GIS data it is difficult to use this data directly within the model.

In terms of direct water quality measurements in the shire, there have been a number of specific water quality based projects in the catchments. QEPA conducted monthly base flow sampling at a number of sites in the Daintree and Mossman catchments between 1994-1999 (Moss et al., Draft). In this study they sampled for conductivity, temperature, pH, dissolved oxygen, turbidity, secchi depth, organic nitrogen, ammonia, nitrate plus nitrite, total nitrogen, total phosphorus, soluble phosphorus and chlorophyll-a. The results from the Daintree suggested that condition ratings for nearly all indicators at all sites were good, with moderate ratings for dissolved oxygen recorded at two sites. In the Mossman, all sites exhibit good condition ratings for most indicators, however, concentrations of nitrogen (oxidised nitrogen) were elevated at sites downstream of sugarcane areas.

Russell et al., (1998) also conducted water quality sampling (generally at base flow) in all four of the Douglas Shire catchments. In this study they sampled for dissolved oxygen, conductivity, temperature, pH, turbidity, total nitrogen and phosphorus, nitrate, ammonium and ortho phosphate. Measures of heavy metals and pesticides were obtained in previous studies (Russell and Hales, 1993; 1996). Overall, the results from this study suggested that the water quality in the catchments was ‘generally good’, although there were some early warning signs regarding acid sulphate soils in the lower parts of the Daintree. A basic study on the water quality (mainly phosphorus and nitrogen) of Mowbray Creek was also conducted by Rubin (1994), however, the detail and rigor of this work only provides preliminary or background data for this area.

Eyre and Davies (1996) and Eyre and Balls (1999) measured wet and dry season suspended sediment and nutrient concentrations in the Jardine, Annan and Daintree catchments. Eyre and Davies (1996) assessed the different export levels against the level of catchment disturbance and found that only mean particulate inorganic phosphorus and dissolved nitrate concentrations increased proportionally with the level of catchment disturbance. Mean dissolved nitrate appears to be the best indicator of the effects of catchment land use on the adjacent waterways (Eyre and Davies, 1996). In this study, the dry season result show that mean TSS concentrations were very low and similar in all three catchments. Mean TP concentrations were highest in the Daintree and lowest in the Jardine. In the wet season, mean TSS concentrations in all three catchments also
increased in the wet season, but not significantly. The highest wet season mean TP concentrations were found in the Daintree and Annan catchments (Eyre and Davies, 1996).

Hydrographic measurements taken after a heavy rainfall event in the Daintree catchment showed that the plume from the Daintree stretched along Cape Kimberly and then away from the coast towards the mid-shelf reefs. The plume was carrying 4-5 times dissolved inorganic nitrogen and twice the amount of dissolved organic nitrogen than the surrounding water (Ayukai et al., 1997).

The recent publication by Furnas (2003) also outlines a range of characteristics for all of the Great Barrier Reef Catchments, including Daintree and Mossman. It provides a range of baseline summary variables including hydrology, geology and sediment and nutrient runoff. The data from this text will not be repeated here. In the study by Furnas (2003), the annual inputs of terrestrial sediment and nutrient runoff were determined by multiplying volume-specific sediment export coefficients appropriate for wet, mixed or dry drainage basins by the mean annual freshwater discharge from each catchment. The results of this approach are given in Table 1.

Sediment and nutrient budgets were produced for the Daintree and Mossman Catchments using the first edition of the SedNet model as part of the National Land and Water Resources (NLWRA, 2001; Prosser et al., 2001a). A more recent project was conducted to refine the NLWRA results, and in particular, improve estimates of the nutrient exports (Brodie et al., 2003). In the 2003 project, the sediment budgets were improved by using better input information where it was available and by some minor modifications to the model itself. Major changes were made to the model nutrient budgets by changing the way dissolved nutrients inputs were derived, by being more specific about the form of nutrients, and by improving methods for representing the transport of nutrients through the river network. The resulting sediment and nutrient exports for the Daintree and Mossman Catchments are given in Table 1. The inputs to the model for this project were, however, still relatively coarse, given the size of the catchment. For example, the stream network and floodplain extent was defined using the AUSLIG 9” (or 250K) DEM of Australia (AUSLIG, 2000).

It is interesting to point out the range of different load estimates obtained for the Daintree and Mossman Catchments (Table 1), which are a function of both different methodologies and different spatial data sets.

In the current project we have further refined the model by using much more detailed data including a DEM based on ~ 10 m grid. This will provide a much improved estimate of the sediment and nutrient budget for each catchment. We have also used hydrological and landuse data that are specific to Douglas Shire region. Other variables such as point source pollution and riparian vegetation will also be specific to the local catchment conditions. In terms of the processes represented in the model, and following extensive aerial photo interpretation, we have determined that gully erosion is not a significant source of sediment in these catchments and therefore, unlike previous projects, gully erosion was not evaluated. However, drains were considered to be an additional source of sediments and nutrients and are represented in the model budget. A detailed description of the data layers that will be incorporated into this study are given in Section 5.4.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Total suspended solids (TSS) (t/yr)</th>
<th>Total Nitrogen (t/yr)</th>
<th>Total Phosphorus (t/yr)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daintree</td>
<td>50,000</td>
<td>499</td>
<td>53</td>
<td>Furnas (2003)</td>
</tr>
<tr>
<td></td>
<td>94,000</td>
<td>684</td>
<td>83</td>
<td>NLWRA (2001)</td>
</tr>
<tr>
<td></td>
<td>167,000</td>
<td>1170</td>
<td>175</td>
<td>Brodie et al., (2003)</td>
</tr>
<tr>
<td>Mossman</td>
<td>20,000</td>
<td>234</td>
<td>25</td>
<td>Furnas (2003)</td>
</tr>
<tr>
<td></td>
<td>15,000</td>
<td>164</td>
<td>20</td>
<td>NLWRA (2001)</td>
</tr>
<tr>
<td></td>
<td>49,000</td>
<td>279</td>
<td>30</td>
<td>Brodie et al., (2003)</td>
</tr>
</tbody>
</table>
Other regional studies of interest

It is acknowledged that the data and knowledge of erosion rates from different landuse in the Douglas Shire Catchments is limited. There are, however, a range of studies from other wet tropics catchments that will be valuable in providing background data for the model where local data from the Douglas Shire Catchments is unavailable.

For example there have been a number of studies that have measured the sediment and nutrient exports from catchments such as the Normanby River (Furnas, 2003), the Barron River (Cogle et al., 1996; Cogle et al., 2000; Cogle et al., In review; Mitchell et al., 1991), the Johnstone River (e.g. Hunter and Walton, 1996; Hunter 1997; Hunter et al., 2001; McKergow et al., 1999; Mitchell et al., 1991; Prove et al., 1995; Prove and Hicks, 1991), the Tully River (e.g. Mitchell et al., 2001; Mitchell et al., 1991) and the Herbert River (Bartley et al., 2003; Bartley et al., submitted; Bramley and Johnston, 1996; Horn et al., 1998; Mitchell and Bramley, 1997; Mitchell et al., 1991; Mitchell et al., 1997; Roth and Olley, In Prep).

There have also been a number of studies (from outside of the Douglas Shire) that have looked at sediment and nutrient loss directly from cane and banana plots. For example McShane et al., (1993), Visser (2002), Thorburn et al., (2003), Prasertsak et al., (2001) and Prasertsak et al., (2002).

Where appropriate data for the Douglas Shire Catchments does not exist, these studies were consulted.

5. Sediment and nutrient source (SedNet) modelling: methods and data inputs

5.1 Background to model

To calculate the supply of sediment and nutrients, their deposition and delivery downstream, we have constructed river sediment and nutrient budgets. We have calculated budgets for two types of sediment: suspended sediment and coarse sediment (or bed-load). The programs used to model sediment transport are collectively referred to as the SedNet: the Sediment River Network model. The additional program used to model the nutrients model is known as ANNEX (Annual Network Nutrient Export).

SedNet and ANNEX were developed for the National Land and Water Resources Audit (NLWRA). Details of the NLWRA model and subsequent applications of SedNet to regional catchments in Australia (e.g. the Burdekin, Mary, Goulburn/Broken and Herbert catchments) can be found in Prosser et al., (2001a; 2001b), DeRose et al., (2002; 2003), Bartley et al., (2003). The methods used in the construction of input data and implementation of the SedNet program itself are described in detail in a number of CSIRO technical or client reports which are available at http://www.clw.csiro.au/publications/scientific_reports.html or by contacting the authors. Consequently only a very brief overview of the model is included in the next section and in particular where this regional application differs from the NLWRA work (http://www.nlwra.gov.au/). Readers should therefore reference previous reports for detail on the models (e.g. Prosser et al., 2001b).

5.2 Sediment delivery through the river network

Sediment are derived from a number of processes which include:

- Runoff on the land, termed surface wash and rill erosion or alternatively hillslope erosion;
- Erosion of gullies formed as a result of land clearing or grazing;
- Erosion of the banks of streams and rivers;
- Erosion of drains;

In many cases one process dominates the others in terms of delivering sediments and nutrients to streams, and the predominant process can vary from one part of a catchment to another.
The basic unit of calculation for constructing a sediment budget is a link in a river network. A link is the stretch of river between any two stream junctions (or nodes; e.g. Figure 3). Each link has an internal watershed, from which sediment is delivered to the stream network by hillslope and gully erosion processes. The internal catchment area is the catchment area added to the link between its upper and lower nodes (Figure 3). For the purpose of the model, the internal catchment area of first order streams is the entire catchment area of the river link. Additional sediment is supplied from bank erosion along the link and from any tributaries to the link.

Sediment is processed sequentially through the river network beginning with first order links and terminating at the catchment outlet (commonly the ocean or a major river). The sediment load output from each link is calculated from the supply of sediment from tributary links and the local watershed, less losses through floodplain deposition (fine sediment, i.e. silt and clay), bed deposition (coarse sediment i.e. sand), and reservoir deposition (coarse and fine sediment). The sediment yield at the terminating link constitutes the total yield of the river network.

![Figure 2: A river network showing links, nodes, Shreve magnitude of each link (Shreve, 1966) and internal catchment area of a magnitude one and a magnitude four link.](image)

The SedNet model calculates, among other things:

- the mean annual suspended sediment output from each river link;
- the depth of sediment accumulated on the river bed in historical times;
- the relative supply of sediment from surface wash, gully and bank erosion processes;
- the mean annual export of sediment to the coast; and
- the contribution of each watershed to that export.

### 5.2.1. Fine (suspended) sediment transport

The suspended sediment budget is illustrated in Figure 3. The main aim of the this budget is to predict the export of suspended sediment after loss of sediment on floodplains. The floodplain widths for the Douglas Shire Catchments were determined based on measurements of Valley Bottom Flatness (VBF) using the DEM (John Gallant, CSIRO Land and Water, unpublished work). These results were assessed against the hydrological record of floodplain extent and gauge data (see [http://www.bom.gov.au/hydro/flood/qld/brochures/daintree/daintree.shtml](http://www.bom.gov.au/hydro/flood/qld/brochures/daintree/daintree.shtml)).

A relatively simple model of floodplain deposition is implemented in SedNet. Floodplain deposition in this case is simply the proportion of sediment that goes over-bank and settles out during a typical flood. It is calculated as the ratio of the median over-bank flow multiplied by the proportion of sediment that would be expected to settle out during over-bank flow (see Figure 3). Particle settling
is a function of the residence time of water on the floodplain. The longer that water sits on the floodplain the greater the proportion of the suspended load that is deposited. The residence time of water on floodplains increases with floodplain area and decreases with floodplain discharge. This simple model of floodplain deposition assumes a uniform sediment concentration and that the majority of suspended sediment is transported at times of high river flow.

\[
D_x = I_x \frac{Q_{h}}{Q_{fx}} \left(1 - e^{-\left(\frac{w_A}{Q_{fx}}\right)}\right)
\]

Figure 3: Conceptual diagram for the suspended sediment budget of a river link. HSDR is hillslope sediment delivery ratio. The equation is for the amount of sediment deposited on the floodplain (t/y), where \(I_x\) is the sediment load input to the link, \(Q_{h}/Q_{fx}\) is the proportion of flow that goes over-bank, \(A/x/Q_{fx}\) is the ratio of floodplain area to floodplain discharge and \(w_A\) is the sediment settling velocity.

### 5.2.2. Coarse sediment transport

The coarse sediment (bedload) budget is illustrated in Figure 4. The main aim of the bedload budget is to predict the formation of sand slugs (large increases in coarse bedload material). These are predicted to occur when there is an excess of sediment supply to a river link beyond the capacity of the link to transport sand sized sediment. This is known as the sediment transport capacity (STC) and is based on Yang’s (1973) relationship to unit stream power (Equation 1).

\[
STC_x = \frac{86S^\frac{1}{3} \sum Q_x^{\frac{1}{4}}}{w_x^{0.4}}
\]

Equation 1

Sediment transport capacity is a function of the river width \((w_x)\), slope \((S_x)\), discharge \((Q_x)\) settling velocity of the bedload particles \((\cdot)\) and hydraulic roughness of the channel. \(\sum Q_x^{\frac{1}{4}}\) represents mean annual sum of daily flows raised to a power of 1.4 \((\text{Ml}^{1.4} \text{y}^{-1})\). The sediment transport capacity (STC) was calculated for each river link \((\text{ty}^{-1})\) using Yang’s (1973) equation, and an average value for Manning’s roughness coefficient of 0.025. The value of \(\cdot\) was determined for particles with a mean diameter of 2 mm, being the average size observed for sediment slug deposits (Rutherford and Budahazy, 1996).
5.2.3. Contribution of Sediment to the Coast

The differentiation of areas that contribute strongly to total river sediment export is an important aspect of catchment management as this enables catchment managers to target areas for rehabilitation. It is not always possible, or sensible, to implement erosion control works effectively across large areas.

Not all suspended sediment delivered to rivers is exported from the catchment as there are extensive opportunities for floodplain deposition along river courses. The contribution that each stream link’s watershed makes to sediment exported at the catchment outlet can be calculated once the mean annual suspended sediment export is known.

Each watershed delivers a mean annual load of suspended sediment ($L_{Fx}$) to the river network. This is the sum of gully, hillslope and riverbank erosion. The watershed delivery and tributary loads constitute the load of suspended sediment ($TIF_{Fx}$) received by each river link. Each link yields some fraction of that load ($YF_{Fx}$); the rest is deposited. The ratio of $YF_{Fx}/TIF_{Fx}$ is the proportion of suspended sediment that passes through each link. It can also be viewed as the probability of any individual grain of suspended sediment passing through the link. The suspended load delivered from each watershed will pass through a number of links on route to the catchment mouth. The amount delivered to the mouth is the product of the loading $L_{Fx}$ from the watershed and the probability of passing through each river link on the way:

$$CO_x = L_{Fx} \cdot \frac{YF_{Fx}}{TIF_{Fx}} \cdot \frac{YF_{F_{x+1}}}{TIF_{F_{x+1}}} \cdot \ldots \cdot \frac{YF_{F_n}}{TIF_{F_n}}$$

Equation 2

where $n$ is the number of links on the route to the outlet. Dividing this by the internal catchment area expresses contribution to outlet export ($CO_x$) as an erosion rate (t/ha/y). The proportion of suspended sediment passing through each river link is $= 1$. A consequence of Equation 2 is that all other factors being equal, the further a watershed is from the mouth, the lower the probability of sediment reaching the mouth. This behaviour is modified though by differences in source erosion rate and deposition intensity between links.

5.3 Nutrient delivery through the river network

The nutrient budget model (Annual Network Nutrient Export – ANNEX; Young et al., 2001), of the SedNet set of programs, predicts the average annual loads of phosphorous (P) and nitrogen (N) in each link in a river network in a similar way to the sediment budget model, with which it is run in
conjunction. The model considers only the physical (not biological) stores of nutrients in the river system, and is also primarily concerned with the physical nutrient transport processes. It does, however, consider denitrification - a biological process resulting in loss of N to the atmosphere, and phosphorous adsorption-desorption, a physical process influenced by biological activity. ANNEX therefore assumes that at the annual time scale, the changes in biological nutrient stores within a river network link, and the fluxes between river network links due to biological transport processes, are small in comparison to the fluxes due to physical nutrient transport processes and the changes in physical nutrient stores.

The main source terms are sediment associated nutrients (from hillslope erosion, gully erosion and riverbank erosion), dissolved organic (DOP and DON) and inorganic loads in runoff water (DIN and DIP), and point sources of total nitrogen (TN) and total phosphorus (TP). Each form of nitrogen is transported independently in the model, while equilibration between sediment associated P and DIP is allowed in each river link. More detail regarding the nutrient model is given in Section 5.4.8.

5.4 **Model Inputs**

5.4.1. **Baseline data on elevation and stream network configuration**

The branching network of streams for the Douglas Shire catchments was built from a 10 m DEM (digital elevation model) grid. The DEM was constructed using TOPOGRIDTOOL in Arc/INFO® with input elevation and drainage data consisting of 1:50,000 topographic contours (source: Wet Tropics Management Authority, WTMA). It was a significant improvement on the DEM used in the National Land and Water Audit (Lu et al., 2001) and subsequent applications of SedNet in the Daintree and Mossman catchments (see Brodie et al., 2003). All previous applications of SedNet in these catchments had used the 1:250,000 mapping.

In this study, the upper branches of the network were defined as any stream longer than 200m with a catchment area of 1 km² or more. These criteria limited the number of links across the assessment area, while providing a good representation of the channel network. Internal catchment areas for each link were determined from the DEM.

5.4.2. **Landuse**

The landuse layers used in this study are summarised for the whole Douglas Shire area in Figure 5 and in more detail for the floodplain in Figure 6. The landuse data for this project was derived from a number of existing landuse maps that had been prepared by various government departments. Table 2 summarises the main data sources and the items listed in bold italics were used either directly (as a layer) or indirectly (to derive a new integrated layer eg. wet sclerophyll).

The data sources used to devise a current landuse and landcover map for the Douglas Shire were the following:

(a) 1:50k DPI Landuse and Wetlands mapping
(b) Mossman Agricultural Services (MAS) data on cane block locations and local roads.
(c) World Heritage area boundary
(d) EPA estate boundary and status information
(e) 1:250K Webb and Tracey vegetation mapping
(f) CSIRO Rainforest/Sclerophyll boundary mapping for western side of catchment.
(g) 2001 Landsat TM imagery.

Many layers did not overlay well due to poor locational information (e.g. cadastres) at the time of mapping. The WTMA topographic layers - relief and drainage) were chosen as the most accurate data set to use as a standard reference set. Landsat imagery, georeferenced well with respect to the WTMA topographic data and was also used as a georeferencing guide.
To create a Landuse/Landcover map for use in the Sednet modelling of the Douglas Shire, the following steps were carried out:

(1) DPI landuse, wetland and EPA estate data was rubbersheeted to match (as well as possible) the Wet Tropics topographic mapping and Landsat image (well registered to WT mapping).

(2) The DPI landuse “Sugarcane” category was redefined by:
   a. Overprinting Mill cane block mapping (extending the “sugarcane” classification where the Cane Block definition extended past the “Sugarcane” class) and then reclassifying any non-cane block “Sugarcane” areas according to whether they were forested or not (based on Landsat albedo).
   b. For non-forested “Sugarcane” areas, a 20m buffer around each cane block was assumed to be “Headland”, all else was classified as “Other”.
   c. Overlaying refined categories of “Sugarcane” landuse back into DPI landuse map.

(3) Created hybrid EPA estate and World Heritage boundary map, ensuring consistency of world heritage boundaries with rubbersheeted EPA estate boundary map.

(4) The DPI landuse map classified anything with natural veg (i.e. all rainforest, eucalypt, and mangrove) as “Forest”. So, we used to following steps to refine the “Forest” areas:
   a. Extended the boundaries of the new DPI landuse mapping to the edges of the catchment boundary and defined all extended areas as “Forest”.
   b. Removed all non-forest type landcover classifications from the Webb and Tracey map, leaving those areas undefined.
   c. Replaced Webb and Tracey mapping with CSIRO’s rainforest sclerophyll boundary mapping, where applicable.
   d. Overlay DPI wetlands mapping on the new Webb and Tracey map.
   e. Overlay the hybrid EPA estate and World Heritage boundaries.

(5) Replaced the “Forest” areas of the extended DPI Landuse map with Hybrid Forest Map created above.

(6) Checked resulting theme for undefined areas (any polygons from step 4.b that were not overprinted at a later stage) and manually defined them based on Landsat interp etc.

(7) Buffered 5m either side of Mill area roads and overlay these as landuse “Road”.
Table 2: List of data that has been collected for the sediment and nutrient modelling work. Data in **bold italics** was used in the landuse mapping. (WTMA = Wet Tropics Management Authority; DSC = Douglas Shire Council; MAS = Mossman Agricultural Services; QDPI = Queensland Department of Primary Industries; QDNR&M = Queensland Department of Natural Resources and Mines; EPA = Environmental Protection Authority)

<table>
<thead>
<tr>
<th>Name</th>
<th>Supplier/Custodian</th>
<th>Scale</th>
<th>Metadata Date</th>
<th>Description</th>
<th>Horizontal Datum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queensland Coast</td>
<td>WTMA</td>
<td></td>
<td>2nd May’02</td>
<td>Position of the Mean High Water mark adjacent to the Wet Tropics World Heritage Area - Townsville to Cape Flattery</td>
<td>GDA94</td>
</tr>
<tr>
<td>Queensland Relief @ 1:50,000</td>
<td>WTMA</td>
<td>50K</td>
<td>5th December’02</td>
<td>Contains contour lines and spot heights across the Wet Tropics Bioregion</td>
<td>GDA94</td>
</tr>
<tr>
<td>Queensland River @ 1:50,000</td>
<td>WTMA</td>
<td>50K</td>
<td>6th August’02</td>
<td>Contains drainage lines in the Wet Tropics Bioregion - All creeks in 50k mapping - no attributes</td>
<td>GDA94</td>
</tr>
<tr>
<td>World Heritage Area Boundary</td>
<td>WTMA</td>
<td></td>
<td>25th June’02</td>
<td>Contains polygon &amp; line features depicting the World Tropics World Heritage area - Townsville to Cape Flattery</td>
<td>GDA94</td>
</tr>
<tr>
<td>Catchment Boundaries</td>
<td>WTMA</td>
<td>n/a</td>
<td></td>
<td>Contains Primary &amp; Secondary catchments in the Douglas Shire Council - detailed subcatchments including descriptive fields such as names and relative locations</td>
<td>GDA94</td>
</tr>
<tr>
<td>DCDB</td>
<td>DSC</td>
<td></td>
<td></td>
<td>Contains property boundaries in the Douglas Shire Council - land tenure - not really landuse - complete coverage</td>
<td>GDA94</td>
</tr>
<tr>
<td>Spot or satellite imagery</td>
<td>MAS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Douglas Shire Landuse</td>
<td>QDPI</td>
<td></td>
<td>Not available</td>
<td>Contains the principal land-uses within the Douglas Shire - doesn't detail horticulture - only sugarcane</td>
<td>AGD84</td>
</tr>
<tr>
<td>Soils Mapping</td>
<td>QDNR&amp;M</td>
<td></td>
<td></td>
<td>Covers almost all developed areas - no coverage into deep rainforest. Soil types with PPF equivs on printed map (for erodibility)</td>
<td></td>
</tr>
<tr>
<td>Douglas Shire Habitat Assessment Sites</td>
<td>DPI</td>
<td></td>
<td>Not available</td>
<td>Contains points identifying habitat ratings</td>
<td>AGD84</td>
</tr>
<tr>
<td>Douglas Shire Riparian</td>
<td>DPI</td>
<td></td>
<td>Not available</td>
<td>Contains condition ratings for riparian areas - textual - &quot;sparse&quot; &quot;narrow&quot; etc..</td>
<td>AGD84</td>
</tr>
<tr>
<td><strong>Douglas Shire Wetlands</strong></td>
<td>DPI</td>
<td></td>
<td>Not available</td>
<td>Contains condition ratings for wetlands &amp; riparian areas</td>
<td>AGD84</td>
</tr>
<tr>
<td>Hydrology</td>
<td>QDNR&amp;M</td>
<td>Gauge data</td>
<td></td>
<td>Stream Gauging sites</td>
<td></td>
</tr>
<tr>
<td>Coastal Rivers</td>
<td>MAS</td>
<td></td>
<td></td>
<td>major coastal rivers relevant to cane areas</td>
<td></td>
</tr>
<tr>
<td>Cane Blocks</td>
<td>MAS</td>
<td></td>
<td></td>
<td>All cane blocks in region</td>
<td></td>
</tr>
<tr>
<td>Cane Roads</td>
<td>MAS</td>
<td></td>
<td></td>
<td>all roads servicing cane to mill</td>
<td></td>
</tr>
<tr>
<td>Tracey and Webb Veg mapping</td>
<td>WTMA</td>
<td>250k</td>
<td></td>
<td>detailed species and structure - whole of wet tropics</td>
<td></td>
</tr>
<tr>
<td>Cane block drains</td>
<td>MAS</td>
<td></td>
<td>Not available</td>
<td>Contains human built drains on sugar cane blocks</td>
<td>GDA94</td>
</tr>
<tr>
<td>DEM</td>
<td>Prepared by WTMA</td>
<td>10 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point Source pollution data</td>
<td>Produced by EPA</td>
<td></td>
<td></td>
<td>Point source data - only for limited sites, mainly sewerage treatment plants</td>
<td></td>
</tr>
</tbody>
</table>
Figure 5: Landuse map for the Douglas Shire catchments
Figure 6: Landuse map for the Douglas Shire catchments – detailed coastal floodplain section
5.4.3. River Hydrology and Channel Form

SedNet incorporates a number of hydrological parameters into the calculation of river sediment budgets. These are used for calculations of patterns of deposition, river bank erosion, and denitrification. The parameters need to be predicted (interpolated) for each river link across the river catchment, based upon observations at hydrological gauging stations within the region. The methods are a further development of those undertaken in the NLWRA project (Young et al., 2001) and are outlined in more detail in Wilkinson et al., (2004). The variables used are:

- the mean annual flow (MAF);
- the median daily flow (Qmd);
- the relative daily Q1.4 for calculating mean annual sediment transport capacity;
- the bankfull discharge (Qbf); and
- a representative flood discharge for floodplain deposition (in this case median overbank flow – Qob).

Because of the lack of gauging stations with sufficient record (10-20 years) in the Douglas Shire Catchments, it was necessary to use gauge data from all of the Wet Tropics catchments to undertake the hydrological regionalisation. A total of 34 stations were used in the analysis and they are listed in Table 3. Gauges downstream of major water storages (e.g. Lower Barron) were excluded from the analysis. It is also important to point out that the diversity in rainfall and topography found in the wet tropics makes these types of regionalisation analyses difficult. However, without improved temporal and spatial data regarding variables such as rainfall, it will be difficult to improve the reliability of these estimates.

For each gauging station the mean annual runoff coefficient (ROC) is determined from the observed mean annual flow, the area of the catchment and its mean annual rainfall. The ROC is then predicted for all other links of the river network as a function of the ratio of the potential evaporation (PET, mm) to the mean annual rainfall (RF, mm) for the catchment area upstream of each link according to Equation 3:

\[
ROC = \left[1 + \left(\frac{PET}{RF}\right)^{a(PET/RF) + b}\right]^{1/[a(PET/RF) + b]} - \frac{PET}{RF}
\]

where \(a\) and \(b\) are empirical values fitted by regression. Equation 3 comes from a conceptual rainfall/runoff model based upon the annual water balance (Zhang et al., submitted). For this study the regression gave \(a = 0.8796, b = 0.7009\), with an \(r^2 = 0.51\).

Once ROC has been predicted for each river link the mean annual flow (MAF, Ml/y) is calculated from the catchment area (A, km²) and mean annual rainfall:

\[
MAF = ROC \cdot RF \cdot A.
\]

Sediment transport capacity, used in the bedload budget is a function of the discharge raised to the power of 1.4 (Prosser et al., 2001b). The mean annual sum of daily contributions to sediment transport capacity is:

\[
\frac{1}{365} \sum_{i=1}^{n} Q_i^{1.4} = RDSQ \cdot \left(\frac{MAF}{365}\right)^{1.4} \cdot 365
\]

where \(RDSQ\) is the relative contribution of daily flow to sediment transport capacity:

\[
RDSQ = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{Q_i}{Q}\right)^{1.4}
\]
where $Q_i$ is the measured daily flow (ML/d), $\bar{Q}$ is mean daily flow for the period of record (ML/d) and $n$ is the number of days of record. Once $RDSQ$ is calculated for each gauging station, it is related empirically to rainfall ($RF$) (Equation 7). That relationship is then used to predict $RDSQ$ for each river link and Equation 5 is used to calculate sediment transport capacity.

$$RDSQ = c(e^{d RF}) + 1$$  \hspace{1cm} \text{Equation 7}

Where $c = 2.49$, and $d = -0.0005$ ($R^2 = 0.62$).

Similarly, the other hydrological parameters were calculated at gauging stations and related to $MAF$. Those relationships were then used to predict the parameters for all stream links. For bankfull discharge the empirical relationship is:

$$Q_{bf} = e^{(MAF)^f}$$  \hspace{1cm} \text{Equation 8}

where $e = 0.066$, and $f = 0.94$ ($R^2 = 0.92$).

For median over-bank flow:

$$Q_{ob} = g^{(MAF)^h}$$  \hspace{1cm} \text{Equation 9}

where $g = 0.1158$, $h = 0.8723$ ($R^2 = 0.63$).

For median daily flow:

$$Q_{med} = i^{(MAF)^j}$$  \hspace{1cm} \text{Equation 10}

Where $i = 0.0002$, $j = 1.1058$ ($R^2 = 0.73$).

The calculations of bankfull discharge and median over-bank flow are based on the average flood recurrence interval determined from the time series of daily flows recorded at rated gauging stations. For this project the gauging stations located within the Douglas Shire were examined across the catchment and these indicated that bank full discharge averaged ~1.5 years.
Figure 7: Rainfall distribution in catchments (based on ANUCLIM).
Table 3: List of gauging stations used in the hydrological regionalisation analysis for the Douglas Shire Catchment

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Gauge Location</th>
<th>Gauge Number</th>
<th>Catchment Area (km²)</th>
<th>Commencement</th>
<th>Years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daintree</td>
<td>Daintree River @ Bards</td>
<td>108002</td>
<td>911</td>
<td>1968</td>
<td>35</td>
</tr>
<tr>
<td>Daintree</td>
<td>Bloomfield River @ China Camp</td>
<td>108003</td>
<td>264</td>
<td>1970</td>
<td>33</td>
</tr>
<tr>
<td>Daintree</td>
<td>Wilyanbeel Creek @ Upstream Little falls Creek</td>
<td>108008</td>
<td>15</td>
<td>1990</td>
<td>13</td>
</tr>
<tr>
<td>Mossman</td>
<td>Mossman River @ Mossman</td>
<td>109001</td>
<td>106</td>
<td>1948</td>
<td>55</td>
</tr>
<tr>
<td>Barron</td>
<td>Barron River @ Picnic Crossing</td>
<td>110003</td>
<td>228</td>
<td>1925</td>
<td>78</td>
</tr>
<tr>
<td>Barron</td>
<td>Flaggy Creek @ Recorder</td>
<td>110011</td>
<td>150</td>
<td>1955</td>
<td>48</td>
</tr>
<tr>
<td>Mulgrave-Russell</td>
<td>Mulgrave River @ Gordonvale</td>
<td>111001</td>
<td>552</td>
<td>1916-1973</td>
<td>65</td>
</tr>
<tr>
<td>Mulgrave-Russell</td>
<td>Behana Creek @ Aloomba</td>
<td>111003B</td>
<td>86</td>
<td>1931-1942</td>
<td>40</td>
</tr>
<tr>
<td>Mulgrave-Russell</td>
<td>Mulgrave River @ Fisheries</td>
<td>111005</td>
<td>357</td>
<td>1966</td>
<td>37</td>
</tr>
<tr>
<td>Mulgrave-Russell</td>
<td>Mulgrave River @ Peats Bridge</td>
<td>111007</td>
<td>520</td>
<td>1972</td>
<td>29</td>
</tr>
<tr>
<td>Mulgrave-Russell</td>
<td>Russell River @ Bucklands</td>
<td>111101C</td>
<td>315</td>
<td>1938-1970</td>
<td>55</td>
</tr>
<tr>
<td>Mulgrave-Russell</td>
<td>Babinda Creek @ Babinda</td>
<td>111102A</td>
<td>82</td>
<td>1926-1934</td>
<td>62</td>
</tr>
<tr>
<td>Mulgrave-Russell</td>
<td>Babinda Creek @ Boulders</td>
<td>111105</td>
<td>39</td>
<td>1966</td>
<td>37</td>
</tr>
<tr>
<td>Johnstone</td>
<td>North Johnstone @ Goondi</td>
<td>112001</td>
<td>936</td>
<td>1928-1968</td>
<td>40</td>
</tr>
<tr>
<td>Johnstone</td>
<td>Fisher Creek @ Nerada</td>
<td>112002</td>
<td>15</td>
<td>1928</td>
<td>75</td>
</tr>
<tr>
<td>Johnstone</td>
<td>North Johnstone @ Glen Allyn</td>
<td>112003</td>
<td>165</td>
<td>1958</td>
<td>45</td>
</tr>
<tr>
<td>Johnstone</td>
<td>North Johnstone @ Tung Oli</td>
<td>112004</td>
<td>925</td>
<td>1966</td>
<td>37</td>
</tr>
<tr>
<td>Johnstone</td>
<td>South Johnstone @ Central Mill</td>
<td>112101A</td>
<td>401</td>
<td>1916-1974</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>112101B</td>
<td></td>
<td>1974-2003</td>
<td>29</td>
</tr>
<tr>
<td>Johnstone</td>
<td>Liverpool Creek @ Upper Japoonvale</td>
<td>112102</td>
<td>78</td>
<td>1970</td>
<td>33</td>
</tr>
<tr>
<td>Tully</td>
<td>Cobbyal @ Powerline</td>
<td>113004</td>
<td>95</td>
<td>1966</td>
<td>37</td>
</tr>
<tr>
<td>Tully</td>
<td>Koolmoon Creek @ Ebony Road</td>
<td>113007</td>
<td>29</td>
<td>1986</td>
<td>17</td>
</tr>
<tr>
<td>Murray</td>
<td>Murray River @ Upper Murray</td>
<td>114001</td>
<td>156</td>
<td>1970</td>
<td>33</td>
</tr>
<tr>
<td>Herbert</td>
<td>Herbert River @ Ingham</td>
<td>116001</td>
<td>8581</td>
<td>1915</td>
<td>87</td>
</tr>
<tr>
<td>Herbert</td>
<td>Herbert River @ Glen Eagle</td>
<td>116004</td>
<td>5236</td>
<td>1959</td>
<td>43</td>
</tr>
<tr>
<td>Herbert</td>
<td>Herbert River @ Abergowrie</td>
<td>116006</td>
<td>7454</td>
<td>1969</td>
<td>33</td>
</tr>
<tr>
<td>Herbert</td>
<td>Gowrie Creek @ Abergowrie</td>
<td>116008</td>
<td>124</td>
<td>1953</td>
<td>49</td>
</tr>
<tr>
<td>Herbert</td>
<td>Blencoe Falls @ Blencoe</td>
<td>116010</td>
<td>226</td>
<td>1960</td>
<td>42</td>
</tr>
<tr>
<td>Herbert</td>
<td>Millstream @ Ravenshoe</td>
<td>116011</td>
<td>89</td>
<td>1960</td>
<td>42</td>
</tr>
<tr>
<td>Herbert</td>
<td>Cameron Creek @ Cameron Creek</td>
<td>116012</td>
<td>360</td>
<td>1961</td>
<td>41</td>
</tr>
<tr>
<td>Herbert</td>
<td>Millstream @ Archer</td>
<td>116013</td>
<td>303</td>
<td>1961</td>
<td>41</td>
</tr>
<tr>
<td>Herbert</td>
<td>Wild River @ Silver Valley</td>
<td>116014</td>
<td>591</td>
<td>1961</td>
<td>41</td>
</tr>
<tr>
<td>Herbert</td>
<td>Blunder Creek at Woorooroa</td>
<td>116015</td>
<td>127</td>
<td>1966</td>
<td>36</td>
</tr>
<tr>
<td>Herbert</td>
<td>Rudd Creek @ Gunawarra</td>
<td>116016</td>
<td>1450</td>
<td>1970</td>
<td>32</td>
</tr>
<tr>
<td>Herbert</td>
<td>Stone River @ Running Creek</td>
<td>116017</td>
<td>157</td>
<td>1970</td>
<td>32</td>
</tr>
</tbody>
</table>

5.4.4. Hillslope erosion hazard

Hillslope erosion from sheet and rill erosion processes is estimated using the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997) as applied in the NLWRA (Lu et al., 2001). The RUSLE calculates mean annual soil loss ($Y$, tonnes ha$^{-1}$ y$^{-1}$) as a product of six factors: rainfall erosivity ($R$), soil erodibility ($K$), hillslope length ($L$), hillslope gradient ($S$), ground cover ($C$) and landuse practice factor ($P$):

$$ Y = RKLSCP $$

Equation 11

The rainfall erosivity factor ($R$) is a function of the intensity and energy of storms, measured over a 30 minute period. The same approach as used in the NLWRA (2001) was applied in this project. The $R$ factor was derived from rainfall stations with continuous records. An empirical relationship of the storm measurements to daily rainfall (Lu and Yu, 2001) was used to interpolate $R$ and measure seasonal values across the region. This method used 20 years (1980 - 1999) of daily rainfall data mapped to a grid across Australia (Jeffrey et al., 2001). From this Australia wide data set we used the GBR region data which was gridded to 5km (i.e. an R value every 5 km at regular
This data was then interpolated to a smooth surface at 20 m intervals to match the detail in the DEM.

Soil Erodibility (K) was generated by using the PPF (principal profile form) equivalencies shown in the published map of the "Soils of the Mossman Cape Tribulation Area, NQ" (Murtha, 1989). These values were then related to a lookup table of PPF versus erodibility values created by QDNR in a continuation of soil characterisation work started with the report "Creation of Soil Attribute Surfaces for Landscape Salinity Hazard Assessment" by Brough (2001) (this work created a QLD-specific set of PPF lookups). For areas not covered by the Wet Tropics soils mapping (mostly rainforest) the PPF equivalencies from the Atlas of Australian Soils (2 million scale) were used.

For the slope length factor \((L)\), we took the same approach as in the Burdekin (Prosser et. al., 2002) and set \(L\) to a constant (1). Slope factor \((S)\) across the Douglas Shire Catchments was derived directly from the DEM (see Table 4 for slope values for each landuse). The landuse practice factor \((P)\) is largely ignored (switched off) in this model as it is too difficult to incorporate the landuse practices of all areas at the sub-catchment level, and at this stage no spatial and or temporal data describing landuse practice is available.

Landcover mapping had been produced (nominally accurate to 50,000 scale) over the whole catchment (See section 5.4.2). Cover factors were estimated for each landcover type using a number of data sources. Results for the different landcover types (e.g. rainforest, bananas and grazing etc) were estimated from Hunter et al., 2001. The C factors for the different cane components were estimated from the results presented in Visser (2003) and Roth and Visser (2003). The C factors for other landcover types (e.g. roads and quarries etc) were then interpolated from this data (Table 4).

In most cases the ‘average’ or ‘typical’ ground cover for each landuse was applied. For example, it is ‘typical’ that fruit trees have little ground cover, and although some farmers are changing this practice, the low amount of cover up to 2004 is assumed for all sites. Also the cane areas were given C factors based on the results of Visser (2003) from the Herbert Catchment, and this study looked at an area that is dominated by trash blanketing, therefore, the C factor assumes trash blanketing. It is not possible, at this stage, to treat plant and ratoon cane differently, as the model does not have the resolution to work at the plot scale. Only average conditions within any one landuse can be applied. Without on ground data from the Douglas Shire Catchment it is difficult to justify these values any further. Again, more data is needed if the model results are to be improved in the future.

The delivery of sediment to streams from sheet and rill erosion on hillslopes is modified by the hillslope sediment delivery ratio (HSDR). HSDR is a measure of the proportion of fine particles eroded from the hillslope which remain suspended long enough to reach a stream channel. For this project, HSDR was set as a uniform 0.1 based on the methods and data presented in Lu et al., (2003) and Lu et al., (submitted). Sediment produced by sheet and rill erosion is assumed to contribute only to the suspended sediment (not coarse sediment) load of rivers.
Table 4: C factor and average slope values used in the USLE calculations for the Douglas Shire Project.
Average slope values for each landuse were obtained from the DEM.

<table>
<thead>
<tr>
<th>Landuse</th>
<th>C factors used in this study</th>
<th>Average hillslope gradient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarry</td>
<td>0.07</td>
<td>1.14</td>
</tr>
<tr>
<td>Fruit trees (e.g. bananas)</td>
<td>0.056</td>
<td>9.94</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>0.056</td>
<td>1.71</td>
</tr>
<tr>
<td>Cleared</td>
<td>0.025</td>
<td>5.08</td>
</tr>
<tr>
<td>Headland</td>
<td>0.017</td>
<td>as for sugarcane</td>
</tr>
<tr>
<td>Grazing</td>
<td>0.016</td>
<td>9.20</td>
</tr>
<tr>
<td>Regrowth</td>
<td>0.015</td>
<td>8.10</td>
</tr>
<tr>
<td>Rural Residential</td>
<td>0.015</td>
<td>12.14</td>
</tr>
<tr>
<td>Production Forestry</td>
<td>0.012</td>
<td>na, area &lt; 1%</td>
</tr>
<tr>
<td>Dry Sclerophyll</td>
<td>0.01</td>
<td>25.48</td>
</tr>
<tr>
<td>Wet Sclerophyll</td>
<td>0.008</td>
<td>25.48</td>
</tr>
<tr>
<td>Rainforest</td>
<td>0.006</td>
<td>28.39</td>
</tr>
<tr>
<td>Road</td>
<td>0.003</td>
<td>2.82</td>
</tr>
<tr>
<td>Tourism areas</td>
<td>0.003</td>
<td>4.62</td>
</tr>
<tr>
<td>Urban</td>
<td>0.003</td>
<td>2.86</td>
</tr>
<tr>
<td>Industrial</td>
<td>0.003</td>
<td>8.39</td>
</tr>
<tr>
<td>Other</td>
<td>0.003</td>
<td>1.14</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>0.003</td>
<td>as for ‘other’</td>
</tr>
<tr>
<td>Dunes</td>
<td>0.001</td>
<td>as for ‘other’</td>
</tr>
<tr>
<td>Coastal Mozaic</td>
<td>0.001</td>
<td>as for ‘other’</td>
</tr>
<tr>
<td>Melaleuca/Transitional</td>
<td>0.001</td>
<td>as for ‘other’</td>
</tr>
<tr>
<td>Water</td>
<td>0.001</td>
<td>as for ‘other’</td>
</tr>
</tbody>
</table>

5.4.5. Gully erosion

Gully erosion mapping was undertaken in the Douglas Shire Catchments using aerial photograph interpretation. For this process, a gully was defined as a non-permanent watercourse with steep, actively eroding banks. An assessment of approximately 100 aerial photos spanning different geographic regions, geologic classes and land uses were assessed. The scale of the photos ranged from 1: 12,000 to 1: 25,000. Geoscape Version 3.0.0 (2002) for Cairns and the Atherton Tablelands region was used for this purpose.

Based on this extensive assessment it was determined that there is no significant gully erosion in the Douglas Shire Catchments. There were some minor areas that showed historical landslide scars and there was very minor evidence of gulling around some of the steeper areas; however, overall the area affected is so small (< 0.01%), and therefore gullying is not considered to be a major sediment source in these catchments. Based on this assessment, we have decided to switch off gully erosion as a major sediment source in the models.

5.4.6. Drains as a sediment source

Although we did not model gully erosion per se, we used the principles of the existing gully erosion calculations to estimate the contribution of sediment from cane drains. Previous studies have shown that cane drains can contribute considerable amounts of fine sediment to local waterways (Visser, 2002).

To estimate erosion rates from drains, a drainage density estimate (D km/km²) was made based on drain mapping of the Saltwater Creek Catchment (data supplied from Mossman Agricultural Services). This mapping represented the constructed drains in the catchment. It was assumed that the drainage density, per unit area of cane, was similar for all of the cane areas in the Douglas Shire Catchments as drain data is not available for the other areas. It is important to note that the drains mapped in this layer represent the major drains only; water furrows and minor drains were not included. Any refinement of this analysis will required improved mapping in the future.

The total sediment supplied to each stream link from drain erosion (DS, kt/y) was calculated as the product of drain density (D = 0.78 km/km²), watershed area (A, km²), average drain erosion rate
per year in m$^2$ \( (C = 0.77 \text{ m}^2) \); this value was calculated from the results in Roth and Visser, 2003 which estimates that there is \(~9 \text{ t/ha/yr} \) of sediment lost from cane drains) and average dry bulk density of soil \((\rho = 1.5 \text{ t/m}^3)\), divided by the time over which drains erode \((t = 1 \text{ year})\) (see Equation 12). It is acknowledged that drains may erode on shorter or longer timescales, however, an annual time step was used as the data presented in Roth and Visser (2003) was based on annual averages.

Therefore, in summary, this model is assuming a uniform erosion rate for all drains, and the amount of drain erosion varies only as a function of catchment area. Therefore, those catchments with more area under cane cultivation, and subsequently more drains, will have a higher loss of sediments from drain erosion. It is important to note that the data provided by Roth and Visser (2003) are expected to be the upper limit of drain erosion for most coastal area’s, however, it is the only data presently available and will provide a useful first estimate of the relative contributions of drain erosion compared to other sources.

\[
DS = \frac{DCA}{t}
\]

Equation 12

For modelling purposes it is assumed that 50% of the drain erosion produced coarse bed-load sediment and 50% produced fine suspended sediment. It is, however, acknowledged that many of soils of the Mossman area have low clay contents and it may be possible in the future to adjust these proportions with more details sediment size analysis data from drains.

5.4.7. River Bank Erosion Hazard

In most of Australia, including the Douglas Shire Catchments, there are few direct measurements of bank erosion (e.g. Figure 8). A global review of river bank migration data (Rutherfurd, 2000) suggested that the best predictor of bank erosion rate \((BE \text{ m/y})\) was bankfull discharge \((Q_{bf})\). The magnitude of bankfull discharge is often equivalent to a 1.58 year recurrence interval. Rutherfurd’s original relationship appears to overestimate bank erosion along the lower reaches of the main rivers when compared with river loads measured at gauging stations. Rutherfurd also found a significant relationship between bank erosion and stream power \((gQ_{bf} \cdot S_x\), where \(S_x\) is the energy slope approximated to the channel gradient). It is assumed that the bank erosion rate decreases as the proportion of remnant riparian vegetation \((PR_x)\) along the river link increases. This produces negligible bank erosion under fully intact riparian vegetation. The resultant equation for bank erosion is:

\[
BE = 0.00002 \cdot \cdot g \cdot Q_{bf} \cdot S_x(1-PR_x)(1-e^{-0.008F_x}) \text{ in m per year}
\]

Equation 13

Where \(PR\) is proportion of riparian vegetation and \(F_x\) is the floodplain width. The average proportion of riparian vegetation within each link was determined using the riparian vegetation data collected by Russell et al., 1998 (see Figure 9). The data in Russell et al., 1998 was given as a description of the amount of vegetation cover for each bank and was converted to an average % bank cover for each reach as follows:

- Sparse tree cover on both sides of a stream = <40%
- Narrow tree cover on both sides of a stream = ~60%
- Wide tree cover on both sides of a stream = >80%
- Sparse tree cover on one side, narrow on the other = 50%
- Narrow tree cover on one side, wide on the other = 70%
- Sparse tree cover on one side, wide on the other = 60%
Figure 8: An example of bank erosion identified on the main channel of the Daintree River upstream of the Daintree township.
Figure 9: Riparian vegetation cover (adapted from Russell et al., 1998)
Nutrient Sources

The nutrient model deals with different forms of nitrogen (N) and phosphorus (P). The main source terms for the nutrient budget are sediment associated nutrients (from hillslope erosion and riverbank erosion), dissolved organic (DOP and DON) and inorganic loads in runoff water (DIN and DIP). Point source pollution is also considered as a nutrient source. The way in which the different nutrient forms and sources are utilised are outlined below.

Sediment associated nutrients

The nutrient load from hillslope erosion is calculated as the product of the hillslope sediment yield (hillslope erosion x HSDR) multiplied by the nutrient concentration of this load (NC). The nutrient concentration of the sediment load is determined from the proportion of clay and nutrient concentration of the bulk soil (SC). ANNEX uses a two-part mixing model that assumes all nutrients are associated with the clay fraction. For internal catchment links when the percentage clay is greater than the HSDR, then all sediment delivered to the channel is assumed to be clay. The nutrient concentration is then the bulk soil concentration enriched by the proportion of clay (Cp) in the hillslope soil:

For \( Cp < HSDR \), \( NC = \frac{SC}{Cp} \times 0.5 \)  

Equation 14

In the few cases where the proportion of clay is less than the HSDR, only a portion of the delivered sediment is clay and so the nutrient concentration is reduced by the ratio of the proportion of clay to the HSDR. In previous projects (see Brodie et al., 2003) it was found that the nutrient enrichment ratio simulated by the above equation gave nutrient concentrations significantly higher than those observed on river sediments in the region. The enrichment ratios were also larger than those recorded in field experiments. Thus the effect of nutrient enrichment was reduced by half (the 0.5 factor in Equation 14). Data on soil clay proportions and nutrient concentrations for P and N was extracted from the Australian Soil Resource Information System (Henderson et al., 2001).

The nutrient loads from riverbank erosion were calculated as the product of their respective sediment yields times the soil nutrient concentration, which for phosphorous will be taken to be 0.25 g kg\(^{-1}\) and for nitrogen 1 g kg\(^{-1}\).

Dissolved nutrients

For this project, the concentrations of DIN (dissolved inorganic nitrogen), DON (dissolved organic nitrogen), FRP (filterable reactive phosphorus) and DOP (dissolved organic phosphorus) were assessed from water quality studies in the north Queensland region, and are summarized in Table 5. The separation of phosphorus into its various forms is defined analytically, and therefore P terminology is often unclear. In this study, filtration through a 0.45 µm filter separates ‘dissolved’ from ‘suspended’ forms of phosphorus. Data for the concentrations of dissolved nutrients were derived from water quality studies where one landuse was dominant. In theory, the concentrations occurring in major runoff events i.e. event mean concentrations (EMCs) were derived. However, in many cases, EMCs were not easily calculated from the existing data sets. Where EMC’s were not available, 80 percentile values from the complete data sets were used. Concentrations of dissolved nutrients in event conditions from catchments with multiple land-uses were also used as a check on individual landuse values.

The nutrient concentration for the internal catchment of a river link was calculated as the area weighted mean for the land uses in that catchment area. The load delivered to the river link is the product of the mean nutrient concentration and the mean annual volume of runoff generated in the internal catchment area. This is the predicted difference in mean annual flow between the upstream and downstream nodes of the stream link. Any differences in runoff between land uses are not accounted for. No distinction is made between surface and subsurface runoff for nutrient concentration.
Table 5: Estimated average concentrations of DIN, DON, FRP and DOP in runoff from land uses Wet Tropics Regions (after Brodie et al., 2003).

<table>
<thead>
<tr>
<th>Landuse</th>
<th>DIN (µg/L)</th>
<th>DON (µg/L)</th>
<th>FRP (µg/L)</th>
<th>DOP (µg/L)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainforest</td>
<td>40</td>
<td>150</td>
<td>10</td>
<td>10</td>
<td>Butler et al., 1996; Cogle et al., 2000; 2002; Devlin et al., 2001;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Faithful, 1990; Faithful and Brodie, 1990; Furnas, in press; Hunter et al., 2001</td>
</tr>
<tr>
<td>Ungrazed savannah/woodland</td>
<td>100</td>
<td>100</td>
<td>20</td>
<td>10</td>
<td>Furnas, 2003; Jackson and Ash, 2001; Prove and Hicks, 1991; Schmidt and Lamble, 2002; O’Reagain et al., 2001</td>
</tr>
<tr>
<td>Grazing</td>
<td>200</td>
<td>250</td>
<td>50</td>
<td>12</td>
<td>Furnas, 2003; Nelson et al., 1996; Noble and Collins, 2000; Prove and Hicks, 1991; O’Reagain et al., 2001; Brodie, unpublished</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>1100</td>
<td>350</td>
<td>40</td>
<td>30</td>
<td>Armour et al., 1999; Baskeran et al., 2002; Bauld et al., 1996;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Biggs et al., 2000; 2001; Bohl et al., 2000, 2001; Bramley and Muller, 1999; Bramley and Roth, 2002; Brodie et al., 1984; Clayton and Pearson, 1996; Congdon and Lukacs, 1996; Devlin et al., 2001; Eyre and Davies, 1996; Hunter et al., 1996; 2001; Mitchell et al., 1997; 2001; Moody et al., 1996; Rasiah and Armour, 2001; Rasiah et al., 2002; Reghrenzani et al., 1996 Verberg et al., 1998; Weier, 1999; Wilhelm, 2001; White et al., 2002</td>
</tr>
<tr>
<td>Horticulture</td>
<td>500</td>
<td>200</td>
<td>30</td>
<td>20</td>
<td>Cogle et al., 2000; 2002; Hashim et al., 1997</td>
</tr>
<tr>
<td>Forestry</td>
<td>150</td>
<td>150</td>
<td>8</td>
<td>8</td>
<td>Bubb et al., 2001; 2002; Bubb and Croton, 2002</td>
</tr>
</tbody>
</table>

Unfortunately the relationship between fertiliser application rates and the loss values of the dissolved nutrients is not readily known for the Douglas Shire Catchments. Essentially this is what the instrumented flume trial will be determining for the Douglas Shire. The flume trial will be looking at what the nutrient losses are (in µg/L) for the current fertiliser application rate as well as for a reduced fertiliser application rate. These results can potentially be used to re-run the models in the future. The current application rates for the Douglas Shire are given in Table 6. Unfortunately, these cannot be used directly in the model until we have a better understanding of what proportion of the fertiliser is removed from the cane plot as runoff, what amount is used by the plant and what proportion is lost to other pathways such as groundwater.

Therefore the nutrient values that will be used in the model (Table 5) assume that the current average application rate of fertiliser was assumed to be ~ 200 kg/ha/yr of nitrogen which is a combination of fertiliser (160 kg/ha/year), trash mineralisation return (30 kg/ha/year) and mill mud/ash (10 kg/ha/year). These values actually don’t deviate considerably from the estimates given for the Douglas Shire in Table 6, and are therefore considered a good first estimate to be used in the model.

Table 6: Current fertiliser application rates for cane in the Mossman mill area (source Allan Rudd, Mossman Agricultural Services)

<table>
<thead>
<tr>
<th>CATCHMENT</th>
<th>2003 AREAS (ha)</th>
<th>FERTILISER USAGE</th>
<th>MUD/ASH MIXTURES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2003 AREAS (ha)</td>
<td>Kg N/ha/yr (ratoon and plant)</td>
<td>Kg N/ha/yr (average for all cane)</td>
</tr>
<tr>
<td>Daintree</td>
<td>87</td>
<td>150</td>
<td>139</td>
</tr>
<tr>
<td>Saltwater</td>
<td>163</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>Mossman</td>
<td>235</td>
<td>150</td>
<td>137</td>
</tr>
<tr>
<td>Mowbray</td>
<td>247</td>
<td>150</td>
<td>124</td>
</tr>
<tr>
<td>Average for Shire</td>
<td>183</td>
<td>150</td>
<td>135</td>
</tr>
</tbody>
</table>
**Point source pollution**

The main nutrient form that is considered relevant to point source pollution in the model is dissolved inorganic nitrogen (DIN), however, the model also assess TN and TP. Only point sources that are located within 5 km of a river link are included in the model analysis, and it is assumed that these loads discharge directly into the nearest river link. Point source pollution data for the Douglas Shire Catchments were compiled by EPA (Brynn Mathews) and DSC (Peter Bradley). Unfortunately, out of the original 24 potential point source sites, only 7 sites had sufficient data that could be used within the model (Table 7). Further improvement of the point source pollution component of the model will require improved data for the remaining sites.

Table 7: Point source data used in the model (data source Brynn Mathews EPA and Peter Bradley DSC)

<table>
<thead>
<tr>
<th>Full name</th>
<th>Site name and type</th>
<th>GPS (lat + long)</th>
<th>City or town</th>
<th>Catchment</th>
<th>Annual N (kg/yr)</th>
<th>Annual P (kg/yr)</th>
<th>Source of data</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Shire Council</td>
<td>Mossman STP</td>
<td>145.3771E 16.4512S</td>
<td>Mossman</td>
<td>Mossman</td>
<td>1580</td>
<td>879</td>
<td>EPA</td>
<td>The single major point source of nutrients on the Mossman River. The use of this effluent for irrigation (c.f. Port Douglas sewage treatment plant) would dramatically reduce the nutrient and sediment loads from this plant.</td>
</tr>
<tr>
<td>Seafarm Pty Ltd</td>
<td>Seafarm</td>
<td>145.4477E 16.4995S</td>
<td>Mossman</td>
<td>Mossman</td>
<td>1022</td>
<td>330</td>
<td>EPA</td>
<td>The single major point source of nutrients and sediment on Dicksons Inlet. Introduction of BMP could greatly reduce this discharge rate.</td>
</tr>
<tr>
<td>Douglas Shire Council</td>
<td>Port Douglas STP</td>
<td>145.4608E 16.4848S</td>
<td>Port Douglas</td>
<td>Mowbray</td>
<td>45</td>
<td>4.4</td>
<td>EPA</td>
<td>The average reuse rate of effluent in irrigation was 87% over the last 18 months. This produced the low measured discharge rates of N, P and sediment as only the balance of effluent (13%) was discharged.</td>
</tr>
<tr>
<td>Wonga Beach</td>
<td>School and residential</td>
<td></td>
<td>Wonga Beach</td>
<td>Daintree</td>
<td>7928</td>
<td>17095</td>
<td>DSC</td>
<td></td>
</tr>
<tr>
<td>Cooya Beach</td>
<td>Residential</td>
<td></td>
<td>Cooya Beach</td>
<td>Mossman</td>
<td>1752</td>
<td>3778</td>
<td>DSC</td>
<td></td>
</tr>
<tr>
<td>Miallo School and Sporting grounds</td>
<td></td>
<td></td>
<td>Miallo Saltwater</td>
<td></td>
<td>376</td>
<td>811</td>
<td>DSC</td>
<td></td>
</tr>
<tr>
<td>Daintree Village</td>
<td>Residential</td>
<td></td>
<td>Daintree</td>
<td></td>
<td>480</td>
<td>1035</td>
<td>DSC</td>
<td></td>
</tr>
</tbody>
</table>

**Nutrient sinks**

ANNEX includes three loss terms: (1) deposition of sediment associated nutrients on floodplains, (2) storage of all forms of nutrients in reservoirs, and (3) denitrification of DIN. The nutrient load deposited with sediment on floodplains and reservoirs is the product of the suspended sediment load (SS). The loss of nutrients to reservoirs was not relevant to this study.

Losses of DIN to denitrification in both in channel and flood flows were modelled as an exponential decay process that is a function of the residence time of water in the river channel or associated floodplain. Residence time is the ratio of water surface area ($w$) to discharge ($Q$). A temperature and substrate dependent assimilation rate coefficient ($k$) was used. The DIN yield from a link is:

$$\text{DIN}_{\text{out}} = \text{DIN}_{\text{in}} e^{-\frac{kw}{Q}}$$

Equation 15
For channel denitrification the channel bed area over which the transformation or loss occurs is estimated as the product of the link mean bankfull width \((w)\) and the link length \((L)\). In reservoirs, the area term is the reservoir area and the representative flow is the median over-bank flow \((Q_{mo})\). On floodplains it is the floodplain area at the median over-bank flow. The transformation rate coefficients \((k, \text{ m/d})\) are based on measurement of denitrification in Australia from Ford (pers. comm.):

\[
k_{\text{SAND}} = 0.0001 * T \quad \text{Equation 16}
\]

\[
k_{\text{MUD}} = 0.0002 * T \quad \text{Equation 17}
\]

where, \(T\) is the mean annual water temperature \((^\circ C)\) which was assumed to be reasonably estimated by the mean annual air temperature. The mean annual air temperature for each link was sourced from the ANUCLIM grid surface (Houlder et al., 2000).

**Phosphorus transformations**

ANNEX assumes that phosphorus exchange occurs between dissolved phase and sediment-adsorbed phase in a fully reversible way. The concentration of P in sediment \((P_{ss}, \text{ g/kg})\) is a constant ratio of the concentration in water \((P_{dis}, \text{ mg/l})\) determined by the adsorption isotherm \((K_d, \text{ m}^3/\text{kg})\):

\[
P_{ss} = K_d * P_{dis} \quad \text{Equation 18}
\]

This, together with inputs of P, is used to determine the filterable reactive phosphorus (or FRP) load dissolved in runoff, and the sediment associated P load for each river link. A \(K_d\) value of 40 applied to the whole catchment gave satisfactory results and is consistent with limited observations (Young et al., 2001).

### 6. Results

#### 6.1 Sediment budget

This section presents the results of the sediment budget for the Douglas Shire Catchments. *It is important to stress that the results are not to be interpreted at a property level.* The data inputs, and thus the results, are based on ‘average’ estimates for particular conditions, and although the natural variability of the landscape is taken into consideration wherever possible, not all levels of variability can be incorporated. For example, it is acknowledged that the level of cover on an area of grazing land or cane plots will vary from property to property and from season to season. However, data describing this variability is not available and therefore an ‘average’ cover level for all landuses on the same vegetation type is used. Hence, the values obtained at the catchment and sub-catchment level can be interpreted as a indicator of the average condition of that area of the catchment, and of course, over time, these values would fluctuate. On the other hand, the variability of other factors such as rainfall, topography etc have been incorporated where suitable data exists.

**Interpreting results**

To help interpret the results from the modelling, the results have been presented individually for each of the four catchments, and then the results were combined to give an overall result for the Douglas Shire. Table 8 summarises the land area of each catchment incorporated into the model outputs; the catchment areas are given in hectares and square kilometres. The ‘additional coastal area’ in Table 8 and the small cream coloured sections (adjacent to the coast) in many of the subsequent figures represent the catchment areas that were too small to be incorporated into the SedNet model. That is, the sediment generated from hillslope erosion in these sections was assumed to move directly to the coast, and there was no deposition or nutrient transformation calculated in this process. The overall losses from these sections were, however, taken into account in the catchment budgets. Some of these areas include the Port Douglas and Dickson Inlet sub catchments that are being dealt with in other smaller scale studies. For the main sediment and nutrient budgets,
the source of sediments/nutrients can be assessed in terms of tonnes per year (t/yr) or as per hectare per year (t/ha/yr).

Table 8: Catchment areas used in the modelling for the Douglas Shire

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area from streams (ha)</th>
<th>Additional coastal area (ha)</th>
<th>% of coastal area in relation to entire catchment</th>
<th>Total area (ha)</th>
<th>Total area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Douglas Shire</td>
<td>181,538</td>
<td>3,375</td>
<td>1.86%</td>
<td>184,913</td>
<td>1,849</td>
</tr>
<tr>
<td>Daintree</td>
<td>132,427</td>
<td>776</td>
<td>0.58%</td>
<td>133,203</td>
<td>1,332</td>
</tr>
<tr>
<td>Saltwater</td>
<td>13,228</td>
<td>369</td>
<td>2.71%</td>
<td>13,597</td>
<td>136</td>
</tr>
<tr>
<td>Mossman</td>
<td>20,492</td>
<td>270</td>
<td>1.3%</td>
<td>20,762</td>
<td>208</td>
</tr>
<tr>
<td>Mowbray</td>
<td>15,391</td>
<td>1,960</td>
<td>11.3%</td>
<td>17,351</td>
<td>174</td>
</tr>
</tbody>
</table>

A summary of the total sediment budget for the Douglas Shire Catchments, as well as for each of the four individual catchments (Daintree, Saltwater, Mossman and Mowbray) is shown in Figure 9. The most important figure in this table is the amount of sediment shown to be delivered to the estuary. Overall for the Douglas Shire Catchments it is estimated approximately 322,000 tonnes of sediment is delivered to the estuaries and coastal region each year. The amount of ‘sediment delivered to the estuary’ is simply the amount of sediment supplied (in table as ‘total losses’) minus the stored sediments (‘total suspended sediment stored’ + ‘total bed sediment stored). The amount of bed sediments stored were less than 1,000 t/yr for all catchments.

Approximately 198,000 t/yr or 61% of the sediment load comes from the Daintree Catchment, however, this is simply because the Daintree makes up 72% of the Douglas Shire area (Table 10). The Mossman Catchment is the second highest contributor of sediment to the estuary with 46,000 t/yr (or 14%) closely followed by Saltwater Creek with 41,000 t/yr (or 13%) and then the Mowbray with 37,000 t/yr (or 11%) (Table 9). It is important to re-emphasise that the SedNet model can estimate the loads reaching the estuary, however, it is uncertain what proportion of the sediment and nutrients getting to estuary actually make to the ocean as the role of wet tropics estuaries in trapping sediment and nutrients is still unknown. A discussion of the different sources of sediment that contribute to this total is discussed in the following sections. The amount of suspended sediment stored was also relatively low and this is a result of the small floodplain area in most of these catchments.
Table 9: Summary of sediment budget for the Douglas Shire Catchments. Values in brackets are in t/ha/yr. PLEASE look at the methods section for how these values were derived.

<table>
<thead>
<tr>
<th>Sediment budget item</th>
<th>Total for Douglas Shire Catchments</th>
<th>Daintree Catchment</th>
<th>Saltwater Catchment</th>
<th>Mossman Catchment</th>
<th>Mowbray Catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hillslope Delivery</td>
<td>221,000 (4.65 t/ha/yr)</td>
<td>162,000 (1.22 t/ha/yr)</td>
<td>16,000 (1.14 t/ha/yr)</td>
<td>21,000 (1.03 t/ha/yr)</td>
<td>22,000 (1.26 t/ha/yr)</td>
</tr>
<tr>
<td>Drain erosion rate 1</td>
<td>79,000 (4.12 t/ha/yr)</td>
<td>12,000 (0.09 t/ha/yr)</td>
<td>24,000 (1.77 t/ha/yr)</td>
<td>26,000 (1.27 t/ha/yr)</td>
<td>17,000 (0.99 t/ha/yr)</td>
</tr>
<tr>
<td>Riverbank erosion rate</td>
<td>41,000 (0.76 t/ha/yr)</td>
<td>32,000 (0.24 t/ha/yr)</td>
<td>5,000 (0.35 t/ha/yr)</td>
<td>3,000 (0.12 t/ha/yr)</td>
<td>1,000 (0.05 t/ha/yr)</td>
</tr>
<tr>
<td>Total sediment supply</td>
<td>341,000 (9.53 t/ha/yr)</td>
<td>206,000 (1.55 t/ha/yr)</td>
<td>45,000 (3.26 t/ha/yr)</td>
<td>50,000 (2.42 t/ha/yr)</td>
<td>40,000 (2.3 t/ha/yr)</td>
</tr>
<tr>
<td>Total suspended sediment stored</td>
<td>19,000</td>
<td>8,000</td>
<td>4,000</td>
<td>4,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Total bed sediment stored</td>
<td>&lt;1,000</td>
<td>&lt;1,000</td>
<td>&lt;1,000</td>
<td>&lt;1,000</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>Sediment delivery to the estuary</td>
<td>322,000</td>
<td>198,000</td>
<td>41,000</td>
<td>46,000</td>
<td>37,000</td>
</tr>
<tr>
<td>Total losses</td>
<td>341,000</td>
<td>206,000</td>
<td>45,000</td>
<td>50,000</td>
<td>40,000</td>
</tr>
</tbody>
</table>

(1) The drain erosion results for this study are considered to be an over-estimate of the amount of sediment lost from drains in the Douglas Shire Catchments. This is because the drainage density data used was based on the Saltwater Creek Catchment only and the erosion rates applied were based on the results in Roth and Visser (2003) for ‘major drains’ only (and did not include minor drains and furrows). The major drains in the study by Roth and Visser (2003) (in the Herbert River Catchment) have high erosion rates as they are large channels, with steeper more erodible walls and less vegetation. It is also acknowledged that the soil types and hydrology vary considerably between the floodplains of the Douglas Shire and the Herbert River. Therefore, the results presented in this report are assumed to be at the upper limit of cane drain erosion expected for the Douglas Shire Catchments.

6.1.1. Hillslope erosion

The total amount of sediment derived from hillslope erosion in the Douglas Shire Catchments is predicted to be approximately 221,000 t/yr. This represents ~65% of the total sediment load delivered to the stream network. The proportion of sediment derived from hillslope erosion varies in each catchment. In the Daintree Catchment a total of 162,000 t/yr is delivered from hillslopes to streams, and this represents 79% of the sediment budget for the Daintree Catchment. In Saltwater Creek a total of 16,000 t/yr is delivered from hillslopes to streams, representing 36% of the sediment budget for that Catchment. In the Mossman Catchment there is a total of 21,000 t/yr (42% of the total budget) and in the Mowbray Catchment a total of 22,000 t/yr (55% of the sediment budget). These results suggest that hillslope erosion is the dominant process in both the Daintree and Mowbray Catchments.

Figure 10 shows the gross or total erosion from hillslopes and Figure 11 shows the contribution of hillslope erosion that actually makes it to the stream network. The two figures show that there is a large difference between the amount of hillslope erosion in the catchments (Figure 10) and the amount of sediment that actually gets to the river system (Figure 11). This is because, on average, only between 5-10% of sediment moving on hillslopes finds its way to streams. In many cases material eroded on a ridge might end up being deposited in colluvial fans on flatter valley bottoms or on river frontage areas before reaching a stream. This process is taken into consideration by applying a hillslope sediment delivery ratio to the data. It is important to note that although not all areas are necessarily contributing to sediment loss to the river network, the area may still be eroding, and this may not be beneficial to agricultural production.
Table 10: Contribution to total sediment load from each catchment. Note % contributions have been rounded to nearest whole number. PLEASE look at the methods section for how these values were derived.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (km²)</th>
<th>% Area of Douglas Shire</th>
<th>Total Sediment Supplied to estuary (t/yr)</th>
<th>% contribution of hillslopes to the total sediment supply for that catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Shire</td>
<td>1849</td>
<td>-</td>
<td>322,000</td>
<td>65%</td>
</tr>
<tr>
<td>Daintree</td>
<td>1332</td>
<td>72%</td>
<td>198,000</td>
<td>79%</td>
</tr>
<tr>
<td>Saltwater</td>
<td>136</td>
<td>7.3%</td>
<td>41,000</td>
<td>36%</td>
</tr>
<tr>
<td>Mossman</td>
<td>208</td>
<td>11.3%</td>
<td>46,000</td>
<td>42%</td>
</tr>
<tr>
<td>Mowbray</td>
<td>174</td>
<td>9.5%</td>
<td>37,000</td>
<td>55%</td>
</tr>
</tbody>
</table>

The results shown in Figure 10 suggest that the highest levels of hillslope erosion are found around the cleared slopes adjacent to the floodplain often in grazing or cleared areas. The most obvious of these sites are on the foot-slopes of Daintree Catchment (mainly around Douglas and Stewart Creeks – not labelled) where hillslope erosion rates are predicted to be as high as > 100 t/ha/yr (Figure 10), however, the incorporation of the hillslope delivery ratio suggests that only ~ 25 t/ha/yr actually makes it to the stream network (Figure 11). The foot-slopes in the Saltwater and Mossman Catchments also have areas yielding as much as 20-25 t/ha/yr (Figure 11). Other areas that show relatively high erosion rates (between 20-50 t/yr gross) can been seen in the steeper mountainous zones of the Daintree Catchment. It is not un-expected that the steep mountainous areas have high erosion rates, as steep slopes and high rainfall (independent of landuse) are strong drivers of hillslope erosion. It is important to note that these sites already have dense vegetation cover, and if they were cleared, the hillslope erosion rates would be much higher.
Figure 10: Predicted Total Hillslope Erosion for the Douglas Shire Catchments (RKLSC is the gross hillslope erosion not including the sediment delivery ratio calculations). PLEASE look at the methods section for how these values were derived.
Figure 11: Contribution of Hillslope erosion to streams (including HSDR estimates). PLEASE look at the methods section for how these values were derived.
6.1.2. Contribution of hillslope erosion from different landuse types

The contribution of soil loss from hillslope erosion for the different landuse areas within the Douglas Shire Catchments is shown in Table 11. The table shows the percentage area of each landuse and the associated slope and erosion rates in t/yr and t/ha/yr. The total loss rates in t/yr suggests that the areas under Rainforest and Sclerophyll forest are the largest contributors to hillslope erosion in the Douglas Shire contributing a total of ~ 130,000t/yr and 60,000t/yr, respectively. The next highest contributor is the ‘other’ category with 13,200 t/yr and then sugarcane with 6000 t/yr. However, when the data is converted to t/ha/yr the highest per unit contributors are fruit trees (4.92 t/ha/yr), sclerophyll forest (1.35 t/ha/yr), grazing (1.23 t/ha/yr) and then rural residential (1.20 t/ha/yr). However, when the data is evaluated on a per unit basis, the % area that the landuse occupies must be kept in mind. For example, although fruit tree crops have the highest per unit contribution, they only occupy < 1% of the Douglas Shire Catchments. It is also important to point out that the reason that there is up to eight times more sediment coming from fruit trees than sugar cane is because the average slope of the area under fruit trees is ~9.94 % and the average slope of the area under sugar cane is 1.71% (see Table 11).

The high hillslope erosion obtained for forested areas is because rainforest/sclerophyll occupies ~87% of the catchment. It is also important to note that most of the forested sites are on extremely steep slopes (~28% slope, see Table 11) with high rainfall. Any other landuse on this type of topography would yield much higher sediment loads, so it is not always suitable to compare loads from lowland or flat landscapes with no vegetation with forested areas on steep slopes.

It is also worth noting that some of the landuse types that currently occupy the floodplain are, in pre-European terms, in a landscape ‘sink’ zone. That is, the floodplain would have been a major storage zone for sediments and nutrients that were transported from the upper catchment areas. The various activities related to some landuse types i.e. constructed drains and cleared areas under fruit tree crops and on roads and headlands now mean that this area is serving as a sediment source. Some areas, in particular the remaining wetlands would still be a net sink, however, other altered parts of the floodplain would no longer undertake this sink function.
Table 11: Contribution of hillslope erosion from each of the major landuse areas with the Douglas Shire Catchments. Note the total losses don’t always match between tables because of rounding errors within the model. Note: these estimates are based on modelled rather than measured data and therefore the results should be used with caution. PLEASE look at the methods section for how these values were derived.

<table>
<thead>
<tr>
<th>Landuse</th>
<th>Area (km²)</th>
<th>Proportion of the Douglas Shire (%)</th>
<th>Average slope** (%)</th>
<th>Predicted total Soil Loss (t/yr)</th>
<th>Average sediment supply to streams (includes HSDR) (t/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit trees (e.g. bananas, pawpaws)</td>
<td>0.5</td>
<td>&lt;1%</td>
<td>9.94</td>
<td>270</td>
<td>4.92</td>
</tr>
<tr>
<td>Sugarcane (includes headlands)</td>
<td>87.8</td>
<td>4.8%</td>
<td>1.71</td>
<td>6,000</td>
<td>0.63</td>
</tr>
<tr>
<td>Cleared</td>
<td>2.9</td>
<td>&lt;1%</td>
<td>5.08</td>
<td>220</td>
<td>0.76</td>
</tr>
<tr>
<td>Grazing</td>
<td>57.3</td>
<td>3.1%</td>
<td>9.20</td>
<td>7000</td>
<td>1.23</td>
</tr>
<tr>
<td>Regrowth</td>
<td>2.8</td>
<td>&lt;1%</td>
<td>8.10</td>
<td>210</td>
<td>0.76</td>
</tr>
<tr>
<td>Rural Residential</td>
<td>9.2</td>
<td>&lt;1%</td>
<td>12.14</td>
<td>1100</td>
<td>1.2</td>
</tr>
<tr>
<td>Production Forestry</td>
<td>&lt;1</td>
<td>&lt;1%</td>
<td>Na</td>
<td>&lt;1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Sclerophyll (wet and dry combined)***</td>
<td>446.3</td>
<td>24.2%</td>
<td>25.48</td>
<td>60,000</td>
<td>1.35</td>
</tr>
<tr>
<td>Rainforest***</td>
<td>1164.3</td>
<td>63%</td>
<td>28.39</td>
<td>130,000</td>
<td>1.12</td>
</tr>
<tr>
<td>Roads</td>
<td>1.8</td>
<td>&lt;1%</td>
<td>2.82</td>
<td>9</td>
<td>0.05</td>
</tr>
<tr>
<td>Tourism areas</td>
<td>1.8</td>
<td>&lt;1%</td>
<td>4.62</td>
<td>10</td>
<td>0.05</td>
</tr>
<tr>
<td>Urban</td>
<td>6.1</td>
<td>&lt;1%</td>
<td>2.86</td>
<td>28</td>
<td>0.05</td>
</tr>
<tr>
<td>Industrial</td>
<td>0.5</td>
<td>&lt;1%</td>
<td>8.39</td>
<td>5</td>
<td>0.17</td>
</tr>
<tr>
<td>Other (includes quarries, aquaculture, melaleuca areas, coastal mosaic, sand dunes)</td>
<td>66.3</td>
<td>3.6</td>
<td>1.14</td>
<td>13,200</td>
<td>0.06</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1847.7</td>
<td>100%</td>
<td></td>
<td>218,000</td>
<td></td>
</tr>
</tbody>
</table>

** Note: the slope values calculated for each landuse are ‘average values’ for the entire catchment, Individual properties may deviate from this value

*** Note: that the soil loss estimates for the forested sections are considered to be an over-estimate compared to the other landuses. The reason for this is explained in detail on p7 of this report.

6.1.3. Constructed Drain Erosion

The total amount of sediment eroded from drains in the Douglas Shire Catchments is predicted to be ~79,000 t/yr, which represents 23% of the total sediment load from the overall budget (Table 9). However, the contribution of drain erosion varies for each catchment with only 6% of sediment in the Daintree Catchment coming from drain erosion, whereas in the Saltwater, Mossman and Mowbray Catchments the contribution was 53%, 52% and 43%, respectively. This suggests that drain erosion is the dominant source of sediment in both the Saltwater and Mossman Catchments, and is a major source of sediment in the Mowbray catchment. The difference in the drain contribution for the various catchments varies according to the proportion of sugar cane in each catchment.

The drain erosion results for this study are considered to be an over-estimate of the amount of sediment lost from drains in the Douglas Shire Catchments. This is because the drainage density data used was based on the Saltwater Creek Catchment only and the erosion rates applied were based on the results in Roth and Visser (2003) for ‘major drains’ only (and did not include minor drains and furrows). The major drains in the study by Roth and Visser (2003) (in the Herbert River Catchment) have high erosion rates as they are large channels, with steeper more erodible walls and less vegetation. It is also acknowledged that the soil types and hydrology vary considerably between
the floodplains of the Douglas Shire and the Herbert River. Therefore, the results presented in this report are assumed to be at the upper limit of cane drain erosion expected for the Douglas Shire Catchments. To improve on the modelling results, a drain erosion survey is required for all of the Douglas Shire Catchments (see Figure 18 in Roth and Visser, 2003, for an example).

Despite the fact that the cane drain results appear to be at the upper limit of expected values, it is important to note that overall cane drain erosion has been identified as a large contributor of sediments in the Douglas Shire catchments. Even if the results given here have an error value as large at 50%, the contribution from cane drains is still a considerable proportion of the overall budget. In many ways, this result is not that unexpected. Drainage systems have been put in place in cane areas to get water off the cane paddocks as quickly as possible. In the process, this water is removing sediments and nutrients from the area. Also, the relatively straight dimensions and un-vegetated state of many cane drains means that they are highly susceptible to high erosion rates.

Table 12: Contribution of cane drain erosion from each of the major catchments within the Douglas Shire. Note % contributions have been rounded to nearest whole number. PLEASE look at the methods section for how these values were derived.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (km²)</th>
<th>Predicted total Soil Loss (t/yr)</th>
<th>% contribution from cane drains to the total sediment supply for each catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Shire</td>
<td>1849</td>
<td>79,000</td>
<td>23%</td>
</tr>
<tr>
<td>Daintree</td>
<td>1332</td>
<td>12,000</td>
<td>6%</td>
</tr>
<tr>
<td>Saltwater</td>
<td>136</td>
<td>24,000</td>
<td>53%</td>
</tr>
<tr>
<td>Mossman</td>
<td>208</td>
<td>26,000</td>
<td>52%</td>
</tr>
<tr>
<td>Mowbray</td>
<td>174</td>
<td>17,000</td>
<td>43%</td>
</tr>
</tbody>
</table>

6.1.4. Riverbank erosion

The total amount of sediment sourced from bank erosion in the Douglas Shire Catchment is predicted to be ~ 41,000 t/yr, which represents ~ 12% of the total sediment budget for the Douglas Shire Catchment. Overall, bank erosion contributed the least amount of sediment to the total budget for each catchment. Proportionally, Daintree had the highest contribution from bank erosion (15%), followed by Saltwater (11%), Mossman (6%) and then Mowbray Catchment (2%). Areas of high bank erosion are not necessarily concentrated in a specific part of the catchment. This is because the rates of bank erosion are controlled largely by the proportion of riparian vegetation that is present (see Figure 9) as well as other features such as channel slope and discharge. The areas with the highest rates of bank erosion were found directly downstream of the junction of the Daintree River and Stewart Creek (20-30 cm) and there are a few small sections on the main channel of the Daintree that suggest there could be up to 100 cm of erosion each year (Figure 12). There are also sections along the lower Saltwater, Mossman and Mowbray channels with erosion rates of between 5-20 cm of erosion each year. Overall, however, most of the bank erosion appears to be < 1 cm/yr.

Table 13: Contribution of bank erosion from each of the major catchments within the Douglas Shire. Note % contributions have been rounded to nearest whole number. PLEASE look at the methods section for how these values were derived.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (km²)</th>
<th>Predicted total Soil Loss (t/yr)</th>
<th>% contribution from bank erosion to the total sediment supply for each catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Shire</td>
<td>1849</td>
<td>41,000</td>
<td>12%</td>
</tr>
<tr>
<td>Daintree</td>
<td>1332</td>
<td>32,000</td>
<td>15%</td>
</tr>
<tr>
<td>Saltwater</td>
<td>136</td>
<td>5,000</td>
<td>11%</td>
</tr>
<tr>
<td>Mossman</td>
<td>208</td>
<td>3,000</td>
<td>6%</td>
</tr>
<tr>
<td>Mowbray</td>
<td>174</td>
<td>1,000</td>
<td>2%</td>
</tr>
</tbody>
</table>
Figure 12: Bank erosion in centimetres per year in the Douglas Shire Catchments. PLEASE look at the methods section for how these values were derived.
6.1.5. Contribution of sediment to the coast

*Suspended Sediment Contribution to the coast*

One of the major strengths of the SedNet model is the ability to show where in the catchment the major sediment sources are derived. Because of the various areas that sediment can be deposited in a landscape, areas that are closer to the coast are more likely to contribute sediment to the coast, even if the actual soil erosion losses (per area) are less than in areas that are further away from the coast. Figure 13 shows the fine sediment contribution to the coast from different parts of the catchment.

Figure 13 suggests that there a number of small watersheds adjacent to the Daintree River that are contributing much higher proportions of sediment than other areas of the catchment (up to and > 30 t/ha/yr). There are also a number of watersheds around the floodplain sections of all four catchments that are contributing between 2.5-5.0 t/ha/yr to the estuary. However, overall, most watersheds contribute < 2.5 t/ha/yr to the catchment outlet.

*Coarse Sediment Contribution to the coast*

The total loss of coarse sediment (assumed to be sand sized sediment ~ 2 mm in size) to the coast is predicted to be ~ 60,000 t/yr for the Douglas Shire Catchments (Table 14). The amount of coarse sediment leaving the Douglas Shire Catchments represents only 18% of the total sediment budget. This is because most of the coarse sediment is stored in various parts of the stream network. The bed-load sediment budget predicts the accumulation of sand and gravel on the bed of rivers as a result of increased rates of bank and cane drain erosion. We consider that where historical bed deposition is in excess of 30 cm, there is likely to be some impact on bed habitats. This might be through filling of pools, smothering of cobble beds with finer grained sediment or reduced diversity of bed forms.

Table 14: Contribution of coarse sediment to the overall budget for each catchment. *PLEASE look at the methods section for how these values were derived.*

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (km²)</th>
<th>Amount of Bedload (t/yr)</th>
<th>Proportion of total load getting to estuary (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Shire</td>
<td>1849</td>
<td>60,000</td>
<td>19%</td>
</tr>
<tr>
<td>Daintree</td>
<td>1332</td>
<td>22,000</td>
<td>11%</td>
</tr>
<tr>
<td>Saltwater</td>
<td>136</td>
<td>14,500</td>
<td>35%</td>
</tr>
<tr>
<td>Mossman</td>
<td>208</td>
<td>14,500</td>
<td>32%</td>
</tr>
<tr>
<td>Mowbray</td>
<td>174</td>
<td>9,000</td>
<td>24%</td>
</tr>
</tbody>
</table>
Figure 13: Total fine sediment contribution to the coast (t/ha/yr). PLEASE look at the methods section for how these values were derived.
6.2 Nutrient budget

The predicted mean annual nitrogen (N) and phosphorus (P) loads for the Douglas Shire Catchments are shown in Table 15 and Table 16, respectively. The tables show the total N and total P from particulate (erosion), dissolved (runoff) and point sources. The amount of ‘nutrient delivery to the estuary’ is simply the amount of nutrient supplied (dissolved + particulate export) minus the floodplain storage. Table 17 presents the data for each catchment as a proportion of the total nutrient input to the coast. The spatial patterns of total N and P contribution are shown in Figure 14 and Figure 15, respectively.

The total amount of nitrogen (N) estimated to be exported by the Douglas Shire Rivers to the estuary is 1,566 t/yr. Due to the size of the Daintree Catchment, it dominates the overall N budget for the Douglas Shire, suggesting that the major form of nitrogen exported from the Douglas Shire is particulate N. This is true for the Daintree Catchment, which is dominated by rainforest and sclerophyll forest; however, dissolved N is the greatest contributor to the N budget in the catchments with large areas of sugar cane (i.e. Saltwater, Mossman and Mowbray). This is due to the application of fertiliser in the cane lands and fruit tree crops on the floodplain. Fertiliser is readily broken down into dissolved fractions. Hillslope erosion contributes more N than both bank and cane drain erosion in all four catchments. Point source pollution represents less than 1% of the total N in all four catchments. The amount of N stored on the floodplains as a proportion of the total N supplied ranges from 2.7% for the Daintree Catchment to 5.4% for the Saltwater Creek Catchment, and up to 5.8% for both the Mossman and Mowbray Catchments. There was little denitrification in any of the catchments due to the short residence times of the water.

Table 15: Components of the nitrogen (N) budget for the Douglas Shire Catchments. PLEASE look at the methods section for how these values were derived.

<table>
<thead>
<tr>
<th>Nutrient budget item</th>
<th>Total for Douglas Shire Catchments</th>
<th>Predicted mean annual rate (t/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daintree</td>
<td>Saltwater</td>
</tr>
<tr>
<td>Hillslope to stream delivery</td>
<td>868 (17.30 kg/ha/yr)</td>
<td>659 (4.95 kg/ha/yr)</td>
</tr>
<tr>
<td>Cane drain erosion</td>
<td>40 (2.06 kg/ha/yr)</td>
<td>6 (0.04 kg/ha/yr)</td>
</tr>
<tr>
<td>Riverbank erosion</td>
<td>19 (0.38 kg/ha/yr)</td>
<td>16 (0.12 kg/ha/yr)</td>
</tr>
<tr>
<td>Dissolved runoff</td>
<td>686 (18.93 kg/ha/yr)</td>
<td>426 (3.2 kg/ha/yr)</td>
</tr>
<tr>
<td>Point source</td>
<td>12 (0.31 kg/ha/yr)</td>
<td>8 (0.06 kg/ha/yr)</td>
</tr>
<tr>
<td>Total supply</td>
<td>1625 (38.99 kg/ha/yr)</td>
<td>1115 (8.38 kg/ha/yr)</td>
</tr>
<tr>
<td>Floodplain storage</td>
<td>59 (0.38 kg/ha/yr)</td>
<td>30 (0.12 kg/ha/yr)</td>
</tr>
<tr>
<td>Denitrification</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Dissolved export</td>
<td>700</td>
<td>435</td>
</tr>
<tr>
<td>Particulate export</td>
<td>866</td>
<td>650</td>
</tr>
<tr>
<td>Nutrient delivery to estuary</td>
<td>1566</td>
<td>1085</td>
</tr>
<tr>
<td>Total losses</td>
<td>1625</td>
<td>1115</td>
</tr>
</tbody>
</table>

The total amount of phosphorus (P) estimated to be exported by the Douglas Shire Rivers to the estuary is 257.5 t/yr. In contrast to the nitrogen budget, particulate P is the dominant form of P exported from all four catchments. This is because P is more commonly transported attached to fine soil particles. Therefore, the P budget will follow a similar pattern to the sediment budget. In the Daintree, Saltwater and Mossman Catchments, hillslope erosion is the dominate source of P, whereas in the Mowbray Catchment, drain erosion is the dominate source of P. The amount of P
contributing to point source pollution varies between catchments representing 8.7% in the Daintree Catchment, 4.3% in Saltwater Creek, 22% in Mossman and <1% in the Mowbray Catchment. The relatively high contribution of P coming from point source pollution in the Mossman Catchment is because of the location of the Mossman Sewerage Treatment Plant, Seafarm aquaculture plant and the Cooya Beach township. There are other point source locations that have higher N and P input values (e.g. Wonga Beach in the Daintree Catchment), however, these sites are often very small when compared to other sources in the catchment (e.g. P is dominated by hillslope erosion in the Daintree Catchment). The amount of P stored on the floodplain also varies between catchments with 3.8% stored in the Daintree, 8.7% in both Saltwater and Mossman Catchments and 13.9% stored in the Mowbray floodplain.

Table 16: Components of the phosphorus (P) budget for the Douglas Shire Catchments. PLEASE look at the methods section for how these values were derived.

<table>
<thead>
<tr>
<th>Nutrient budget item</th>
<th>Total for Douglas Shire Catchments</th>
<th>Predicted mean annual rate (t/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total for Douglas Shire Catchments</td>
<td>Daintree</td>
</tr>
<tr>
<td>Hillslope to stream delivery</td>
<td>162 (2.55 kg/ha/yr)</td>
<td>138 (1.04 kg/ha/yr)</td>
</tr>
<tr>
<td>Cane drain erosion</td>
<td>15 (0.84 kg/ha/yr)</td>
<td>1 (0.01 kg/ha/yr)</td>
</tr>
<tr>
<td>Riverbank erosion</td>
<td>5 (0.09 kg/ha/yr)</td>
<td>4 (0.03 kg/ha/yr)</td>
</tr>
<tr>
<td>Dissolved runoff</td>
<td>66 (1.53 kg/ha/yr)</td>
<td>47 (0.36 kg/ha/yr)</td>
</tr>
<tr>
<td>Point source</td>
<td>24 (0.44 kg/ha/yr)</td>
<td>18 (0.14 kg/ha/yr)</td>
</tr>
<tr>
<td>Total supply</td>
<td>272 (5.45 kg/ha/yr)</td>
<td>208 (1.57 kg/ha/yr)</td>
</tr>
<tr>
<td>Floodplain storage</td>
<td>14.5</td>
<td>8</td>
</tr>
<tr>
<td>Dissolved export</td>
<td>62</td>
<td>43</td>
</tr>
<tr>
<td>Particulate export</td>
<td>195.5</td>
<td>157</td>
</tr>
<tr>
<td>Nutrient delivery to the estuary</td>
<td>257.5</td>
<td>200</td>
</tr>
<tr>
<td>Total losses</td>
<td>272</td>
<td>208</td>
</tr>
</tbody>
</table>

Both the TN and TP budgets for the Douglas Shire are dominated by the Daintree Catchment (Table 17) which contributes ~70% of TN, and ~78% of TP to the total budget. It is important to note, however, that in the Daintree catchment, both N and P are predominantly sourced from forested areas (most probably from organic matter). The other catchments (Saltwater, Mossman and Mowbray) are much smaller, and therefore contribute much less to the overall N and P budgets for the Douglas Shire, however, it is important to point out that often the dominant forms of N and P are from non-natural sources such as fertiliser or point source pollution.

Table 17: Contribution of N and P from each catchment. Note % contributions have been rounded to nearest whole number. PLEASE look at the methods section for how these values were derived.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (km²)</th>
<th>Total N delivery to estuary (t/yr)</th>
<th>Proportion of total N load getting to estuary from this catchment (%)</th>
<th>Total P delivery to estuary (t/yr)</th>
<th>Proportion of total P load getting to estuary from this catchment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Shire</td>
<td>1849</td>
<td>1566</td>
<td>-</td>
<td>257.5</td>
<td>-</td>
</tr>
<tr>
<td>Daintree</td>
<td>1332</td>
<td>1085</td>
<td>70%</td>
<td>200</td>
<td>78%</td>
</tr>
<tr>
<td>Saltwater</td>
<td>136</td>
<td>175</td>
<td>11%</td>
<td>21</td>
<td>8%</td>
</tr>
<tr>
<td>Mossman</td>
<td>208</td>
<td>192</td>
<td>12%</td>
<td>21</td>
<td>8%</td>
</tr>
<tr>
<td>Mowbray</td>
<td>174</td>
<td>114</td>
<td>7%</td>
<td>15.5</td>
<td>6%</td>
</tr>
</tbody>
</table>
Figure 14: Pattern of TN delivered to streams from each watershed within the Douglas Shire Catchments. PLEASE look at the methods section for how these values were derived.
Figure 15: Pattern of TP delivered to streams from each watershed within the Douglas Shire Catchments. PLEASE look at the methods section for how these values were derived.
6.3 Effect of improved modelling on results

The results of the sediment and nutrient budgets for the Douglas Shire Catchments represent significant improvements over those produced for the national scale National Land and Water Audit Project (NLWRA) and other applications of SedNet to the region (eg. Brodie et al., 2003). The biggest improvement is the differentiation of the Douglas Shire Catchments into the four major catchments (Daintree, Saltwater, Mossman and Mowbray). In previous applications of SedNet, Saltwater Creek and Mowbray catchment were incorporated into the results for the Daintree and Mossman Catchments, respectively. This improvement means that catchment management can now be better targeted within the Shire. Other specific improvements to the results are summarized below.

- Using the local NR&M gauging station data from all of the wet tropics catchments (total of 34 gauges) allowed for improved regionalisation of flow parameters and their prediction throughout the channel network. These in turn improved estimation of sediment transport and deposition.
- This was the first SedNet study to model the input from cane drain erosion as a source of sediments and nutrients. In two out of the four catchments, cane drain erosion was found to be the dominant source of sediment.
- The combination of a better land use map, and measurements of slope angle from the high resolution digital elevation model improved estimation of hillslope erosion, particularly for the Mossman Catchment, where the proportion of sediment from hillslope erosion changed from 73% (NLWRA) to 42% in this study.
- Previous applications of SedNet to the Daintree and Mossman Catchments did not include point source pollution as an input. This study found that point sources may be a considerable input particularly in the Mossman Catchment.
- The results from the NLWRA suggested that there was ~94,000 t/yr of sediment lost from the Daintree Catchment. This study has greatly improved that estimate and now suggests that the total sediment supply to Daintree estuary is ~198,000 t/yr.
- The results from the NLWRA suggested that there was ~15,000 t/yr of sediment lost from the Mossman Catchment. This study has greatly improved that estimate and now suggests that the total sediment supply to Daintree estuary is ~46,000 t/yr.

6.4 Comparison of results with other studies and summary of outputs

In other catchments where the SedNet model has been applied to assess the overall sediment and nutrient loads within a catchment, as well as to determine the major processes and sources contributing to the overall loads, it has been possible to some to degree, to compare the results of the modelling work with measured data. This has usually been done using long term sediment records from QNR&M gauging stations or using data collected by other agencies (e.g. AIMS). For example, when the results of the application of the SedNet model in the Herbert River Catchment were compared to five years of measured data (using data collected by AIMS), the modelled results came within 10% of the annual average measured data (see Bartley et al., 2003 for more detail).

Unfortunately, for the Douglas Shire Catchments there is very little or no long term load data that we can use to assess the reliability of the modelled results. However, based on the results from the Herbert Catchment (which is also considered to be a wet tropical catchment), and the good agreement between the measured and modelled data, it is anticipated that the results for the Douglas Shire are reliable enough for use as a planning tool in terms of focused catchment management and planning rehabilitation.

There are, however, some results from the previous studies described in Section 4 that support the findings of this work. For example, the elevated concentrations of nitrogen (oxidised nitrogen) found in areas downstream of sugar cane by Moss et al., (Draft) were consistent with the findings from this study that suggested that dissolved N was the greatest contributor to the nitrogen budgets.
in catchments dominated by sugar cane. Also the high DIN and DON values in the flood plume off the Daintree River (Ayuki et al., 1997) is consistent with the modelled export discharge values for the Daintree Catchment.

It is also possible to use studies in other catchments to assess the reliability of the load values presented in this report. The Johnstone River Catchment has some of the most comprehensive load estimate data of all of the Wet Tropics catchments. Hunter et al., (2001) published load estimates for individual landuse types in the Johnstone Catchment (see Table 18). These data are modelled estimates that were calibrated against 5-6 years of measured data (pers. comm. Heather Hunter). The results obtained in the SedNet study from the Douglas Shire are compared with the Johnstone data in Table 18. The main difference in the data presented in Table 18 is that the values for the Douglas Shire are for hillslope erosion only, and the values for the Johnstone Catchment are total load values from all erosion processes (i.e. hillslope, gully, bank and drain erosion). Nonetheless, the values from the Douglas Shire and Johnstone Catchments are very similar, particularly for the rainforest, banana and pasture areas, as these landuse types are dominated by hillslope erosion. The reason why the sugar cane values for the Douglas Shire SedNet results are much lower than the Johnstone Catchment values can easily be explained by including drain erosion. Constructed drains were found to be the major source of sediment in cane areas in the Douglas Shire Catchments (not captured in Table 18) and this would have been incorporated in the Johnstone Catchment study, therefore showing a higher sediment loss.

Table 18: Comparison of modelled results from the Douglas Shire with data from the Johnstone Catchment for suspended sediments that are based on 6 years of measured/modelled water quality data (source Hunter et al., 2001). Note the SedNet results are for hillslope erosion only, however, this was the dominant source of sediment in most catchments.

<table>
<thead>
<tr>
<th>Landuse</th>
<th>Douglas Shire SedNet (this study) - hillslope erosion only</th>
<th>Johnstone Catchment (Hunter et al., 2001; Table 3.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainforest</td>
<td>1.12</td>
<td>1.2</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>0.63</td>
<td>3.9</td>
</tr>
<tr>
<td>Bananas</td>
<td>4.92</td>
<td>4.0</td>
</tr>
<tr>
<td>Pasture</td>
<td>1.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Overall, the application of the SedNet model in the Douglas Shire Catchments determined that:

Hillslope erosion is highest in the steep, cleared foot-slopes of all of the catchments, but it is particularly high in the cleared grazing slopes of the Stewart and Douglas catchments in the Daintree;

The main landuse contributing to the hillslope erosion budget are the rainforest and sclerophyll forest areas, however, on a per area basis fruit tree crops, sclerophyll forest, grazing and rural/residential are the highest contributors;

Overall cane drain erosion is contributing ~ 79,000 t/yr of sediment to the overall sediment budget, whereas the total amount of sediment eroded from cane blocks is ~ 6,000 t/yr. This finding suggests that there may be up to 10 times more sediment coming from cane drain erosion than from the cane blocks;

Bank erosion is contributing ~ 41,000 t/yr or 12% to the overall sediment budget and the main problem areas are found on the main channel of the Daintree River;

The major sources of N are coming from particulate rainforest sources in the Daintree Catchment and dissolved fertiliser sources in the Saltwater, Mossman and Mowbray Catchments.

The major sources of P are coming from particulate sources from hillslope erosion in the Daintree, Saltwater and Mossman Catchments. Cane drain erosion is the dominant source of P in the Mowbray Catchment. There is also a considerable contribution of P from point source pollution in the Mossman Catchment.
6.4.1. Uncertainty and the outputs of the SedNet model

It is acknowledged that there is a need to understand the confidence or uncertainty associated with the models that are used to estimate sediment and nutrient loads. This is because of the strong link between the modelling outputs and the decision making process being made at a catchment scale. However, estimating the error associated with both the model inputs and outputs is an extremely difficult scientific task, and well beyond the scope of this study.

The very nature of scientific inquiry associated with environmental research means that there will be some element of uncertainty that places a qualifier on any scientific conclusions or recommendations (see http://www.pce.govt.nz/reports/allreports/1_877274_09_7.shtml for more detail). It is probably also appropriate to mention that ‘verification and validation of numerical models of natural systems is impossible…models can be confirmed by the demonstration of agreement between observation and prediction but confirmation is inherently partial’ (Oreskes et al., 1994). In saying that, it is the role of the scientist and/or researchers to provide the decision makers with knowledge on the strengths and limitations of the science being presented, so that appropriate decisions can be made with an understanding of the potential risk involved.

Therefore within this project, attempts have been made to evaluate the models using the real time data collected (see previous section). However, a complete understanding of the models performance, and the uncertainty associated with the modelling process, is not only reliant on model evaluation, but also on have appropriate long term data sets from the natural system against which to test.

With respect to this report, there are a number of spatial data sets that could do with considerable improvement. These include mapping and description of the constructed drain systems, the distribution and role of unsealed roads and pigs as a sediment/nutrient source and, in the future, improved landuse mapping of the coastal floodplain to reflect the changing landuse. There is also considerable need for an understanding of many other ‘processes’ occurring in tropical catchments and these are described in more detail in Section 6.5.

6.4.2. Applying the model results to target setting: suggestions and recommendations

It is acknowledged that the results of this work are going to be used to guide and evaluate the load target setting process for the Douglas Shire Catchments. During this process, it is important always to keep in mind the limitations of the modelling process, and make sure that all parties involved are aware of the ‘interim’ nature of these load targets. It is anticipated that the results presented in this report will actually match favourably with actual long term measured annual average data, however, this will not be known until there has been sufficient evaluation of the model.

It is also important to point out that using end of catchment targets will always be VERY difficult to evaluate in the long term, and in many ways, they are not particularly useful for assessing if on ground management change has made any difference to the water quality entering streams and rivers, and ultimately the Great Barrier Reef Lagoon. There are a number of reasons for this:

If you set an average target of say ‘300,000 t/yr’ for the Douglas Shire Catchments, and for three years running you measure a load of 200,000 t/yr. Does that mean that landuse practice has significantly improved and lowered sediment loss from the catchments? or was it simply a run of three dry years with much lower than average rainfall and therefore discharge?

Using the same average target, what if in one year the load at the end of each catchment is measured as 500,000 t/yr. Was this because the land practices of a number of industries actually increased sediment runoff? or was it simply a very wet year? or was there a large landslide high up in the back of the catchment in the World Heritage area?
The points outlined above also highlight the need for quality data and careful planning with respect to any sampling strategy. Some other points to keep in mind are outlined below.

It is important to have good estimates of discharge (Q) (not only water quality or concentration) at the mouth of each river or at least at the top of the estuary. [Unfortunately the location, tidal nature and logistics of obtaining discharge data at the mouth of many catchments will currently restrict load estimates to the top of the estuary]. Discharge data, and associated rating curves, are crucial for determining the amount of water moving down a catchment at any one time. This will allow targets to be evaluated on a per unit volume basis. This is particularly important for cyclone years. For example the work of Hunter et al., (2001) in the Johnstone Catchment found that the suspended sediment load during the four days of flooding associated with cyclone Sadie was nearly five times the combined loads of the two previous years of below average rainfall.

It is important to evaluate the impact or affect of different land management practices (i.e. riparian buffers, trash blanketing, lower fertiliser levels, off river stock watering points) on water quality at the sub-catchment level or at least downstream of areas that are dominated by a particular landuse. It is also useful to have smaller controlled evaluation sites at a small paddock scale, however, these trials can be expensive and it must always be kept in mind that discharge data is always needed to make the water quality data useful for load estimates.

### 6.5 Recommendations and areas of further research

Despite the improvements made in this study using revised data and models, there are still numerous areas of further research needed to increase the reliability of estimates made in this report. The type of data needed to improve the modelled results are given in Table 19. Without this data, further improvements to the results presented in the study will be difficult.

<table>
<thead>
<tr>
<th>Data improvements needed</th>
<th>Related projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured sediment loads at the mouths of all catchments and from rainforest areas</td>
<td>Will be carried out in 2003/04 wet season, however, further funding is required to continue work beyond Sept 2004</td>
</tr>
<tr>
<td>Measured nutrient loads at the mouths of all catchments and from rainforest areas</td>
<td>Will be carried out in 2003/04 wet season, however, further funding is required to continue work beyond Sept 2004</td>
</tr>
<tr>
<td>Measurements of bank erosion from a range of sites across the entire catchment</td>
<td>A CSIRO project being carried out through the Reef and Rainforest CRC will hopefully provide sufficient data within the next 3 years</td>
</tr>
<tr>
<td>Measured loss of nutrients from cane lands</td>
<td>Is being carried as part of the flume study in Saltwater Creek, however, further funding is required to continue work beyond Sept 2004</td>
</tr>
<tr>
<td>Measured loss of sediments and nutrients from dirt roads</td>
<td>No work planned</td>
</tr>
<tr>
<td>Measured hillslope erosion rates from different grazing areas</td>
<td>No work planned</td>
</tr>
<tr>
<td>Improved understanding of the role of the coastal mosaic (wetlands, estuaries and mangroves) in filtering sediments and nutrients to the coast</td>
<td>Work considered under Healthy Country although no funding available as yet</td>
</tr>
<tr>
<td>Improved understanding of floodplain hydrology and in particular the role of distributary channels in transporting and storing sediments and nutrients</td>
<td>No work planned</td>
</tr>
<tr>
<td>More data on the contribution of point source sites (e.g. B&amp;B’s and dirt roads) and diffuse sources (e.g. pigs) to the overall sediment and nutrient budget</td>
<td>No work planned</td>
</tr>
<tr>
<td>Cane drain density data for all catchments</td>
<td>No work planned</td>
</tr>
<tr>
<td>Cane drain erosion rates</td>
<td>No work planned</td>
</tr>
<tr>
<td>Movement of nutrients within groundwater systems</td>
<td>No work planned</td>
</tr>
<tr>
<td>Improved rainfall and gauge data for the hydrological analysis</td>
<td>No work planned, although the new gauge stations will contribute some data to this</td>
</tr>
<tr>
<td>Spatial mapping of land practices on different landuse types</td>
<td>No work planned</td>
</tr>
<tr>
<td>The contribution of water and sediments from forests and roads and entering constructed drains</td>
<td>No work planned</td>
</tr>
</tbody>
</table>
7. Discussion and Conclusion

Management aimed at reducing sediment and nutrient transport will target each erosion process quite differently. For example, stream bank erosion is often best targeted by managing stock access to streams, and/or revegetating bare banks and reducing sub-surface seepage in areas with erodible sub-soils. Surface wash erosion is best managed by promoting consistent groundcover, maintaining soil structure, promoting nutrient uptake and promoting deposition of eroded sediment before it reaches the stream. Erosion in cane areas is best done by keeping high ground cover levels in drains, headlands and trafficked areas. Consequently it is quite important to identify the predominant sediment and nutrient delivery process before undertaking catchment remediation or making recommendations for changed practices.

The present estimates of sediment and nutrient loads in the Douglas Shire Catchments represent significant improvements over those that have been previously undertaken. This is a direct result of the incorporation of better regional information. It is clear that all erosion processes contribute significant amounts of sediment to the channel network and owing to the reasonably strong connectivity between source supply and export to the coast, much of this is directly exported from the catchment.

All erosion processes are highly variable across the catchment with localised hotspots evident in places. Hillslope erosion is the greatest contributor of sediment to the stream network in the Douglas Shire Catchments, with the highest overall losses being from rainforest and sclerophyll forest areas, however, the per hectare losses are greatest from the fruit tree crops, sclerophyll forest, grazing and rural/residential areas. It is important to note that the areas covered by ‘forest’ contribute 87% of the total sediment lost from hillslopes. The erosive potential in the forested areas is much greater than the flat depositional landscapes of the floodplain. Any other landuse (other than forests) on this type of topography would yield much higher sediment loads, and it is not necessarily appropriate to compare loads from lowland or flat landscapes with no vegetation, with forested areas on steep slopes.

Cane drain erosion is proportional to the amount of land covered by cane, therefore the major contribution from cane drain erosion comes from the Saltwater and Mossman catchments as these have the highest area under cane cultivation. Riverbank erosion contributes 41,000 t/yr or 12% of the total sediment yield, yet there is no obvious pattern to bank erosion in the catchment. The main areas that appear to undergo higher than average rates of bank erosion are along the main channel of the Daintree River.

The predominant source of nutrients are in the particulate form for nitrogen in the Daintree Catchment and in the dissolved form in all other catchments. The predominant source for phosphorus (P) is from hillslope erosion in the Daintree, Saltwater and Mossman Catchments, and from cane drain erosion in the Mowbray Catchment.

The patterns of erosion sources differ suggesting that each process is fairly independent and that in each location an assessment needs to be made of the dominant source of sediment. Given that the highest rates of erosion occur in localised patches, this suggests that erosion control measures targeted to specific areas will be effective in reducing sediment supply to, and loads in, the stream network. Despite the improvements used in this model, there are still areas of further research that would increase the reliability of estimates made in this report, including measured sediment and nutrient load data. Also other issues such as the impact of un-sealed roads and the influence of pigs have not been assessed due to the lack of data and these issues warrant assessment in any future study. Without this data, further improvements to the results presented in the study will be difficult.

The outputs from this research should assist natural resource management agencies and land managers to appropriately target critical areas, so that a comparatively large benefit in reducing sediment and nutrient loads delivered downstream can be achieved with less effort.
8. References


Murtha, G.G. and Smith, C.D. (1994) Key to the soils and land suitability of the wet tropical coast: Cardwell – Cape Tribulation. CSIRO.


