Sources of sediment and nutrients to the Gippsland Lakes: Preliminary modelling results

Report to the Victorian Department of Sustainability and Environment

Scott Wilkinson, Gary Hancock, Arthur Read and Briohny Davey

CSIRO Land and Water Client Report

April 2005

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Acknowledgements

We acknowledge the financial support of the Victorian Department of Sustainability and Environment in funding this work. This report is funded under the Gippsland Future Directions and Actions Plan for the “Our water, our future” initiative of the State Government of Victoria. We also acknowledge the assistance of Gary Caitcheon, CSIRO Land and Water, for reviewing a draft of this report, and Heinz Buettikofer, CSIRO Land and Water, for assistance publishing the report.

Executive Summary

This report presents the results of preliminary modelling of sediment erosion and transport undertaken in the catchments of the Gippsland Lakes by CSIRO Land and Water. The report and the modelling described herein make up Phase 1 of a three year study jointly funded under the Gippsland Future Directions and Actions Plan and CSIRO Land and Water.

The study's aim is to determine the source of sediment and nutrients delivered to the Gippsland Lakes. This will enable catchment management agencies to effectively target and prioritise remedial actions in the Lakes' catchments aimed at reducing sediment and nutrients loads being delivered to the Lakes. The need for a reduction of sediment load was a key outcome of the CSIRO environmental study into the factors affecting algal blooms in the Lakes (Webster et al., 2001).

We use the SedNet model, which is a physically based model that accounts for the major sources and sinks of sediment and nutrients across large catchments (Prosser et al., 2001). The model identifies the dominant erosion processes and source areas, providing the opportunity to target specific management actions to hotspots within the catchment. Recent model improvements, and regional scale data sets have been incorporated into this study.

The main outcomes of this report are:

1. Channel bank erosion is the dominant source of suspended sediment in the Gippsland Lakes catchments. Hillslope and gully erosion are relatively smaller sources.
2. A significant proportion of suspended sediment supplied to the Latrobe and Thomson Rivers is deposited within the catchment on floodplains and in reservoirs. In the Mitchell and Tambo Rivers, a smaller proportion of sediment is deposited.
3. Bank erosion and dissolved catchment runoff are important sources of Phosphorus and Nitrogen

The report demonstrates the types of outputs the project will produce. The report contains maps showing preliminary predictions of spatial patterns in erosion and sediment movement, and also provides preliminary estimates of the relative sediment and nutrients loads from each of the tributary catchments. Because of the work remaining in the study, the results are preliminary estimates, and the detailed loads and spatial patterns reported are likely to change.

As well as drawing together the important project findings to date, a key purpose of this report is to provide a platform for Phase 2 of the project. Phase 2 utilises sediment tracers to assess sediment sources and test the model's predictions.

The report highlights opportunities to further improve the data used in the model, in collaboration with the Catchment Management Authorities. Further refinements to the modelling are planned for Phase 3 of the project, including the incorporation of outcomes from Phase 2, and developing improved datasets.

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1 Introduction

In January 2004 a three year study commenced to determine the sources of sediment delivered to the Gippsland Lakes. This study is being funded under the Gippsland lakes Future Directions and Action Plan through the Department of Sustainability and Environment, and by CSIRO Land and Water. The project includes three activities;

1) modelling of sediment erosion within the catchment and its delivery to the Lakes through the river network;
2) tracer-based assessment of catchment sources of sediment delivered to the Lakes;
3) sedimentation rates in the lakes.

This report describes the preliminary modelling work. Refinements to the modelling will be undertaken following completion of the tracing and sedimentation studies, in the final year of the project.

1.1 Background to the study

In November 2001 the CSIRO study of the biochemical function of the Gippsland Lakes (Webster et al., 2001) was completed. The report addressed the factors controlling water quality and algal blooms in the Lakes, and identified the delivery of sediment and associated nutrients to the Gippsland Lakes as the major factor affecting the health of the Lakes. The report estimated that a minimum 40% reduction in the load of sediment entering the Lakes was required to substantially reduce the intensity of algal blooms.

Current information on sediment loads generated in the catchment consist of a combination of modelling and environmental monitoring. Monitoring data has been used to estimate sediment and nutrient loads (Grayson et al., 2001). More recently Grayson and Argent (2002) estimated sediment and nutrient loads to the Lakes by modelling the generation of sediment and nutrient loads in the Lakes' tributaries using a range of catchment topographic, land-use and climatic properties. They used the EPA data to calibrate and test the model.

The work described in this report is an extension of modelling undertaken in the National Land and Water Audit (Prosser et al., 2001). The approach taken is described in the following section, and involves applying the SedNet model (Prosser at al., 2001) to quantify sources and sinks of sediment and nutrients in the Lakes' catchments, and estimate sediment and nutrient loads being delivered to the Lakes.

1.2 Summary of our approach

The approach taken in this project is to use a combined modelling and sediment tracing approach to determine the sources and sinks of sediment and nutrients in the Gippsland Lakes' catchments. The sediment tracing provides data at specific locations, on the relative sizes of contemporary surface (hillslope) and sub-surface (gully and riverbank) sediment sources, and also on the relative contemporary contribution of different tributaries. However, sediment tracing can only provide information for those locations sampled.

Modelling provides the opportunity to incorporate the tracing results, as well as a suite of environmental datasets on stream flow, landuse, topography and vegetation cover, to determine sediment sources and sinks for the whole of the Lakes' catchments. This can assist in targeting specific management actions that will be most effective in reducing sediment and nutrients delivery to the Lakes.

The SedNet model differs from the model applied previously (Grayson and Argent, 2002) in several ways:

- The catchment is divided into hydrologically defined sub-catchments, each draining to a river link. The sediment is routed through the river network to the catchment outlets.
- Hillslope, gully and riverbank erosion processes are explicitly represented, using empirical models parameterised using GIS spatial datasets. The specificity of the SedNet model in separating erosion processes into surface and sub-surface soil also means that the model's predictions can be tested using sediment tracing.
- Deposition of sediment and nutrients in reservoirs and on floodplains, between upstream sources and the Lakes are accounted for in SedNet. The model uses this information to help determine where in the catchments most of the sediment and nutrients delivered the Lakes originates from.
- The sediment and nutrient budgets are long-term averages for conditions over the past 30 years. The model focus is on spatial patterns in sources and transport, rather than temporal variability.
- A budget for bedload sediment is also constructed, although this is not reported here.
- While the main focus of the Grayson and Argent (2002) modelling was to investigate the relative importance of main land use types (forest, dryland and irrigation) to contaminant loading of the Gippsland Lakes, the SedNet modelling is focussed on providing a greater level of detail to assist in targeting specific management actions to high priority areas.

The SedNet model is tested against observed sediment loads, as for previous models. Because of the different technical basis of the SedNet model, some differences between this work and previous modelling in the spatial patterns of predicted sources are expected.

The SedNet approach has been extensively tested in NLWRA, and in numerous regional studies (e.g: DeRose et al., 2003; Wilkinson et al., 2004; Brodie et al., 2004). Studies have indicated that targeting erosion control using the model can result in much greater reductions in sediment loads (Lu et al., 2004).

2 Characteristics of the Gippsland Lakes catchments

The features of catchments are briefly summarised below. Much of the summary is taken from Aldrick et al. (1988).

2.1 Catchment topography

The Gippsland Lakes catchment is mainly made up of six river major catchments which can be broadly separated into the western and eastern catchments, with the rivers in the western catchment flowing into Lake Wellington, and those of the east flowing into Lake King. For this work we have considered the Macalister River as part of the Thomson River system. The six major catchments and their areas are shown in Figure 1. Several other smaller catchments totalling less than 900 km^2 (white area) surround the margins of the Lakes.

The topography of the catchment is shown in Figure 2. The catchment topography shows a clear distinction between steep headwater areas and lowland floodplains, with the catchment being broadly divided into two regions; the “uplands” (the hills and mountains mainly in the north of the catchment) and the “lowlands” (the relatively flat terrain in the south). The Latrobe, Thomson and Avon rivers have much larger floodplain areas than the other rivers (Figure 2).

2.2 Land Use

Land use is shown in Figure 3 (after Sposito et al., 2000). About one third of the catchment is cleared, mostly for grazing of cattle and sheep. Higher stocking rates of cattle occur in the higher rainfall areas to the west and in the Macalister Irrigation District where dairying and beef production occur. Most of the pastures are improved by the application of fertiliser.

Cropping is mainly for vegetable production and stock feed. Potatoes are grown around Thorpdale in the west and other vegetables are grown on the alluvial flats near Bairnsdale in the east. Much of the cropped area is irrigated.

Forest covers about two thirds of the Lakes’ catchments and occupies much of the upland areas. Approximately half of the forests are logged. Softwood plantations (*Pinus radiata*) occur mainly in the western catchments.

2.3 Climate and hydrology

Mean annual rainfall varies considerably, the uplands receiving three times more than precipitation that the lowlands. Rain shadows occur in some areas of the Macalister, Tambo and Wonnangatta Rivers, and the lowlands between Traralgon and Bairnsdale. Seasonal variation on rainfall is greatest in the uplands with a winter precipitation regime dominating. The seasonal effect is reduced in the lowlands. Although 72% of stream flow occurs in winter and spring, in general heavy rainfall which can lead to flooding is more likely in summer.

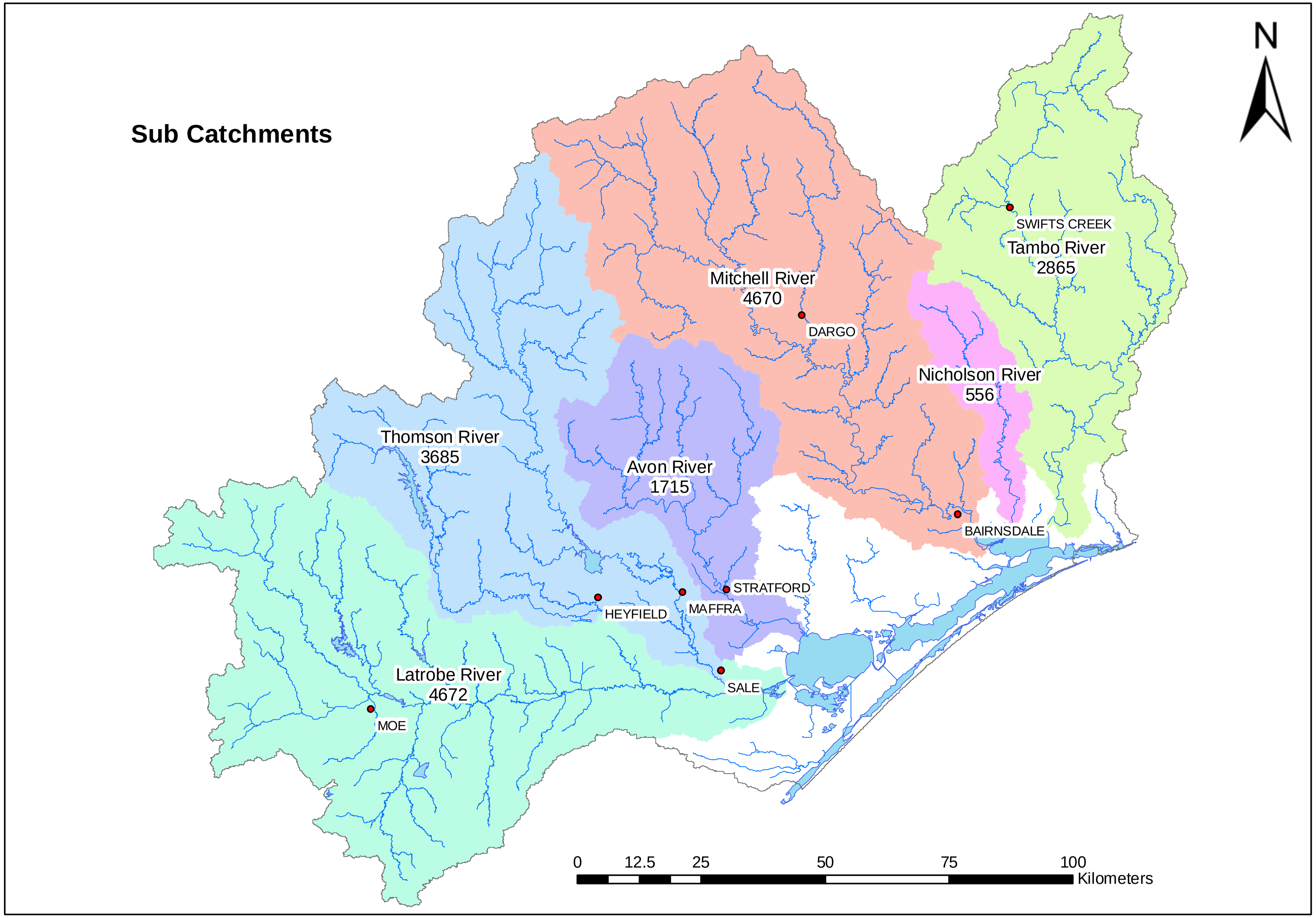

Figure 1: The major river catchments and catchment areas (km^2) draining to the Gippsland Lakes

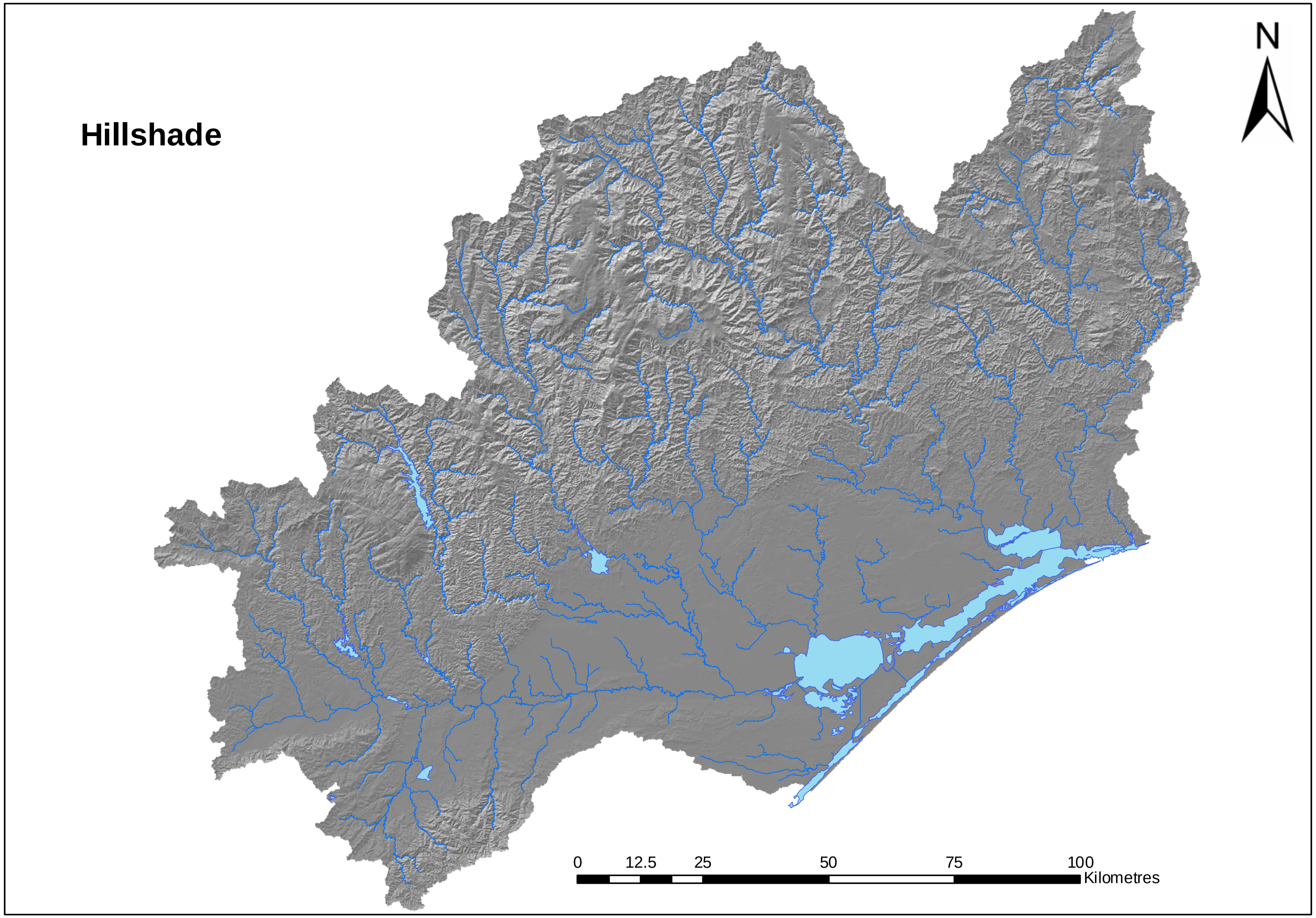

Figure 2: Hill-shaded Digital Elevation Model of the Gippsland Lakes catchments

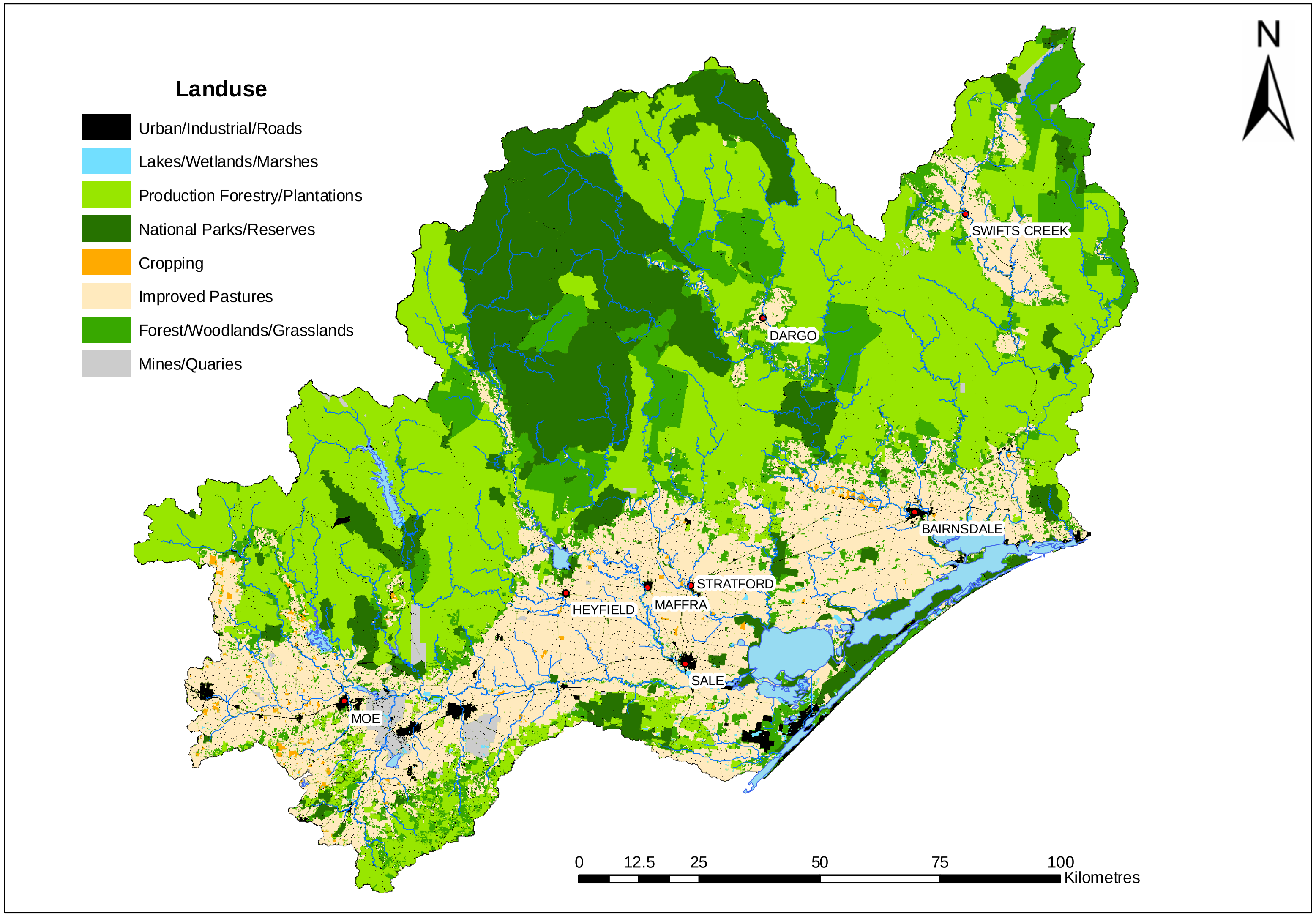

Figure 3: Land use in the Gippsland Lakes catchments

3 Modelling methods

3.1 Introduction

Sediment and nutrient budgets for the catchments were modelled using the SedNet model (Prosser et al., 2001). Both the model and the input data sets used here have been further developed from those used in the National Land, Water and Rivers Audit (NLWRA) (Prosser, et al., 2001). Details about the model as applied to the Gippsland Lakes catchments are provided below.

3.2 Sediment Modelling Method

The SedNet model developed for the National Land and Water Resources Audit (Prosser, et al., 2001) is a physically-based process model. It constructs sediment and nutrients budgets of a river network and identifies the major sources, stores and loads of material. In the model the river network is divided into a series of links, which are the basic unit of calculation for the sediment and nutrients budgets. A link is the stretch of river between adjacent stream junctions. Each link has an internal sub-catchment, which is the catchment area added to the link between its upper and lower nodes (Figure 4). Sediment inputs to each link are determined from the hillslope erosion, gully erosion and riverbank erosion, and from upstream tributaries (Figure 5).

Hillslope, gully, and riverbank erosion supply sediment to each link of the river network. Sediment is then either deposited within the link or is transported downstream. This process is carried out in each river link working from the top of the catchment to the bottom, so that by the final link the mean annual export is calculated. An advantage of this spatial budget approach to estimating sediment exports is that the exported sediment can be tracked back upstream in the model to identify its origins.

Bedload and suspended sediment loads are dealt with separately in the model. Gully and riverbank erosion supply 50 % of their sediment to the bedload budget and 50 % to the suspended load budget. Hillslope erosion only supplies sediment to the suspended load budget. Only suspended sediment results are included in this report.

The suspended sediment loads of Australian rivers, and rivers in general, are supply limited (Olive and Walker, 1982; Williams, 1989). That is, rivers have a very high capacity to transport suspended sediment, and sediment yields are limited by the amount of sediment delivered to the streams. Consequently, if sediment delivery increases, sediment yield increases proportionally.

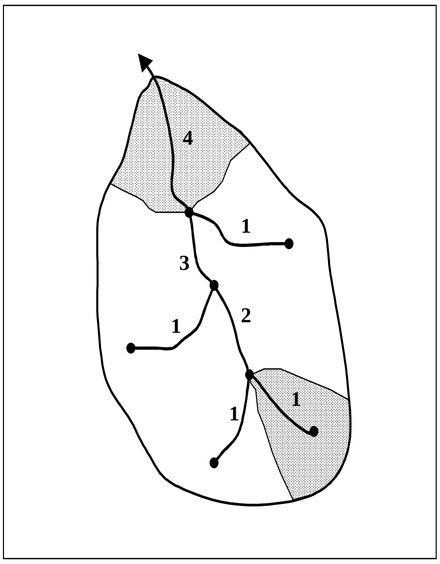

Figure 4: Link node network as used in SedNet, showing link Shreve order, and sub-catchments for first and fourth order links.

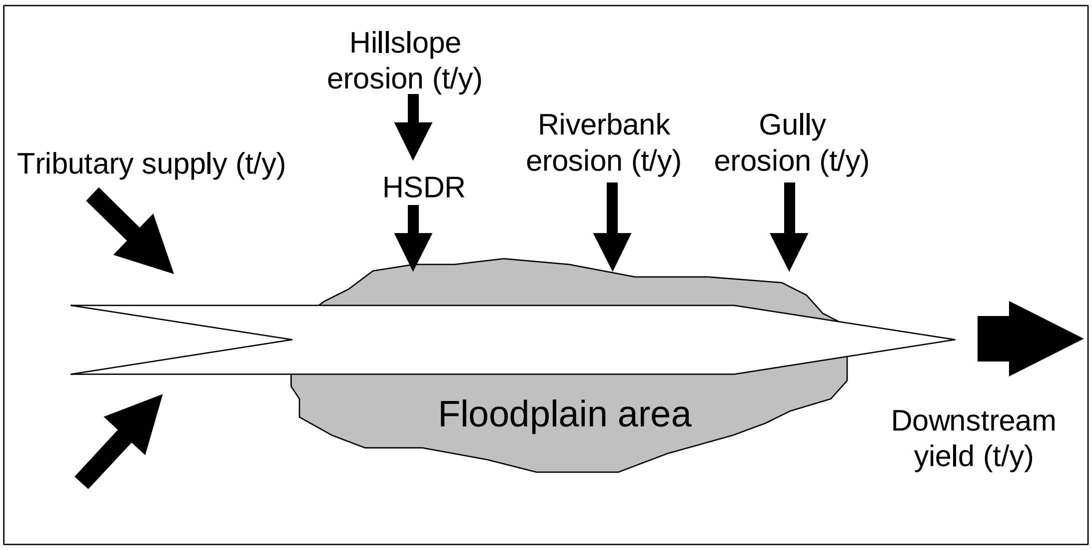

Figure 5: Conceptual diagram of the SedNet river sediment budget for one river link. HSDR is hillslope sediment delivery ratio.

3.2.1 Defining the river network and associated catchments

The river network and associated internal catchment areas were defined from the 20m DEM. Each link in the river network was defined as beginning at a catchment area of 20 km^2. This link area was selected to limit the number of links across the assessment area, while providing a good representation of the channel network. First order links shorter then 1km long are removed to simplify the stream network.

3.2.2 Hillslope Erosion

The input from hillslope erosion is estimated using the Revised Soil Loss Equation (RUSLE; Renard et al., 1997) as applied in the National Land and Water Resources Audit (NLWRA; Lu et al., 2001,2003a). Very little soil eroded from the hillslope is delivered to the stream; most of the sediment is trapped on the hillslope. The extent of this trapping is represented by the hillslope sediment delivery ratio (HSDR). Yields from catchments dominated by hillslope erosion indicate that 5% is an appropriate value for hillslope delivery in southern Australia (Prosser et al., 2001).

3.2.3 Gully Erosion

Gully erosion is defined as incision and erosion of drainage lines since European settlement. In particular, gully erosion represents erosion of drainage lines that are not represented on the modelled stream network due to their small catchment areas.

Sediment supply from gullies is calculated as the product of gully length, average cross-sectional area (10 m^2) and average dry bulk soil density (1.5 t/m^3), divided by the time over which gullies have developed (100 years). This provides a 100 yr average for the supply of sediment from gullies.

Detailed mapping of gully networks in the Gippsland catchments was not available. At present the gully density model from the NLWRA (Hughes et al. 2001) is used to determine sediment load sourced from gullies in the catchment. The NLWRA gully density mapping in the Gippsland catchments probably underestimates the extent of gully erosion in some areas. Rutherfurd (1994) reports on sediment volumes supplied from gully erosion in a region of the Latrobe catchment (Table 1 and Figure 6). This information has been added to the NLWRA gully data.

Table 1: Sediment volumes delivered to the Latrobe River (after Rutherfurd, 1994)

Creek Name	Average Volume exported to Latrobe River (m^3/y)
Rintoul Creek	3463
Eaglehawk Creek*	9112
Fells Creek	2576
Flynns Creek	1220

*Eaglehawk Creek includes Stoney and Yorkies Creeks

There is some evidence to suggest that in general, gully activity in south-eastern Australia has declined since the initial rapid growth of gullies (Wasson *et al.,* 1998; Rutherfurd, 1994). To reflect this and provide a contemporary estimate of gully sediment yield, the long term average suspended sediment generation calculated from the NLWRA gully data has been reduced by 50%.

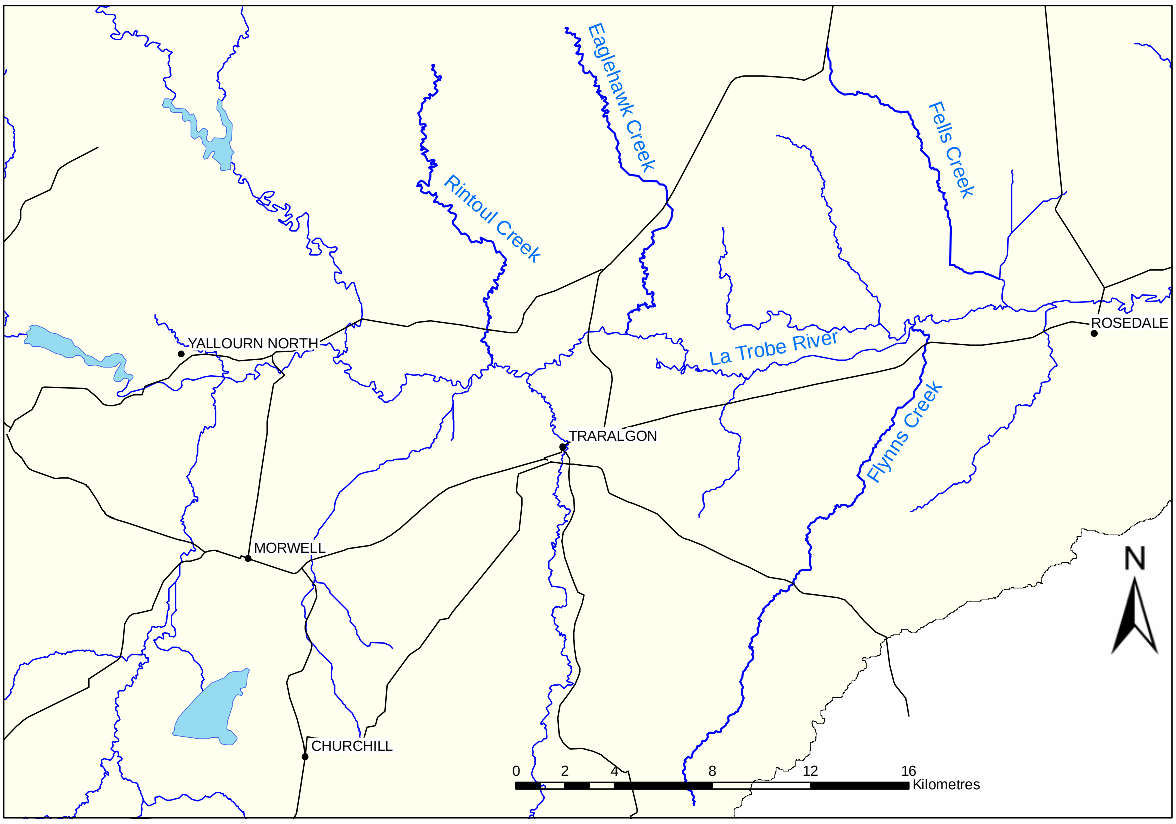

Figure 6 Gullied streams (named) in the Latrobe catchment, from Rutherfurd (1994)

3.2.4 River Bank Erosion

Although it is known that degradation of riparian vegetation, drainage schemes and other impacts on rivers have resulted in greatly increased rates of riverbank erosion, there remains little data on the rates of river bank erosion and the environmental factors controlling those rates. The NLWRA used an empirical rule for meander migration and bank erosion proposed by Rutherfurd (2000) following a review of global literature. This rule has since been modified to better reflect the observed pattern of historical river widening in Australian rivers. The new rule predicts the mean annual bank erosion rate (BE_x, m/y) along a river link x as a function of stream power, and the proportion of erodable banks along the link:

$$BE_x = 0.0002 \rho g Q_{bf} S_x E_x$$

where ρ is the density of water, g is the acceleration due to gravity, Q_{bf} is bankfull discharge, S_x is the river bed slope, E_x is the proportion of the river link with erodable soil. The coefficient 0.0002 is calibrated to produce bank erosion rates so that they are consistent with rates measured from historical plan surveys (DeRose et al., 2005). Bankfull discharge was assumed to be equivalent to a 1.58 year recurrence interval discharge on the annual maximum series (Wilkinson et al., 2004). River bed slope was measured directly from the 20m DEM.

Erodable river banks are identified using the MRVBF terrain analysis technique to identify deposition (erodable) soils in the riparian zone (Gallant and Dowling, 2003). The absence of depositional soils in the riparian zone is assumed to indicate a steep gorge reach, and in those areas zero bank erosion is predicted. Where the riparian zone contains depositional soils, the presence of woody vegetation reduces bank erosion to 5% of the potential rate that would occur in the absence of vegetation. Riparian vegetation data was extracted from the Bureau of Rural Sciences Land Cover 95 dataset (25m cell size; Barson et al., 2000). The riparian zone was defined as a 40m strip either side of the channel margin.

For sediment budgets, the erosion rate is expressed in units of tonnes per year of sediment eroded along the length of each river link. This is determined as the bank erosion rate multiplied by the length of the river link, the height of the bank (based on a catchment area regionalisation using data from Drummond (1985) and the dry density of sediment (1.5 t/m^3).

3.2.5 Hydrology

Runoff from each sub-catchment is predicted using regionalisation relationships that are fitted to observed runoff from 57 non-regulated gauged catchments throughout the Gippsland Lakes catchments, together with grids of mean annual rainfall and potential evapotranspiration. The runoff volume is then accumulated through the river network. For links downstream of reservoirs, the regionalisations are modified to reflect contemporary changes in flow volume and variability. Four flow measures are regionalised (for different terms in the sediment budgets); mean annual flow (reservoir deposition), daily flow variability (bedload transport), bankfull flow (bank erosion), and median overbank flow (floodplain deposition) (Wilkinson et al., 2004; Wilkinson *et al,.* submitted).

3.2.6 Floodplain deposition

Deposition of suspended sediment becomes significant when flows spread onto floodplains, or enter reservoirs, because flow velocity is greatly reduced in these environments. The amount of deposition on a floodplain depends upon the residence time of water on the floodplain and the sediment concentration of flood flows. Some rivers have narrow floodplains with deep, fast overbank flows providing short residence times of water and little opportunity for deposition. Others have broad open floodplains on which water can sit for several weeks, providing greater opportunity for deposition. The equation used to calculate floodplain deposition is given in Prosser et al. (2001).

A new method for defining floodplain area has been developed for the present application. In the NLWRA floodplains were defined by hydraulic modelling of the 250 m DEM, and significantly over predicted floodplain extent, particularly in upland streams. The method developed for the present application uses a terrain analysis technique called Multi Resolution Valley Bottom Flatness (MRVBF) (Gallant and Dowling, 2003). By identifying the flattest valley bottoms at a range of scales it is possible to define areas of floodplain deposition.

3.2.7 Deposition in reservoirs

Sediment deposition in reservoirs is a function of an empirical rule based upon the mean annual inflow into the reservoir and its total storage capacity (Heinemann, 1981). Details about reservoir capacities and construction dates are given in Table 2. The sediment and nutrients budgets are valid for the period since reservoir construction.

Table 2: Reservoir construction dates and capacity

Reservoir	Construction date	Capacity (gigalitres)
Thomson	1983	1122
Yallourn	1961	8.02
Blue Rock	1984	200
Moondarra	1961	30.4
Lake Glenmaggie	1927	190

3.2.8 Contribution of Suspended Sediment the Gippsland Lakes

Because of losses to floodplain and reservoir deposition, not all sediment and nutrients are exported to the Lakes. If the objective is to reduce sediment export to the Lakes, we want to not just target areas with high erosion rates, but areas which supply sediment to the river network that is actually exported to the lakes. Therefore, we calculate the proportion of the suspended sediment supplied to each link and sub-catchment that reaches the catchment outlet. This represents a sediment delivery ratio for the river network (*RSDR*), calculated for link *n* as the ratio of sediment yield to sediment supply for each link between the outlet and link *n* (Equation 1).

For each link, the contribution to suspended sediment export ($Cont_x$; t ha^{-1} y^{-1}), is the product of suspended sediment supply and *RSDR* for that link, given by Equation 5.

Each river link catchment area delivers a mean annual load of suspended sediment ($S_x = H_x + G_x + B_x$, the sum of hillslope, gully and river bank erosion delivered from that sub-catchment. The sub-catchment delivery and tributary loads constitute the total load of suspended sediment (T_x) received by each river link. Each link yields some fraction of that load (Y_x). The rest is deposited on floodplains or in reservoirs. The ratio of yield to supply is the proportion of suspended sediment that passes through each link, and will always be less than or equal to one. It can also be considered as the probability of any individual grain of suspended sediment passing through the link. The suspended load delivered from each sub-catchment will pass through a number of links en route to the Lakes. The proportion delivered to the Lakes is the probability of sediment passing through all river links on the way, and this is termed a River Sediment Delivery Ratio (*RSDR*). For link *x*, the RSDR is described in Equation 1, where *n* is the number of links on the route to the outlet.

The contribution (t /y) of a link/sub-catchment pair to suspended sediment export is then the supply from local erosion sources, S_x multiplied by the RSDR for that link (Equation 2). Dividing this by the sub-catchment area A_x, expresses the contribution to export ($Cont_x$) as an intensity (t/ha/y).

$$RSDR_x = \frac{Y_x}{T_x} \times \frac{Y_{x+1}}{T_{x+1}} \times \ldots \times \frac{Y_n}{T_n}$$ **Equation 1**

$$Cont_x = RSDR_x \times \frac{S_x}{A_x}$$ **Equation 2**

A consequence of Equation 1 is that, all other factors being equal, the further a sub-catchment is from the Lakes the lower the probability of sediment reaching the Lakes. This behaviour is modified, however, by differences between links in erosion and deposition rates.

3.3 Nutrient Modelling Method

The nutrient budget model (Annual Network Nutrient Export – ANNEX; Young et al., 2001), works in conjunction with SedNet to predict the average annual loads of P (phosphorus) and N (nitrogen) in each link of the river network. For each link, ANNEX determines values for the sediment-bound and dissolved nutrient inputs from the immediate catchment of the river link. The model then routes nutrient loads through the river network estimating the losses associated with floodplain and reservoir deposition, and in-stream processes.

The main nutrient sources are hillslope erosion, gully erosion, river bank erosion, dissolved loads in runoff water, and point sources such as sewage treatment plants. Suspended nutrient load from hillslope erosion is calculated as the product of the hillslope sediment yield multiplied by the nutrient concentration of this load. This latter concentration is determined from the soil clay proportions and nutrient concentration for P and N extracted from the Australian Soil Resource Information System (ASRIS). Suspended nutrient loads from riverbank and gully erosion are calculated as the product of their sediment load times the soil nutrient concentration (which is assumed to be 0.25 g of P per kg of sediment, and 1g of N per kg of sediment).

Estimation of dissolved loads due to surface and sub-surface runoff are determined as the sum of the load from each of the major contributing land uses within a catchment link. The load for each land use is calculated as the product of the typical nutrient concentration in runoff multiplied by the mean annual volume of runoff. The concentration of soluble N and P are normally assessed from gauging station records and small scale catchment nutrient studies for regions with a single dominant land use. In this study we are using concentration from landuse values from previous ANNEX modelling in the Latrobe and Goulburn-Broken catchments (

Table 3). These values have been mapped to the entire Gippsland catchment using landuse data as described by Sposito et al. (2000). Because these concentration values are applied to the total runoff volume, they are generally lower than the event mean concentrations applied in Grayson et al. (2002).

Point sources of nutrients are obtained from the national pollution inventory (NPI) for the 2004 reporting year. The NPI provides nutrient loads discharged from industrial and other urban point sources. The total P and Total N point sources are supplied to the budget of the nearest stream link. The loads applied are listed in Table 4.

To help target management actions that will reduce nutrients export to the Lakes, the contribution of each sub-catchment to nutrients export (kg/ha/y) is determined using a similar approach to that used for suspended sediment, by accounting for nutrient loss to floodplain and reservoir deposition.

Table 3: Concentrations of dissolved nutrients in surface runoff

Land use	Dissolved N concentration (µg/l)	dissolved P concentration (µg/l)
National parks, forestry	287	4
Livestock grazing, grasslands	510	8
Mines, quarries	800	8
Cropping	500	22
Grazing improved pastures	700	210
Irrigated cropping	1350	320
Irrigated improved pastures	1125	500
Urban and industrial areas	3450	605

Table 4: Point sources of nutrients to the river network

Facility	Total N (kg)	Total (kg)
Warragul Wastewater Treatment Plant	519	0
Moe Wastewater Treatment Plant	17200	0
Morwell Wastewater Treatment Plant	384	0
International Power	35	0
Yallourn Power Station	27000	0
Maryvale Mill	40300	3320
Bairnsdale Wastewater Treatment Plant	1670	0

4 Preliminary modelling results

This section reports the preliminary modelling results. It is important to note that the quantitative estimates of erosion rates and sediment transport will be subject to change as the modelling is refined and the spatial data is improved during the remainder of the project. Because of the uncertainties associated with current model predictions, the maps of model results use relative rather than absolute scales. The remaining work will refine the detail of these patterns to assist targeting of management actions. A key purpose in presenting these results is to demonstrate the types of outputs the project will produce.

4.1 River network characteristics

The stream network defined from the Digital Elevation Model has a total length of 4,570 km, with an average link length of 7.5 km (614 links). The average sub-catchment area is 33 km^2.

4.2 Catchment hydrology

The modelled runoff volumes from the outlet of each river catchment are reported in Table 5. The Latrobe, Thompson and Mitchell are the dominant sources of discharge to the lakes, with the Tambo providing less discharge than these catchments, relative to its catchment area (Figure 1). Across the 57 gauges used to fit the hydrology model, the median difference between the modelled and gauged runoff volumes is 15%. This is acceptable, considering the uncertainty in gauging procedures. The predicted runoff depth grid (Figure 7) shows that runoff depth is much greater in the higher parts of each catchment.

Table 5: Runoff volumes for each catchment

Catchment	Lake	Runoff (GL/y)	% of total
La Trobe	Lake Wellington	997	26
Thomson	Lake Wellington	1104	29
Avon	Lake Wellington	176	5
Mitchell	Jones Bay	1030	27
Nicholson	Jones Bay	57	2
Tambo	Lake King	323	8
Other small catchments		77	2

4.3 Hillslope Erosion

The pattern of hillslope erosion, as estimated from the Revised Universal Soil Loss Equation, is shown in Figure 8. Hillslope soil erosion is generally low (< 1 t/ha/y) throughout much of the Gippsland Lakes catchments, largely due to the high levels of vegetation cover, particularly on the steeper slopes that are more susceptible to erosion. Some higher levels of soil erosion (> 5 t/ha/y) are predicted in the grazing areas but these are considered quite low on a national scale. Factoring in the hillslope delivery ratio, a total of 27 kt/y of hillslope soil is delivered to the rivers draining to the Gippsland Lakes, which equates to an average supply rate of 0.1 t/ha/y.

4.4 Gully Erosion

The spatial pattern of gully density, as obtained by the NLWRA project, (Figure 9) shows that gullies only occur in a small part of the Gippsland catchment and at relatively low densities (up to 0.35 km/km^2). The NLWRA gully density map is augmented in the Latrobe River catchment to represent the gullies described by Rutherfurd (1994) (Figure 6).

4.5 Riverbank Erosion

The relative levels of bank erosion in the Gippsland catchment are shown in Figure 10. It can be seen that the Latrobe, Thomson and Mitchell rivers are all modelled as having a high rate of bank erosion along extensive sections of their river channels.

The predicted rates of bank erosion are supported by the rates calculated from historical channel surveys (DeRose et al., 2005): The SedNet-predicted rate of channel expansion in lowland reaches of the Latrobe is 0.08 m/y; lower than the rate measured from historical channel surveys (0.16-0.32 m/y). For the floodplain reaches of the Mitchell River the predicted rate is 0.22 m/y, within the measured range (0.17-0.33 m/y), and for the Avon River the predicted rate is 0.1 m/y, less than the measured rate (0.2-0.35 m/y). Since the principal purpose of the bank erosion equation is to determine spatial patterns in bank erosion across the entire catchments, we have not calibrated the equation to match the observed rates in the middle to lower Latrobe and the lower Avon. Unlike other parts of the river network, these reaches have experienced artificial meander cut-offs and drainage schemes, accompanied by catastrophic rates of erosion (Rutherfurd, 2000).

4.6 Suspended Sediment Budget

By adding together the link sediment budgets we can report a total sediment budget for the Gippsland Lakes catchments (Table 6). This modelled sediment budget indicates that over 80% of suspended sediment is derived from river bank erosion, with gully and hillslope erosion being relatively minor sources. Of the total suspended sediment delivered to streams, a significant fraction (40%) is deposited on floodplains or in reservoirs. This is highest in the West (54%) where the floodplains of the Latrobe and Avon Rivers catch a large proportion of sediment delivered to these rivers.

Table 6: Preliminary total catchment budget for suspended sediment, showing the contributions of western and eastern catchments

Suspended sediment budget	total (kt/y)	west (kt/y)	East (kt/y)
Hillslope erosion input to streams	27	14	13
Gully erosion input to streams	16	10	5
Bank erosion input to streams	295	192	103
Total erosion input	338	216	121
Floodplain and reservoir deposition	140	116	24
Suspended load export to lakes	198	100	98

The variation of suspended sediment load throughout the network is shown in Figure 11. The proportion of suspended sediment delivered to the Gippsland Lakes coming from each of the main catchments is described in Table 7. The predicted suspended sediment export from the Mitchell catchment is slightly higher than that from the Latrobe catchment, and this may differ from expectations based on observations. One explanation is the larger deposition on floodplains and in reservoirs in the Latrobe catchment (indicated in Table 6).

Table 7: Preliminary estimates of suspended sediment exported to the Gippsland Lakes from each of the major catchments

CATCHMENT	Suspended sediment exported to lakes (kt/y)	% of total
Latrobe River	51	26
Thomson River	47	24
Avon River	8	4
Mitchell River	67	34
Nicholson River	2	1
Tambo River	22	11

The spatial pattern in suspended sediment contribution is indicated in Figure 12. This map illustrates the amount of sediment that is transported from each sub-catchment and delivered to the Gippsland Lakes. Comparing this pattern with that of bank erosion (Figure 10), the contribution of high bank erosion rates to sediment export can be seen. Once this map is refined, it will assist in determining the priorities for reducing suspended sediment export to the Gippsland Lakes.

4.7 Nutrient modelling

Each of the sediment sources together with point sources and the diffuse dissolved contributions from runoff deliver nutrients to the streams in the Gippsland Lakes catchments (Table 8, Table 9). Diffuse dissolved inputs dominate the P and N budgets for the West Gippsland catchments. The same is also true for the N budget for East Gippsland, but the dissolved P budget for the eastern catchments is slightly lower than particulate sources, perhaps due to the lower density of intense land uses such as dairying.

The spatial patterns of total P and N sources are shown in Figure 13 and Figure 14 respectively. Note that the patterns indicated are relative, within-catchment comparisons, and “high” values are not necessarily high by Australian standards. The pattern of N inputs is largely reflecting the dissolved nutrient inputs, which tend to be higher in areas with higher runoff volumes (Figure 7). In the western catchments the high levels of N are a combination of moderate dissolved loads and particulate input from bank erosion. In contrast, the pattern of P inputs indicates much higher loads in the western catchments. The high levels of P are in general associated with diffuse dissolved sources from the grazing, cropping and urban areas, which tend to have high concentrations of dissolved P, as well as areas with high bank erosion rates (Figure 10).

Table 8: Sources of P

P sources	Total (t/y)	West (t/y)	East (t/y)
Hillslope particulate	32	16	16
Gully particulate	4	3	1
Bank particulate	74	48	26
Diffuse dissolved	150	119	31
Point source	3	3	0

Table 9: Sources of N

N budget	Total (t/y)	West (t/y)	East (t/y)
Hillslope particulate supply	339	158	181
Gully particulate supply	16	10	5
Bank particulate supply	295	192	103
Diffuse dissolved	1453	963	490
Point source supply	87	85	2

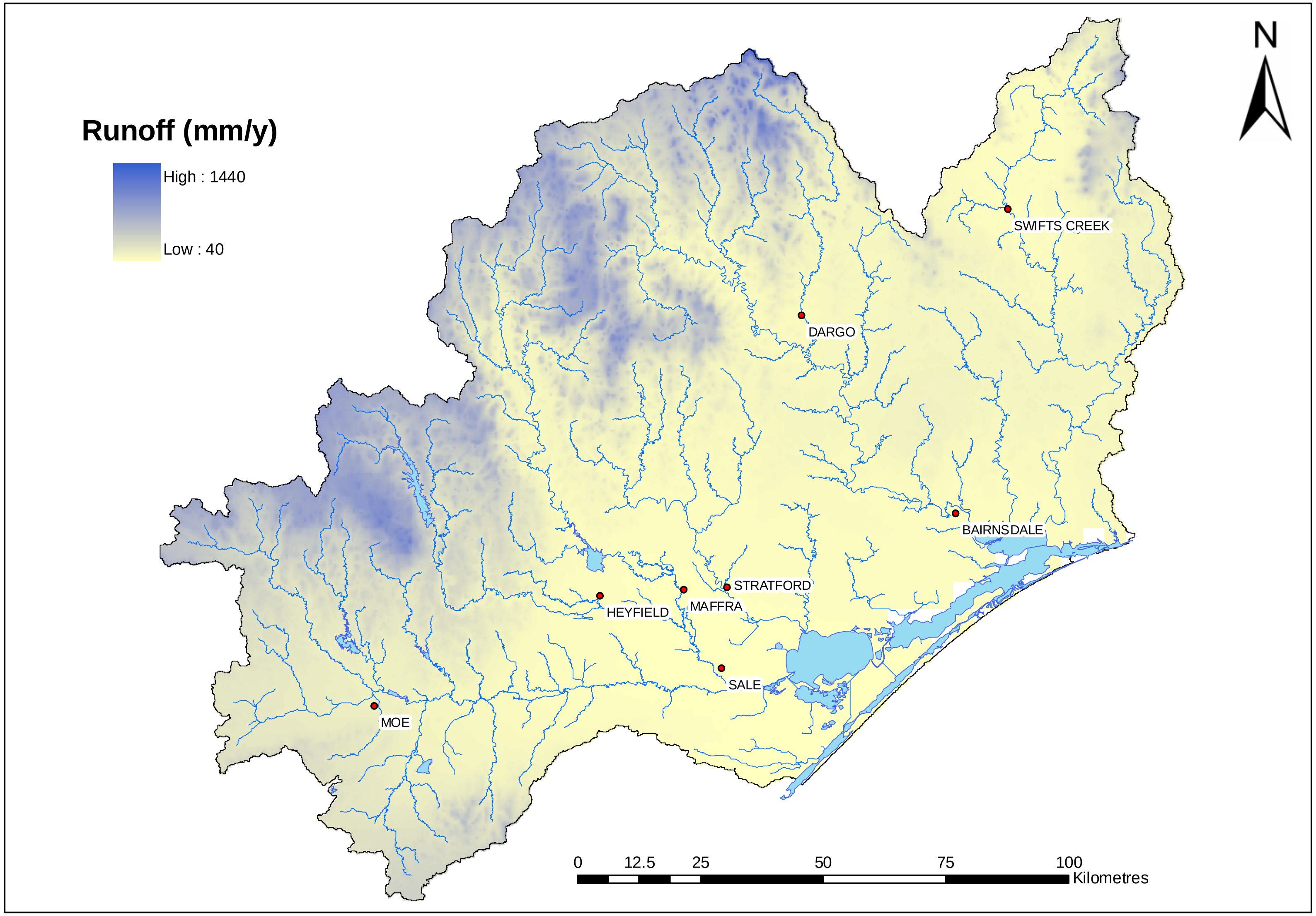

Figure 7: Predicted Mean annual runoff depth (mm/y)

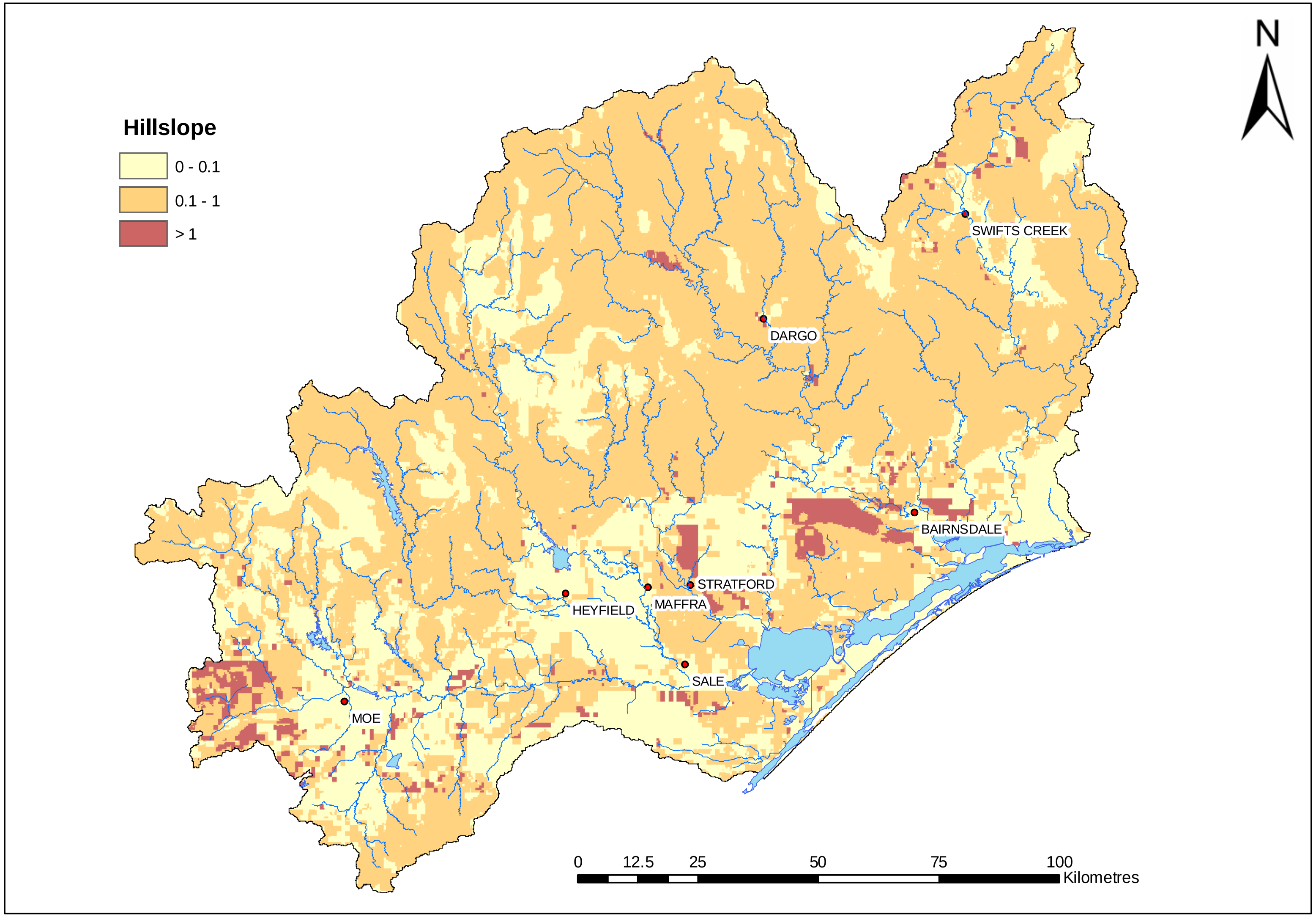

Figure 8 Predicted hillslope erosion in the Gippsland Lakes catchments (t/ha/y).

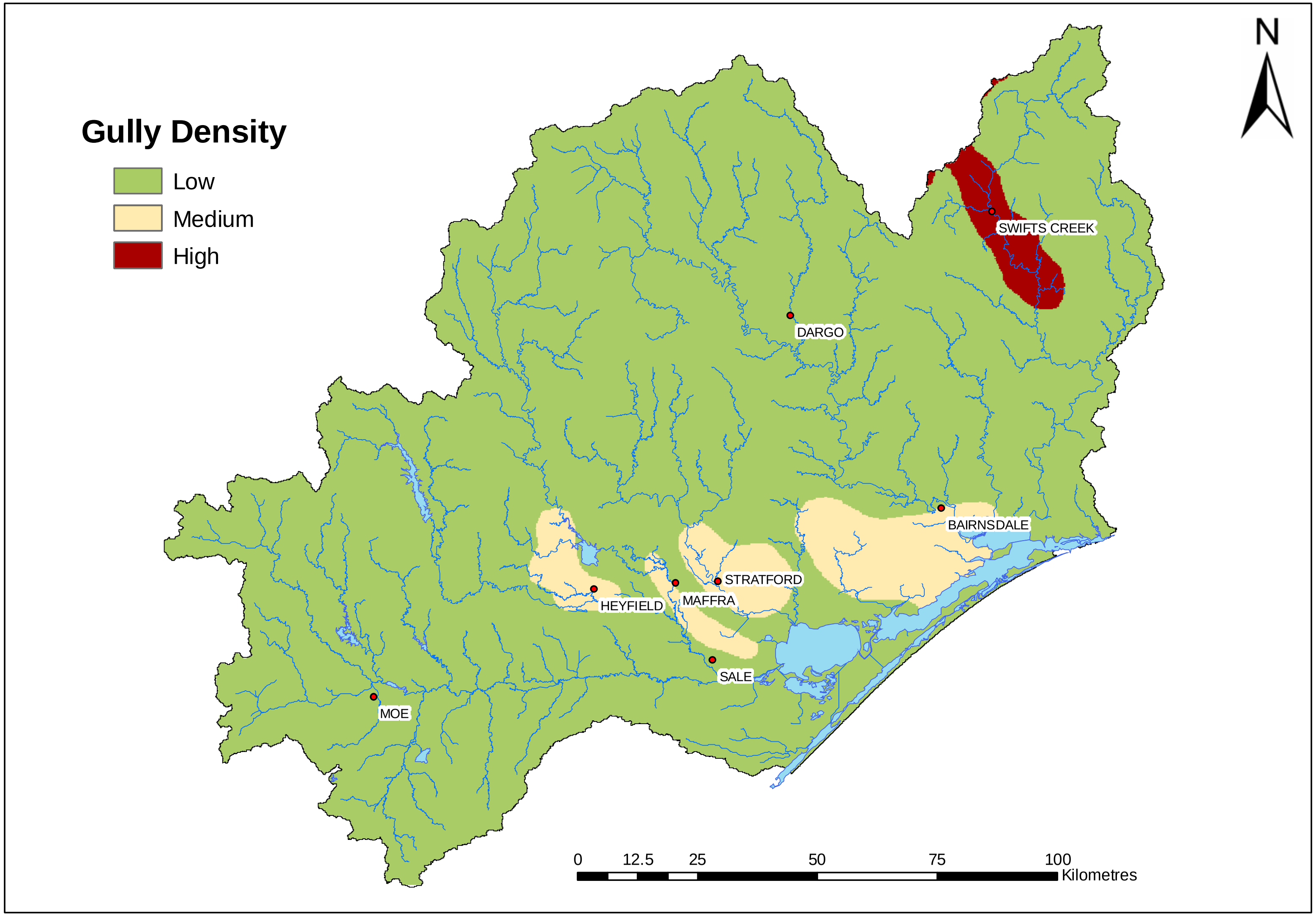

Figure 9 Gully Density in the Gippsland Lakes catchments

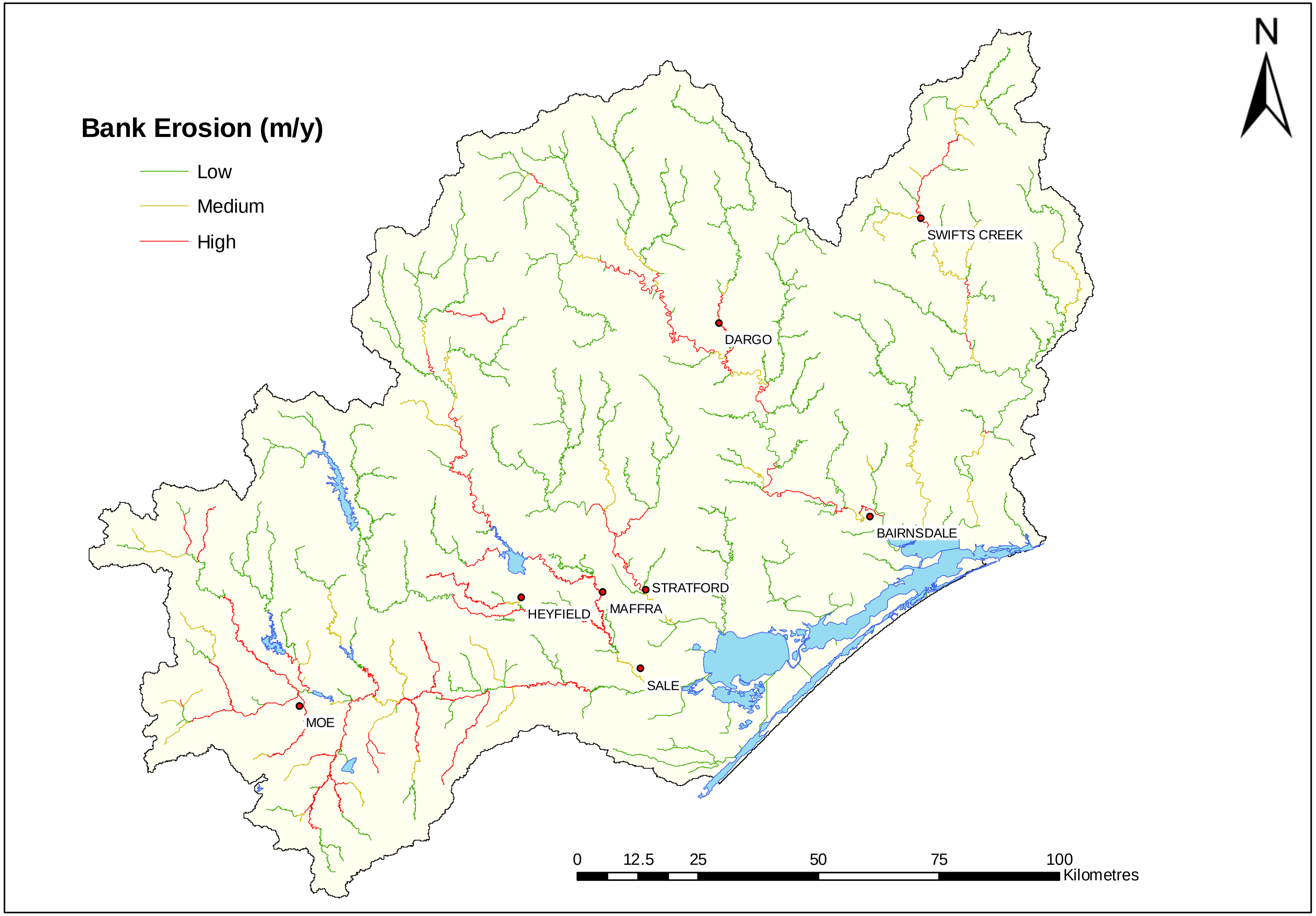

Figure 10 Relative levels of bank erosion in the Gippsland Lakes catchments.

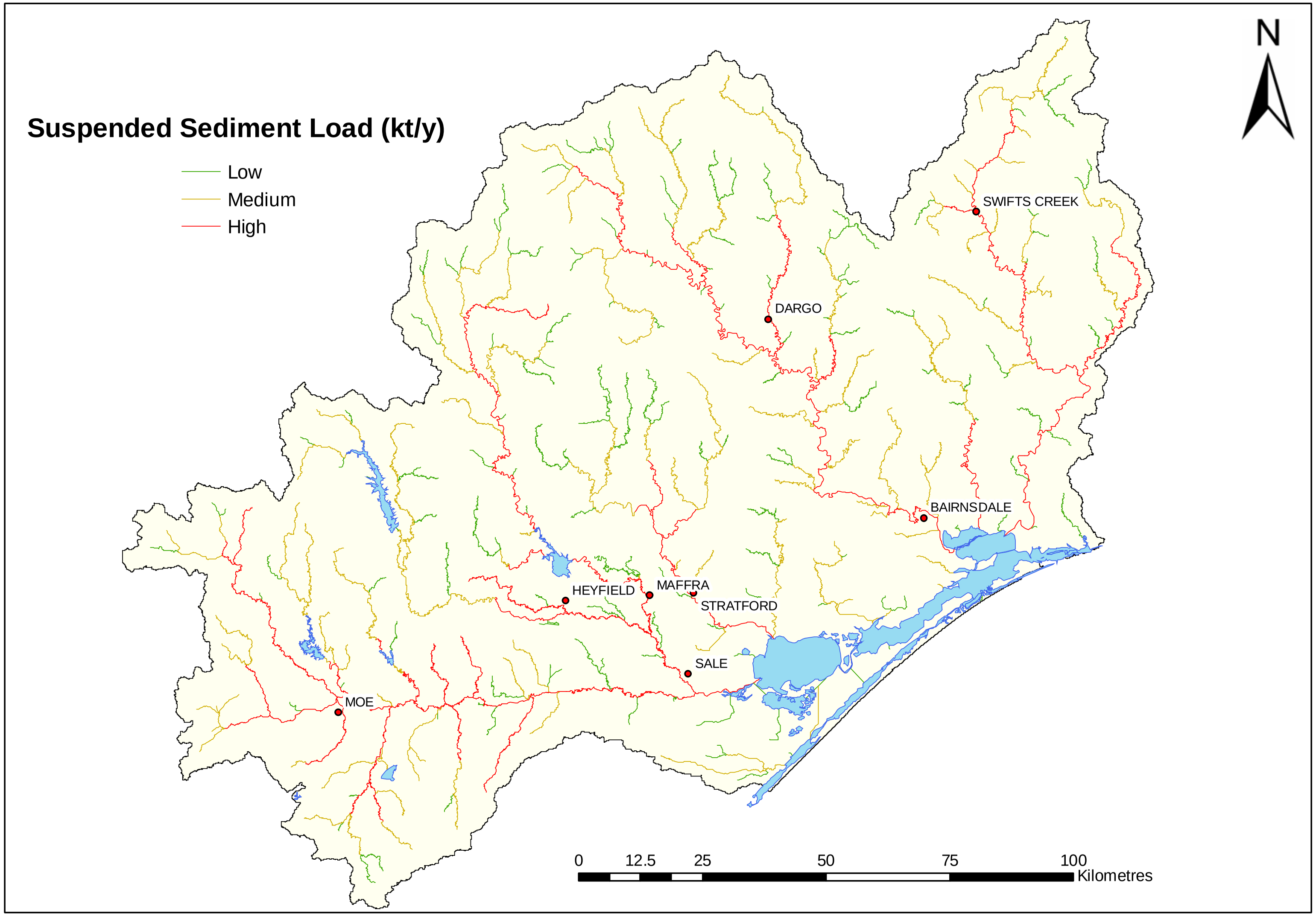

Figure 11 Relative suspended sediment load in the Gippsland catchments.

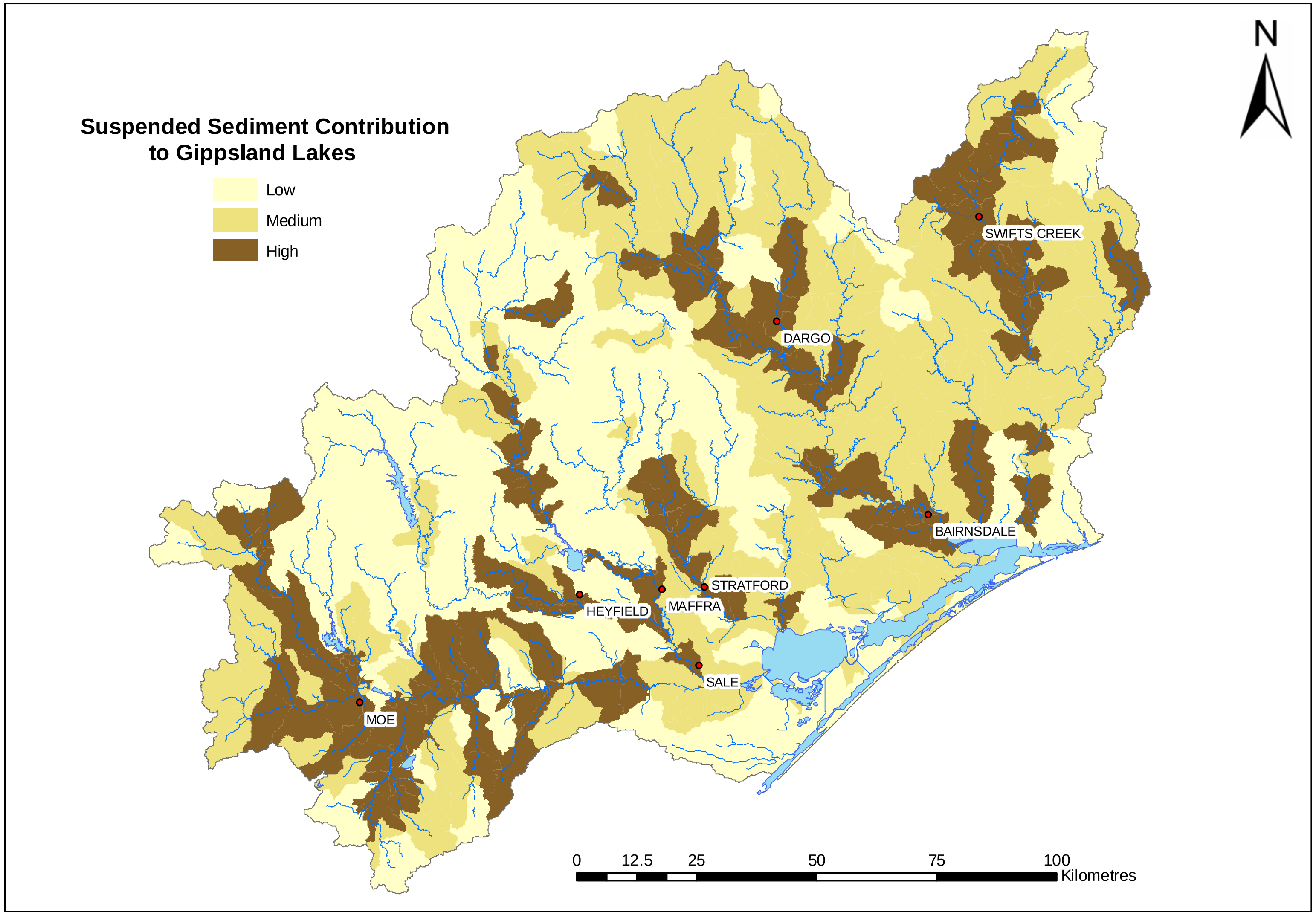

Figure 12: Spatial pattern of contribution of suspended sediment to the Gippsland Lakes

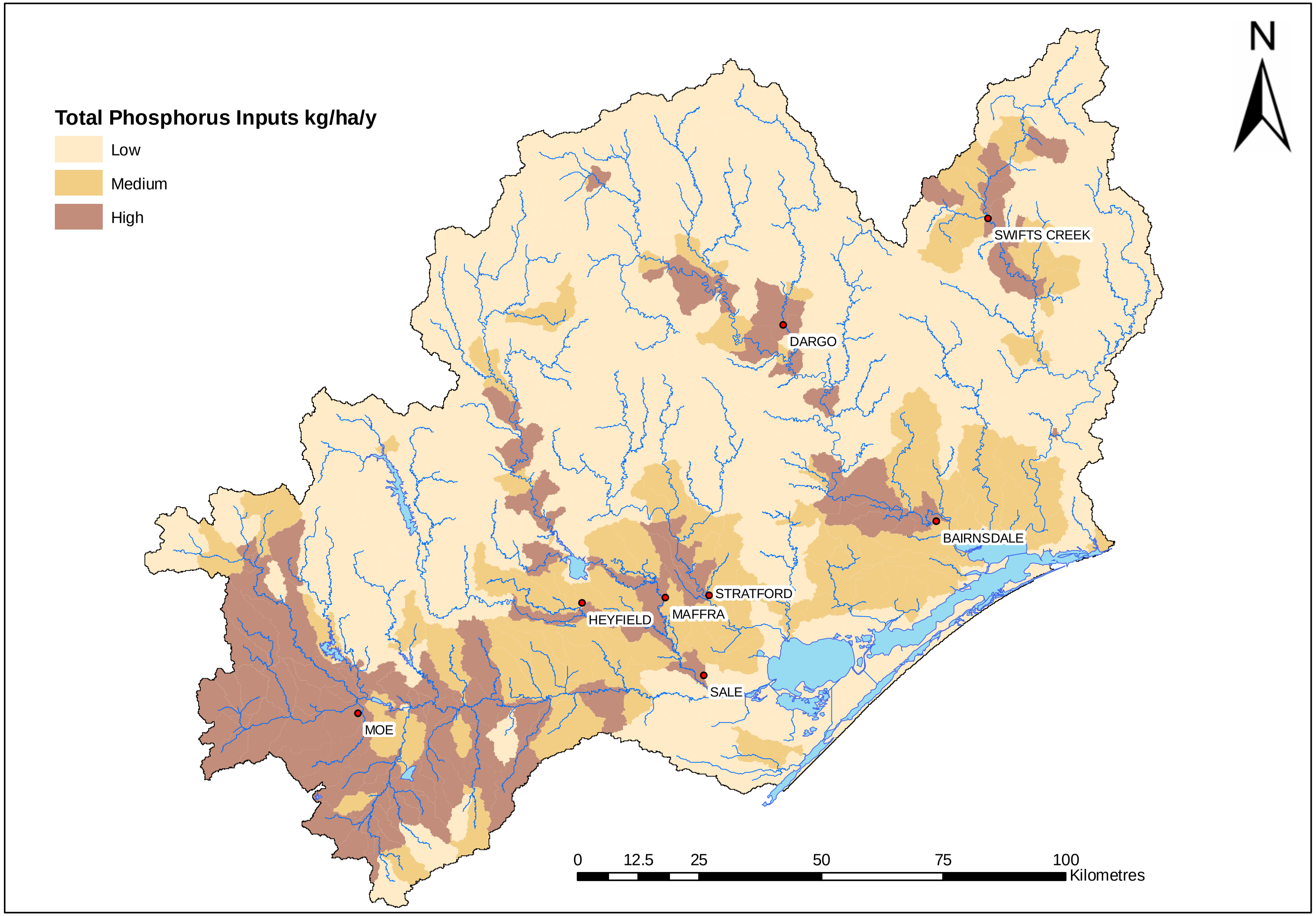

Figure 13: Total P supply (kg/ha/y)

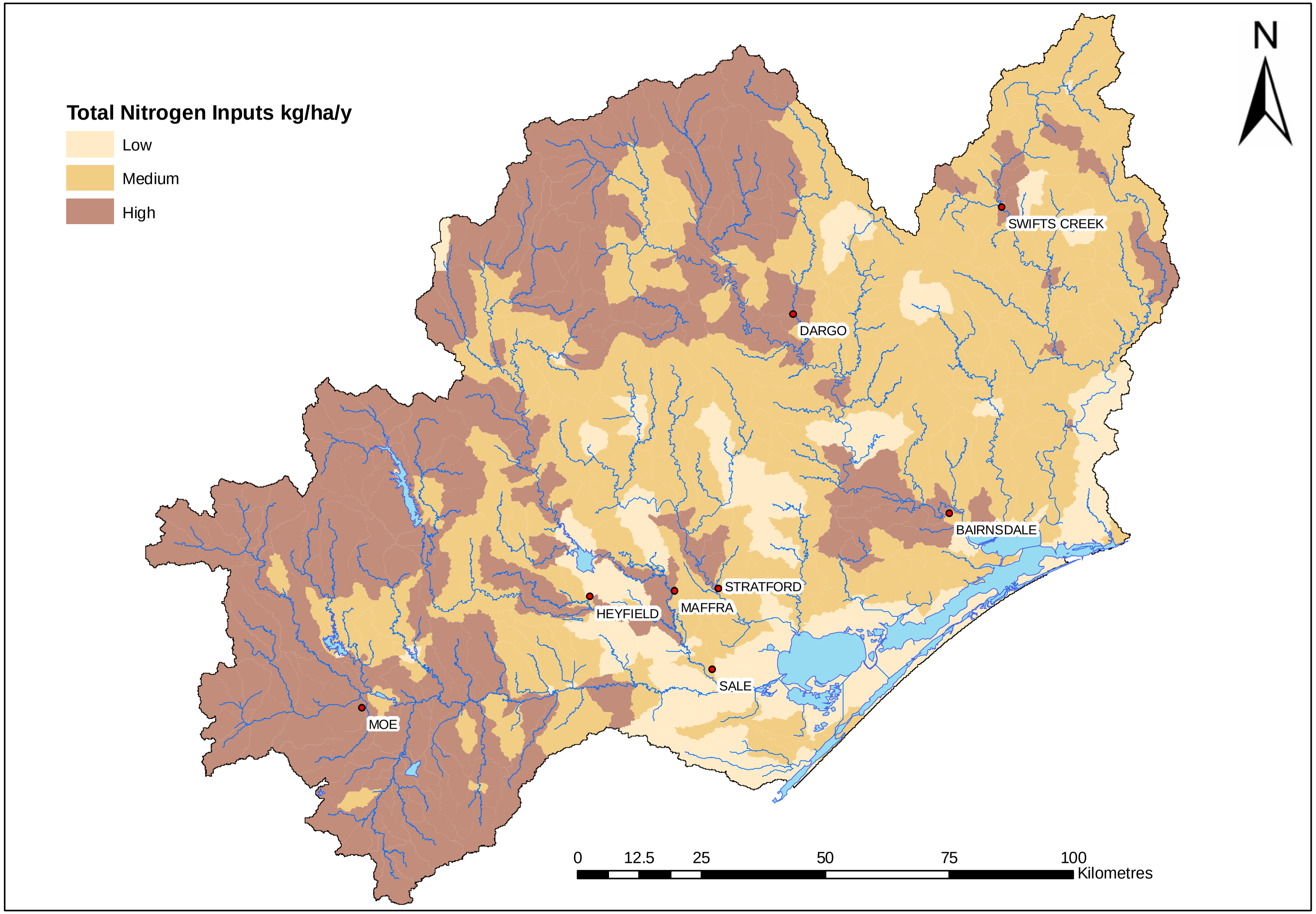

Figure 14: Total N supply (kg/ha/y)

5 Discussion

5.1 Comparison between modelled loads and previous estimates

A comparison was made between the SedNet predictions and the loads calculated from water quality monitoring records by Grayson et al. (2001). The Grayson et al. study has been selected as a benchmark because it is based on water quality monitoring data (EPA Victoria, 1975-1999). Because suspended sediment concentration sampling was not continuous, Grayson et al. (2001) used a discharge-concentration rating curve to estimate the long-term suspended sediment load. Although this approach can help correct for periods when crucial high flow data is missing, a monitoring approach to load estimation is largely dependent on how well large events have been captured during the monitoring period. High uncertainties in calculated loads are introduced when rating curves are based on only a small number of samples taken during high event flows.

The SedNet load predictions have not been calibrated using loads calculated by Grayson et al., and we regard calibration as inappropriate given the uncertainties in the estimated loads, and because we are in a preliminary stage of modelling. Nonetheless, the outputs of the SedNet modelling are compared with the estimated loads to give an indicative evaluation of the predicted suspended sediment loads (Table 10).

The variation between SedNet loads and estimated loads is not necessarily a cause for concern, given the uncertainties inherent in both methods. The preliminary SedNet modelling predicts suspended sediment loads in the Latrobe and Avon Rivers that are significantly lower than the estimates, and significantly higher for the Mitchell and Tambo. This may reflect an under-prediction of bank erosion rates in middle and lower reaches of the Latrobe and Avon, and over-prediction for the Mitchell and Tambo Rivers in the east (see discussion below). Alternatively, and quite likely, the differences for the Mitchell and Tambo Rivers may be caused by under-estimation in the estimated load, given the fact that their rating curves are based on relatively few event data points (Table 10), a point acknowledged by Grayson and Argent (2002). The differences in the loads estimates for the Thomson and Nicholson rivers are relatively minor.

Table 10 : Suspended sediment load at downstream monitoring stations. Estimated loads are from Grayson et al. (2001). Note that the predicted sediment loads given here differ from those in Table 7, due to floodplain deposition occurring between these stations and the catchment outlet. This is particularly significant for the Latrobe and Thomson rivers.

			SedNet		Estimated	
CATCHMENT	**Gauge location**	**Event samples used for rating curve**	**kt/y**	**t/km^2/y**	**kt/y**	**t/km^2/y**
Latrobe River	260600	18	61.8	14.2	89.4	20.6
Thomson River	250900	7	48.4	13.7	36.2	10.3
Avon River	Stratford	2	9.8	6.7	25.7	17.6
Mitchell River	Rosehill	5	74.4	16.8	21.9	5.0
Nicholson River	230200	2	2.7	4.8	5.4	9.6
Tambo River	230100	3	24.8	8.8	7.6	2.7
Catchment average		**-**		**12.9**		**10.9**

5.2 Model limitations

5.2.1 Bank erosion

Uncertainties in bank erosion estimates can arise from uncertainties in the bank migration rates used (section 4.5) and lack of precision in the channel slope as calculated from the Digital Elevation Model. For the latter, the uncertainty can be reduced by smoothing, but unquantified error remains. Further research is required to reduce the uncertainty associated with predicting this erosion process at catchment scale.

As noted earlier, river bank erosion rates are subject to a range of values. Comparison with observed channel migration rates (section 4.5) shows that the current predicted values are conservative. This adds support to our finding that river bank erosion accounts for most of the predicted sediment load delivered to the Lakes. In addition to the comparison with observed channel migration rates, a comparison with other estimates of West Gippsland sediment loads (Table 10) indicates that the modelled loads are, if anything, too low. Reducing the river bank erosion rate in the Latrobe and Avon rivers would also reduce the estimated load to Lake Wellington even further below the load estimate of Grayson et al., (2001). In East Gippsland the predicted suspended sediment load for the Mitchell and Tambo rivers are much higher than those of Grayson et al., and it is conceivable the model has over-estimated the river bank component for these rivers. Further data on historical bank erosion rates, particularly in upland areas, will reduce uncertainty in the overall prediction of bank erosion.

5.2.2 Gully and tunnel erosion

As noted earlier, very little mapped gully information is available for the Gippsland Lakes' catchments, and it is likely that there are small incised streams not represented in the current mapping. To improve the gully data we suggest that mapping of gullies using aerial photography or similar methods be undertaken. Tunnel erosion is another subsoil source that at this stage is not currently represented in the modelling, and may be an important sediment source in some areas. Incorporation of both gully and tunnel erosion sources into the model could significantly increase total sediment yields above those given in this report.

5.2.3 Hillslope erosion

Hillslope erosion is predicted to be only a minor contributor to sediment delivery to the Lakes. There are several limitations that may be affecting this prediction:

- The hillslope erosion rate, estimated by the Revised Universal Soil Loss Equation, utilises landuse mapping and satellite images to estimate vegetation cover. At present the high-resolution land use mapping has not been applied. The national dataset used correctly represents landuse where it occurs in large blocks, but is less accurate in the transition zone between land uses.
- Satellite data is used to assess the spatial and temporal variation in vegetation cover within each land use across the region. These data extends from 1981 to 1994 (Lu et al., 2001), and so changes in vegetation cover within each land use since 1994, as may have occurred following the recent bushfires, are not represented. In predicting native state forest vegetation cover, there are also assumptions about harvest cycles (20 years) and post-harvest cover (>50% within 12 months) that may not apply in the Gippsland region.
- Erosion on unsealed roads is not captured well with the current, coarse-resolution land use mapping.
- The uniform value of hillslope sediment delivery ratio (HSDR), 5%, is based on limited data from south-eastern Australia (Prosser et al., 2001), and deviations from this

value will introduce uncertainty in the hillslope component of the predicted sediment load. Certainly, within a region there will be spatial variation in HSDR due to changes in rainfall intensity, vegetation cover, slope and drainage density. Although neglecting spatial variation is potentially a major weakness at the scale of individual hillslopes, on a larger scale this variation is greatly diminished. For example, at the model sub-catchment scale (>20 km^2) HSDR could be as high as 20% for hillslopes with a steep gradient, but at the catchment scale encompassing more gently sloping pastures and forested slopes the spatially-averaged value of HSDR is unlikely to exceed 10%, especially in regions with a temperate climate. In fact, 10% is the value routinely applied to tropical catchments where frequent intense rainfall events are common. Taking the extreme case of applying a HSDR of 10% to the entire Gippsland catchment increases hillslope erosion by a factor of two over the value given in Table 6, so it would still only be a minor component when compared to bank erosion.

5.2.4 Nutrients

The dominance of the dissolved nutrient sources highlights the importance of having accurate values for the concentrations of dissolved nutrient in catchment runoff. Since much of the concentration data used here comes from the Goulburn catchment, there remains uncertainty as to its suitability for the Gippsland Lakes catchments (

Table 3). Obtaining further local data on dissolved nutrient concentrations will reduce uncertainty in the nutrient budgets.

6 Where to from here: next phases in the project

6.1 Project timeline

The project is due to be completed by the end of 2006. The final project outputs will include a summary of the results of all phases and a discussion of the implications for catchment management.

6.2 Phase 2: Sediment tracing

We are undertaking the sediment tracing study in parallel to the model development work. The next phase of the study will provide independent information on erosion processes based on the tracing results to test the model's predictions. This work is due for completion in Jan 2006.

6.3 Phase 3: Lake-bed sediment coring

Analysis of cores from the Lakes will provide information on pre and post-European sedimentation rates, and estimates of "natural" (undisturbed catchment) post-European sediment loads being delivered to the Lakes. This work is due for completion in April 2006.

6.4 Phase 4: Final modelling cycle

Modelling improvements

Further refinement of the modelling will reduce the uncertainty in the relative importance of erosion sources, and in loads from individual catchments. The final phase of the work is an opportunity to develop the modelling data, focussing on the limitations identified by this initial modelling phase, and the subsequent project phases. Potential improvements are listed below. Some of these improvements will require research external to this project and so not all developments may be achievable within this project.

1. The prediction of bank erosion can be improved by removing uncertainty from channel slope.
2. Better mapping of gully extent using aerial photographs and field reconnaissance will improve estimation of gully sediment yields; similarly, data on sediment yields from tunnel erosion could be incorporated.
3. The estimation of vegetation cover in the riparian zone can be improved by replacing the current national tree cover dataset with the Victorian SPOT-based TREEDENS25 dataset, or considering other measures of riparian condition such as the Index of Stream Condition.
4. The prediction of hillslope erosion can be improved by using high resolution land use mapping to predict vegetation cover, and by refining the representation of vegetation cover to suit local conditions, particularly in forest areas. The longer-term impacts on sediment yield following recent bushfires could also be incorporated provided data is available on recovery of vegetation cover.

5. Sediment yield from unsealed roads could be better represented using the high resolution landuse data and studies of sediment yields from forest roads.
6. The sediment tracing phase of the project will provide data to test the current model predictions of the relative contributions of surface and sub-surface erosion.
7. Some minor further development of the method for defining floodplains is possible, to improve estimates of floodplain deposition
8. Further data on dissolved nutrient supply from intensive landuses can be incorporated as it becomes available.

7 Preliminary Conclusions

- Preliminary SedNet modelling of the Gippsland Lakes' catchments indicates that river bank erosion is the primary source of suspended sediment being delivered to the Lakes.
- The hillslope (topsoil) erosion rate is found to be generally low.
- In West Gippsland a significant fraction (54%) of the suspended sediment input to streams is estimated to be deposited on the riverine floodplains of the Latrobe and Thomson Rivers. In the East this fraction is much lower (20%).
- The dominant nutrient sources are supply of suspended sediment from bank erosion, and also dissolved runoff. Industrial and treatment plants play a relatively minor role.
- Future work will use the results of tracer studies and river monitoring data to test and improve the model outputs. It is therefore likely that the loads estimated in this report will be improved.

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