A catchment sediment and nutrient budget for the Mitchell River, Queensland

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- Paul Rustomji undertook the SedNet modelling and was the lead report author.

- Jeff Shellberg provided the sediment yield data for alluvial gully erosion, the estimate of the proportion of coarse and fine sediment in alluvial gully sediments, preliminary data on floodplain deposition, advice and text on sediment budget conceptual frameworks and budget components, cautionary text on the use of surface collected TSS data for load analysis, background and literature review on land use in the Mitchell catchment, air photo analysis of upper catchment sediment sources and anthropogenic disturbance history, literature review and text on the fractal scales of drainage networks and sediment budget implications, review of the residual nature of some sediment budget terms, and advice and suggestions on approaches to modelling the catchment sediment budget and pitfalls there within.

- Andrew Brooks supplied specific knowledge on the erosion and landscape processes in the Mitchell catchment, provided advice and suggestions on approaches to modelling the catchment sediment budget and pitfalls there within, contributed to the generation of the alluvial gully erosion and LandSat derived bank erosion data, and contributed to the analysis of residual and fractal issues in sediment budgeting.

- John Spencer contributed to the generation of the alluvial gully erosion and LandSat derived bank erosion data, provided an analysis of fractal scales of drainage networks and sediment budget implications, and provided general suggestions on approaches to modelling catchment sediment budgets.

- Gary Caitcheon provided the geochemical tracer data for the catchment and was the project leader.
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Executive Summary

This report presents a sediment and nutrient budget for the Mitchell River catchment, located on the western flanks of Cape York and draining to the Gulf of Carpentaria. A catchment sediment (or nutrient) budget accounts for the major sources, transport pathways and sinks of sediments and nutrients within a catchment. It is difficult to measure all of the relevant components of a catchment sediment budget across space and time. Consequently a modelling framework is useful to bring together the individual components of the budget in a coherent manner, whether derived from local empirical data or theoretical models. The SedNet and ANNEX models have been used in this study; these models have been widely applied in tropical Queensland settings and elsewhere in Australia. Each sediment budget term comprises its own sub-model and here, a combination of national-scale models (terrain, hillslope erosion, colluvial gully density and surface soil nutrient concentrations), state-wide data sets (foliage projected cover) and locally-derived models (alluvial gully erosion, floodplain extent) have been used for input data. For some aspects of the model, such as the dissolved nutrient concentrations in overland flow, no local data were available and values have been derived from reference to the literature. Some budget components (particularly floodplain deposition, and also partially hillslope erosion) have been derived as “residual value” terms; that is model parameters and/or terms have been adjusted to match other data with limited independent constraint on the exact magnitude of that budget term. These residual terms contain not only the data attributed to them, but also unmeasured components of the sediment budget and the associated error from the known or directly measured components, such as total load at gauges and alluvial gully erosion.

The model predicts budgets for the fine suspended (silt, clay) washload and coarser sand-sized bed material load, as well as nutrients. The model has been calibrated to (a) station-based fine sediment washload estimates at nine gauging stations, (b) geochemical tracer data indicating relative tributary contributions of fine sediment at river confluences, and (c) the ratio of surface to sub-surface soil being transported by the river at a number of locations. These empirical data are critical to obtaining sensible model results. The model calibration process involved capping some extremely high predicted hillslope erosion rates, varying the hillslope sediment delivery ratio and modifying the bank erosion and overbank sediment settling velocity parameters. The modification to the hillslope erosion data was needed to account for an inferred over-prediction of hillslope erosion rates in certain areas. The geochemical tracer data and station-based load data were particularly valuable in constraining sediment inputs from hillslope erosion.

The model predicts 2.9 Mt per year of fine suspended sediment (silt and clay) washload export from the Mitchell River outlet. Alluvial gully erosion is predicted to be the dominant fine sediment source and is spatially restricted to the floodplains and megafan areas adjacent to the main channels once the river leaves the bedrock uplands. Previous SedNet applications in tropical regions have not explicitly represented alluvial gullies as a sediment source, yet based on this study these features appear an important sediment source. Sediment deposition upon floodplains (3.4 Mt) is predicted to account for approximately half the fine sediment supply, although this value is yet to be empirically verified. Contemporary fine sediment yields are estimated to be approximately twice those of pre-European settlement conditions, although again dating of historical rates of sediment accumulation on floodplains could provide empirical insights into this prediction.

Modelling of bed material load indicated that response times in the lower catchment to variations in upstream coarse sediment input exceed 100 years. This implies that in terms of bed material (sand sized particles and larger), the full effects of the introduction of European land management practices in the upper catchment may not yet be completely manifest. There may still be substantial coarse sediment pulses moving downstream through the river network that may impact on the lower reaches of the Mitchell River in coming decades. Independent verification of this hypothesis via dating of in-channel sediment deposits as a measure of sediment residence times is the subject of ongoing research within TRaCK. Whilst net aggradation of
bed material over a nominal 200 year period was predicted to be generally < 1m, the approximate doubling of pre-European sediment input means that more coarse sediment is likely to be in-transit and thus available for deposition. This may have consequences for dry season aquatic habitat preservation. The modelled nutrient budgets predict 6.5 and 1.5 kt per year of nitrogen and phosphorus export respectively, with the majority of this predicted to be nutrients attached to fine sediment. The spatial pattern of nutrient contribution was similar to that of fine suspended sediment.

This modelling exercise has highlighted some major knowledge and data gaps that limit our ability to better predict contemporary sediment dynamics within the Mitchell River catchment (which is comparatively rich in data) and other similar tropical savannah catchments in northern Australia. This is especially true due to components of the sediment budget for which inadequate data exists (e.g. sediment generation from small headwater channels, mining, roads) and the inherent residual effect these terms have on other modelled components such as hillslope erosion and floodplain deposition. Consequently, we regard these model runs as a starting point around which a future program of field data collection should be framed to test hypotheses developed here. We also strongly advise that other future sediment budget studies in tropical Australia should use a combination of geochemical tracer data and station-based load estimates to constrain the modelling. Finally we note that our results have been focussed on an end-of-catchment perspective and are heavily influenced by the presence of alluvial gully erosion in the mid-catchment region. Headwater tributaries of the Mitchell River may have substantially different erosion process balances as a result of localised activities (such as mining) that may not have been adequately captured here due to the use of national scale data. These headwater rivers are important river systems in their own right and further research is warranted on local scale sediment budget studies for these headwater tributaries.

Key data gaps in the Mitchell River catchment include:

1. Hydrological data at many discontinued gauge sites (e.g., the Lynd catchment) to measure changing land use and climate impacts on water and sediment yields.
2. Sediment concentration measurements at additional gauge sites in the catchment measured using width and depth-integrated suspended sediment concentration methods, continuous turbidity measurements, and improved correlation techniques between turbidity and suspended sediment concentration at the event scale.
3. Sediment production data from both alluvial and hard rock mining activities.
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8. Soils data at a higher spatial resolution to better predict soil depth and areas of supply limitation.
9. Floodplain sedimentation data.
10. Bank erosion data on in both large and small alluvial channels.
11. Tracing data at a higher density of source and sink points at the sub-catchment scale.
12. Measurements of sediment residence time for bed material sediments to assess the impacts of historic land use change on aquatic habitat.
Key knowledge gaps identified include:

1. Understanding of hillslope sediment production and supply limitations in tropical savannah landscapes.

2. Understanding of the full extent to which alluvial gully erosion dominates sediment budgets in the Mitchell or other northern Australian catchments, relative to the other unknown components of the budget as listed above.

3. Understanding of the fate of fallout radionuclide signatures of surface and sub-surface sediments in tropical savannah landscapes, especially in situations where surface soils have been rapidly stripped of fine sediment from intense rainfall and low ground cover that typifies the savannah landscapes, and where active bioturbation of savannah soils by termites influences surface/sub-surface labelling.
1 Introduction

This document describes the calibration and application of the SedNet model (Prosser et al. 2001; Wilkinson et al. 2004, 2006) for calculating sediment and nutrient budgets for the Mitchell River catchment in north Queensland. This research has been undertaken as a part of the Tropical Rivers and Coastal Knowledge (TRaCK) research program. TRaCK’s objectives are to:

- Increase our understanding of the social, cultural, economic and environmental benefits that our tropical rivers and estuaries provide.
- Develop methods and tools for assessing the implications of current use and potential developments.
- Identify opportunities to develop sustainable enterprises.
- Build the capacity and knowledge of local communities to manage Australia’s tropical rivers and estuaries.

1.1 Model Conceptual Framework

SedNet is a catchment-scale sediment and nutrient budget model that can be used to predict the major source areas of these potential pollutants in a catchment (Prosser et al. 2001). A catchment sediment budget, as modelled here, provides a consistent framework to account for the major sediment (and associated pollutants) sources, stores, and sinks within the catchment, in both spatial and a-spatial (total mass of sediment) senses. The fundamental unit of the SedNet model is the river link (Figure 1), which typically occurs at the river segment scale of 1,000 to 100,000 meters, depending on tributary junctions of the drainage network being modelled. At this scale, the inputs, storage, and outputs of sediment are calculated for different budget terms described in more detail below. Figure 1 is a schematic representation of the sediment budget as calculated for each river link.

![Figure 1: Components of the sediment budget for each river link. Note that the erosion sources are handled differently between the bed material load (>63 µm) and washload (fine suspended sediment <63 µm) budgets. Note that alluvial gully erosion has not been included as a sediment source in previous SedNet studies.](image)

SedNet uses theoretical equations within sub-models to predict sediment transport at the scale of each link, which are then integrated to the catchment scale. It is calibrated to empirical data at gauging stations, geochemical tracer data of proportionate tributary contributions, and the proportionate geochemical tracer data of surface vs. sub-surface sediment sources. The
model is also used to examine changes in the catchment sediment budget that are associated with the transition from pre-European land use to European style land uses that occurred in the 1800’s.

Fundamental to any sediment budget is the definition of how sediment is transported, by source or mechanism, and thus how field data will be measured and compared to modelled data. The total sediment load carried by rivers can be divided into two alternatively valid budget frameworks (Knighton 1998; Hicks and Gomez 2003):

1. Total load = bed material load + washload + dissolved load (i.e. load by source)
2. Total load = bedload + suspended load + dissolved load (i.e. load by mode of transport)

The dissolved load carried in water solution is not dealt with in SedNet (except for nitrogen and phosphorus). The bed material load consists of grains sourced from material on the channel bed, usually coarser than 63 µm. The washload consists of grains usually finer than 63 µm that travel readily in suspension at the same speed of the flow and which are usually not found in appreciable quantities in the shifting portion of the channel bed. Material >63 µm sourced from the bed (bed material load) can be transported either along the bed via rolling, sliding or saltating at velocities less than those of the surrounding flow, termed bedload, or in temporary suspension in the water column, as part of the suspended load. The suspended load consist of both material sourced from washload <63 µm and the finer fraction of bed material load >63 µm (i.e. sand) that is temporarily maintained in the water column by turbulent mixing processes (Knighton 1998; Hicks and Gomez 2003).

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The conceptual framework of SedNet sediment budget follows a load by source framework (number 1 above) and sums the bed material load component (Yang (1973); Wilkinson et al. (2006)) with the washload component (fine suspended sediment < 63 µm) to get total sediment transport. Sediment sourced from hillslopes enters directly into the fine suspended sediment (washload) budget. Material sourced from gullies and banks is divided into two groups split at the 63 µm size class, with material coarser than 63 µm entering into the bed material load budget and material finer than 63 µm entering into the fine suspended sediment (washload) budget. As a default in SedNet, sediment eroded from gullies and stream banks are assigned 50 % to the bed material load budget and 50 % to fine suspended sediment (washload) budget (Prosser et al. 2001). This default value can be adjusted, as discussed below, where local data exist on the particle size distribution of source material. Geochemical tracing used to evaluate model predictions also use separate size factions, with particles <10 µm used for tracing fine suspended sediment (washload) and coarse sand particles (250 µm – 2 mm) used for tracing the bed material load (Caitcheon et al. in preparation).

It is important to note that these budget terms and definitions have specific meanings and can not be used interchangeably. For examples, the total particulate load of a catchment or river link can not be summed by adding the bed material load to the suspended load, whether theoretically or empirically derived, as this would double count sand travelling in suspension. “No data are independent of the (conceptual) models which led to their measurement. For this reason, it is absolutely fundamental to follow a conceptual model that is not demonstrably incorrect” (Wainwright et al. 2010).

This report comprises the following sections:

1. A description of the hydrologic, channel morphology and channel network sub-models.
2. A description of the sediment and nutrient sources currently represented in the model.
3. A results section documenting an iterative calibration process where selective changes are made to the model’s input data and parameters to bring model predictions into line with a range of independent empirical data sources.
4. A discussion section considering some of the major knowledge gaps, uncertainties and sensitivities identified in the modelling process.

1.2 Modelling Purpose and Goals

It is worthwhile at the outset considering some of the reasons for applying a model such as SedNet to the task of calculating a catchment sediment budget and for this we must consider some of the conceptual uses of models in general, as outlined by Silberstein (2006). The first use is as a framework to assemble our process understanding and to explore the implied system behaviours that come from that understanding. This is certainly a valid aspect for this particular study in as much as there exists an existing and growing body of work documenting some of the major sediment sources and sinks for the Mitchell River catchment specifically (Brooks et al. 2008, 2009; Shellberg, Brooks, Spencer, Knight and Pietsch 2010) as well as national scale data sets that extend across the Mitchell River catchment (e.g. Lu et al. 2003).

A model such as SedNet has many inbuilt conceptualisations of how sediment is generated, redistributed and stored in a catchment. When such a model is applied to a catchment there will inevitably be error and poor predictions. The critical task is to understand why errors and mis-predictions are arising and to ask what this tells us about either our conceptualisation of the system and its processes, or potentially about aspects of the data and parameters that have been used to run the model. One particular aspect of data that is crucial to the functioning of any model is spatial scale, in which the scale of the input data should not be vastly dissimilar to the scale at which the processes being modelled occur. In this sense, a poorly performing model is as or more useful than a well performing model as it highlights knowledge and data gaps and deficiencies, thus leading us to an improved understanding of the system in question.

A second use of a model is as a mechanism to test data and check for data inconsistencies and errors. Certainly as will be seen below, the modelling process followed here has identified issues with a number of extant data sets that are used to construct elements of the catchment sediment budget. The third use of models is to explore scenario options. One scenario explored here is a “pre-European” catchment conditions scenario, which is useful in examining the relative changes in the catchment sediment budget associated with European settlement of the catchment in the late 1800’s. A fourth related use to this is using modelling as a tool for hypothesis generation, which is perhaps the most important use for a model such as the one presented here. In this sense a model can be used to elucidate system behaviour and facilitate targeted field based sampling that can allow for testing of key system behaviours, assuming these characteristics can be measured in a practical way.

1.3 Balancing the Budget: Direct, Residual, and Missing Budget Components

The practical realities of constructing a sediment budget for a large, fairly remote catchment like the Mitchell River catchment means that many of the budget components are difficult to empirically measure in the field, or to represent via modelling. Of the budget components represented, only contributions from alluvial gullies have been locally measured, though as is shown below our estimate is that this process represents the main catchment sediment source at the catchment outlet. Of the remaining variables, most are modelled via non-local empirical or theoretical equations (e.g. hillslope surface erosion, colluvial gully erosion, floodplain deposition and sediment transport). Of these variables, several such as hillslope erosion and floodplain deposition are adjusted in different model iterations in order to match modelled load outputs with the estimates from gauge sites and geochemical tracer data. These variables effectively become “residual” variables that are used to represent the both attributes given to them and the remainder of the unaccounted sediment sources and sinks (Kondolf and Matthews 1991).

Kondolf and Matthews (1991) argue a sediment budget can only be considered “balanced” if all budget components are independently measured and errors properly quantified. While full field quantification of all budget components should be strived for, in reality full quantification remains
elusive and residual and missing terms will exist. The unmeasured residuals incorporate not only the sediment budget components attributed to them, but also the net sum of all errors in measured components (Kondolf and Matthews 1991). Thus it becomes imperative to clearly acknowledge and identify budget components obtained through subtraction or residual analysis, identify components that are missing from the budget, and quantify the errors in all terms to the greatest extent possible.

Unquantified and missing components in this current budget framework include:

- Sediment sources and sinks in headwater streams. There are an estimated 50,030 km of drainage line features within catchment areas < 20 km² (ie. below the threshold used to define SedNet river links), as estimated from 1:50,000 scale topographic mapping (Australian Defence Force 2010). Comparing the 9” DEM drainage length > 20 km² (13,275 km) used in this version of the SedNet model, to the total 1:50,000 drainage length (178,593 km), only 7.4% of the 1:50,000 drainage network is represented.

- Erosion related to mining.

- Erosion related to roads.

- Erosion related to mass movement on hillslopes.

Residual components in this current budget framework (in the sense of Kondolf and Matthews 1991) include:

- Hillslope surface erosion

- Bank erosion

- Floodplain deposition

The nature of some of these missing and residual components are considered further in the Discussion section. Hence, we are aware that there are many unaccounted for components to this budget due to lack of empirical field data, and that the budget as it is relies heavily on the use of unmeasured residuals. Considerable caution should be exercised when interpreting the results of this model in its current form. Nevertheless, we regard this model run as a starting point around which a future program of field data collection should be framed to drive future iterations of sediment budget model development.
2 Catchment Description

The Mitchell River Australian Water Resources Commission (AWRC) drainage basin covers an area of 71,000 km$^2$ and drains the western flank of Cape York Peninsula, flowing to the Gulf of Carpentaria. Most of the basin comprises the main Mitchell River catchment (63,000 km$^2$) with the Nassau River being an additional sub-catchment. It is worth noting that while the AWRC basin depicts a distinct catchment boundary in the lower third of the catchment, it is known that there are significant cross basin transfers of flow, and presumably sediment, into the adjacent Staaten River catchment at flows greater than about a 1 in 10 yr average recurrence interval event. The water and sediment transfers associated with these events are not accounted for in the modelling. Galloway et al. (1970) conducted a landscape suitability assessment of the Mitchell River catchment and surrounding areas and the following catchment characteristics are summarised from this report (unless otherwise noted):

- **Relief:** The eastern third of the catchment comprises a bedrock dominated landscape of varying degrees of dissection of granitic, volcanic and sedimentary lithology (the ‘Eastern Highlands’ and ‘Central Uplands’ regions). A series of alluvial plains, aged from Tertiary to modern, dominate the landscape westwards of these uplands (Grimes and Doutch 1978) through to a narrow coastal plain 3-25 km in width fringing the western extent of Cape York. The Mitchell River has incised into these alluvial plains (referred to as a ‘megafan’ by Brooks et al., 2009), with maximum incision occurring approximately 400 km upstream of the coast and decreasing coastwards (Brooks et al. 2009). The morphological apex of the megafan is near the junction of the Mitchell and Lynd Rivers (see Figure 13), though the current hydrologic/delta apex is located below the confluence of the Mitchell and Palmer Rivers (Brooks et al. 2009). Below this apex, flood flows spread extensively across a large number of distributary channels (e.g. Nassau River) before reaching the coastal plains and ultimately the sea.

- **Climate:** The area has a sub-humid to humid tropical climate with marked wet and dry seasons. Practically all rains falls in the months from November to April inclusive. Catchment rainfall is moderate (~ 1200 mm/yr in the vicinity of the Gulf of Carpentaria and decreases inland to below 800 mm/yr in the southern and western regions. Small zones of high rainfall (> 2000 mm/yr) occur in the catchments in the north-eastern and eastern headwaters. Historic maximum daily observed rainfall values at Kowanyama Airport are ~ 300-350 mm, with values of ~ 300mm per day being recorded at other locations in the catchment (http://www.bom.gov.au/climate/averages/). Temperatures are fairly high throughout the year, varying between 17 °C and 23 °C in the dry season and 32 °C and 37 °C in the wet season (Crowley and Garnett 2000).

- **Vegetation:** Eucalypt and paperbark woodlands are common throughout the study area though grasslands predominate on the alluvial plains flanking the main river channels (Neldner et al. 1997).

- **Land Use:** Since prehistoric times, the Mitchell catchment has been the country of dozens of aboriginal tribes who managed the land with traditional practices, with some of these practices continuing into present times. For the last 130 years, grazing of beef cattle on native pastures upon leasehold land has been the most widespread land use in the catchment. Both dryland and irrigated horticultural activity covers approximately 2.6% (1865 km$^2$) of the upper Mitchell catchment. Generally there has been minimal clearance of native tree cover, with the exceptions of extensive clearing in the upper Walsh River catchment for crop agriculture in the Mareeba-Dimbulah Irrigation District (Chapman et al. 1996), land clearing for alluvial and hardrock mining described below, patchy land clearing for improved pasture trials (Eady and Gillard 1985; Shaw and Ticknell 1993; Arnold 1997); land clearing for homestead development on large lease properties in addition to urban development (e.g. Dimbulah, Chillagoe, Mt Molloy, Kowanyama, etc.), and land...
clearing for water resource development (e.g. Southedge area). In open savannah woodlands, there is some evidence in the region for Melaleuca encroachment into grassland environments due to altered burning regimes (Crowley and Garnett 1998). The discovery of gold along the Palmer River in the 1870s was the main impetus for European settlement of the catchment and lead to a gold rush lasting several decades (Holthouse 1967). Subsequently, over 3000 historic and current mine sites have been established across the catchment (MRWMG (Mitchell River Watershed Management Group) 2000; Queensland Department of Employment, Economic Development and Innovation 2010). Both alluvial and reef gold mining still occur within the catchment, in addition to the mining of other metals such as tin, copper, and tungsten (Plimer 1997; Bartareau et al. 1998; McDonald and Dawson 2004; Pyatt and Pyatt 2004; Willmott and Trezise 2004; Butler et al. 2007).
3 Channel Morphology

3.1 River Network Definition

The national nine second digital elevation model has been used to define the stream network for the Mitchell River catchment, using a threshold catchment area of 20 km$^2$ for representing SedNet river links. This stream network is shown in Figure 2 and comprises 1039 river links and associated sub-catchments, with a total modelled channel length of 13,280 km. This modelled channel length is less than the 16,390 km of channel mapped at 1:250,000 scale for areas with catchment area greater than 20 km$^2$. The mean internal catchment area for the SedNet sub-catchments is 69 km$^2$ (i.e. each sub-catchment on average covers an area 7 by 9.8 kilometres in size) and the mean link length is 13.2 km. It should be pointed out that while this model formulation assumes channels only commence at a minimum catchment area of 20 km$^2$, in reality there are many channels that originate at catchment areas significantly less than this (i.e. <1 km$^2$), including channels that have floodplains and behave as true alluvial channels exhibiting bank erosion and even floodplain deposition. The sediment budget implications are that it is assumed that any sediment contributing to the budget from these sub-catchments must be sourced from either hillslope erosion or colluvial gully erosion. Hence, material sourced from bank or bed erosion in these sub-catchments will be attributed to one of these other sources. This is one of many potential sources of error in the modelling process. Across the Mitchell River catchment approximately 32% of the total catchment area is represented by sub-catchments with an internal catchment area less than 20 km$^2$.

Figure 2: Shaded relief digital elevation model of the Mitchell River catchment with the links and nodes of the SedNet river network plus sub-catchment boundaries.
3.1.1 Scale Issues and Unquantified Portions of the Drainage Network

The SedNet model was designed to be a large scale catchment sediment budget model. This implies some subjective choices need to be made in configuring the model where the need for small scale (detailed) representation of catchment features is balanced against problems of adequately parameterising a greater number of discrete catchment elements. Future model configurations could be applied at a more detailed scale, ideally with other required data at matching scale. In the Mitchell River catchment, 19,730 km$^2$ of catchment area (27.8% of total area) occurs upstream of the 20 km$^2$ threshold used to define channels in this SedNet configuration. Upstream of this threshold, no channels are depicted or modelled. The distribution of these ‘zero-order basins’ is shown in Figure 3. This threshold catchment area is consistent with many previous applications of the SedNet model. However, it should be noted that 1:250,000 topographic mapping does indicate some 45,610 km of channel above the 20 km$^2$ area threshold. Thus at the 1:250,000 scale, approximately two thirds of the channel network length is not explicitly represented, nor is sediment sourced from erosion of such channels. If one were to examine 1:50,000 topographic mapping (Australian Defence Force 2010), the total channel length is 178,600 km, of which 50,030 km (28%) occurs within sub-catchments of less than 20 km$^2$, and the $\sim$ 13,000 km of the SedNet channel network represents 7.4% of the total 1:50,000 scale drainage network. Table 1 summarises the different lengths of channel represented at different scales.

Headwater streams in the Mitchell catchment make up a large proportion of the channel network and are known to be important sources and storage areas for both fine and coarse sediment (Loughran et al. 1992; Brierley and Fryirs 1998; Benda et al. 2005; Hancock and Evans 2006; Bartley et al. 2007). The SedNet model as currently configured was not designed to represent...
Table 1: Different total length of drainage lines as modelled here, derived from the 9" digital elevation model with a 20 km$^2$ channel threshold and as represented in 1:250,000 and 1:50,000 topographic mapping.

<table>
<thead>
<tr>
<th></th>
<th>9° DEM (SedNet)</th>
<th>1:250,000 Topographic Mapping</th>
<th>1:50,000 Topographic Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total channel length (km)</td>
<td>62000</td>
<td>178600</td>
<td></td>
</tr>
<tr>
<td>Channel length above 20 km$^2$ (km)</td>
<td>1380</td>
<td>45610</td>
<td>128570</td>
</tr>
<tr>
<td>Channel length below 20 km$^2$ (km)</td>
<td>16390</td>
<td>50030</td>
<td></td>
</tr>
<tr>
<td>% of total channel length modelled here</td>
<td>21</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

fine scale erosion processes and sediment sources. Future modelling could make use of higher resolution drainage data (e.g. 1:50,000) and a much smaller catchment area cut-off between colluvial-hillslope processes and alluvial-channel processes.

### 3.2 Channel Width

Channel width was measured at 323 locations in the Mitchell River catchment using remotely sensed imagery accessible via the Google Earth software. The date of image acquisition is unknown however it is likely to have been in the last few years. Figure 4 shows the location of the 323 channel width measurement sites. Here width is defined as the active channel (sand bars, water, bare bench surfaces etc) observable in the imagery. The capacity to measure channel width using this methodology is impaired in areas with dense vegetation obscuring the channel margin and for small channels with poorly defined banks in areas of low resolution imagery. Areas poorly sampled in the current data due to these constraints include tributaries of the Alice River and many upper tributaries in the western extent of the catchment. River width measurements ranged from 6 to 1497 m in the data considered here. One aspect to note from Figure 4 is that channel width along the Mitchell River reaches a maximum in the middle reaches of the catchment. The largest Mitchell River width measurements are found downstream of the river’s junctions with the Lynd and Palmer Rivers. From approximately 50 km downstream of the Mitchell River’s junction with the Palmer river, channel width (and longitudinal variability) decreases towards the estuary. The Mitchell River is consistently around 100 m wide in the vicinity of its confluence with the Alice River. This characteristic is only subtly visible in the distribution of channel width against variables such as catchment area or mean annual flow as shown in Figure 5, which shows a suite of potential predictive variables.

Of all the potential predictive variables plotted against channel width in Figure 5, there is arguably no one variable with a substantially better correlation than any other. A reasonable positive relationship is evident between log transformed width and log transformed upstream catchment area, suggesting this could be modelled using a power function. Indeed such a model was fitted to the data, with a coefficient of 4.24 and an index value of 0.40. This model is however monotonically increasing and fails to capture the decline in channel width along the lower reaches of the Mitchell River. Instead, an alternative model has been adopted where channel width has been modelled as a function of shreve stream order using a Loess fit (Cleveland et al. 1992). Loess models do not provide a simple model form and to use them in a predictive capacity with other data requires predictions to be made at nominal values within the range of data used to define the model, which when aggregated serve as a look-up table to be used for prediction. Whilst the shreve stream ordering is peculiar to the river network defined in this study, it is sufficiently discriminating of the observed channel width measurements as to be a useful predictive variable. Figure 6 shows the relationship between channel width and shreve stream order and the fitted Loess model. Note that the river link with the largest shreve order and river width measurement had a shreve order of 467, yet the entire Mitchell River SedNet network extended to a shreve order of 477. Over this region the predicted value at order = 467 of 136 m has been extended to orders $> 467$. The fitted model predicts a minimum width of 28 m for first order links (catchment area ~ 30 km$^2$) and peaks at 384 m in the region of shreve order = 255. One characteristic that the loess model fails to represent is the large channel widths.
associated with shreve orders of approximately 350 (along the Mitchell River downstream of the Lynd and Palmer river junctions), which extend up to 1497 m. Four river links in this reach of the river have had their width measurements manually adjusted to the mean of any channel width measurements made along their respective lengths. These adjusted widths ranged from 493 to 1027 m. Figure 7 shows the modelled channel widths across the catchment. Channel width is predicted to reach a maximum along the main stem of the Mitchell River downstream of its confluence with the Palmer River.

Figure 4: Channel width measurement sites in the Mitchell River catchment.
Figure 5: Pairs plot of channel width measurements and potential explanatory variables. Variables are as follows: width = channel width (m), stream order = shreve stream order, outdist = distance to outlet (km), PET/rain = ratio of potential evapotranspiration to rainfall, rainfall = mean upstream catchment annual rainfall, slope = channel slope (%), area = upstream catchment area (km²) and MAF = mean annual flow (ML). Note some variables have been log transformed.
Figure 6: Relationship between channel width and Shreve stream order for the Mitchell River catchment. Observations are shown as dots and the fitted loess model is shown by the red line. Note widths for orders 467 to 477 have been fixed at 136 m.
Figure 7: Modelled channel width (top) and depth (bottom) for the Mitchell River catchment.
3.3 Channel Depth

The data used to define the channel depth model are based on surveyed cross sections at gauging stations (where alluvial river banks could be discerned from the profiles) and channel depth measurements based on river channel cross sections derived from a ∼ 30m digital elevation model (DEM) of the catchment at locations where the channel-floodplain boundary could be reliably estimated. The measurement locations for the combined data are shown in Figure 8. The ∼ 30m DEM is derived from shuttle radar topography mission (SRTM; Farr et al., 2007) elevation observations but have had vegetation height removed to construct a ground elevation model. The original SRTM data has a notional 90% accuracy rate of ±6m for Australia (Farr et al. 2007; Rodriguez et al. 2005) though the error distribution is bell-shaped and most points have an error of less than ±6m. The SRTM-derived DEM has a pixel size of 30.25 m at the latitude of the Mitchell River catchment and hence is thus potentially suitable for measurement of channel cross sections and hence channel widths and depths for the larger channels of the Mitchell River catchment.

The Figures 9 and 10 show comparisons of SRTM-DEM derived river cross sections with those manually surveyed at a selection of gauging stations. Note gauging stations for which no agreement with the SRTM-DEM could be found have not been plotted here. There were a number of such stations but these tended to be at smaller catchment areas where channel dimensions were smaller and the 30.25 m resolution of the SRTM-DEM data was unsuitable for measurement. Whilst not in perfect agreement, the SRTM-DEM cross sections are sufficiently comparable with the manually surveyed cross sections, particularly when it comes to identifying overall bank height. They were judged to be suitable for determining bank height when used with care. One advantage of using this method is that it allows a larger data set to be collected than could be reasonably obtained by hand survey alone.

Brooks et al. (2009) have published a set of bank height observations along the main stem of the Mitchell River from the coast upstream for a distance of 400 km, based on SRTM observations. These bank heights refer to the depth (or relative relief) from the channel thalweg as defined within the SRTM-DEM, and the elevation of the uppermost alluvial surface adjacent to the thalweg. Given that there are many compound channels within the Mitchell River catchment, these values represent the maximum potential “bank height” or the macro-channel bank height (both for the model of Brooks et al. and that developed here). In many cases the effective bank height of the active channel could be somewhat less than these values.

Hence two models of bank height have been used in the Mitchell River. The first is a Loess model fitted to the Brooks et al. (2009) data (with distance upstream of the coast being the predictive variable), which is used to predict bank heights along the channels of the main river links that have a catchment area of 11,000 km² or greater. A point 350 km upriver from the coast along the Mitchell River approximately corresponds to a catchment area of 11,000 km². This first model and accompanying data are shown in Figure 11. The second model is a Loess-based model fitted to the SRTM-DEM bank height observations made for catchments areas 11,000 km² or less, with catchment area being the predictive variable. Figure 12 shows the data and fitted model for this case. Figure 7 shows the modelled channel depths across the catchment. Maximum depths are predicted along the Mitchell River between its confluences with the Walsh and Lynd Rivers, after which channel depth decreases rapidly downstream.
Figure 8: Channel depth measurement sites in the Mitchell River catchment. Note data used to derived the main stem channel depth model can be found in Brooks et al. (2009).
Figure 9: Hand-surveyed channel cross sections (grey lines) at gauging stations in the Mitchell River catchment along with corresponding profiles assembled from the shuttle radar topography mission, digital surface model. The dashed line shows the maximum observed stage at each gauging station.
Figure 10: Hand-surveyed channel cross sections (grey lines) at gauging stations in the Mitchell River catchment along with corresponding profiles assembled from the shuttle radar topography mission, digital surface model. The dashed line shows the maximum observed stage at each gauging station.
Figure 11: Bank height observations along the main stem of the Mitchell River obtained from Brooks et al. (2009) with fitted loess model.

Figure 12: Left: Relationship between bank height and catchment area along with fitted loess model. Right: Map showing bank height measurement sites (red and blue circles denote points with catchment areas less than and greater than 11,000 km² respectively. The heavy black stream lines are those with a catchment area > 11,000 km² for which the Loess model based on distance upstream was used to model bank height (see Figure 11).
4 Hydrologic Parameterisation

In order to apply the SedNet model to the Mitchell River catchment, a number of hydrologic variables related to the generation, transport and deposition of sediments and nutrients are required to be derived for each link of the river network. This requires that empirical models be developed to predict the value of these variables based on independent data available for each SedNet subcatchment. The relevant hydrologic metrics have been calculated using a Microsoft Excel spreadsheet and statistical modelling of hydrologic variables has been undertaken using the R statistical software (R Development Core Team 2005).

4.1 Station Selection

The calibration of SedNet’s hydrologic sub-models for the Mitchell River catchment are based on analysis of river and stream gauging data collected and provided by the Queensland Government. A listing of the gauging stations in the Mitchell River catchment is provided in Table 2 along with the data used to select suitable stations for analysis. Of the 27 potentially suitable gauging stations in the catchment, a number had no field discharge measurements at high water stages and consequently had a very large portion of their total discharge volume occurring above the maximum measured discharge and were rejected on the basis that their discharge predictions were likely to be substantially inaccurate.

Table 3 lists key hydrologic metrics used in the hydrologic regionalisation process for the 20 selected stations. Figure 13 shows the location of these gauging stations along with the catchment topography. These twenty stations have catchment areas ranging from 90 km$^2$ to 46,050 km$^2$. 
<table>
<thead>
<tr>
<th>station</th>
<th>station name</th>
<th>area (km²)</th>
<th>start date</th>
<th>end date</th>
<th>percent &lt; fair data</th>
<th>MGS (stage m)</th>
<th>observed (stage m)</th>
<th>flow above MGS (%)</th>
<th>volume (%)</th>
<th>include</th>
<th>notes</th>
</tr>
</thead>
<tbody>
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<td>919001B</td>
<td>Mary Creek at Mary Farms</td>
<td>89</td>
<td>25/2/1970</td>
<td>25/7/1986</td>
<td>11.7</td>
<td>3.91</td>
<td>5.25</td>
<td>0</td>
<td>0</td>
<td>in</td>
<td>combine with 919001C</td>
</tr>
<tr>
<td>919001C</td>
<td>Mary Creek at Mary Farms</td>
<td>88</td>
<td>24/5/1985</td>
<td>20/12/1988</td>
<td>31.09</td>
<td>2.81</td>
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Table 2: Gauging stations in the Mitchell River catchment with data used to determine whether or not a gauge’s data was suitable for hydrologic regionalisation (indicated by the “include” column). MGS denotes maximum gauge stage.
<table>
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<tr>
<th>Station Name</th>
<th>Start Date</th>
<th>End Date</th>
<th>N (days)</th>
<th>Area (km²)</th>
<th>Rainfall (mm/yr)</th>
<th>PET/R</th>
<th>AMS</th>
<th>Q₁₀₀₅₀</th>
<th>MAF</th>
<th>Q₄₀₀₀₀</th>
<th>ROC</th>
<th>RDSQ</th>
<th>Q₄₀₀₀₀</th>
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Table 3: Gauging station details for selected gauges in the Mitchell River catchment. Column abbreviations are as follows: PET/R = ratio of potential evapotranspiration to rainfall; n AMS = number of years of from which annual maximum flood series was calculated, Q₁₀₀₅₀ = mean daily flow; MAF = mean annual flow, Q₄₀₀₀₀ = median daily flow; ROC = runoff coefficient; RDSQ = discharge effect on mean annual sediment transport capacity; Q₄₀₀₀₀ = 1 in 4 year recurrence interval flood taken to be indicative of bankfull discharge; Q₄₀₀₅₀ = median overbank flow.
4.2 Mean Annual Flow

Mean annual flow is modelled here as a function of an estimated runoff coefficient, catchment area and rainfall:

\[ MAF = R_c PA \]  

(1)

Wilkinson et al. (2006) present an algorithm which explicitly accounts for the spatial variation in a catchment's runoff coefficient driven by the local water balance parameters and this has been adopted here. Wilkinson et al. (2006) show that the runoff coefficient, \( R_c \), can be calculated as a function of annual precipitation (\( P \)) and potential evapotranspiration (\( E_0 \)) in the upstream catchment:

\[ R_c = \left[ 1 + \left( \frac{E_0}{P} \right)^w \right]^{\frac{1}{w}} - \frac{E_0}{P} \]  

(2)

Note that Wilkinson et al. (2006) recommend using stations from a relatively constrained range of catchment areas for determining \( w \) (which here is a fitted parameter). Here, catchments with areas < 10,000 km\(^2\) have been used (i.e. the gauges with the two largest catchment areas were omitted). For the Mitchell River, \( w = 1.849 \) and was a highly significant parameter. The fitted runoff coefficient model is shown in Figure 14 along with observed and predicted mean annual flow values.
A scale independent picture of model performance can be obtained using the distribution of a discrepancy ratio statistic, $D_R$:

$$D_R = 10^{\log(\text{Observed}) - \log(\text{Predicted})}$$

(3)

$D_R = 1$ indicates perfect agreement whilst $D_R = 2$ indicates a factor of two difference between observed and predicted. Figure 15 shows that for 19/20 stations have predicted values that agree to within a factor of $\sim 1.6$ of the observed values and 50% have a discrepancy ratio below 1.25.

Figure 14: Left: Fitted runoff (mm) model. Right: Observed versus predicted plot of mean annual flow.

Figure 15: Discrepancy ratio for mean annual flow model. The discrepancy ratio indicates the factor by which the observed and predicted MAF values agree within. Perfect agreement is indicated by 1.
4.3 RDSQ: Mean Annual Sediment Transport Capacity Coefficient

The SedNet variable \( RDSQ \) reflects the time-integrated effect of discharge on the sediment transport capacity of each river link and is used in the bed material transport model (Prosser et al. 2001; Wilkinson et al. 2006) and represents the “discharge term” in the sediment transport capacity model. \( RDSQ \) is calculated as:

\[
RDSQ = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{Q_i}{\bar{Q}} \right)^{1.4}
\]  

(4)

where \( Q_i \) is discharge of the \( i \)th of \( n \) days (ML) and \( \bar{Q} \) is mean daily flow (ML). Whilst this parameter needs to be predicted for each link in the river network, there is little theoretical basis for selection of the predictive variables. For the Mitchell River catchment, weak but useable correlations were evident between \( RDSQ \) and \( E_0/P \) and upstream catchment rainfall, hence a model of the following form was adopted:

\[
RDSQ = k_1 + k_2 \times \frac{E_0}{P} + k_3 \times \text{rain}
\]  

(5)

The parameters were estimated as follows: \( k_1 = 8.77 \), \( k_2 = -1.48 \) and \( k_3 = -0.0031 \). Figure 16 shows the observed RDSQ values versus the model predictions and the regression diagnostics are listed below:

Coefficients:

| Estimate | Std. Error | t value | Pr(>|t|) |
|----------|------------|---------|----------|
| 8.7707  | 3.1278     | 2.804   | 0.0122 * |
| -1.4783 | 0.8634     | -1.712  | 0.1050   |
| -0.0031 | 0.0014     | -2.148  | 0.0464 * |

Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 . 0.1 ’’ 1

Residual standard error: 0.331 on 17 degrees of freedom
Multiple R-squared: 0.331, Adjusted R-squared: 0.2371
F-statistic: 3.952 on 2 and 17 DF, p-value: 0.03895

The intercept and rainfall coefficients are statistically significant at \( \alpha = 0.05 \) however the \( k_2 \) is not significant. This model has a relatively poor quality of fit and the data shown in Figure 16 indicate that their may be some systematic under-prediction of RDSQ values for locations with naturally high RDSQ conditions. In effect this means that the sediment transport capacity of these locations may be underpredicted by the model. However, it can be seen from Figure 17 that the maximum discrepancy between observed and predicted data is a factor of 1.2. Thus whilst the model may have some deficiencies in terms of predictive capability, the available data indicate the largest discrepancy is still only a modest 20% deviation.
Figure 16: Observed versus predicted RDSQ values for the Mitchell River catchment.

Figure 17: RSDQ discrepancy ratio for the Mitchell River catchment.
4.4 Bankfull Discharge

Bankfull discharge, denoted $Q_{BF}$, is another hydrologic parameter for which prediction is required for each link in the SedNet network. Bankfull discharge was assumed to have a recurrence interval of 4 years, consistent with the finding of Rustomji (2010) who identified increasing losses of flood flows to distributary channels in the lower catchment (e.g. at the Koolatah gauge 919009A) for events with a return period greater than 5 years. Bankfull discharge in the upper catchment was difficult to quantify due to the prevalence of bedrock reaches or inability to define the alluvial channel margin from remote data. Thus we have consequently applied the 4 year value throughout the catchment. Empirical relationships against a range of different catchment variables were examined for prediction of bankfull discharge and the best predictive relationship was obtained using catchment rainfall as a predictive variable for $Q_{BF}$ normalised by catchment area:

$$\frac{Q_{BF}}{\text{area}} = k_4 + \text{rain} \times k_5$$ (6)

Note that station 919012A was omitted from the model fit as it appears as an outlying point. The fitted curve and observed versus predicted plot for bankfull discharge are shown in Figure 18 whilst Figure 19 shows the discrepancy ratio in the bankfull discharge estimates. The diagnostics for the model fit are listed below. Both model parameters are highly significant. For the calibration data, the maximum discrepancy ratio between the observed and predicted bankfull discharge values was <2 which can be compared with a 60-fold variation in $Q_{BF}$ across the catchment.

Coefficients:

|          | Estimate | Std. Error | t value | Pr(>|t|) |
|----------|----------|------------|---------|----------|
| $k_4$    | -38.72424| 11.35317   | -3.411  | 0.00333 ** |
| $k_5$    | 0.07348  | 0.01082    | 6.790   | 3.15e-06 *** |

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 11.79 on 17 degrees of freedom
Multiple R-squared: 0.7306, Adjusted R-squared: 0.7148
F-statistic: 46.1 on 1 and 17 DF, p-value: 3.153e-06

![Graph showing the relationship between bankfull discharge and rainfall](image1)

Figure 18: Left: Relationship between rainfall and bankfull discharge (as represented by $Q_4$) for the Mitchell River catchment. Right: Observed versus predicted plot of bankfull discharge.

4.5 Median Overbank Flow

Median overbank flow, $Q_{MO}$, is used in the modelling of sediment deposition on floodplains and is calculated as the median value of all historic daily flows in excess of the nominated bankfull discharge rate. A
A power function based on $E_0/P$ was found to be the best model for predicting this variable:

$$Q_{MO} = k_6 \times \left( \frac{E_0}{P} \right)^{a_7}$$  (7)

The regression diagnostics are listed below and the fitted curve along with the observed versus predicted plot for this variable are shown in Figure 20 whilst Figure 21 shows the discrepancy ratios for the fitted values. The agreement between observed and predicted values of $Q_{MO}$ is within a factor of 2.1 for all stations and 50% agree with a factor of 1.5.

Parameters:

|       | Estimate | Std. Error | t value | Pr(>|t|) |
|-------|----------|------------|---------|----------|
| $k_6$ | 44.530   | 11.854     | 3.757   | 0.00144 ** |
| $k_7$ | -2.386   | 0.609      | -3.918  | 0.00101 ** |

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Figure 20: Left: Relationship between $E_0/P$ and median overbank flow for the Mitchell River catchment. Right: Observed versus predicted plot of median overbank flow.

Figure 21: Discrepancy ratio plot for predicted median overbank flow.
4.6 Median Daily Flow

Median daily flow ($Q_{MED}$) is used in the annual nutrient export sub-model of SedNet known as ANNEX. In catchments such as the Mitchell River with a highly seasonal discharge pattern, the median daily flow is strongly related to the baseflow characteristics of the upstream catchment, which in turn is determined substantially by the catchment’s hydrogeology and to a lesser extent by rainfall. Consequently no suitable relationships could be discerned between median daily flow (or median daily flow normalised by catchment area) measured at gauging stations and any climatic variables. Here, a linear relationship between $Q_{MED}$ and catchment area has been adopted reflecting the fact that the median flow appears larger at greater catchment areas:

$$Q_{MED} = k_8 + Area \times k_9$$  \hspace{1cm} (8)

The intercept parameter $k_8$ could not be well resolved with the current data however the $k_9$ parameter was highly significant. Figure 22 shows the fitted relationship and the relationship between observed (gauged) and predicted values whilst Figure 23 shows the discrepancy ratios for the fitted values. The agreement between observed and predicted values of $Q_{med}$ is within a factor of 3 for 11/20 the stations, whilst for 4 stations a discrepancy ratio could not be calculated as these stations had zero observed median daily flow. One station (919007A) has a discrepancy ratio of <200. However this station has a $Q_{med}$ value of 0.23 ML/day (or 2.6 l/s) which, for a catchment of 1710 km$^2$ in size could effectively be considered zero flow.

| Estimate | Std. Error | t value | Pr(>|t|) |
|----------|------------|---------|---------|
| k8       | 27.604177  | 27.604956| 1.00    | 0.331   |
| k9       | 0.023818   | 0.002331 | 10.22   | 6.41e-09*** |

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 107.8 on 18 degrees of freedom
Multiple R-squared: 0.8529,  Adjusted R-squared: 0.8448
F-statistic: 104.4 on 1 and 18 DF,  p-value: 6.41e-09

Figure 22: Left: Relationship between catchment area and median daily discharge for the Mitchell River catchment. Right: Observed versus predicted plot.
Figure 23: Discrepancy ratio plot for predicted median daily flow. Note station 919007A has a discrepancy ratio of <200 and is not shown on this figure.

4.7 Scale Correction Factor for Runoff Coefficient

Internal catchment runoff for each SedNet subcatchment is predicted on a grid cell by grid cell basis (278 m x 278 m) using national scale surfaces of rainfall and then aggregated up for each SedNet sub-catchment. As Wilkinson et al. (2006) describe, a number of scale issues arise when modelling runoff at the grid-cell scale using parameterisations derived from gauging stations within sub-catchments, necessitating a runoff correction factor to be applied. This correction factor is calculated by estimating mean annual flow on a grid cell basis and then iteratively estimating a correction factor to be applied to these estimates such that no systematic bias exists between observed and predicted values. In the case of the Mitchell River catchment, a runoff correction factor of 0.84473 achieved this purpose.
5 Sediment and Nutrient Budget Terms

This section of the report describes the main data sets used to model the catchment’s sediment and nutrient sources and sinks.

5.1 Hillslope Erosion

Gross hillslope erosion is represented using a national grid of mean annual erosion rate predictions prepared for the National Land and Water Resources Audit (Lu et al. 2003). The term gross hillslope erosion is used here to denote total fine sediment movement on hillslopes via sheet erosion (i.e. silt, clay; excluding sand transport rockfalls, landslides, debris flows, creep, etc that are capable of moving larger clast sizes >63 µm). In summary, modelled gross hillslope erosion was estimated by (Lu et al. 2003) using remotely sensed ground cover imagery, daily rainfall data and digital maps of soil and terrain properties. Figure 24 shows a map of modelled gross hillslope erosion for the Mitchell River catchment. Note this map is not a map of sediment delivery to the river network because gross hillslope erosion is larger than the actual amount of sediment delivered to the river network (due to storage of eroded sediment prior to reaching a drainage line). Gross hillslope erosion rates are highest in the north eastern uplands of the catchment (particularly amidst the headwaters of the Palmer, Mitchell and Walsh Rivers) whilst relatively low rates prevail amidst the western region of the catchment where the catchment gradient is lower.

It is worth noting that the hillslope erosion sub-model is based on the revised universal soil loss equation (RUSLE, Renard et al., 1997), which essentially assumes that there is an unlimited supply of soil on all hillslopes, regardless of slope, with supply mediated by a vegetation cover factor and rainfall erosivity. Hence, the model always predicts that gross hillslope erosion rates increase with slope. In some environments, steeper slopes may have been stripped of their soil mantle by the intense monsoonal rains that occur every year on slopes that have often been burnt in the late dry season, leaving very little vegetative cover. Consequently gross hillslope erosion may be systematically over-predicted by the model in parts of this landscape, a point acknowledged as a possibility by Lu et al. (2003), who state: “erosion rate(s) could be overestimated in some of the steeper arid and tropical mountain ranges, which are predicted to have some of the highest erosion rates in the country. The vegetation cover is sparse in those areas and the land is steep but the erosion rate is limited by shallow soils with frequent wind erosion, rock outcrops, and high gravel content. These conditions are not represented in the USLE”.

5.1.1 Hillslope Sediment Delivery Ratio

Only a proportion of the gross hillslope erosion within a sub-catchment is considered to be delivered to the river network due to redeposition of eroded hillslope sediment prior to reaching the stream network. The ratio of gross hillslope erosion to the amount of fine suspended sediment (silt and clay) reaching the river network is referred to as the hillslope sediment delivery ratio (HSDR) and this requires specification in the model. In many previous applications of SedNet, a spatially uniform HSDR value has been used due to difficulties in parameterising a spatially variable value. However Lu et al. (2006) modelled the hillslope sediment delivery ratio across the Murray Darling basin and predicted HSDR values ranged from 0 to 0.7, though obtained a basin wide mean value of 0.052. Spatially uniform HSDR values in the range 0.05–0.10% have been successfully used in a number of SedNet modelling studies. In two south eastern Australia applications of the SedNet model where geochemical tracer data have been available to assess the ratio of surface versus sub-soil erosion (Wilkinson et al. 2009; Rustomji et al. 2008), approximately similar values have been adopted, though both of these studies have suggested higher ratios may be appropriate in certain settings such as steeper catchments. The geochemical tracer data provide a useful method of assessing whether a hillslope sediment delivery ratio is producing reliable model predictions.

Here, an approach to estimating the HSDR parameter incorporating catchment-scale terrain and vegetation coverage parameters is adopted in attempt to capture the spatial variability that is likely to prevail in this term. A number of studies (Lu et al. 2006; Jain and Kothyari 2000) have modelled the HSDR as a function of the travel time of overland flow. These studies are based on the concept that hillslopes with short travel times will have higher connectivity to the drainage network (and hence higher HSDR values) than those with longer travel times with a greater likelihood of any eroded suspended sediment reaching the drainage network. Such estimates are typically made on a pixel by pixel basis using flow path length coupled with the hydraulic variables slope and hydraulic roughness (which determine flow velocity) in conjunction with rainfall parameters.
As a first order approximation, and to generalise this approach spatially to a sub-catchment scale from a pixel scale and using data available for the catchment, the following concepts are proposed as a basis for modelling spatially variable hillslope sediment delivery rates:

- Steeper sub-catchments will have a higher HSDR due to shorter travel times due to the positive effect of slope on flow velocity.
- Sub-catchments with greater hydraulic roughness will have a lower HSDR due to long travel times due to the negative effect of hydraulic roughness on flow velocity.

Mean sub-catchment slope is used here as a measure of catchment slope and mean sub-catchment foliage projected cover (FPC) is used as a proxy for vegetation-related hydraulic roughness. The FPC values are derived from the SLATS dataset (Armston et al. 2004; Danaher 2002) which is a gridded dataset of values ranging from 0-1 with 0 being no cover and 1 being complete cover within a grid cell. It is assumed that there is a positive relationship between canopy cover and hydraulic roughness on the ground, though this remains to be verified and alternate models based on geologic characteristics (which may influence surficial rock cover) and ground vegetation cover for example may be worthy of future research.

Let $x_i$ be an index representing HSDR for the $i$th sub-catchment:

$$x_i = \left(1 - \frac{S_{\text{max}} - S_i}{S_{\text{max}}}\right) \times w_1 + (1 - C_i) \times w_2$$  \hspace{1cm} (9)$$

with $S_{\text{max}}$ being the maximum slope for sub-catchments $i = 1, 2, 3... n$, $S_i$ be the mean slope of sub-catchment $i$, $C_i$ be the mean sub-catchment roughness, $w_1$ and $w_2$ being the relative weights assigned to the slope and roughness terms, subject to $w_1 + w_2 = 1$. In this case $w_1 = w_2 = 0.5$, i.e. equal weighting is given to each variable. Thus for each sub-catchment $x_i$ is readily calculated using sub-catchment means of the gridded surfaces (percent slope and foliage projected cover).
If the assumption is then made that the catchment-wide mean HSDR $\bar{\chi}$ should equal $\chi$ (for example $\chi = 0.05$, or 5%, see for example Lu et al., 2006), the $x_i$ values can be scaled according to:

$$HSDR_i = x_i \times \frac{\chi}{\bar{\chi}}$$

i.e. such that the mean of $HSDR_{1,2,3,...,n} = \chi$.

Figure 25 shows the distribution of mean sub-catchment slope across the Mitchell River catchment. Clearly there are strong topographic influences on mean sub-catchment slope, with high mean slope areas in the northeast of the catchment and much lower values elsewhere.

Figure 26 shows individual pixel and mean sub-catchment values of foliage projected cover for the year 2006. The pattern of foliage projected cover shows distinct local variability, though the northern half of the catchment generally has higher cover values.

Based on these data, $x_i$ values have been computed and summary statistics for the distribution of $x_i$ values ($n = 1039$) are listed below:

<table>
<thead>
<tr>
<th>Min.</th>
<th>1st Qu.</th>
<th>Median</th>
<th>Mean</th>
<th>3rd Qu.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3263</td>
<td>0.4217</td>
<td>0.4492</td>
<td>0.4774</td>
<td>0.5181</td>
<td>0.8457</td>
</tr>
</tbody>
</table>

The modelled distribution has a mean $x$ of 0.477 and a maximum $x$ value of 0.846. The ratio $\frac{\chi}{\bar{\chi}} = 0.104$ assuming $\bar{\chi} = 0.05$. Thus the re-scaled distribution of HSDR values, shown in Figure 27, can be summarised as follows:

<table>
<thead>
<tr>
<th>Min.</th>
<th>1st Qu.</th>
<th>Median</th>
<th>Mean</th>
<th>3rd Qu.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03418</td>
<td>0.04417</td>
<td>0.04705</td>
<td>0.05000</td>
<td>0.05427</td>
<td>0.08858</td>
</tr>
</tbody>
</table>

Following this approach, HSDR values are predicted to range from 0.034 to 0.085, with 75% of sub-catchments having an HSDR value $\leq 0.044$ and 25% falling in the upper range of 0.054 – 0.088. The difference between the lowest and highest HSDR values is a factor of approximately 2.5. Figure 28 shows the spatial distribution of the variable hillslope sediment delivery ratio values across the Mitchell River catchment. The general pattern is of higher HSDR values amidst the north-eastern uplands where catchments tend to have higher mean slopes. A cluster of sub-catchments with locally higher HSDR
Figure 26: Top: Raster representation of projected foliage cover for year 2006 overlain on shaded relief digital elevation model. Bottom: Mean sub-catchment foliage projected cover.
values are predicted in the vicinity of the Nassau River amidst the southern fan region where low levels of foliage projected cover occur, as well as along the main stem of the Mitchell River once it leaves the uplands, again due to locally low foliage projected cover values and the presence of large areas of alluvial gully erosion (Brooks et al. 2009). Applying this spatially variable hillslope erosion rate to the surface of mean sub-catchment gross hillslope erosion rates produces estimates of fine suspended sediment supply (silt and clay) to the river network from hillslope erosion, as shown in Figure 29. High rates of predicted fine suspended sediment supply to the river network occur in the north-east uplands and locally elevated rates are predicted along the main stem of the Mitchell River amidst the megafan region. As is highlighted in the model calibration section below, modification of the mean value of the HSDR distribution is warranted to align the model’s predictions with geochemical tracer data, though this does not change the spatial pattern of fine suspended sediment input from hillslope erosion from that shown in Figure 29.

**Figure 27:** Histogram of modelled hillslope sediment delivery ratio for the Mitchell River catchment.

![Histogram of modelled hillslope sediment delivery ratio for the Mitchell River catchment.](image)

**Figure 28:** Predicted spatially variable hillslope sediment delivery ratio for the Mitchell River catchment.

![Predicted spatially variable hillslope sediment delivery ratio for the Mitchell River catchment.](image)
Figure 29: Modelled fine suspended sediment (silt and clay) input to the river network for the Mitchell River catchment under a 5% mean hillslope sediment delivery ratio.
5.2 Gully Erosion

Two main types of gully erosion are recognised within the Mitchell River catchment. One is that eroding into older floodplain alluvium (silt and clay deposits from river flooding) amidst the Mitchell River megafan, as described by Brooks et al. (2009). These gullies are referred to as “alluvial gullies”. The second type of gully erosion can be referred to as “colluvial” gullies. These are the gullies occurring within colluvial (or minor alluvial) deposits in bedrock dominated landscape settings, usually at the base of hillslopes or in hillslope hollows. Colluvial deposits are often interfingered with downstream alluvium transported by water in small channels. Colluvial or hillslope gullies in the upper Mitchell may be similar in morphology, processes and evolution to gullying common in the headwaters of the Great Dividing Range in southeastern Australia, but this requires further investigation. Both alluvial and colluvial gullying are sensitive to anthropogenic disturbance, often forming rapidly followed by either permanent degradation or eventual stabilisation and partial re-aggradation.

5.2.1 Colluvial Gully Erosion

A modelled grid of colluvial gully erosion density (kilometers of gully length per square kilometer area) exists for the Mitchell River catchment, as generated for the National Land and Water Resources Audit in 2001 (Hughes et al. 2001). This modelled surface utilised a data-mining algorithm driven by gully density measurements made from air photographs and a range of landscape attributes which were used as predictive variables. The Mitchell River catchment was modelled as part of a “coastal Queensland” sub-region. There were no direct measurements of colluvial gully density made in the Mitchell River catchment as part of this modelling exercise. For this “coastal Queensland” region, the correlation coefficient (observed versus predicted) for the gully density calibration data was 0.81, though for a quarantined evaluation data set (i.e. data not used in the model formulation) the correlation coefficient was 0.43. Modelled colluvial gully density values for the Mitchell River catchment ranged from 0 to 0.48 km/km², with a mean value of 0.16 km/km², as shown in Figure 30. Gully density was predicted to be highest in the south east of the catchment and low rates of colluvial gully erosion are predicted for the megafan region where alluvial gully erosion is now known to be dominant (Brooks et al. 2009).

The sediment contribution to river link \( x \) from colluvial gully erosion \( GC \) is modelled (Prosser et al. 2001) according to the following function:

\[
GC_x = \frac{LA}{\tau \gamma}
\]

where \( L \) is the length of the gully network in sub-catchment \( x \), \( A \) is mean gully cross sectional area taken here to be 23 m² based on data from south-eastern Australia (Rustomji 2006), \( \rho \) is the bulk density of gully sediments, assumed to be 1.65 t/m³, \( \tau \) is the age of the gully network (assumed here to be 100 years) and \( \gamma \) is the gully production ratio. This ratio is used to scale the long term sediment yield from gully erosion (typically downwards) to reflect the changes in sediment yield that occur over a gully’s lifetime. Values of \( \gamma < 1 \) are typically used for older, established gully networks where lower rates of extension and gully stabilisation lead to sediment yields below the long term average rate. The sediment contribution from colluvial gully erosion is further divided proportionally into fine suspended load (silt and clay) and bed material load components (sand size and larger), with this proportion set at 0.5 with a particle size cutoff of 63 µm. Note that the assumed age of 100 years for the colluvial gully network implies that changes in land management associated with the introduction of European land management practices was the dominant control on initiating colluvial gully activity in the catchment (e.g. Prosser 1991, 1996). This remains to be verified in the case of the Mitchell River.

5.2.2 Alluvial Gully Erosion

The extent of alluvial gully erosion in the Mitchell River catchment was determined by remote sensing, as described by Brooks et al. (2008) and Brooks et al. (2009) with slight modification \(^1\) due to initial errors in their spatial data set. The median gully retreat rate across this distribution of gullies was measured from air photos over the period 1949-2007 at 18 field sites covering 43,163 meters of scarp length (Shellberg unpublished data but forthcoming; preliminary data in Shellberg, Brooks, Spencer, Knight and Pietsch 2010). Scarp heights were estimated from a model of scarp height, relative to floodplain elevation, described in Brooks et al. (2008) and Brooks et al. (2009). Scarp perimeter per pixel was also determined from methods in Brooks et al. (2008) and Brooks et al. (2009). These data were then combined into raster datasets of sediment yield (tonnes per pixel per year). By way of description,
Figure 30: Colluvial and alluvial gully density for the Mitchell River catchment. Brown colors denote pixel-based colluvial gully density derived from national scale gully density modelling undertaken in 2001 for the National Land and Water Resources Audit. The green shading indicates alluvial gully erosion intensity, expressed in terms of an equivalent gully density (after accounting for the higher gully production ratio term for alluvial gully erosion) and shown as mean values per SedNet sub-catchment for the purposes of legibility. Note the major difference in scale between the two data sets.

Figure 31 shows the alluvial gully erosion data in terms of an equivalent vertical incision rate along with a representation of the cap applied.

Figure 31: Distribution denudation rate equivalents for the alluvial gully erosion data.

The distribution of alluvial gully erosion values (expressed as a vertical incision rate per pixel) was strongly positively skewed and values extended up to 0.248 m/yr of incision. Most of the very high values occur in the Lynd River catchment where there are no monitoring data. It was suggested that the presence of alluvial gully...
To incorporate this alluvial gully erosion data into the SedNet model, it must be expressed in terms of an equivalent “colluvial” gully density (kilometres of gully per kilometre squared) and corrected for the cross sectional area and density terms in the traditional colluvial gully erosion model. Firstly, the alluvial gully sediment yield data (tonnes per pixel per year) is converted to a yield $X$ in units of tonnes per kilometre square per year. Then for the $i$th pixel, the yield $X_i$ can be expressed as:

$$X_i = \frac{L_i \times A \times \rho \times \gamma}{\tau}$$  \hspace{1cm} (12)

where $L_i$ is an equivalent gully length per kilometre squared and other terms are as defined above. Thus:

$$X_i = \frac{L_i \times 23 \times 1.65 \times 0.2}{100}$$  \hspace{1cm} (13)

Then solving for $L_i$ (meters per kilometers squared):

$$L_i = \frac{X_i}{0.0759}$$

However as the units for $GC_x$ are km/km$^2$, $L_i$ needs to be converted to kilometers:

$$L_i = \frac{X_i}{0.0759} \times \frac{1}{1000}$$

$$L_i = \frac{X_i}{75.9}$$

Following this approach, $L_i$ values (km/km$^2$ equivalent) ranging from 0.001 to 1413 km/km$^2$ were obtained. The distribution was strongly positively skewed as is evident from the following summary statistics where the mean value is approximately four times the median:

<table>
<thead>
<tr>
<th>Min.</th>
<th>1st Qu.</th>
<th>Median</th>
<th>Mean</th>
<th>3rd Qu.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>4.796</td>
<td>15.380</td>
<td>58.010</td>
<td>48.940</td>
<td>1413.000</td>
</tr>
</tbody>
</table>

Note that whilst these alluvial gully densities are relatively high as compared to colluvial densities when expressed as an equivalent gully density, the lower colluvial densities are influenced by using gully production ratio value of 0.2. In contrast, a gully production ratio of 1 has been assumed for sediment generation from alluvial gully erosion on the basis that these features appear to be yielding sediment at or close to their long term rate (Shellberg unpublished data but forthcoming; preliminary data in Shellberg, Brooks, Spencer, Knight and Pietsch 2010), unlike colluvial gullies which typically expand rapidly before their rate of extension and sediment generation declines. As for colluvial gully erosion, sediment generated by alluvial gully erosion is divided between fine suspended sediment (silt and clay) and bed material (sand size and greater) budgets. However in contrast to the 50:50 split for colluvial gully erosion, 20% of alluvial gully erosion contributes to the bed material load budget (i.e. >63 µm) and 80% to the fine suspended load budget (i.e. < 63 µm, Shellberg unpublished data but forthcoming). This proportion differs because the alluvial gully erosion processes are incising into older floodplain material that is generally finer in texture than that occurring in colluvial gully settings.

erosion in this area was also questionable, and had entered into the modelled alluvial gully erosion surface due to a mis-classification in the geologic mapping for the area. Essentially some areas in the Lynd River were mapped as alluvium when in fact they were indurated silcrete deposits. To address this two steps have been undertaken. First, the sediment generation from alluvial gully erosion data have been capped at 150% of the maximum vertical incision rate measured at monitoring sites in the catchment (which was 0.043 m/yr, i.e. the cap applied was equivalent to a denudation rate of 0.065 m/yr). This cap only affected the upper 0.37 percent of the total distribution. For comparison, the median denudation rate was 0.001 m/yr. Secondly, alluvial gully erosion in the vicinity of the confluence of the Lynd and Tate Rivers has been set to zero.
Figure 32: Fine suspended sediment (silt and clay) input from gully erosion (both alluvial and colluvial) for the Mitchell River catchment. Note that the spatial pattern of sediment input is strongly dominated by the presence or absence of alluvial gullies as these are much higher yielding features than colluvial gullies.
Riverbank Erosion

Riverbank erosion is another source of sub-soil sediment to the river network. The potential river bank erosion retreat rate \( R \) (metres of bank retreat per year) is modelled according to Wilkinson et al. (2006) as a function of stream power:

\[
R = k \rho_w g \times Q_{BF} \times S
\]  

(14)

where \( k \) is a coefficient (= 5 \times 10^{-6} \) for final model iteration, revised from the default value of = 2 \times 10^{-5}), \( \rho_w \) is the density of water \(1000 \text{ kg/m}^3\), \( g \) is gravitational acceleration, \( Q_{BF} \) is bank full discharge and \( S \) is the average slope of each link. The term "active bank", \( B_{act} \) is defined as the proportion of river bank along each link that is potentially erodible:

\[
B_{act} = \left[ 1 - \left( \text{ripveg} \times \left( \frac{95}{100} \right) \right) \right] \times \text{bank}_\text{erodible}
\]  

(15)

where \( \text{ripveg} \) is the proportional cover or riparian vegetation along the river bank and \( \text{bank}_\text{erodible} \) is the proportion of the river bank that has potentially erodible soils (i.e. alluvial banks). The proportional cover of riparian vegetation is determined by calculating the mean Foliage Projected Cover value [range 0-1] of all cells within 600 m of each link in the stream network (approximately two grid cells). It is acknowledged that because of the large size of the channels in the Mitchell catchment and the shifting nature of the channel thalweg through time (up to 100 m laterally per year in places), that there is a significant margin for error in this metric. The \( \text{bank}_\text{erodible} \) term is calculated by identifying the proportion of cells within 600 m of each link in the stream network that have a MrVBF value \( \geq 1.5 \). MrVBF is an index of valley bottom flatness, described by Gallant and Dowling (2003). The rationale for this is that flat areas situated low in the landscape (i.e. with high MrVBF values) are likely to be deposited alluvial sediments (which are hence relatively erodible) as opposed to steeper and high regions which are likely to be bedrock dominated and hence not particularly erodible (at least within the timescales over which SedNet operates). Figure 33 shows the spatial distribution of the \( \text{ripveg} \) and \( \text{bank}_\text{erodible} \) terms along with the data used to derive these values. The 95/100 term implies that even when there is full riparian vegetation cover (i.e. \( \text{ripveg} = 1 \)), a minimum active bank coefficient will result as bank erosion is still likely to occur at a low rate.

Total sediment input from bank erosion, \( B_T \) is then calculated as:

\[
B_T = B_{act} L H R \rho_{sed}
\]  

(16)

where \( L \) is link length, \( H \) is bank height, \( R \) is the bank retreat rate as defined in equation 14 and \( \rho_{sed} \) is the bulk density of sediment (= 1.65 t/m\(^3\)). The fine suspended \( (B_S) \) (silt and clay; aka washload) and bed material \( (B_B) \) (sand and larger) input terms from bank erosion are simply:

\[
B_S = B_T \times (1 - c) \quad B_B = B_T \times c
\]  

(17)

where \( c \) is the percentage of eroded sediment that is coarse (>63µm), taken to be 0.5 here. Figure 34 shows the spatial distribution of fine suspended sediment input from river bank erosion (as tonnes per year normalised by link length). Generally it is the main river channels that appear as significant bank erosion sediment sources. This is due to their combination of larger bank full discharges and larger bank heights than other reaches, though obviously characteristics such as riparian vegetation cover and valley bottom flatness influence the spatial pattern of bank erosion.
Figure 33: Top: Foliage projected cover raster (percentage) and mean riparian zone foliage projected cover (proportion, 0-1) for each SedNet river link. Bottom: Multi-resolution valley bottom flatness (MrVBF) index shown as a raster and proportion of each link’s riparian zone with MrVBF values $\geq 1.5$, indicating proportion of link length which is potentially erodible by bank erosion processes. High MrVBF values indicate flat ground in a low topographic position.
Figure 34: Fine suspended sediment input (silt, clay) from bank erosion (tonnes of sediment per meter of channel per year). The main river channels are predicted to be strong contributors of sediment because of their high bankfull discharges and bank heights.
5.4 Floodplain Deposition

Loss of sediment from the river to deposition on floodplains is represented using an algorithm based on the residence time of sediment-laden water upon floodplains and the predicted sediment load. This requires that floodplain areas be defined for each link in the river network and the mean floodplain width calculated. The one-dimensional step-backwater hydraulic model of Pickup and Marks (2001) has been used to map areas of floodplain inundation. This model defines valley bottom cross sections from the nine second digital elevation model (∼ 278 m pixels). For each cross section, Equation 18 is used to predict the peak flood discharge (m$^3$s$^{-1}$). In this case the one in five year recurrence interval event has been chosen to delineate floodplain areas. The one in five year event is still largely accumulative downstream along the major channel (ie. peak flood magnitude increases with catchment area) in the manner modelled by the floodplain inundation model. However, for events rarer and larger than this, flow bifurcation into distributary channels (which are not handled by the model of Pickup and Marks) start to become a more important component of the hydrologic characteristic of the catchment. In the model, the floodplain area used to model deposition also includes the channel area. Rustomji (2010) shows that the one in five year recurrence interval event on the Mitchell River can be modelled using the equation:

\[
Q_5 = 0.32 \times \sqrt{\text{area} \times \text{rain}}
\]

where area is upstream catchment area and rain is mean upstream catchment rainfall. Hydraulic modelling is then used to "fill" each cross section to the appropriate level and the inundated width of all the cross sections are combined to produce a map of inundated areas. Figure 35 shows the predicted floodplain area used in the SedNet modelling based on a one in five year recurrence interval event. The mean and median floodplain width is 1.2 km and the maximum floodplain width is 8.6 km.
Figure 35: Top: Raster image of modelled floodplain area for 1 in 5 year recurrence interval event shown against the catchment’s shaded relief digital elevation model. Bottom: mean floodplain widths for each SedNet link.
5.5 Nutrient Budget Modelling

The Annual Network Nutrient Export (ANNEX) of Young et al. (2001), which is a companion model of SedNet, has been used to construct a preliminary nutrient budget for the Mitchell River. Like SedNet, ANNEX predicts the average annual loads of phosphorus and nitrogen in each link in the river network under given catchment conditions. The model represents both dissolved and particulate nutrients and is thus highly dependent upon the catchment suspended sediment budget for both nutrient input and losses, though also includes denitrification processes (loss of nitrogen gas to the atmosphere).

In each link of the river network, the mean annual yield of nitrogen or phosphorus \((Y_i, \text{tonnes per year})\) is:

\[
Y_i = T_i + H_i + G_i + B_i + D_i + P_i - L_i
\]

where \(T_i\) is tributary particulate and dissolved input, \(H_i\) is particulate input from hillslope erosion, \(G_i\) is particulate input from gully erosion, \(B_i\) is particulate input from river bank erosion, \(D_i\) is diffuse dissolved input, \(P_i\) is point source dissolved input and \(L_i\) is the net loss of particulate and dissolved forms during transport through the river link. Mean annual particulate inputs were calculated as the product of mean annual fine sediment (silt and clay) erosion rate multiplied by soil nutrient concentration. For hillslope erosion, national scale grids (at nine arc-second resolution) of surface sediment phosphorus and nitrogen concentrations produced as part of the Australian Soil Resources Information System (ASRIS) project (Henderson et al. 2001; Johnston et al. 2003) were used. Nutrient loads from riverbank and gully erosion were estimated on “default” values of 0.25 g/kg of phosphorus and 1 g/kg of nitrogen, given the lack of local concentration measurements from these sources. These values are described in McKergow et al. (2005) as being derived from a personal communication from Jon Olley. No point sources are included in this modelling as no point sources were listed within the National Pollutant Inventory database (http://www.npi.gov.au/) for the catchment.

Estimation of diffuse dissolved input typically involves specification of a nominal dissolved nutrient concentration that is then applied to the runoff volume generated within each sub-catchment to generate a load. Commonly, concentration values are assigned to specific land use classes (e.g. DeRose et al., 2002 or Bartley et al., 2004). As a first pass analysis for the Mitchell River, dissolved nutrient concentrations consistent with unfertilised grazing landuse are applied everywhere (notwithstanding the presence of a relatively small area of intensive agriculture in the catchment’s headwaters where fertiliser application may occur). Reviews of dissolved nutrient concentrations by Bartley et al. (2004), McKergow et al. (2005) plus analysis of more recent monitoring data from the Burdekin River analysed by Bainbridge et al. (2007), have indicated concentrations of total dissolved phosphorus from unfertilised grazing land typically average 10 to 60 µg/l and for total dissolved nitrogen, 200 to 400 µg/l. Here dissolved phosphorus and nitrogen concentrations of 20 and 200 µg/l have been applied respectively. These values are at the lower end of the potential ranges and thus the loads from these sources will likely be minimum loads.

Figures 36 and 37 show the spatial patterns of nitrogen and phosphorus input to the river network. For both nutrients, the main areas of hillslope derived particulate nutrients (which was in essence the only nutrient term for which spatially variable concentration data were used) are the catchment headwaters where hillslope erosion rates are highest. The bank and gully erosion inputs are simply reflections of the patterns of the sediment generation by these processes, as no spatially variable concentration data were used. Similarly, the dissolved input is a reflection of catchment runoff generation, with high rates of input in the north east of the catchment and near the coast where rainfall is highest.
Figure 36: Modelled nitrogen sources for the Mitchell River catchment.
<table>
<thead>
<tr>
<th>Hillslope Erosion (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 - 0.10</td>
</tr>
<tr>
<td>0.11 - 0.20</td>
</tr>
<tr>
<td>0.21 - 0.40</td>
</tr>
<tr>
<td>0.41 - 0.80</td>
</tr>
<tr>
<td>0.81 - 2.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bank Erosion (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000 - 0.012</td>
</tr>
<tr>
<td>0.013 - 0.020</td>
</tr>
<tr>
<td>0.021 - 0.060</td>
</tr>
<tr>
<td>0.061 - 0.500</td>
</tr>
<tr>
<td>0.501 - 1.500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gully Erosion (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000 - 0.020</td>
</tr>
<tr>
<td>0.021 - 0.040</td>
</tr>
<tr>
<td>0.041 - 0.080</td>
</tr>
<tr>
<td>0.081 - 1.000</td>
</tr>
<tr>
<td>&gt; 1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dissolved Input (t/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003 - 0.004</td>
</tr>
<tr>
<td>0.005 - 0.006</td>
</tr>
<tr>
<td>0.007 - 0.008</td>
</tr>
<tr>
<td>0.009 - 0.010</td>
</tr>
<tr>
<td>0.011 - 0.020</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Input (kg.ha⁻¹.yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.07 - 0.10</td>
</tr>
<tr>
<td>0.11 - 0.20</td>
</tr>
<tr>
<td>0.21 - 0.40</td>
</tr>
<tr>
<td>0.41 - 1.00</td>
</tr>
<tr>
<td>1.01 - 18.75</td>
</tr>
</tbody>
</table>

Figure 37: Modelled phosphorus sources for the Mitchell River catchment.
5.6 Bed Material Transport Modelling

The bed material transport model within SedNet is based on the total bed material load formula of Yang (1973), which predicts the transport of sand sized particles and larger either along the bed or in suspension. Wilkinson et al. (2006) describe the modification and incorporation of Yang’s model within SedNet. Given flow expressed in units of megalitres per day, a modified version of Yang’s formula can be expressed as:

\[ STC_x = \frac{16.80 \alpha_a S^{1.3}}{\omega W^{0.4} n^{0.6}} \]  

(20)

where \( STC_x \) is sediment transport capacity for link \( x \) in tonnes per year, the 16.80 value is a combination of a units conversion term and a simplified coefficient, \( \alpha_a \) represents the effect of water discharge on sediment transport capacity as defined by the \( RDSQ \) variable above (Equation 4), \( S \) is the average slope of link \( x \), \( \omega \) is the terminal fall velocity of the particles being modelled, \( w \) is channel width and \( n \) is the hydraulic roughness of the channel (Manning’s \( n = 0.04 \)). Spatial variation in bed material transport capacity is essentially captured by spatial variation in discharge (i.e. \( \alpha_a \)), slope \( S \) and channel width \( w \). Spatially uniform parameters are the particle fall velocity \( \omega \) and channel roughness, \( n \), which are ultimately combined into a single total load transport coefficient. Values for \( \omega \) are calculated according to Dietrich (1982)\(^2\). This algorithm requires specification of two shape parameters. The first parameter is Power’s roundness coefficient (Powers 1953), which ranges from 0 (perfectly angular) to 6 (perfectly round); here an arbitrary value of 4.5 has been chosen. The second is the Corey shape factor, which ranges from > 0 to 1 and is the ratio of the cross sectional area of a sphere to the maximum cross sectional area of an ellipsoid. The smaller the value of this shape factor the flatter the particle. Here, an arbitrary Corey shape factor of 0.7 has been adopted. A critical aspect of selecting an appropriate particle fall velocity is selecting an appropriate particle size. Figure 38 shows the effect of different particle sizes on the total load transport coefficient (assuming Manning’s \( n \) of 0.04). Strong variation in total load transport rates would be predicted by selecting different particle sizes in the 1 to 3 mm size range; beyond this load estimates are less sensitive to the nominated particle size.

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\(^2\)An online calculator for this model is available at [http://woodshole.er.usgs.gov/staffpages/csherwood/sedx_equations/RunSedCalcs.html](http://woodshole.er.usgs.gov/staffpages/csherwood/sedx_equations/RunSedCalcs.html)
The constant of proportionality $k$ has units of tonnes per square metre and can be considered to represent the mean bed material mass per unit area of channel that is in active transport:

$$k = \rho_s d_s$$

where $\rho_s$ is sediment bulk density (1.65 t/m$^3$) and $d_s$ is conceptually an active depth of transient storage. The mean time it takes bed material to travel through a link of length $L_x$ is then $r_{t,x}$ years:

$$r_{t,x} = \frac{L_x}{V_{s,x}} = \frac{\rho_s d_s w_s L_x}{STC_x}$$

In the transient mode, the residence time modifies the supply to each link in the bed material budget such that sediment delivered to a link from tributaries in year $i$ contributes to the load in year $i + r_{t,x}$. Coarse sediment supply (i.e. sand) from bank and gully erosion along each link is also modelled to increase linearly from zero to the full mean annual rate over $r_{t,x}$ years. The transient budget is computed at an annual time step over $T = 200$ years. Here, $d_s$ has been set to 0.15 m, similar to the value adopted by Wilkinson et al. (2006). It should be noted that $d_s$ and $r_{t,x}$ are positively related, and at present there is no strong independent data by which values for $d_s$ can be set, though the resulting timeseries of bed material transport rates can be examined for reasonableness. Finally, a maximum bed material accumulation depth of 10 m has also been adopted.

has been applied to the Mitchell catchment, explicitly represents the variable velocity of sediment transport between links. A mean bed material velocity, $V_{s,x}$ (m/yr) for link $x$ is defined as proportional to the sediment transport capacity per unit width:

$$\frac{STC_x}{w_x} = kV_{s,x}$$

(21)
6 Results

6.1 Fine Suspended Sediment Loads (Washload) as Estimated From In-Stream Samples

6.1.1 Total Suspended Solids Sampling

The Queensland Government has been collecting Total Suspended Solid (TSS) (American Public Health Association 1995) samples of suspended sediment (clay, silt, sand) at a number of gauging stations in the Mitchell River catchment since the 1970's. The collection procedure for these samples is most often from single grab samples taken from the surface of the centre of the channel, with a few stations more recently having fixed depth intakes into automatic samplers. Whole samples are subsequently sub-sampled and processed via the TSS laboratory method (American Public Health Association 1995). Unfortunately, width- and depth-integrated sampling (Edwards and Glysson 1998; United States Geological Survey 2003; Wong et al. 2003) has not been undertaken in the Mitchell catchment. The month of sampling and TSS concentration for these samples is shown in Figure 39. Sampling has often occurred in the months with high flow volumes, which is desirable from a load estimation perspective. TSS concentrations during the wet season are generally less than 1000 mg/l, though approach or exceed this value on occasion at stations 919013A (McLeod River at Mulligan Highway), 919309A (Walsh River at Trimbles Crossing), 919009A (Mitchell River at Koolatah) and 919204 (Palmer River at Drumduff).

Measuring suspended sediment concentration via the total suspended solids (TSS) method (American Public Health Association 1995) has been found to cause major analytical bias (Gray et al. 2000) due to the potential exclusion of certain particle sizes (e.g., sand) during the TSS sub-sampling process. Suspended sediment concentrations (SSC, Guy,1969) derived using complete sample processing techniques leads to less bias in concentration estimates (American Society for Testing and Materials 2002; Gray et al. 2000). Due to the lack of particle size splitting at 63 µm before TSS analysis, it is unknown how much suspended sand (bed material load) is represented by historic TSS values in the Mitchell River data. However since the TSS data are known to significantly underestimate sand concentrations and samples were collected at the water surface where sand concentrations in the Mitchell are known to be a minimum (based on recent field measurements, Brooks and Shellberg, unpublished data), these surface TSS measurements are likely closer to representing washload concentrations of silt and clay. Since the conceptual framework of SedNet essentially sums the bed material load component (Yang 1973; Wilkinson et al. 2006) with the washload component (fine suspended sediment < 63µm) derived from hillslopes, gullies, and banks, the use of an empirical estimate of washload at gauging stations is preferable to validate and calibrate the SedNet model. Therefore, we deem it reasonable here to use these surface TSS samples to develop estimates of washload (fine suspended sediment) at gauging stations for comparison with predictions generated by SedNet.

Figure 40 shows the relationship between surface TSS concentration and discharge for the stations with TSS observations. The presence of sufficient data to characterise this relationship is critical for estimating fine suspended sediment loads. At a number of stations, the data are clearly too sparse to establish the nature of this relationship (either due to too few samples or insufficient sampling of higher discharges). However at nine stations it was judged that sufficient data was present to enable washload estimation.
Figure 39: Monthly total suspended solids (TSS) sampling distribution and monthly flow volumes for gauging stations in the Mitchell River catchment.
Figure 40: Relationships between total suspended solid (TSS) concentration and discharge (mean daily flow). The horizontal grey bars indicate the median TSS value within selected discharge classes and it is only for these stations that loads have been calculated. The vertical dashed line indicates the maximum observed instantaneous discharge for each gauging station.
Due to the relative scarcity of data and bias of surface TSS measurements, a rudimentary load estimation procedure has been adopted for these available data to estimate washload (suspended silt and clay, <63 µm). The median TSS value has been calculated for a limited number of arbitrarily chosen discharge classes (corresponding to order of magnitude variations in discharge). These median TSS values and the discharge ranges over which they have been applied are shown as grey horizontal bars in Figure 40. The class-median values range from 4 to 457 mg/l, depending on the station, and apart from one case, class-median TSS values increase with discharge class. The median TSS concentrations were applied to the corresponding mean daily discharge values for each station to calculate a daily suspended sediment load. The daily discharge values were aggregated into water-year totals (October to September). The temporal distribution of annual load estimates is shown in Figure 41 and Table 4 lists summary statistics for these load estimates.

### Table 4: Summary statistics for annual (water-year) fine suspended sediment load estimates for the Mitchell River catchment. All values are in units of kt/yr.

<table>
<thead>
<tr>
<th>Station</th>
<th>Minimum</th>
<th>1st Quartile</th>
<th>Median</th>
<th>Mean</th>
<th>3rd Quartile</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>919005A</td>
<td>0.4</td>
<td>2.6</td>
<td>5.9</td>
<td>7.6</td>
<td>12.1</td>
<td>31.0</td>
</tr>
<tr>
<td>919009A</td>
<td>228.0</td>
<td>766.0</td>
<td>1455.0</td>
<td>2079.0</td>
<td>2603.0</td>
<td>8986.0</td>
</tr>
<tr>
<td>919011A</td>
<td>75.0</td>
<td>158.0</td>
<td>368.0</td>
<td>527.0</td>
<td>852.0</td>
<td>2306.0</td>
</tr>
<tr>
<td>919013A</td>
<td>0.3</td>
<td>3.6</td>
<td>12.5</td>
<td>28.2</td>
<td>44.5</td>
<td>92.0</td>
</tr>
<tr>
<td>919021A</td>
<td>0.3</td>
<td>1.9</td>
<td>4.1</td>
<td>4.9</td>
<td>6.1</td>
<td>18.4</td>
</tr>
<tr>
<td>919024A</td>
<td>16.0</td>
<td>59.0</td>
<td>254.0</td>
<td>289.0</td>
<td>469.0</td>
<td>827.0</td>
</tr>
<tr>
<td>919030A</td>
<td>22.0</td>
<td>62.0</td>
<td>130.0</td>
<td>168.0</td>
<td>231.0</td>
<td>701.0</td>
</tr>
<tr>
<td>919310A</td>
<td>0.6</td>
<td>10.4</td>
<td>21.3</td>
<td>39.5</td>
<td>57.0</td>
<td>228.7</td>
</tr>
<tr>
<td>919311A</td>
<td>0.6</td>
<td>3.0</td>
<td>5.7</td>
<td>8.4</td>
<td>11.0</td>
<td>46.4</td>
</tr>
</tbody>
</table>

Area specific, mean-annual, fine suspended sediment load estimates range from 3 to 53 t km$^{-2}$ yr$^{-1}$. As can be seen from Figure 42, these yields are consistent in magnitude with a collection of area specific sediment yields for other Australian catchments collated by Wasson (1994), though arguably the area specific yield of 45 t km$^{-2}$ yr$^{-1}$ for the downstream most station (919009A, 46050 km$^2$, Koolatah gauge) is relatively high. Caution should be utilized when interpreting these continental data, as methods of data collection varied between data sources cited in Wasson (1994), such as the quantity of data for each gauge site and the quality of the suspended sediment data (i.e. TSS vs. SSC, point vs. depth integrated). For the Mitchell River, the trend of an increase in area specific sediment yield from station 919011A (20460 kmsq) to 919009A (46050 km$^2$) is unusual as typically area specific sediment yields decline downstream as depositional opportunities increase. This increase most likely reflects the contribution of alluvial gully erosion as a major sediment source downstream of station 919011A.

For use as washload estimates (suspended silt and clay <63 µm), these surface TSS vs. discharge data may be representative of the washload component of the sediment budget, as mentioned above. However for use as total suspended sediment load estimates (suspended sand, silt and clay), these TSS vs. discharge data are likely to be conservative (or minimum) values for several reasons. First, the TSS protocol underestimates the true suspended sediment concentrations due to the bias against sand (Gray et al. 2000). Second, median concentrations have been used in each class, which are lower than the corresponding mean concentrations given the positive skew in the TSS data. Third, mean daily flow has been used and this typically gives a lower load estimate than using higher frequency observations (such as 15 minute interval data) due to the non-linearity in the discharge-TSS relationship. Fourth, the model avoids extrapolation of TSS concentrations above the range of observed values in the prediction of TSS concentrations at high discharges. Fifth, TSS samples were collected from the water surface during all flow conditions, with no width- or depth-integrated sampling. Surface suspend sediment concentrations are typically lower than concentrations at depth, or from width- and depth-integrated, discharge-weighted concentrations (Edwards and Glysson 1998; United States Geological Survey 2003). For example, isokinetic SSC measurements from a boat at the Koolatah gauge (919009A) on the 14th Feb 2009, during a discharge of 4,145 m$^3$s$^{-1}$ indicated that surface SSC measurements were 31% lower than width and depth-integrated SSC measurements (Brooks and Shellberg unpublished data).

These issues highlight the challenges of calculating “observed” suspended sediment loads from limited or biased data at gauging stations (Walling and Webb 1988; Olive et al. 1994, 1995; Edwards and Glysson 1998; Gray et al. 2000). Additional water quality data at gauging stations would allow better constraints upon these load estimates, especially since suspended sediment (wash load and suspended bed material) is the dominant mechanism for sediment transport in the Mitchell River. For example,
80% of the total load (suspended- and bed-load) measured on 14th Feb 2009 at 4145 m$^3$s$^{-1}$ was in the suspended component. Future field measurement efforts at existing stage and discharge gauges should focus on 1) adoption of the more robust SSC protocol (Guy 1969; Gray et al. 2000; American Society for Testing and Materials 2002), 2) collection of width- and depth-integrated, discharge-weighted, suspended sediment concentration (SSC) data (Edwards and Glysson 1998; United States Geological Survey 2003), 3) collection of continuous turbidity data to define the episodic transitions from sediment supply- to transport-limited conditions, 4) the development of suspended sediment load estimates from correlations between continuous turbidity and periodically measured SSC data at the event scale (e.g. Gippel 1995, Grayson et al. 1996, Sun et al., 2001, Lewis and Eads, 2001).

Figure 41: Annual fine suspended sediment load estimates from surface TSS data for the Mitchell River catchment (note that load estimates are for a water year extending from October to September).
Figure 42: Mean-annual area-specific suspended sediment loads from the Mitchell River catchment shown as black circles. For reference, a range of other suspended sediment yields from Australian catchments, as collated by Wasson (1994) are shown as grey crosses.
6.2 Total Nitrogen Load Calculation

Figure 43 shows the relationship between total nitrogen concentration and discharge for four gauging stations where there was sufficient data to enable nutrient load estimates to be derived. The procedure adopted for nutrient load estimation is the same as for fine suspended sediment loads outlined above with the resulting annual load estimates shown in Figure 44 and summary statistics given in Table 5.

Figure 43: Relationships between total nitrogen concentration and discharge (mean daily flow). The horizontal grey bars indicate the median total nitrogen value within selected discharge classes. The vertical dashed line indicates the maximum observed instantaneous discharge for each gauging station.

Figure 44: Annual total nitrogen loads based on in-stream water quality data for four gauges in the Mitchell River catchment.

<table>
<thead>
<tr>
<th>Station</th>
<th>Minimum</th>
<th>1st Quartile</th>
<th>Median</th>
<th>Mean</th>
<th>3rd Quartile</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>919009A</td>
<td>0.50</td>
<td>1.40</td>
<td>2.60</td>
<td>3.70</td>
<td>4.60</td>
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<td>0.06</td>
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<td>8.20</td>
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<td>919309A</td>
<td>0.07</td>
<td>0.18</td>
<td>0.36</td>
<td>0.47</td>
<td>0.65</td>
<td>1.95</td>
</tr>
</tbody>
</table>

Table 5: Summary statistics for annual (water-year) total nitrogen load estimates for the Mitchell River catchment. All values are in units of kt/yr.

6.3 Total Phosphorus Load Calculation

Figure 45 shows the relationship between total phosphorus concentration and discharge for four gauging stations where there was sufficient data to enable load estimates to be derived. The procedure adopted for nutrient load estimation is the same as for fine suspended sediment loads outlined above with the resulting annual load estimates shown in Figure 46 and summary statistics given in Table 6.
Figure 45: Relationships between total phosphorus concentration and discharge (mean daily flow). The horizontal grey bars indicate the median total phosphorus value within selected discharge classes. The vertical dashed line indicates the maximum observed instantaneous discharge for each gauging station.

Figure 46: Annual total phosphorus loads based on in-stream water quality data for four gauges in the Mitchell River catchment.

<table>
<thead>
<tr>
<th>Station</th>
<th>Minimum</th>
<th>1st Quartile</th>
<th>Median</th>
<th>Mean</th>
<th>3rd Quartile</th>
<th>Maximum</th>
</tr>
</thead>
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<td>0.03</td>
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<td>0.40</td>
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<tr>
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<td>0.03</td>
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</tr>
<tr>
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<td>0.09</td>
<td>0.12</td>
<td>0.16</td>
<td>0.49</td>
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</tbody>
</table>

Table 6: Summary statistics for annual (water-year) total phosphorus load estimates for the Mitchell River catchment. All values are in units of kt/yr.
6.4 SedNet Calibration and Indicative Fine Suspended Sediment Budget

The approach adopted here is to apply the SedNet model initially with essentially “default” parameter values as a first pass analysis and then, after evaluation against both geochemical tracer and gauging station based load data (as described above), apply targeted modifications to relevant model parameters to try and improve the model’s predictions. The geochemical data pertain to fine suspended sediment particles (<63µm) and include the relative contribution of surface derived sediment (as determined using fallout radionuclides) as well as data used to determine relative sediment contributions from selected tributaries at river junctions (which employ both fallout radionuclides and major and minor element concentrations). Further details of these geochemical tracer data can be obtained in other reports documenting the sediment tracing research in the Mitchell and Daly catchments (Caitcheon et al. in preparation) and another example of the application of geochemical tracer data to tropical river catchment sediment budget research can be found in Wasson et al. (2010) for the Daly River catchment.

In total, five model iterations are presented below. They are presented to provide an understanding of why the model predictions differed from the tracer data, and highlight the effects of changing model parameters to improve predictions. This is a highly informative process from both a modelling perspective and a physical process based understanding of key aspects of the catchment's sediment budget. Finally, the calibration emphasis is clearly on the fine suspended sediment (washload) budget, primarily due to the dearth of other observational data to calibrate either the nutrient or bed material load models. However, the modification of budget components (hillslope erosion, bank erosion, floodplain depositions) to balance the modelled and empirical loads at gauging stations and geochemical tracing data highlight the issue that these variables are essentially residual terms. Residual terms contain not only the data attributed to them, but also unmeasured components of the sediment budget and the associated error from the known or directly measured components such as total load at gauges and alluvial gully erosion. However informative the calibration process is, the results from the calibrations processes should be used with caution due to residual effect and missing budget components.

6.4.1 Iteration One (MITCH13A)

An initial fine suspended sediment (washload) budget estimate for the Mitchell River is presented in Table 7, derived using essentially default model parameters. The fine suspended sediment yield for the Mitchell River is 13.7 Mt/yr (Table 7) which equates to an area specific sediment yield of 216 t/km²/yr. This is a relatively high fine suspended sediment yield by Australian standards (particularly for such a large catchment) and as is shown in Figure 47. The modelled sediment yields greatly exceed the values calculated at the gauging stations using the water sample data.

Under this modelling scenario, hillslope erosion is predicted to be the main fine sediment source. The upper Mitchell, Walsh and Palmer rivers are modelled as the main sources of hillslope-derived fine suspended sediment. This is due to the combination of relatively high predicted hillslope erosion rates and high sediment delivery ratios for these sub-catchments on account of their steepness and low vegetation cover in places. The geochemical tracer data (Table 8) indicate a strong sub-soil dominance prevailing across the entire catchment, which is in direct contrast to the modelling results. The modelled and observed tributary contributions are in very close agreement with the exception of the Lynd-Mitchell River confluence, where the relative sediment contribution from the Mitchell River appears to be overestimated.

Floodplain deposition (3.5 Mt/yr) accounts for 20% of total sediment input in this default model scenario. The final point to note is the size of river bank erosion as a sediment source. Currently this input is approximately double the sediment input rate from gully erosion (both alluvial and colluvial). The predicted spatial distribution of bank erosion shows the greatest contribution rates along the main channel. These reaches have both large bank heights and flow volumes so predicted bank retreat rates would involve significant sediment input.

The conclusions to be drawn from this model iteration are:

1. Modelled fine suspended sediment yields are too high.
2. The over prediction appears to stem in large part from an over prediction of fine sediment delivery to the river network from hillslope erosion.
3. This could be because predicted hillslope erosion rates are too high or the hillslope sediment delivery ratio is too high, or a combination of both. In the case of the latter, whilst hillslope sediment delivery ratios were variable across the catchment, their distribution was arbitrarily scaled to have
a mean value of 5%. This scaling factor could be reduced in order to reduce the mean of the distribution.

Figure 47: Observed versus predicted fine suspended sediment yields for first model iteration (left panel shows absolute loads and right panel shows area specific loads).

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Area (km²)</th>
<th>Hillslope input (kt/yr)</th>
<th>Gully input (kt/yr)</th>
<th>Riverbank input (kt/yr)</th>
<th>Floodplain deposition (kt/yr)</th>
<th>Sediment yield (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmer</td>
<td>8449</td>
<td>1725</td>
<td>399</td>
<td>667</td>
<td>544</td>
<td>2247</td>
</tr>
<tr>
<td>Upper Mitchell</td>
<td>9938</td>
<td>3028</td>
<td>674</td>
<td>613</td>
<td>871</td>
<td>3445</td>
</tr>
<tr>
<td>Walsh</td>
<td>8965</td>
<td>2323</td>
<td>641</td>
<td>477</td>
<td>776</td>
<td>2665</td>
</tr>
<tr>
<td>Tate</td>
<td>4375</td>
<td>287</td>
<td>56</td>
<td>226</td>
<td>148</td>
<td>422</td>
</tr>
<tr>
<td>Lynd (Upper)</td>
<td>4661</td>
<td>289</td>
<td>57</td>
<td>221</td>
<td>126</td>
<td>442</td>
</tr>
<tr>
<td>Lynd</td>
<td>11975</td>
<td>632</td>
<td>492</td>
<td>861</td>
<td>372</td>
<td>1614</td>
</tr>
<tr>
<td>Alice</td>
<td>12835</td>
<td>226</td>
<td>133</td>
<td>577</td>
<td>135</td>
<td>802</td>
</tr>
<tr>
<td>Mitchell at Koottah</td>
<td>45952</td>
<td>7848</td>
<td>3935</td>
<td>3791</td>
<td>3226</td>
<td>12348</td>
</tr>
<tr>
<td>Mitchell Outlet</td>
<td>63472</td>
<td>8138</td>
<td>4144</td>
<td>4987</td>
<td>3542</td>
<td>13726</td>
</tr>
</tbody>
</table>

Table 7: Summary fine suspended sediment (washload) budget for the Mitchell River (first iteration). All values are mean annual rates (i.e. rates per year). Note that gully input includes both colluvial and alluvial gully sources.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Fine suspended load (model, kt/yr)</th>
<th>Contribution (model %)</th>
<th>Contribution (tracer %)</th>
<th>Hillslope contribution (model %)</th>
<th>Hillslope contribution (tracer %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell upstream of Walsh</td>
<td>3557</td>
<td>57</td>
<td>60 ± 3</td>
<td>64</td>
<td>8 ± 4</td>
</tr>
<tr>
<td>Walsh upstream of Mitchell</td>
<td>2665</td>
<td>43</td>
<td>40 ± 3</td>
<td>63</td>
<td>11 ± 7</td>
</tr>
<tr>
<td>Mitchell downstream of Walsh</td>
<td>6233</td>
<td>100</td>
<td></td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Lynd</td>
<td>7503</td>
<td>82</td>
<td>68 ± 3</td>
<td>52</td>
<td>1 ± 4</td>
</tr>
<tr>
<td>Lynd upstream of Mitchell</td>
<td>1614</td>
<td>18</td>
<td>32 ± 3</td>
<td>27</td>
<td>7 ± 9</td>
</tr>
<tr>
<td>Mitchell downstream of Lynd</td>
<td>9142</td>
<td>100</td>
<td></td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Palmer</td>
<td>9913</td>
<td>82</td>
<td>82 ± 3</td>
<td>44</td>
<td>6 ± 4</td>
</tr>
<tr>
<td>Palmer upstream of Mitchell</td>
<td>2247</td>
<td>18</td>
<td>18 ± 3</td>
<td>57</td>
<td>10 ± 8</td>
</tr>
<tr>
<td>Mitchell downstream of Palmer</td>
<td>12162</td>
<td>100</td>
<td></td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Alice</td>
<td>12715</td>
<td>94</td>
<td>90 ± 1</td>
<td>44</td>
<td>2 ± 4</td>
</tr>
<tr>
<td>Alice upstream of Mitchell</td>
<td>802</td>
<td>6</td>
<td>10 ± 1</td>
<td>22</td>
<td>36 ± 5</td>
</tr>
<tr>
<td>Mitchell downstream of Alice</td>
<td>13533</td>
<td>100</td>
<td></td>
<td>42</td>
<td>3 ± 4</td>
</tr>
</tbody>
</table>

Table 8: Comparison of geochemical tracer data with SedNet model results for first model iteration.
6.4.2 Iteration Two (MITCH13B)

Figure 48 shows the cumulative distribution of RUSLE modelled hillslope erosion values for the Mitchell River catchment. Both erosion rates (tonnes per hectare per year) and equivalent denudation rates (assuming a bulk density of sediment of 1.5 tonnes per metre cubed) are shown on vertical axes. 75% of all cells have an estimated erosion rate of 15.3 tonnes per hectare per year or less yet the distribution is strongly positively skewed and extends out to 600 tonnes per hectare per year. By way of reference, an erosion rate of 100 tonnes per hectare per year equates approximately to a denudation rate of 6.06 mm/yr and 4.3% of the Mitchell River catchment is predicted to have hillslope erosion rates exceeding this value. Over 100 years, such a denudation rate equates to approximately 70 cm which is a very high rate. Such high rates could potentially be sustained for short periods (especially during an initial disturbance phase in a catchment) but it is difficult to envisage how they could be maintained over a 100+ year timescale given the thin soils common to Australia.

For this iteration, annual hillslope erosion rates have been capped at 50 tonnes per hectare per year. Whilst both the absolute and area specific load estimates are still greatly in excess of the values estimated at the gauging stations from the surface TSS data, the over estimation has been greatly reduced. Scaling the spatially variable hillslope sediment delivery ratio to a mean value of 1% as opposed to the current value of 5% could result in substantially better predictions and is explored next.
6.4.3 Iteration Three (MITCH13C)

In this iteration, the distribution of hillslope sediment delivery ratio values has been scaled to have a mean value of 0.01 (or 1%). This has further reduced the SedNet model’s over prediction of fine sediment loads. It is important to note that for two small sub-catchments in the headwaters of the Mitchell River [upstream of gauging stations 919005A (Rifle Creek) and 919013A (McLeod River)], the modelled area specific load agrees almost perfectly with the area specific loads predicted from the surface TSS data. Under the previous scenario, these small sub-catchments had substantial over prediction of their area specific loads. They are both small, steep, granitic catchments in relatively wet and well vegetated areas where hillslope erosion probably dominates the sediment supply. Thus they arguably indicate that the two modifications to the treatment of hillslope erosion have been worthwhile. Further improvements in model performance are likely to be obtained from adjustments to other sediment sources.

Apart from these two headwater sub-catchments just described, there still remains an over prediction of fine suspended sediment loads throughout much of the river network, including the lowermost gauge (919009A) at Koolatah. Comparison of Tables 7 and 9 show that the fine suspended sediment supply from hillslope erosion has been reduced from 8.1 to 1.1 Mt/year due to the combination of capping the hillslope erosion values and reducing the hillslope sediment delivery ratio, such that hillslope erosion is now only a minor source of sediment. This is consistent with the geochemical tracer data (Table 10).

Of the two remaining terms, gully erosion is predicted to account for 4.1 Mt/year of fine suspended sediment (washload) and river bank erosion another 5.0 Mt/year. Given that the gully erosion data are fairly well constrained, the approach of reducing the riverbank erosion input is adopted next.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Area km²</th>
<th>Hillslope input (kt/yr)</th>
<th>Gully input (kt/yr)</th>
<th>Riverbank input (kt/yr)</th>
<th>Floodplain deposition (kt/yr)</th>
<th>Sediment yield (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmer</td>
<td>8449</td>
<td>208</td>
<td>399</td>
<td>667</td>
<td>147</td>
<td>1128</td>
</tr>
<tr>
<td>Upper Mitchell</td>
<td>9938</td>
<td>364</td>
<td>674</td>
<td>613</td>
<td>197</td>
<td>1455</td>
</tr>
<tr>
<td>Walsh</td>
<td>8965</td>
<td>284</td>
<td>641</td>
<td>477</td>
<td>205</td>
<td>1198</td>
</tr>
<tr>
<td>Tate</td>
<td>4375</td>
<td>56</td>
<td>56</td>
<td>226</td>
<td>70</td>
<td>268</td>
</tr>
<tr>
<td>Lynd (Upper)</td>
<td>4661</td>
<td>57</td>
<td>57</td>
<td>221</td>
<td>63</td>
<td>273</td>
</tr>
<tr>
<td>Lynd</td>
<td>11975</td>
<td>124</td>
<td>492</td>
<td>861</td>
<td>209</td>
<td>1269</td>
</tr>
<tr>
<td>Alice</td>
<td>12835</td>
<td>45</td>
<td>133</td>
<td>577</td>
<td>94</td>
<td>661</td>
</tr>
<tr>
<td>Mitchell at Koolatah</td>
<td>45952</td>
<td>1009</td>
<td>3935</td>
<td>3791</td>
<td>1262</td>
<td>7473</td>
</tr>
<tr>
<td>Mitchell Outlet</td>
<td>63472</td>
<td>1067</td>
<td>4144</td>
<td>4987</td>
<td>1476</td>
<td>8722</td>
</tr>
</tbody>
</table>

Table 9: Summary fine suspended sediment budget for the Mitchell River (third iteration). All values are mean annual rates (i.e. rates per year). Note that gully input includes both colluvial and alluvial gully sources.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Fine suspended load (model, kt/yr)</th>
<th>Contribution (model %)</th>
<th>Contribution (tracer %)</th>
<th>Hillslope contribution (model %)</th>
<th>Hillslope contribution (tracer %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell upstream of Walsh</td>
<td>1563</td>
<td>56</td>
<td>60 ± 3</td>
<td>18</td>
<td>8 ± 4</td>
</tr>
<tr>
<td>Walsh upstream of Mitchell</td>
<td>1198</td>
<td>43</td>
<td>40 ± 3</td>
<td>17</td>
<td>11 ± 7</td>
</tr>
<tr>
<td>Mitchell downstream of Walsh</td>
<td>2772</td>
<td>100</td>
<td></td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Lynd</td>
<td>4054</td>
<td>76</td>
<td>68 ± 3</td>
<td>12</td>
<td>1 ± 4</td>
</tr>
<tr>
<td>Lynd upstream of Mitchell</td>
<td>1269</td>
<td>24</td>
<td>32 ± 3</td>
<td>7</td>
<td>7 ± 9</td>
</tr>
<tr>
<td>Mitchell downstream of Lynd</td>
<td>5350</td>
<td>99</td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Palmer</td>
<td>6129</td>
<td>84</td>
<td>82 ± 3</td>
<td>9</td>
<td>6 ± 4</td>
</tr>
<tr>
<td>Palmer upstream of Mitchell</td>
<td>1128</td>
<td>16</td>
<td>18 ± 3</td>
<td>14</td>
<td>10 ± 8</td>
</tr>
<tr>
<td>Mitchell downstream of Palmer</td>
<td>7271</td>
<td>100</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Alice</td>
<td>7860</td>
<td>92</td>
<td>90 ± 1</td>
<td>9</td>
<td>2 ± 4</td>
</tr>
<tr>
<td>Alice upstream of Mitchell</td>
<td>661</td>
<td>8</td>
<td>10 ± 1</td>
<td>5</td>
<td>36 ± 5</td>
</tr>
<tr>
<td>Mitchell downstream of Alice</td>
<td>8544</td>
<td>100</td>
<td></td>
<td>9</td>
<td>3 ± 4</td>
</tr>
</tbody>
</table>

Table 10: Comparison of geochemical tracer data with SedNet model results (third iteration).
Figure 50: Observed versus predicted fine suspended sediment yields for third model iteration (left panel shows absolute loads and right panel shows area specific loads).
6.4.4 Iteration Four (MITCH13D)

In iteration four, the bank erosion coefficient was changed from 0.00002 to 0.00001 (i.e. a 50% reduction). This has had the effect of further reducing the over prediction of area specific load, though the discrepancies are still relatively large (typically greater than a factor of 2). One problem emerging at this point however is that due to the reduction in sub-soil derived sediment sources (through the halving of the bank erosion coefficient), the relative hillslope fine suspended sediment concentrations have increased and are now generally well above the proportions indicated by the tracer data.

![Graph 1: Observed versus predicted fine suspended sediment yields for fourth model iteration (left panel shows absolute loads and right panel shows area specific loads).]

Figure 51: Observed versus predicted fine suspended sediment yields for fourth model iteration (left panel shows absolute loads and right panel shows area specific loads).

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Area km²</th>
<th>Hillslope input (kt/yr)</th>
<th>Gully input (kt/yr)</th>
<th>Riverbank input (kt/yr)</th>
<th>Floodplain deposition (kt/yr)</th>
<th>Sediment yield (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmer</td>
<td>8449</td>
<td>208</td>
<td>399</td>
<td>333</td>
<td>123</td>
<td>818</td>
</tr>
<tr>
<td>Upper Mitchell</td>
<td>9938</td>
<td>364</td>
<td>674</td>
<td>307</td>
<td>173</td>
<td>1172</td>
</tr>
<tr>
<td>Walsh</td>
<td>8965</td>
<td>284</td>
<td>641</td>
<td>238</td>
<td>178</td>
<td>986</td>
</tr>
<tr>
<td>Tate</td>
<td>4375</td>
<td>56</td>
<td>56</td>
<td>113</td>
<td>53</td>
<td>172</td>
</tr>
<tr>
<td>Lynd (Upper)</td>
<td>4661</td>
<td>57</td>
<td>57</td>
<td>111</td>
<td>47</td>
<td>178</td>
</tr>
<tr>
<td>Lynd</td>
<td>11975</td>
<td>124</td>
<td>492</td>
<td>431</td>
<td>159</td>
<td>888</td>
</tr>
<tr>
<td>Alice</td>
<td>12835</td>
<td>45</td>
<td>133</td>
<td>289</td>
<td>64</td>
<td>403</td>
</tr>
<tr>
<td>Mitchell at Koolatah</td>
<td>45952</td>
<td>1009</td>
<td>3935</td>
<td>1896</td>
<td>1093</td>
<td>5747</td>
</tr>
<tr>
<td>Mitchell Outlet</td>
<td>63472</td>
<td>1067</td>
<td>4144</td>
<td>2493</td>
<td>1247</td>
<td>6458</td>
</tr>
</tbody>
</table>

Table 11: Summary fine suspended sediment budget for the Mitchell River (fourth iteration). All values are mean annual rates (i.e. rates per year). Note that gully input includes both colluvial and alluvial gully sources.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Fine suspended load (model, kt/yr)</th>
<th>Contribution (model %)</th>
<th>Contribution (tracer %)</th>
<th>Hillslope contribution (model %)</th>
<th>Hillslope contribution (tracer %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell upstream of Walsh</td>
<td>1270</td>
<td>56</td>
<td>60 ± 3</td>
<td>22</td>
<td>8 ± 4</td>
</tr>
<tr>
<td>Walsh upstream of Mitchell</td>
<td>986</td>
<td>44</td>
<td>40 ± 3</td>
<td>21</td>
<td>11 ± 7</td>
</tr>
<tr>
<td>Mitchell downstream of Walsh</td>
<td>2262</td>
<td>100</td>
<td></td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Lynd</td>
<td>3384</td>
<td>79</td>
<td>68 ± 3</td>
<td>14</td>
<td>1 ± 4</td>
</tr>
<tr>
<td>Lynd upstream of Mitchell</td>
<td>888</td>
<td>21</td>
<td>32 ± 3</td>
<td>10</td>
<td>7 ± 9</td>
</tr>
<tr>
<td>Mitchell downstream of Lynd</td>
<td>4286</td>
<td>100</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Palmer</td>
<td>4826</td>
<td>85</td>
<td>82 ± 3</td>
<td>12</td>
<td>6 ± 4</td>
</tr>
<tr>
<td>Palmer upstream of Mitchell</td>
<td>818</td>
<td>14</td>
<td>18 ± 3</td>
<td>19</td>
<td>10 ± 8</td>
</tr>
<tr>
<td>Mitchell downstream of Palmer</td>
<td>5647</td>
<td>100</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Alice</td>
<td>5937</td>
<td>93</td>
<td>90 ± 1</td>
<td>12</td>
<td>2 ± 4</td>
</tr>
<tr>
<td>Alice upstream of Mitchell</td>
<td>403</td>
<td>6</td>
<td>10 ± 1</td>
<td>9</td>
<td>36 ± 5</td>
</tr>
<tr>
<td>Mitchell downstream of Alice</td>
<td>6350</td>
<td>100</td>
<td></td>
<td>12</td>
<td>3 ± 4</td>
</tr>
</tbody>
</table>

Table 12: Comparison of geochemical tracer data with SedNet model results (fourth iteration).

From Figure 51, it is apparent that the SedNet load predictions at the two downstream most gauging stations (Koolatah and Gamboola) are approximately 2-3 times greater than the loads estimated using...
the surface TSS data. For example the SedNet load prediction at the Koolatah gauge is 5747 kt, yet the loads estimated at the gauging station using the surface TSS data is 2079 kt (see Table 4). Potential options to improve the model fit at this point include:

1. Further decreasing sediment supply from bank erosion. An additional halving of the bank erosion coefficient (from 0.00001 to 0.000005) would reduce the modelled yields at the Koolatah gauge (919009A) by approximately 1200 kt. This amount would still not be sufficient to produce an exact match but would arguably be acceptable given the uncertainties in the load estimates. However, this would further negate the improvements in the agreement between surface and sub soil sediment proportions obtained up to the third model iteration.

2. Further reducing the hillslope sediment delivery ratio to say 0.5% would counter the effects of the above point by decreasing the hillslope sediment input. However, a further 50% reduction in this parameter would only yield an additional 500 kt reduction at the Koolatah gauge, which alone would be insufficient to bring the two data sets into agreement. However a mean hillslope sediment delivery ratio of 0.5% would be at the very lower limit of values generally adopted for such modelling.

3. An alternative to the above point is to extend the capping of the hillslope erosion surface from its current value of 50 tonnes per hectare per year to say 35 tonnes per hectare per year. This would affect approximately the top 20% of all grid cells in the hillslope erosion surface.

4. An alternative again is to increase the settling velocity of floodplain sediments to enhance floodplain deposition.

6.4.5 Fifth and Final Iteration (MITCH13E)

The fifth and final model calibration step involves the following changes:

1. Capping the hillslope erosion surface at 35 tonnes per hectare per year.

2. Increasing the sediment settling velocity from $1 \times 10^{-6}$ to $1 \times 10^{-5}$ to increase fine sediment deposition on floodplains. Applying Stokes law and assuming a sediment particle density of 1500 kg/m$^3$ and a viscosity of water at 20 degrees Celsius of 0.001 kg/ms, this increase in fine sediment settling velocity is equivalent to varying the effective particle size from approximately 2 to 6.5 microns.

3. An additional halving of the bank erosion coefficient (from 0.00001 in Mitch13D to 0.000005).

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Area km$^2$</th>
<th>Hillslope input (kt/yr)</th>
<th>Gully input (kt/yr)</th>
<th>Riverbank input (kt/yr)</th>
<th>Floodplain deposition (kt/yr)</th>
<th>Sediment yield (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmer</td>
<td>8449</td>
<td>169</td>
<td>399</td>
<td>167</td>
<td>358</td>
<td>378</td>
</tr>
<tr>
<td>Upper Mitchell</td>
<td>9938</td>
<td>292</td>
<td>674</td>
<td>153</td>
<td>413</td>
<td>706</td>
</tr>
<tr>
<td>Walsh</td>
<td>8965</td>
<td>227</td>
<td>641</td>
<td>119</td>
<td>446</td>
<td>514</td>
</tr>
<tr>
<td>Tate</td>
<td>4375</td>
<td>53</td>
<td>56</td>
<td>57</td>
<td>110</td>
<td>56</td>
</tr>
<tr>
<td>Lynd (Upper)</td>
<td>4661</td>
<td>55</td>
<td>57</td>
<td>55</td>
<td>101</td>
<td>66</td>
</tr>
<tr>
<td>Lynd</td>
<td>11975</td>
<td>119</td>
<td>492</td>
<td>215</td>
<td>368</td>
<td>459</td>
</tr>
<tr>
<td>Alice</td>
<td>12835</td>
<td>45</td>
<td>133</td>
<td>144</td>
<td>133</td>
<td>190</td>
</tr>
<tr>
<td>Mitchell at Koolatah</td>
<td>45952</td>
<td>834</td>
<td>3935</td>
<td>948</td>
<td>2904</td>
<td>2814</td>
</tr>
<tr>
<td>Mitchell Outlet</td>
<td>63472</td>
<td>892</td>
<td>4144</td>
<td>1247</td>
<td>3364</td>
<td>2919</td>
</tr>
</tbody>
</table>

Table 13: Summary fine suspended sediment budget for the Mitchell River (Fifth iteration). All values are mean annual rates (i.e. rates per year). Note that gully input includes both colluvial and alluvial gully sources.

This fifth iteration budget indicates:

1. The modelled confluence tracing proportions are generally in good agreement with the tracer data, with the largest discrepancy being 13 percentage points for the Mitchell-Lynd River confluence, where sediment input from the Mitchell River is over predicted as related to the tracer data.

2. The modelled proportional contributions of surface soil sediment are in good agreement with the tracer data for most sampling locations. The only major discrepancy is for the Alice River, where the contribution of surface derived sediment is substantially underestimated.
### Table 14: Summary fine suspended sediment budget for the Mitchell River (fifth iteration) at gauging stations. All values are mean annual rates (i.e. rates per year). Note that gully input includes both colluvial and alluvial gully sources.

<table>
<thead>
<tr>
<th>Gauging Station</th>
<th>Area km²</th>
<th>Hillslope input (kt/yr)</th>
<th>Gully input (kt/yr)</th>
<th>Riverbank input (kt/yr)</th>
<th>Floodplain deposition (kt/yr)</th>
<th>Sediment yield (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>919005A</td>
<td>370</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>919009A</td>
<td>45952</td>
<td>834</td>
<td>3935</td>
<td>948</td>
<td>2904</td>
<td>2814</td>
</tr>
<tr>
<td>919011A</td>
<td>20370</td>
<td>526</td>
<td>2065</td>
<td>287</td>
<td>1186</td>
<td>1692</td>
</tr>
<tr>
<td>919013A</td>
<td>538</td>
<td>17</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>919201A</td>
<td>538</td>
<td>21</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>919204A</td>
<td>7845</td>
<td>167</td>
<td>359</td>
<td>146</td>
<td>285</td>
<td>387</td>
</tr>
<tr>
<td>919309A</td>
<td>8658</td>
<td>225</td>
<td>504</td>
<td>109</td>
<td>402</td>
<td>436</td>
</tr>
<tr>
<td>919310A</td>
<td>4929</td>
<td>171</td>
<td>54</td>
<td>45</td>
<td>161</td>
<td>109</td>
</tr>
<tr>
<td>919311A</td>
<td>2790</td>
<td>90</td>
<td>28</td>
<td>13</td>
<td>70</td>
<td>61</td>
</tr>
</tbody>
</table>

Table 14: Summary fine suspended sediment budget for the Mitchell River (fifth iteration) at gauging stations. All values are mean annual rates (i.e. rates per year). Note that gully input includes both colluvial and alluvial gully sources.

### Table 15: Comparison of geochemical tracer data with SedNet model results (fifth iteration).

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Fine suspended load (model, kt/yr)</th>
<th>Contribution (model %)</th>
<th>Contribution (tracer %)</th>
<th>Hillslope contribution (model %)</th>
<th>Hillslope contribution (tracer %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell upstream of Walsh</td>
<td>769</td>
<td>59</td>
<td>60 ± 3</td>
<td>13</td>
<td>8 ± 4</td>
</tr>
<tr>
<td>Walsh upstream of Mitchell</td>
<td>541</td>
<td>41</td>
<td>40 ± 3</td>
<td>10</td>
<td>11 ± 7</td>
</tr>
<tr>
<td>Mitchell downstream of Walsh</td>
<td>1310</td>
<td>100</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Lynd</td>
<td>1959</td>
<td>81</td>
<td>68 ± 3</td>
<td>7</td>
<td>1 ± 4</td>
</tr>
<tr>
<td>Lynd upstream of Mitchell</td>
<td>459</td>
<td>19</td>
<td>32 ± 3</td>
<td>6</td>
<td>7 ± 9</td>
</tr>
<tr>
<td>Mitchell downstream of Lynd</td>
<td>2414</td>
<td>100</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Palmer</td>
<td>2544</td>
<td>89</td>
<td>82 ± 3</td>
<td>6</td>
<td>6 ± 4</td>
</tr>
<tr>
<td>Palmer upstream of Mitchell</td>
<td>378</td>
<td>13</td>
<td>18 ± 3</td>
<td>11</td>
<td>10 ± 8</td>
</tr>
<tr>
<td>Mitchell downstream of Palmer</td>
<td>2859</td>
<td>102</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitchell upstream of Alice</td>
<td>2769</td>
<td>95</td>
<td>90 ± 1</td>
<td>6</td>
<td>2 ± 4</td>
</tr>
<tr>
<td>Alice upstream of Mitchell</td>
<td>190</td>
<td>6</td>
<td>10 ± 1</td>
<td>11</td>
<td>36 ± 5</td>
</tr>
<tr>
<td>Mitchell downstream of Alice</td>
<td>2927</td>
<td>101</td>
<td>7</td>
<td></td>
<td>3 ± 4</td>
</tr>
</tbody>
</table>

Table 15: Comparison of geochemical tracer data with SedNet model results (fifth iteration).

3. There is a positive trend in area specific sediment loads, with a mild bias towards over prediction. However, given the gauging station load estimates are likely to be underestimates, this bias towards over prediction is considered acceptable. There are some areas where the area specific loads are less than satisfactorily estimated however (such as for gauge 919311A, Walsh at Flatrock), however model calibration has been focussed on station 919009A (the downstream most gauge at Koolatah) where model performance is good. The load estimates for this gauge in particular can be brought onto the 1:1 line with modest adjustments to the floodplain settling velocity parameter, though as noted above, we have opted for a mild overestimate given the nature of the station-based fine suspended sediment load estimates.

Overall, this budget indicates a mean annual fine suspended sediment (washload) yield at the outlet of the Mitchell River into the Gulf of Carpentaria of 2.9 Mt/yr. Of this total 4.1 Mt/yr is sourced from gully erosion (and the vast majority of this comes from alluvial gully erosion), 1.2 Mt/yr comes from river bank erosion and 0.9 Mt/yr from hillslope erosion. Floodplain deposition accounts for 3.4 Mt/yr of fine sediment. Below its confluence with the Alice River, approximately 93% of the Mitchell River’s fine sediment load is derived from sub-soil sources. This final calibrated budget represents a yield approximately one sixth of the size of the uncalibrated model (MITCH13A scenario) and reverses the incorrect prediction of a surface soil dominance that was also obtained under this scenario.
Figure 52: Observed versus predicted fine suspended sediment yields for fifth model iteration (left panel shows absolute loads and right panel shows area specific loads).
Figure 53: Fine suspended sediment contribution to the outlets of the Mitchell and Nassau Rivers into the Gulf.
Figure 54: Fine suspended sediment contribution to the outlet of the Mitchell and Nassau Rivers into the Gulf, indicating both rate of contribution (normalised by sub-catchment area) and sediment source, namely hillslope (blue), gully (green) or river bank (red) erosion. For example, heavy green lines indicate a high rate of contribution to catchment export from a given river link, and secondly that input for the link is dominated by gully-derived sediments.

Table 16 summarises the changes to the model’s input data and parameters used to obtain this fit whilst Table 17 summarises the actual changes in budget terms between the first “default” model iteration and the fifth, final iteration.

<table>
<thead>
<tr>
<th>Item</th>
<th>Original Value</th>
<th>Problem</th>
<th>Revised value</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hillslope erosion</td>
<td>uncap  esti     over prediction of yields</td>
<td>capped at 35 t/ha/yr</td>
<td>Lower yields, lower proportion of surface derived sediment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mates extending to 600 t/ha/yr</td>
<td>proportion of surface derived sediment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hillslope sediment delivery ratio</td>
<td>mean = 0.05</td>
<td>as above</td>
<td>mean = 0.01</td>
<td>as above</td>
</tr>
<tr>
<td>Bank erosion coefficient</td>
<td>$2 \times 10^{-5}$</td>
<td>over prediction of yields</td>
<td>$5 \times 10^{-6}$</td>
<td>yields reduced</td>
</tr>
<tr>
<td>Setting velocity for</td>
<td>$1 \times 10^{-6}$</td>
<td>over prediction of yields in lower</td>
<td>$1 \times 10^{-5}$</td>
<td>more accurate yields in lower</td>
</tr>
<tr>
<td>floodplain deposition</td>
<td></td>
<td>catchment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 16: Summary of changes to model parameters in model calibration process.
Table 17: Changes in fine suspended sediment budget terms for the Mitchell River catchment outlet between first and fifth iterations.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Area (km²)</th>
<th>Hillslope input (kt/yr)</th>
<th>Gully input (kt/yr)</th>
<th>Riverbank input (kt/yr)</th>
<th>Floodplain deposition (kt/yr)</th>
<th>Fine suspended sediment yield (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell Outlet (Iteration 1)</td>
<td>63472</td>
<td>8138</td>
<td>4144</td>
<td>4987</td>
<td>3542</td>
<td>13726</td>
</tr>
<tr>
<td>Mitchell Outlet (Iteration 5)</td>
<td>63472</td>
<td>892</td>
<td>4144</td>
<td>1247</td>
<td>3364</td>
<td>2919</td>
</tr>
<tr>
<td>Change</td>
<td>-7246</td>
<td>0</td>
<td>-3740</td>
<td>+178</td>
<td>-10807</td>
<td></td>
</tr>
</tbody>
</table>
6.5 Catchment Nutrient Budget Results

The modelled catchment nutrient budget is given in Table 18. Particulate nitrogen and phosphorus are predicted to be the dominant nutrient sources, with hillslope and gully erosion contributing approximately equally in terms of total mass of input. Given that gully erosion is a much larger source of fine sediment, this reflects greater nutrient concentrations in hillslope-derived surface soils relative to the values applied to sub-surface gully-derived soils. Predicted deposition of particulate nutrients on floodplains accounts for approximately half of the total nutrient supply. Dissolved nutrient export is approximately one fifth of the total load. Figure 55 shows the spatial pattern of contribution to catchment export. For total nitrogen contribution, the pattern is dominated by the distribution of alluvial gully erosion, though the secondary influence of relatively high nitrogen concentration is evident in moderate contribution rates from some areas in the north east of the catchment. Again, given the large predicted losses of particulate nitrogen to floodplain deposition, the poor connectivity of these hillslopes to the catchment outlet negates the relatively large predicted input of particulate nitrogen from hillslope erosion. For total phosphorus contribution, the predicted main source areas are those in close proximity to the major channels in the lower elevation region of the catchment that are dominated by alluvial gully erosion and bank erosion.

<table>
<thead>
<tr>
<th>Budget item</th>
<th>Total Nitrogen (kt/yr)</th>
<th>Total Phosphorus (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hillslope input</td>
<td>7.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Gully input</td>
<td>5.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Bank input</td>
<td>2.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Dissolved input</td>
<td>2.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Total supply</td>
<td>17.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Floodplain deposition</td>
<td>9.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Denitrification</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Particulate export</td>
<td>5.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Dissolved export</td>
<td>1.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Total export</td>
<td>6.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 18: Summary nutrient budget for the Mitchell River outlet to the Gulf of Carpentaria.

The accuracy of these predictions can be evaluated by reference to Figures 56 and 57 which show the SedNet model predictions in relation to the load estimates derived from the in-stream water quality samples at four gauging stations. For both total nitrogen and phosphorus there is a positive trend between observed and predicted values and the values are of the right order of magnitude which is encouraging. However the SedNet predictions are greater than the station based nutrient load estimates in all cases. This is not necessarily a matter for concern because, as noted above, the station based nutrient load estimation procedure has a bias towards low-range value, due to the use of class median nutrient concentration values, no extrapolation of concentration values and use mean daily flow as opposed to higher frequency discharge data. Thus the station based loads could conceivably be twice the values reported if alternate load calculation methods were adopted, which would result in the majority of stations having good agreement between load estimates derived using the two methods.

The nutrient budget terms can be placed into some context against previous research, such as the study of nitrogen and phosphorus delivery to the Great Barrier Reef (GBR) lagoon, again using SedNet. Total nitrogen and phosphorus delivery from the entire GBR lagoon catchment (423,000 km² versus 63,000 km² for the Mitchell River) was estimated as 100 kt/yr, which is about five times higher than the Mitchell River’s contribution to the Gulf of Carpentaria estimated here as 22 kt/yr for the Mitchell. Thus the per-unit area contribution rates are higher for the Reef lagoon. This reflects higher inputs from both point and non-point sources plus higher inputs from areas of more intense agriculture in the Reef catchments. In addition, there are potentially higher input rates in the Reef from hillslope erosion. For example, the same hillslope erosion grids were used in both regions, but the Reef had a higher hillslope sediment delivery ratio and without the capping of very high rates as was necessary in the case of the Mitchell River. Interestingly in the Reef, predicted total exports were \( \geq 50\% \) of total inputs, whereas in the Mitchell River, net export is lower as a proportion of input. This is attributed to the very large floodplain area of the Mitchell attenuating upstream supply to a greater extent than is the case for the Reef catchments, where intensive supply areas are located in close proximity to the coast.
Figure 55: Spatial patterns of total nitrogen and phosphorus contributions to the catchment outlet.

6.6 Comparison with Pre-European Catchment Conditions

The SedNet model can be configured to investigate changes in the catchment sediment budget associated with the introduction of European land use practices. Such analyses allow for an estimate of the change associated with the large scale shift in land use to be quantified, which in turn can be used to examine changes in other aspects of the riverine ecosystem influenced by changes in the catchment’s sediment budget. The pre-European landscape scenario and can also potentially provide a target to guide catchment restoration works.

Modelling pre-European catchment conditions is accomplished by changing the input erosion sources
and/or other model parameters for which there may be justification. Riparian vegetation modification via clearing of over-story trees is considered to be minimal in the Mitchell River catchment, notwithstanding dramatic change in weed infestation in the riparian zone such as rubber vine (Cryptostegia grandiflora) and noogoora burr (Xanthium pungens). Thus without more data on changes in riparian understory vegetation cover and erosion resistance, there is no strong justification for considering any changes to the bank erosion component of the catchment sediment budget that models erosion as a partial function of vegetation cover. In contrast, hillslope erosion rates are likely to have been affected by changed land use patterns (such as the introduction of grazing activities, agricultural development and clearing, and the thousands of historic and current mine sites). There is also evidence from back-extrapolation of alluvial gully erosion rates and historical reports from early European explorers that alluvial gully erosion is largely a post-European settlement phenomena (Shellberg, Brooks, Spencer, Knight and Pietsch 2010; Shellberg, Brooks and Spencer 2010, Shellberg unpublished data but forthcoming). Thus we have opted to change aspects of the colluvial (hillslope) and alluvial gully erosion terms in the model as follows:

- a pre-European settlement hillslope erosion surface, which, to be consistent with the calibration process adopted above, has been capped at 35 tonnes per hectare per year
- a reduction in the sediment generation rate from alluvial gully erosion to 5% of current values. Colluvial gully erosion rates are modelled as for current conditions, i.e. assuming that the current yields, equating to 20% of the long term (post-European settlement) rate, are broadly representative of, or at least represent and upper limit to, pre-European conditions.

Tables 19 and 20 show the changes in the fine suspended sediment (washload) budget for the Mitchell River catchment, expressed in tonnes and as a percentage of the “current condition” values. Pre-
European hillslope erosion conditions represent the delivery of approximately 486 kt per year less sediment to the river network. However, sediment deposition on floodplains is also predicted to be 408 kt per year lower such that there is a net reduction of 79 kt per year being delivered to the outlet. This equates to a 3% reduction in fine sediment load at either the Koolatah gauge (919009A) or the catchment outlet, though higher proportional load reductions are predicted amidst the sub-catchments and headwaters where hillslope erosion rates are higher and represent a greater proportion of the sediment load. Hillslope erosion has already been established as a minor fine sediment source for the whole catchment, so it is not surprising that only a relatively small percentage change was predicted as a result of changing this sediment source term.

It should be recognised that direct measurement of floodplain deposition rates in the major sub-catchments (Palmer, Walsh, Lynd, Mitchell) above the influence of alluvial gullies on the megafan would allow for a better quantification of the changes in upper-catchment sediment sources associated with the introduction of European landuse practices. As will be highlighted in the discussion, it is known that numerous budget components not included in this model (e.g. widespread mining and changes in small channel sediment sources) have changed dramatically post-European settlement (see for example Figures 67 and 68).

### Table 19:
Variations in the fine suspended sediment budget for the Mitchell River under capped pre-European hillslope erosion rates from “current” conditions.

<table>
<thead>
<tr>
<th>Gauging Station</th>
<th>Area km²</th>
<th>Hillslope input (kt/yr)</th>
<th>Gully input (kt/yr)</th>
<th>Riverbank input (kt/yr)</th>
<th>Floodplain deposition (kt/yr)</th>
<th>Fine suspended sediment yield (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>919005A</td>
<td>370</td>
<td>-4</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>-3</td>
</tr>
<tr>
<td>919009A</td>
<td>45952</td>
<td>-477</td>
<td>0</td>
<td>0</td>
<td>-394</td>
<td>-84</td>
</tr>
<tr>
<td>919011A</td>
<td>20370</td>
<td>-297</td>
<td>0</td>
<td>0</td>
<td>-223</td>
<td>-73</td>
</tr>
<tr>
<td>919013A</td>
<td>538</td>
<td>-13</td>
<td>0</td>
<td>0</td>
<td>-5</td>
<td>-8</td>
</tr>
<tr>
<td>919020A</td>
<td>536</td>
<td>-16</td>
<td>0</td>
<td>0</td>
<td>-5</td>
<td>-11</td>
</tr>
<tr>
<td>919020A</td>
<td>7845</td>
<td>-121</td>
<td>0</td>
<td>0</td>
<td>-89</td>
<td>-33</td>
</tr>
<tr>
<td>919309A</td>
<td>8658</td>
<td>-124</td>
<td>0</td>
<td>0</td>
<td>-101</td>
<td>-23</td>
</tr>
<tr>
<td>919310A</td>
<td>4929</td>
<td>-115</td>
<td>0</td>
<td>0</td>
<td>-75</td>
<td>-39</td>
</tr>
<tr>
<td>919311A</td>
<td>2790</td>
<td>-64</td>
<td>0</td>
<td>0</td>
<td>-35</td>
<td>-30</td>
</tr>
<tr>
<td>outlet</td>
<td>63472</td>
<td>-486</td>
<td>0</td>
<td>0</td>
<td>-408</td>
<td>-79</td>
</tr>
</tbody>
</table>

### Table 20:
Percentage variations in the fine suspended sediment budget for the Mitchell River under capped, pre-European hillslope erosion rates from “current” conditions.

<table>
<thead>
<tr>
<th>Gauging Station</th>
<th>Area km²</th>
<th>Hillslope input (%)</th>
<th>Gully input (%)</th>
<th>Riverbank input (%)</th>
<th>Floodplain deposition (%)</th>
<th>Fine suspended sediment yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>919005A</td>
<td>370</td>
<td>-67</td>
<td>0</td>
<td>0</td>
<td>-50</td>
<td>-60</td>
</tr>
<tr>
<td>919009A</td>
<td>45952</td>
<td>-57</td>
<td>0</td>
<td>0</td>
<td>-14</td>
<td>-3</td>
</tr>
<tr>
<td>919011A</td>
<td>20370</td>
<td>-56</td>
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<td>0</td>
<td>-19</td>
<td>-4</td>
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<tr>
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<td>538</td>
<td>-76</td>
<td>0</td>
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<td>-71</td>
<td>-57</td>
</tr>
<tr>
<td>919201A</td>
<td>536</td>
<td>-76</td>
<td>0</td>
<td>0</td>
<td>-71</td>
<td>-65</td>
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<tr>
<td>919204A</td>
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<td>-5</td>
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<td>919310A</td>
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<td>-67</td>
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<td>0</td>
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<td>919311A</td>
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<td>-49</td>
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<tr>
<td>outlet</td>
<td>63472</td>
<td>-54</td>
<td>0</td>
<td>0</td>
<td>-12</td>
<td>-3</td>
</tr>
</tbody>
</table>

Tables 21 and 22 however list equivalent changes resulting from altering both hillslope and alluvial gully density terms in the model. Under this representation of pre-European conditions, fine sediment input from alluvial gully erosion is 54-76% below current conditions, with this change focussed on the lower reaches of the catchment. Floodplain deposition is also 63% lower (on account of the reduced loads) and overall catchment fine sediment yields are 69 and 64% lower at the Koolatah gauge (919009A) and the catchment outlet, respectively. Alternatively put, contemporary fine sediment yields are estimated to be 177 to 225% higher than (or roughly double) pre-European conditions. However, this conclusion is sensitive to the assumed pre-European rate of fine sediment generation from alluvial gully erosion. Measurement of historical rates of floodplain deposition would provide greater clarity around any changes in catchment sediment yields associated with European settlement of the catchment.
<table>
<thead>
<tr>
<th>Gauging Station</th>
<th>Area km²</th>
<th>Hillslope input (kt/yr)</th>
<th>Gully input (kt/yr)</th>
<th>Riverbank input (kt/yr)</th>
<th>Floodplain deposition (kt/yr)</th>
<th>Fine suspended sediment yield (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>919005A</td>
<td>370</td>
<td>-4</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>-3</td>
</tr>
<tr>
<td>919009A</td>
<td>459.52</td>
<td>-477</td>
<td>-3.355</td>
<td>0</td>
<td>-1884</td>
<td>-1949</td>
</tr>
<tr>
<td>919011A</td>
<td>203.70</td>
<td>-297</td>
<td>-17.81</td>
<td>0</td>
<td>-774</td>
<td>-1304</td>
</tr>
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<td>-8</td>
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<tr>
<td>919201A</td>
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<td>-16</td>
<td>0</td>
<td>0</td>
<td>-5</td>
<td>-11</td>
</tr>
<tr>
<td>919204A</td>
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<td>-121</td>
<td>-285</td>
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<td>-238</td>
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<tr>
<td>919309A</td>
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<td>-300</td>
</tr>
<tr>
<td>919310A</td>
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<td>-39</td>
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<td>-30</td>
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<td>outlet</td>
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<td>-486</td>
<td>-3497</td>
<td>0</td>
<td>-2116</td>
<td>-1867</td>
</tr>
</tbody>
</table>

Table 21: Variations in the fine suspended sediment budget for the Mitchell River under capped pre-European hillslope erosion rates and 5% alluvial gully erosion rates, relative to “current” conditions.

<table>
<thead>
<tr>
<th>Gauging Station</th>
<th>Area km²</th>
<th>Hillslope input (%)</th>
<th>Gully input (%)</th>
<th>Riverbank input (%)</th>
<th>Floodplain deposition (%)</th>
<th>Fine suspended sediment yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>919005A</td>
<td>370</td>
<td>-67</td>
<td>0</td>
<td>0</td>
<td>-50</td>
<td>-60</td>
</tr>
<tr>
<td>919009A</td>
<td>459.52</td>
<td>-57</td>
<td>-85</td>
<td>0</td>
<td>-65</td>
<td>-69</td>
</tr>
<tr>
<td>919011A</td>
<td>203.70</td>
<td>-56</td>
<td>-86</td>
<td>0</td>
<td>-65</td>
<td>-77</td>
</tr>
<tr>
<td>919013A</td>
<td>538</td>
<td>-76</td>
<td>0</td>
<td>0</td>
<td>-71</td>
<td>-57</td>
</tr>
<tr>
<td>919201A</td>
<td>536</td>
<td>-76</td>
<td>0</td>
<td>0</td>
<td>-71</td>
<td>-65</td>
</tr>
<tr>
<td>919204A</td>
<td>784.5</td>
<td>-72</td>
<td>-79</td>
<td>0</td>
<td>-59</td>
<td>-61</td>
</tr>
<tr>
<td>919309A</td>
<td>8.658</td>
<td>-55</td>
<td>-77</td>
<td>0</td>
<td>-52</td>
<td>-69</td>
</tr>
<tr>
<td>919310A</td>
<td>49.29</td>
<td>-67</td>
<td>0</td>
<td>0</td>
<td>-47</td>
<td>-36</td>
</tr>
<tr>
<td>919311A</td>
<td>2.79</td>
<td>-71</td>
<td>0</td>
<td>0</td>
<td>-50</td>
<td>-49</td>
</tr>
<tr>
<td>outlet</td>
<td>634.72</td>
<td>-54</td>
<td>-84</td>
<td>0</td>
<td>-63</td>
<td>-64</td>
</tr>
</tbody>
</table>

Table 22: Percentage variations in the fine suspended sediment budget for the Mitchell River under capped, pre-European hillslope erosion rates and 5% of sediment input from contemporary alluvial gully erosion, relative to “current” conditions.
6.7 Model Sensitivity to Fine Sediment Supply Variations

Here the sensitivity of the fine suspended sediment load predictions to spatially uniform proportional variations in sediment supply from hillslope, river bank and gully erosion are examined. This analysis serves two purposes:

1. It provides a sensitivity analysis of model predictions to variations or uncertainties in sediment input terms.
2. It provides some guidance concerning likely changes in sediment loads from management actions that either increase or decrease sediment generation.

Figure 58 show the variation in fine suspended sediment load estimates at four points in the river network to a sequence of proportional variations in sediment generation extending to ± 15% of modern conditions. The response is linear within this range, thus allowing for a series of response coefficients to be calculated that express the proportional change in load from a proportional change in input. These response coefficients are summarised in Table 23. All coefficient values are < 1 which is not surprising given the dampening effect of floodplain deposition on catchment loads. Coefficient values for hillslope erosion are lowest (< 0.11) indicating for each unit change in sediment generation from hillslope erosion at the source, this only translates into a maximum 0.11 units change in load estimates at downstream locations. Gully erosion has the largest coefficient values (0.62 – 0.81) reflecting the strong connectivity of this fine sediment source to the catchment outlet. This highlights the fact that these sensitivity coefficients are dependent upon the spatial pattern of sediment sources and sinks within the catchment and thus would vary at other locations.

![Graphs showing variations in fine suspended sediment load transport at four locations as a function of variations in sediment input from hillslope, river bank and gully erosion.](image)

Figure 58: Variations in fine suspended sediment load transport at four locations as a function of variations in sediment input from hillslope, river bank and gully erosion.

6.8 Spatially Variable versus Spatially Uniform Hillslope Sediment Delivery Ratio

One of the novel aspects of the SedNet modelling conducted here has been the use of a spatially variable hillslope sediment delivery ratio as opposed to the simpler approach of adopting a spatially uniform value. The SedNet model was run with a spatial uniform rate of 1% to examine the difference such a change makes to the model predictions. No substantial changes were evident in model performance as a result
<table>
<thead>
<tr>
<th>Location</th>
<th>Hill</th>
<th>Bank</th>
<th>Gully</th>
</tr>
</thead>
<tbody>
<tr>
<td>919204A</td>
<td>0.11</td>
<td>0.24</td>
<td>0.62</td>
</tr>
<tr>
<td>919011A</td>
<td>0.09</td>
<td>0.10</td>
<td>0.81</td>
</tr>
<tr>
<td>919009A</td>
<td>0.06</td>
<td>0.19</td>
<td>0.74</td>
</tr>
<tr>
<td>Outlet</td>
<td>0.07</td>
<td>0.24</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Table 23: Response coefficients expressing relative change in fine suspended sediment load to variations in hillslope, river bank and gully erosion. A response coefficient of 0.1 indicates a unit change in sediment supply yields a 0.1 unit response in terms of sediment load at the catchment outlet.

of this; the estimated proportions of hillslope derived sediment were with a few percentage points of the values listed in Table 15 and the correlation in area specific loads was essentially the same, with a Pearson correlation coefficient of 0.35 in each case. This result thus provides neither validation or refutation of the spatially variable hillslope sediment ratio model proposed here but does indicate, that had a simpler approach been adopted, the results would have been very similar. This result also reflects the relatively minor contribution of hillslope derived fine sediment to the river network, implying that the Mitchell River may not have been an optimal test case for evaluating this method.

### 6.9 Bed Material Transport Modelling

As noted earlier, the magnitude of the modelled bed material transport rates are sensitive to the selection of settling velocity and hence particle size adopted in the model. To examine this sensitivity, the bed material load model has been run using six nominal particles sizes (1 to 6 mm in 1 mm increments) over a modelling time span of 220 years. This 220 year duration was selected as it was at the upper extent of the duration that could be supported by the current computational capacity. The variation in predicted load as a function of particle size at two locations (the Koolatah Gauge 919009A and the catchment outlet) are shown in Figure 59. At the Koolatah gauge, total bed material load estimates ranged from 1188 kt per year for a 1 mm nominal particle size to 388 kt per year for a 6 mm nominal particle size, after 220 years.

![Figure 59](image.png)

Figure 59: Variations in predicted bed material load transport at the Koolatah gauge and catchment outlet as a function of nominal particle size (right hand side axis) and total load transport coefficient (left hand side axis).

One important aspect of the transient bed material load budget is the prediction of a conceptual time series of bed material sediment load. This time series does not reflect a time series driven by the actual historical flow sequence per se, but rather reflects a conceptual downstream passage of bed material load over time under a specified duration of “average” transport conditions. Figure 60 shows a 220 year time series of bed material load transport rates at five gauge locations plus the catchment outlet.
For some upper catchment locations with relatively high transport capacity (such as at gauges 919006A, 919008A and 919204A), bed material load transport rates reach steady state in 10 to 20 years. The fact that for 919006A and 919008A (Lynd/Tate) have virtually indistinguishable bed material load transport rates between the different size classes reflects the abundant sediment transport capacity relative to supplied load. For the Mitchell River at Gamboola (919011A), the stepped increase in transport rates reflects the downstream migration to this point in the network of sediment pulses originating in its various tributaries. Rates reach a steady state level of 500 to 600 kt per year after 80 to 150 years. However, further down the network at gauge 919009A (Mitchell River at Koolatah) and the outlet, even after 220 years it cannot be conclusively resolved that steady state conditions have been reached (though this potentially is the case for the 1 and 2 mm particle sizes). It is thus possible that there may still be bed material pulses from upstream that have not yet fully propagated downstream to these locations for the larger particle sizes.

What this modelling indicates is the likely response times for changes in bed material load to be seen at different points in the river network. In essence at gauging stations such as Gamboola and Koolatah, an upward shift in bed material input from the upstream catchment (such as that effectively modelled here) takes approximately 100 years to manifest completely. At mid to lower catchment locations such as Koolatah and below, the response time could be up to 200 years.

Figure 61 shows the pattern of the downstream accumulation of mean residence time of bed material sediment across the Mitchell River catchment for a 2 mm nominal particle size (and with a maximum individual link sediment residence time of 50 years). The spatial pattern is fairly well organised, with low residence times in the catchment headwaters. Amongst the small tributaries, residence times increase
westwards as the catchment gradient reduces, with decadal or centennial residence times associated, not surprisingly, with the near-coastal floodplains. Accumulative residence times along the main channel's are generally greater than 100 years, reflecting the timescale of passage of sediment waves through the river network. Note that any load in transit at the end of the wet season will be deposited as wet-season flows subside and a higher rate of bed material transport (relative to natural conditions) will entail enhanced deposition upon the river bed. This will likely have implications for the preservation of pools within the channel.

![Bedload Residence Time](image)

### Figure 61: Mean residence time of bed material sediment across the Mitchell River catchment for a nominal particle size of 2 mm.

Another aspect of the predicted bed material residence time is the net bed material accumulation within the channel over 220 years, as shown in Figure 62, again for a nominal 2 mm particle size. The headwaters of the catchment show negligible bed material accumulation (commonly none), indicating again the relatively high sediment transport capacity of discharge-slope combinations within this region. Areas of substantial predicted bed material accumulation are very restricted and this lack of spatial coherence arguably indicates that the results are somewhat an artefact of “noise” in aspects such as catchment slope and/or sediment input terms rather than genuine sediment budget characteristics. Along the main stem of the Mitchell River, net bed material accumulation rates are predicted to be less than 1 m for virtually its entire length. What this means in practise is that there is predicted to be a relatively low level of net aggradation along the main channel, even given the modelled modern (i.e. post-European settlement) sediment load across the catchment. Given that much of the Mitchell River within the megafan region has a sand bed, the current modelling indicates a < 1 m contribution from the current suite of sediment generation processes modelled here. However this conclusion must be interpreted with care. As demonstrated above, contemporary rates of fine sediment supply may be roughly double those of the pre-European period, however the changes in bed material load are less certain. In addition, whilst wet season sediment transport capacity may be easily sufficient to move the supplied load, a greater load in-transit during the wet season will also translate to greater deposition of bed material (sand) during the dry season. Thus whilst the model suggests limited net bed material aggradation, seasonal deposition at the end of the dry season may be substantially greater than pre-European conditions and have consequences for the preservation of aquatic habitats such as pools. Bed material accumulation may also not be evenly spread within a link and would likely preferentially accumulate in certain areas (perhaps pools) such that localised deposition rates may greatly exceed a reach averaged rate. In addition, poor prediction of the RDSQ variable used to model sediment transport capacity and unexplained variation in channel width may also influence actual localised deposition rates in a way not accounted for in the model.
Finally, it is possible to compare the relative tributary contributions of the bed material load transport modelling to equivalent contribution percentages estimated by Caitcheon et al. (in preparation), based on the geochemistry of transported sediment samples collected from the river, as is shown in Table 24. For the confluences of the Mitchell River with the Palmer and Alice Rivers, the model is in good to fair agreement with the geochemistry-based estimates. For the Mitchell-Walsh confluence, the model’s predictions do not match the tracer data in any strong way and for the Mitchell-Lynd River confluence, the relative contributions are opposite to the tracer data.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Bed Material load (model, kt/yr)</th>
<th>Contribution (model %)</th>
<th>Contribution (tracer %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitchell upstream of Walsh</td>
<td>260</td>
<td>52</td>
<td>73 ± 2</td>
</tr>
<tr>
<td>Walsh upstream of Mitchell</td>
<td>237</td>
<td>48</td>
<td>27 ± 2</td>
</tr>
<tr>
<td>Mitchell upstream of Lynd</td>
<td>812</td>
<td>72</td>
<td>19 ± 2</td>
</tr>
<tr>
<td>Lynd upstream of Mitchell</td>
<td>312</td>
<td>28</td>
<td>81 ± 2</td>
</tr>
<tr>
<td>Mitchell upstream of Palmer</td>
<td>683</td>
<td>73</td>
<td>73 ± 2</td>
</tr>
<tr>
<td>Palmer upstream of Mitchell</td>
<td>246</td>
<td>27</td>
<td>27 ± 2</td>
</tr>
<tr>
<td>Mitchell upstream of Alice</td>
<td>913</td>
<td>82</td>
<td>73 ± 3</td>
</tr>
<tr>
<td>Alice upstream of Mitchell</td>
<td>190</td>
<td>18</td>
<td>27 ± 3</td>
</tr>
</tbody>
</table>

Table 24: Comparison of bed material load (here a 1 mm particle size is examined) confluence proportions as predicted by SedNet with equivalent proportions estimated from the geochemical properties of the sediment.
7 

Discussion

In this discussion, a number of key aspects of the catchment sediment and nutrient budget are considered in terms of the major uncertainties and knowledge gaps.

7.1 Hillslope Erosion

The modelling in this report has provided support for the use of a relatively low hillslope sediment delivery ratio for the Mitchell River catchment (mean of 1% as opposed to commonly used value of 5%). What is considered more significant however has been the capping of the RUSLE hillslope erosion surface of Lu et al. (2003) at 35 tonnes per hectare per year (uncapped rates extended up to 600 tonnes per hectare per year). In the absence of such a cap, modelled catchment sediment yields were markedly too high, and a hillslope derived sediment dominance was modelled, which was in direct contradiction to the erosion process tracer results.

There are several issues around the modelling of hillslope erosion rates in this way. The first issue to note is that the use of a low HSDR could in fact be compensating for a more general over-prediction of hillslope erosion rates and we cannot necessarily rule this out as a plausible scenario. In this case, “real” HSDR values could be higher than those currently modelled if lower rates of gross hillslope erosion were predicted across the landscape as both approaches would notionally yield the same total mass of fine sediment input to the river network. Inspection of high resolution satellite imagery on Google Earth of areas with predicted very high rates of hillslope erosion in the Mitchell River catchment were not areas of intensive agriculture, where such rates could conceivably occur. Rather they are nondescript areas of savannah woodland, sometimes though not always, located in hilly terrain. However, such areas typically have thin soils, less than complete soil cover or rocky lag surfaces. Despite sometimes steep gradients and having what may be poor cover and experiencing high intensity rainfall (three important factors in the RUSLE model), these hillslopes may be incapable of supporting very high hillslope erosion rates on a decadal basis without the store of erodible soil being exhausted. These areas are thus conceivably “supply limited” with respect to fine sediment generation, rather than being transport limited in the manner that the RUSLE model is formulated. The possibility that this would be an issue with the RUSLE model predictions was flagged by Lu et al. (2003) however it has only been through the use of the geochemical sediment tracing that we have been able to more confidently confirm it to be an issue of importance.

The degree to which similar over-predictions may be an issue in other areas of Australia (the current RUSLE surface covers all of Australia) is an open question. A companion TRaCK study to this Mitchell River study from the Daly River catchment in the Northern Territory (Rustomji and Caitcheon in preparation) has revealed similar patterns of steep rocky ridges having very high predicted soil erosion rates, yet with thin soil cover in places. Capping of high RUSLE values and reductions in the hillslope sediment delivery ratio were necessary in the Daly River SedNet modelling to bring the predictions into agreement with load estimates and geochemical erosion process tracer data. Some recent studies have identified issues with the cover factor in the RULSE modelling of Lu et al. (2003) and have utilised different methods to calculate this variable (Dougall et al. 2007), resulting in reductions in predicted hillslope erosion rates. This study of Dougall et al. (2007) unfortunately however lacks a comparison between the prediction of the proportion of surface versus subsoil sediment and equivalent values measured by erosion process tracer data, as is presented here for the Mitchell River. Dougall et al. (2009) do present an erosion process comparison between modelling results (with the modified RUSLE C-factor) for a tributary of the Fitzroy River (Queensland). However the comparison is fairly limited (to only one creek) and thus does not enable a clear understanding of whether the modifications to the RUSLE model improved its predictions at the catchment scale. At a national scale, Hairsine et al. (2009) have questioned the accuracy of the RUSLE predictions of Lu et al. (2003) for tropical regions. This assessment is however largely based on expert judgement rather than quantitative analysis.

7.2 Gully Erosion

As noted in the methods section it was necessary to use a colluvial gully density surface for the Mitchell River catchment that was generated at a national scale, which had relatively poor predictive performance in Queensland, and for which no Mitchell River based observations were used in its formulation. All of these factors imply that this model input is likely to be particularly inaccurate. Likewise, virtually all of the gully erosion parameters (such as cross sectional area, gully production ratio etc.) are derived from non-local observations in south-eastern Australia. However, at the catchment scale, colluvial gully erosion was predicted to contribute only ~10% of the total sediment input from both colluvial and alluvial gully
erosion. Unless colluvial gullies in the Mitchell are much denser and larger in cross-sectional area than in south-east Australia, inaccuracies in this model input suggest it will have a second order influence on the end of catchment budget. Further field investigation of colluvial gully forms and process in the Mitchell should be undertaken to verify this assertion.

Under the current model configuration, alluvial gully erosion is predicted to be the dominant fine sediment source. However, this conclusion could be influenced by several factors including: 1) that alluvial gully erosion was measured and modelled at a much finer resolution than other budget parameters, 2) that > 165,000 km of channel length in headwater streams (i.e. 1:50,000 scale) was not modelled as a sediment source, 3) other budget components were missing from the budget and 4) that residual terms such as floodplain deposition and hillslope erosion could be inaccurate due to the unquantified error in the other present or missing terms.

7.3 Riverbank Erosion

Sediment input from riverbank erosion is typically a difficult term to assess. The bank erosion coefficient was adjusted here to help bring the modelled loads into line with the station-based load estimates. This highlights that it is essentially a residual term used to minimize the difference between the modelled and empirical loads at gauging stations and tracing data. Thus this term contains not only the bank erosion data attributed to it, but also error inherent in other directly measured budget components and other unmeasured components of the sediment budget.

There is ongoing work examining bank erosion along the major rivers of the Mitchell River catchment, which may allow some future refinement of this model term. However, anecdotal field reports certainly indicate a moderate level of bank erosion along the major channels and the current bank erosion input, constituting 25% of the total input would seem to be a plausible value.

An independent analysis undertaken as part of TRaCK project 4.4, using LandSat data to determine bank erosion rates across a 1680 km section of the Mitchell River mainstem and primary tributary channels (the methods of which are summarised in Appendix 8), has estimated that a minimum mean annual rate of sediment input from bank erosion between 1987 and 2007 was $\sim 580$kt per year. The SedNet predictions for the comparable river reaches sum to 1836 kt and Figure 63 shows the relationship between these two independent estimates of sediment input from bank erosion. There is obviously no strong relationship between these two data sets. One point to note is that of the $\sim 580$kt estimated input from the Landsat data, almost half (253 kt per year) is source from a single river reach (though this is also one of the links which SedNet predicts as having a relatively high rate of bank erosion). The LandSat data does provide a basis for a revised model of bank erosion in the Mitchell River catchment which can be explored in future research.

![Figure 63](image-url)

Figure 63: Comparison of link-based estimates of sediment generation from bank erosion derived from the SedNet model and an analysis of channel morphology change gained from Landsat data.
7.4 Floodplain Deposition

Like bank erosion, assessing the model's prediction of floodplain deposition is challenging due to strong variability across a range of spatial and temporal scales. The settling velocity parameter for overbank sediment was used as a calibration parameter; hence the floodplain deposition term is another residual term, representing both floodplain deposition processes but potentially also errors in other model components. At a catchment scale, the model predicted a mean deposition rate of 0.21 kg/m² over an estimated floodplain area of 16,835 km² (equivalent to about 20% of the catchment area). Preliminary field data (Shellberg unpublished data) of contemporary sediment deposition at a number of bench and floodplain locations along the mainstem of the Mitchell River suggest up to or greater than 2 kg of sediment per square meter being deposited during average flood conditions (over one wet season). A rate of 2 kg/m² equates to a vertical aggradation rate of 1.2 mm/yr or 6 m over the last 5000 yrs. This is a moderately high rate by Australian standards and one that could be anticipated in near-channel floodplains and benches, for example. However the proportion of the 16,000 km² total floodplain area that such high-deposition zones comprise is unknown. The sampling domain of the observational data is much smaller than the model domain or actual floodplain area of the lower Mitchell (which is potentially up to 31,000 km², Brooks et al., 2009). Additional floodplain deposition data are therefore needed across larger areas of the Mitchell River megafan and active floodplains, such as in distal floodplain areas and in-channel zones of deposition not explicitly modelled here. Therefore for model purposes here, it is considered desirable for the model's deposition rates to be at the lower end of those observed above on the basis that the model's depositional area is substantially larger and average rates likely lower.

7.5 Nutrient Budgets

The nitrogen and phosphorus budgets are dependent upon a number of very poorly constrained parameters beyond those associated with the catchment sediment budget. These include the subsoil nutrient concentration that apply to gully and riverbank erosion, which are of particular importance given sub-soil dominance of the catchment's sediment budget. There were no locally derived data pertaining to dissolved nutrient concentrations. Dissolved nutrient concentrations may be five to ten times higher from intensive agriculture (McKergow et al. 2005) of which a spatially limited amount occurs in the Mitchell River catchment headwater and which has not been explicitly represented here.

7.6 Directly Measured versus Residual Budget Parameters

As initially highlighted in the introduction, both unmeasured terms and residual terms in sediment budgets can lead to erroneous results (Kondolf and Matthews 1991). This is especially true when determining the contributions of internal budget components to the total yield when only a few budget components are known or directly measured, and the remaining components are calculated by residual difference or through adjustment during model iterations. These residual terms then become lumped terms that contain not only the data attributed to them, but also unmeasured components of the sediment budget and all of the associated error from the known or directly measured components.

For example in this SedNet sediment budget, the missing budget components highlighted below are lumped into one of the other budget components, such as hillslope surface soil erosion determined using RUSLE. The hillslope modelling exercise using the RUSLE adjusted the contribution of this source to match other known or directly measured budget components, such as the total fine sediment yield estimated at gauging stations and geochemical tracer data. Thus by adjusting the modelled hillslope sediment contribution to these measured budget components, the hillslope component essentially becomes a large residual term that potentially contains the errors of other budget components and any unaccounted for budget sources. The floodplain deposition term was treated in a similar manner. Obviously further quantification of the various unaccounted for sources will better constrain the catchment sediment budget.

7.7 Sediment Sources and Sinks not Currently Represented

Several well recognised sediment sources are not currently represented in the modelling primarily due to lack of quantitative data about rates of sediment generation:

- Mining: Both hard rock and alluvial mining operations of gold, copper, tin, tungsten, etc. were historically and are currently widespread across the upper Mitchell sub-catchments (Holthouse
1967; Plimer 1997; Bartareau et al. 1998; McDonald and Dawson 2004; Pyatt and Pyatt 2004; Willmott and Trezise 2004; Butler et al. 2007). However, few quantitative data exist on the historic and current production of hillslope and gully sediment from these distributed sources, or the heavy metals these mining sediments often contain.

There are 3142 abandoned mines in the Mitchell River catchment (predominantly in the upper half), with 24 larger operating mines and at least 708 additional mining claims (Figure 64). While many mines have been abandoned, new mines are being opened and operated, such as the extensive alluvial gold mining on the Palmer and Hodgkinson Rivers (e.g. compare Figures 65 and 66). Several new large mines are also proposed or in progress in the catchment, both hard rock and alluvial. Therefore, mining sediment sources are likely one of the biggest sediment budget data gaps in the current analysis.

While speculative, some inference about the possible end of catchment load responses to the effects of mining could be made through reference to the sensitivity coefficients listed in Table 23. As both hard rock and alluvial mining operations are focussed on the bedrock dominated catchment headwaters, any additional inputs from these sources could dampened by downstream floodplain deposition. If it is assumed that the 0.24 response coefficient for bank erosion for the catchment outlet may be a suitable value to consider for alluvial mining operations for example, roughly one quarter of sediment mobilised through these operations could manifest at the catchment outlet.

- Roads: The Mitchell catchment has at least 10,525 km of unpaved roads compared to 803 km of paved roads (Figure 69). This estimate does not include the thousands of kilometres of unmapped tracks, or rill and gully offshoots of drainage water from unpaved roads. These roads and associated sediment sources are not explicitly covered in this SedNet budget. Connectivity of surface runoff from roads to the stream network is typically high meaning erosion from roads could be an important sediment source.

- Agriculture: Both dryland and irrigated agriculture covers approximately 2.6% (1865 km$^2$) of the upper Mitchell catchment (McDonald and Dawson 2004). Much of this agricultural land came into production during the 1940's especially during the post-World War Two economic boom where land was cleared of native woodlands and converted to agriculture. Due to the high intensity of land use and soil disturbance in these agricultural areas, they have the potential to produce relative high levels of sediment per unit area, similar to other agricultural catchments in Australia. From initial observations, the river and creek banks in these areas also have extensive areas of alluvial gullying not mapped nor included in this report (e.g. Figures 68 and 67). Therefore future field research should focus on quantifying the erosion and sediment yield from this portion of the Mitchell catchment.

- Sediment sources and stores in small channels: The SedNet configuration for the Mitchell River catchment currently represents 7.4% of the drainage network represented at 1:50,000 scale (Table 1), and does not represent the >50,030 km of channels in headwater catchments. The significance of these “unrepresented links” in the catchment sediment budget is unknown. In the future, the use of a higher resolution drainage layer (i.e. 1:50,000) and a much smaller catchment area cut-off between colluvial-hillslope processes and alluvial-channel processes may be warranted.

- In-channel sediment storage: While the current model does include a large floodplain sediment sink term, this zone only represents deposition during overbank flooding. Preliminary field data of sediment deposition upon in-channel bench and inset floodplain locations along the Mitchell River suggest up to or greater than 2 kg of sediment per square meter being deposited during average to below average flood conditions (Shellberg unpublished data). This style of deposition within macro-channels is not currently represented within SedNet. However, it could be an important component of the sediment budget and examination of in-channel deposition rates will likely yield an improved picture of changes in catchment sediment yield associated with European settlement.

### 7.8 Key Data and Knowledge Gaps in the Mitchell River Catchment

Key data gaps in the Mitchell catchment include:

1. Hydrological data: While historically there has been a good coverage of gauging stations within the Mitchell catchment, this situation has changed in recent years with many formerly active gauges being closed. If we are to continue to be able to predict changes in catchment water and sediment yields with varying rainfall, and to determine the implications of changing land use and climate on sediment yields, reopening many of the gauges that have been discontinued in this and other catchments (e.g. the Lynd catchment) would be beneficial.
Figure 64: Catchment map showing documented abandoned mines, existing claims, operating mines, and proposed new large mines (Queensland Department of Employment, Economic Development and Innovation 2010).

Figure 65: Mine site on the North Palmer River in 1985, before mining activity commenced.

Figure 66: Mining related activity (channel excavation, roads, dams) on the North Palmer River in 2002.
Figure 67: Agricultural area on the Walsh River in 1949, before agricultural activity commenced.

Figure 68: Agricultural area on the Walsh River in 2006, after agricultural activity commenced. Note the extent of bare surface alluvial gullies next to the drainage lines.

Figure 69: Catchment map showing documented roads, major agricultural areas, existing dams and weir, and proposed dams.
2. Sediment load data: Our ability to model catchment sediment yields is entirely dependent on the availability of high quality sediment load data from field measurements, with as wide a spatial and temporal distribution in the catchment, and as wide a range as possible of sampling of the flow range. We strongly recommend that a program of sediment load sampling be continued and expanded at all sites where it has historically been collected, and ideally at additional sites, particularly lower in the catchment. Future field measurement efforts at existing stage and discharge gauges should focus on 1) abandonment of the TSS laboratory protocol and adoption of the more robust SSC protocol, 2) collection of width- and depth-integrated, discharge-weighted, suspended sediment concentration (SSC) data 3) collection of continuous turbidity data to define the episodic transitions from sediment supply- to transport-limited conditions, 4) the development of suspended sediment load estimates from correlations between continuous turbidity and periodically measured SSC data at the event scale.

3. Soils data: Adequate soils data are required at sufficiently high spatial resolution (say 1:100 000 scale) to better predict soil depth and the extent of the land surface not mantled by soil), which would allow for improved modelling of hillslope erosion rates for example. Soil nutrient concentration data would also improve predictions of the catchment nutrient budget.

4. Sediment budget characteristics from drainage lines not explicitly represented by the current scale of modelling. This potentially represents 165,000 km of channel when mapped at 1:50,000 scale.

5. Agriculturally related sediment production data from the Dimbulah Irrigation District, the Julatten Area, and Mary Creek (Farms) from sources not accounted for via the hillslope erosion modelling.

6. Mining sediment production data from both alluvial and hard rock mining areas.

7. Road Sediment production data from the >10,000 km length of unpaved road in the Mitchell

8. Mass movement sediment production data, such as sources of sediment from creep, debris flows, debris avalanches, rock fall and avalanche, and dry ravel.

9. Colluvial gully data: the collection of locally derived data on the distribution of colluvial gullies, coupled with data on their rates of activity and the relative contributions to fine suspended and bed material load sediment fractions.

10. Bank erosion data: Local data on river bank erosion rates in both large and small alluvial channels are lacking. One particular focus could be on quantifying bank erosion input from drainage lines not explicitly represented by the current scale of modelling. There are fluvial channels at catchment areas < 20 km² and currently sub-soil input from these is conceptually lumped with gully erosion.

11. Floodplain sedimentation data: The modelling undertaken in the Mitchell catchment highlights the importance of floodplain deposition in the catchment sediment budget. As yet there are few empirical data on floodplain deposition (or indeed on bench, bar and island surfaces) within the Mitchell catchment, or most tropical rivers in northern Australia. More spatially and temporally distributed deposition data on are needed across larger areas of the Mitchell megafan, both on active floodplains and benches and especially distal floodplain areas.

12. Geochemical tracing data: Higher quantities of tracing data with a denser spatial and temporal distribution will allow improved calibration of catchment scale sediment budget models. This study utilized 13 main-stem river sediment samples tracing sediment from 29 headwater soil samples in a catchment area larger than Tasmania or Ireland (Caitcheon et al. in preparation). These data collected during this two year study also do not address temporal variability of source area contributions and transport processes. A more detailed tracing study should be undertaken at the sub-catchment scale to underpin ongoing modelling and field data collection.

13. Nutrient data: Surface and sub-surface soil nutrient concentration data are needed, especially from sub-surface gully and riverbank erosion sites, which are of particular importance given sub-soil dominance of the catchment’s sediment (and hence nutrient) budget. Dissolved nutrient concentrations data are lacking for streams draining intensive agriculture areas of the upper Walsh catchment, in addition to less intensive areas of the catchment.

14. In-channel sediment residence time data: The model results infer that there may be considerable lags (100 yrs +) in the migration of bed material through the catchment. This assertion needs to be further tested in the field, because if true, the impacts of the land use changes from a century ago, possibly associated with the original introduction of cattle or of historical mining operations, may yet to be felt in the lower reaches of the Mitchell River.

Key knowledge gaps:
1. The present hillslope erosion sub-model (RUSLE) which is being used as standard practice when running SedNet in tropical Australia, would appear to be problematic, on the evidence from this study (and that of a companion study in the Daly River). The key problem appears to be related to an assumption of an unlimited supply of erodible sediment everywhere in the landscape, a limitation noted by Lu et al. (2003) but the significance (in terms of potential over-prediction) of which has not previously been fully appreciated. Future research aimed at identifying supply limited zones in the landscape and building these supply limitations into a model structure for hillslope erosion would be worthwhile by building on existing models (e.g. Wainwright et al. 1995 and 1999, Sharmeen and Willgoose 2007, Smith et al., 2010; Wainwright et al., 2010). The geochemical tracer data have been beneficial in constraining sediment input from hillslope erosion and other sediment budget studies should strongly consider utilising such data.

2. The apparent importance of alluvial gully erosion as a source of sediment in the Mitchell is not likely to be unique to the Mitchell River catchment (although it is likely to be at the upper end of the spectrum in Australia). Alluvial gullies are a characteristic of many tropical rivers, and have been extensively mapped throughout catchments draining to the Gulf of Carpentaria (Brooks et al. 2006), as well as in some east coast tropical rivers (Brooks 2010). As this type of gully erosion has not been explicitly incorporated into previous SedNet model applications (as distinct from colluvial gully erosion) this may have consequences for the accuracy of these model predictions, both in terms of loads and relative contributions from different erosion processes. This obviously has implications for targeting management actions aimed at reducing sediment inputs from gullies to the river network.

3. The tracer data have been used extensively here for model calibration. Yet the use of fallout radionuclides in tropical Australian environments is relatively novel and there remains scope for further demonstration that the key assumptions regarding sediment labelling by fallout radionuclides for example hold true in these environments. For example if surface soils have been rapidly stripped in recent decades as a result of the intense rainfall and low ground cover that typifies the savannah at the end of the northern dry season, sediment currently being delivered via hillslope erosion processes may be labelled in a manner typically thought to represent sub-surface sediments. Also, the active bioturbation of savannah soils, by termites for example, may be contaminating the surface sediments with sub-surface soil material and again confounding the assumed surface/sub-surface labelling.
8 Conclusions

This report has presented catchment sediment and nutrient budgets for the Mitchell River in northern Queensland. The key conclusions from this report are summarised below:

1. Alluvial gully erosion within the Mitchell River megafan is predicted by our modelling to be the dominant source of sediment reaching the catchment outlet. Whilst this conclusion is consistent with the geochemical tracer data, it should be recognised that uncertainty exists over a number of other budget terms, some of which have been estimated as “residual values” or measured at different scales.

2. Sediment yields from the Mitchell River catchment are high by Australian standards, most likely on account of the high rates of sediment generation from alluvial gully erosion.

3. Hillslope erosion is predicted to contribute 6–13% of total catchment fine sediment load (varying according location), thus it is likely a minor component of the catchment sediment budget.

4. The SedNet model was able to be calibrated to provide predictions of catchment sediment and nutrient loads that were reasonably consistent with loads derived from monitoring data, the relative contributions at major tributaries and the balance between surface and sub-surface soil being transported by the river. However the relative contribution of internal budget sources is subject to some uncertainty due to unmeasured (modelled) residual budget components which have been used to balance the difference between measured or known components.

5. Bed material load (i.e. sand) pulses generated in the upper catchment will likely take 100+ years to work their way through the full length of the catchment. This means bed material pulses generated by historic landscape disturbance may impact upon the lower reaches of the river in coming decades.

6. Key contribution areas for catchment nutrient export mirror the key contribution zones of fine sediment because the majority of the nutrient load is predicted to be sediment-attached.

7. Contemporary fine sediment loads are predicted to be approximately twice those under pre-European conditions. However these predictions should be augmented by measured historical floodplain deposition rates to provide greater certainty around this issue.

8. This study has highlighted systematic over prediction of hillslope erosion rates in tropical savannah environments by the RUSLE-based national hillslope erosion model of Lu et al. (2003). The possibility of over prediction in these regions was recognised by Lu et al. (2003) at the time and a more recent review has highlighted this issue (Hairsine et al. 2009). Some recent SedNet applications in Queensland have adopted different algorithms and data for calculating the cover factor within the RUSLE (Kinsey-Henderson et al. 2007; Dougall et al. 2007), which have reduced hillslope erosion rate predictions. However these studies have not had sufficient erosion process tracer data to evaluate the effectiveness of their changes.

9. The combination of station based load estimates and the geochemical tracer data is highly beneficial in being able constrain key aspects of the catchment modelling and should be used in other catchment scale sediment and nutrient studies. A number of further measurement topics have been raised in this report and will provide greater constraint on key aspects of the catchment sediment and nutrient budget.
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Appendices

Measurement of Bank Erosion and Channel Turnover in the Mitchell River Catchment

An assessment of bank erosion and channel change was undertaken using the Landsat data archive (≈ 25 m resolution) across 1680 linear kilometres of the Mitchell River main-stem and major tributary channels. Only years having a complete coverage of the study area during the dry season were used, so it was not possible to undertake the analysis at an annual time step. Nevertheless, there was sufficient coverage to undertake a full analysis of changes between the following years: 1988, 1992, 1996, 1999, 2002, 2004, 2005, 2006, 2007, 2008.

Each image was classified into 6 classes: sand, deep water, shallow water, sparse vegetation, medium vegetation and dense vegetation, as shown in Figure 70. These classes were used because they relate directly to distinct geomorphic units within the channel, for which we can assign an average elevation above or below mean low flow water level. A change detection analysis between consecutive images was then undertaken to measure changes from one class to another, and these changes were interpreted as either representing channel scour or deposition. A subset of the change classes was interpreted as representing bank erosion because they could be clearly interpreted as representing a change from the inset floodplain adjacent to the main active channel zone (i.e. medium or dense vegetation), to channel (bare sand or water). With additional information about the average elevation of the various units it is then possible to convert these areal changes into volumetric changes through time (Figure 71). Average bank height was determined by overlaying the landsat change polygons on a number of segments of LiDAR data. The average elevation of each class was determined for slices across the channel, over which the change in elevation due to channel slope was negligible (i.e. beyond the resolution of the data, Figure 72). Due to variations in the average bank heights and elevations of the various geomorphic units in different parts of the channel network, two elevation matrices were used across the study area based on the LiDAR blocks shown in Figure 73.

The bank erosion change classes were then edited, firstly by removing all resultant change polygons less than or equal to two pixels. These were generally considered to be unreliable, often representing shadow at the edge of the channel or the result of slight variations in image alignment. A second manual editing process was then undertaken to remove any polygons in the centre of the channel that might have represented the erosion of mid-channel islands rather than bank erosion, or features distal to the channel that represented some other change between images. Bank erosion contributions were then summed and annualised for the same river segments used in the SedNet analysis, across the period 1988–2008.
Figure 70: Classified Landsat image of a section of the lower Mitchell River during the dry season showing the three vegetation classes, sand and water. The water category was further subdivided into deep and shallow water based on its optical properties.

Figure 71: Matrix showing average depths of scour (blue) and fill (orange) used to convert areal change to volumetric changes in sediment storage or supply from a given river segment with the change from one class to another. The darker blue classes represent those change classes indicative of bank erosion. Matrix A is representative of the elevations of the geomorphic units in the lower part of the Mitchell River network, while Matrix B, is indicative of the upper catchment.
Figure 72: An example of the segments of LiDAR data used to determine the average bank height (Figure 71). The red blocks represent the areas in which channel slope is negligible, and therefore does not bias the elevation analysis. The green outlines are the polygon from the Landsat classification.

Figure 73: Locations of Lidar blocks within the Mitchell catchment from which the bank height data, and hence bank erosion rates, were derived.
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