VOLUME 1

The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting

Edited by:
Cogle, A.L., Carroll C., Sherman B.S.

The National Heritage Trust (NHT) was set up by the Australian Government to help restore and conserve Australi'a's environment and natural resources. The National Action Plan for Salinity and Water Quality (NAPSWQ) is a joint Australian and Queensland Government initiative under the NHT that encourages governments and regional communities to work together to address salinity and water quality issues in priority catchments throughout Queensland. The project was funded by NHT and NAPSWQ using Australian and Queensland Government financial support including that of the Coastal Catchments initiative, an NHT program.

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Preface

The Joint Steering Committee, who has responsibility for overseeing the implementation of NAP and NHT in Queensland, recognised a need to increase the science support to regional Natural Resource Management (NRM) bodies to meet Reef Water Quality Protection Plan (RWQPP) timelines. This report provides an overview and broad results of a project, which provided modelling support to the NRM bodies.

The Short Term Modelling project was undertaken by a team of scientists from the Queensland Department of Natural Resources Mines and Water and CSIRO Land and Water. The project team included:

Department of Natural Resources Mines and Water
- Southeast Region (Graeme Esslemont, Mark Sallaway, Ross Searle, Peter Wilson,)
- Central Region (Chris Carroll, Cameron Dougall, Bronwyn Masters, Glen Millar, Bob Packett, Ken Rohde)
- North Region (John Armour, Lex Cogle, Ian Duncan, Louise Hateley, Paul Nelson and Georgina Pitt)
- NRSc (Banti Fentie, Daniel Brough, Michael Daly)

CSIRO Land and Water
- Canberra (Yun Chen, Arthur Read, Brad Sherman)

Australian Centre for Tropical and Freshwater Research
- Jon Brodie

Great Barrier Reef Regional Bodies
- Far North Queensland Natural Resource Management Ltd
- Burdekin Dry Tropics NRM
- Mackay Whitsunday Natural Resource Management Group
- Fitzroy Basin Association
- Burnett Mary Regional Group for Natural Resource Management

The project team sincerely thanks people nominated by the five NRM bodies for their time and commitment in working together to provide the outputs presented in this report.

The project benefited greatly during the conception and support building phase from the contributions of Andy Steven, Heather Hunter, Chris Robson and Don Begbie.

The report has several volumes. The first deals with matters covering all the NRM regions. Separate volumes have been completed for each individual NRM region to cover regionally specific information.

The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting:

- *Volume 1 - Overview and Great Barrier Reef Outcomes*
- *Volume 2 - Sediment and nutrient modelling in the Far North Queensland NRM region*
- *Volume 3 - Sediment and nutrient modelling in the Burdekin NRM region*
- *Volume 4 - Sediment and nutrient modelling in the Mackay Whitsunday NRM region*
- *Volume 5 - Sediment and nutrient modelling in the Fitzroy NRM region*
- *Volume 6 - Sediment and nutrient modelling in the Burnett Mary NRM region*

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List of Acronyms

ALUM	Australian Land Use Management
ANNEX	Annual Nutrient Export
ASRIS	Australian Soil Resource Information System
BDT	Burdekin Dry Tropics
BMRG	Burnett Mary Regional Group
CCI	Coastal Catchments Initiative
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEH	Department of Environment and Heritage
DEM	Digital Elevation Model
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
EPA	Environmental Protection Agency
FBA	Fitzroy Basin Association
FNQ	Far North Queensland
FRP	Filterable Reactive Phosphorus
GBR	Great Barrier Reef (*Lagoon*)
GBRMPA	Great Barrier Reef Marine Park Authority
GIS	Geographical Information System
HSDR	Hillslope Delivery Ratio
JSC	Joint Steering Committee
MAF	Mean Annual Flow
MWNRM	Mackay Whitsunday Natural Resource Management
N	Nitrogen
NAPSWQ	National Action Plan for Salinity and Water Quality
NHT	National Heritage Trust
NLWRA	National Land and Water Resources Audit
NPI	National Pollutant Inventory
NRM	Natural Resource Management
NRMW	Natural Resources Mines and Water
NRSc	Natural Resources Sciences
P	Phosphorus
PET	Potential Evapotranspiration

PN	Particulate Nitrogen
PP	Particulate Phosphorus
PSD	Point Source Database
QLUMP	Queensland Land Use Mapping Project
RUSLE	Revised Universal Soil Loss Equation
RWQPP	Reef Water Quality Protection Plan
SALI	Soil and Land Information
SedNet	Sediment River Network
SIP	State-level Investment Project
SLATS	Statewide Landcover and Trees Study
SMART	Specific Measurable Achievable Relevant & Timed
SS	Suspended Sediment
STM	Short Term Modelling Project
TIME	The Invisible Modelling Framework
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Sediment
WQ	Water Quality
WQCG	Water Quality Coordination Group
WRMC	Water Resources Management Committee

Executive Summary

(Carroll C; Cogle A.L. and Sherman B.S.)

The aim of the Short Term Modelling project was to support the NRM regional bodies adjacent to the GBR with their target setting (Action H1) responsibilities under the Reef Water Quality Protection Plan. The project team provided modelling capacity to the five NRM regional bodies so that they could utilise modelling as one of the tools used to set water quality targets. The main difference between this project and the approach adopted by previous modelling activities was the emphasis placed on the communication, engagement and scenario development with NRM Regional bodies and their nominees.

A communication strategy was developed by the project team working with the NRM boards and their nominees to demonstrate the value of models in developing management action targets. The strategy encompassed:

- an extension program to temper expectations on the utility of modelling for target setting, and
- an iterative dialogue to develop scenarios, and
- advice on the outcomes and implications of the modelling results.

Long-term average annual sediment and nutrient loads delivered to the Great Barrier Reef Lagoon were modelled using SedNet/ANNEX for the five NRM regions between Bundaberg and Cairns. Improved and more recent input data sets were acquired to achieve better resolution of topographic and landuse features. The benefit of using SedNet was that it had previously been used to predict sediment and nutrient loads for continental Australia for the National Land and Water Audit and for other modelling activities in GBR catchments.

Teams located in each of the NRM regions performed the sediment modelling. These teams provided their SedNet model results to a CSIRO nutrient modelling team who subsequently computed nutrient loads using ANNEX. An important part of the project was the engagement and communication of the strengths and weaknesses of models as well as the development of model scenarios, which represent management actions defined in NRM plans.

The project demonstrated to the NRM groups that the SedNet/ANNEX model is a valuable tool for identifying potential 'hotspot' areas and management practices that can provide a relative improvement in water quality. SedNet/ANNEX modelling showed that an overwhelming majority of sediment and nutrient supplied to the GBR originates within 80-90 km of the coast in areas from landscapes with high rainfall and steep slopes that are used for grazing or intensive agriculture. Further inland, particulate nutrient loads dominate but these loads are, for all practical purposes, deposited on flood plains, river beds and in reservoirs and therefore do not reach the coast in a reasonable timeframe.

For any particular catchment, effective management of sediment and nutrient loads may require separate strategies. Strategies to manage particulate nutrient loads have little effect on dissolved nutrient loads and vice versa. Management strategies targeting improved vegetation (ground) cover in grazing lands delivered the greatest reductions in sediment and particulate nutrient loads. Implementation of best management practice (fertiliser application and tillage methods) produced the greatest reduction in dissolved nutrient loads for intensive agricultural systems.

Total phosphorus loads exported to the coast were dominated by particulate phosphorus in all regions. Total nitrogen loads were more evenly comprised of both particulate and dissolved forms with dissolved forms dominant in Far North Queensland and the Mackay Whitsunday regions. In the Burdekin, Fitzroy and Burnett Mary regions grazing accounts for more than 75% of landuse and particulate nitrogen is the dominant component of the total nitrogen load.

To further improve the accuracy of catchment models and their utility to assist management of GBR catchments the following actions are recommended:

- Improve the soil nutrient and clay content of spatial data sets by incorporating observations (i.e. SALI datasets) where available. This is perhaps the single greatest source of uncertainty in modelling particulate nutrient loads.
- Include all small coastal subcatchments in future model runs.
- Include contaminant loads from coastal flood plain areas draining into tidally-driven river reaches.
- Empirically determine the true impact of dams on sediment deposition in the dry tropics, e.g. the impact of Burdekin Falls Dam, where sediment load has a very high proportion of fine particles and significant spill events occur intermittently.
- Support field studies to determine the role that floodplains, and other landscape features play as sediment sinks in the dry tropics.
- Use a spatially variable C-factor for grazing lands. At present all grazing land within a catchment is considered to have the same vegetation (ground) cover.
- Use spatially variable fertilizer management.
- Support field studies to improve the mapping between landuse and dissolved nutrient concentrations in receiving water. Increase the number of landuse groups for better spatial resolution.

The project provides important information for the setting of water quality targets in Reef catchments. The NRM Boards have the latest information available on modelled outputs, which they can combine with other information (e.g. local and regional water quality information) to set targets. However, it is imperative that this is done with stakeholders in their individual regions. The project has identified some key components that are required when setting water quality targets:

- Ownership and partnership; everyone (landholders, governments, regional bodies, industries, etc) needs to agree on the target setting process.
- Delivery; everyone needs to deliver their part, this may be a partnership or it may be achieved through coordinated but individual deliveries.
- Review: review of targets is essential, particularly as new information becomes available and review must occur in a timely manner. The review helps to improve the accuracy of the model, manage expectations and prioritise future actions.
- Consequences of non-delivery of targets need to be determined and barriers that constrain implementation regularly discussed and addressed.

1 Introduction

(Carroll C., Sherman B.S. and Cogle A.L.)

The Great Barrier Reef World Heritage Area is an area of national and international significance, with outstanding natural, social and economic values. Over the past 150 years reef catchments have been extensively modified leading to a decline in water quality entering the Great Barrier Reef (GBR) lagoon. The health of the GBR is a concern (Arthington *et al.* 1997; Brodie 2002; Furnas 2003), with the degradation of coral reefs attributed to elevated levels of sediment, nutrients and pesticides entering the reef lagoon from adjacent coastal catchments (Van Woesik *et al.* 1999, Haynes *et al.* 2000).

A joint Queensland and Australian government initiative has responded to these water quality concerns and threats with the production of the Reef Water Quality Protection Plan (RWQPP) (Anon., 2003). The overall goal of the RWQPP is to halt and reverse the decline in water quality entering the reef within ten years, with the specific objectives to:

- Reduce the load of pollutants from diffuse sources in the water entering the Reef.
- Rehabilitate and conserve areas of the Reef catchment that have a role in removing water borne pollutants.
  See: http://www.thepremier.qld.gov.au/News/Initiatives/reef_water_quality_protection

The RWQPP has identified 9 broad strategies (A-I) to achieve its objectives and each strategy contains a number of actions. Strategy H: Priorities and Targets, recognises that areas within the GBR catchments need to be prioritised, and that the development of water quality targets is an important approach. In particular two actions, which identify water quality targets, are:

H1 – Develop water quality targets for the Reef catchment waterways with a major focus on:

- Improving water quality.
- Investing in remedial action that ensures adequate protection and rehabilitation of wetlands, riparian and other vegetation important to water quality.

H4 – In partnership with Regional NRM Bodies identify subcatchment hotspots responsible for delivering disproportionate quantities of sediment, nutrient and pesticides to the reef.

The RWQPP relies on the support of the National Action Plan for Salinity and Water Quality (NAPSWQ) and National Heritage Trust (NHT) frameworks to meet its objectives. These frameworks, delivered by the Australian Government working in association with State and Territory Governments, aim to facilitate integrated delivery of Natural Resource Management priority issues. Investments under the NAPSWQ and NHT are driven by regional Natural Resource Management Plans. These regional plans are developed by local communities and supported by Government and the best available science to improve natural resources on a regional scale. Details of the NRM planning process can be found at http://www.nrm.gov.au.

There are 6 Regional NRM Bodies in Queensland adjacent to the GBR (Cape York, Far North Queensland, Burdekin Dry Tropics, Mackay Whitsunday, Fitzroy Basin Association, and Burnett Mary). These regional bodies are responsible through their regional plans to meet the RWQPP actions to identify subcatchment hotspot areas and develop water quality targets for their region, as identified above.

Brief history of sediment and nutrient modelling in the GBR catchments

Catchment sediment and nutrient load modelling in various GBR catchments has been completed at a range of scales. Moss *et al.* (1992) estimated sediment and nutrient exports from Queensland coastal catchments using a desktop approach, as a preliminary assessment of the impact of land based activities. In 2001, the National Land and Water Resources Audit undertook a whole-of-GBR estimate of sediment and nutrient loads using SedNet/ANNEX (Young *et al.* 2001). As time has progressed the SedNet/ANNEX model was revised and input data refined to improve the accuracy of model predictions. In 2003, Brodie *et al.* (2003) completed a comprehensive SedNet/ANNEX modelling study of GBR catchments and added the capability of ANNEX to simulate dissolved organic nutrients and modify loads based on residence times experienced by flows in downstream reservoirs.

While the Audit and Brodie *et al.* (2003) modelling used a spatial resolution of 250 m, there has been higher spatial resolution modelling of some individual GBR catchments using SedNet/ANNEX. These have typically been performed at a resolution of ca. 100 m for the Mary (DeRose *et al.* 2002), Herbert (Bartley *et al.* 2003) and Bowen (Bartley *et al.* 2004) catchments and for the Douglas Shire (Ellis *et al.* 2005) as well. Kinsey-Henderson *et al.* (2005) have applied SedNet to the Weany Ck subcatchment of the Burdekin using a resolution of 5 m to investigate the effect of employing spatially variable hillslope delivery ratios.

On an individual catchment basis, a range of models have been utilised from simple approaches such as CMSS in the Barron River catchment (Cogle *et al.* 2000) to application of EMSS in the Maroochy River catchment (Searle 2005) and in the Fitzroy River basin (Dougall *et al.* 2005). In the Johnstone River catchment there was sufficient data available to allow the use of the very data-intensive and highly parameterised model HSPF (Walton and Hunter 1997) that includes both surface and groundwater in estimating loads. Bormans *et al.* (2004) applied the much simpler SedNet/ANNEX model to the Johnstone catchment, and found that its predictions compared reasonable well with those of HSPF. The ANNEX TP and TN loads were 10% and 28% higher than those predicted using HSPF.

The Short Term Modelling Project

The Short Term Modelling (STM) project commenced in January 2005 to support the regional NRM bodies adjacent to the GBR with their target setting responsibilities under RWQPP (Action H1). The Joint Steering Committee recognised in late 2004 that the regional NRM bodies needed increased science support with developing water quality targets, if RWQPP timelines were to be met. A project team was formed with science providers across State Agencies, CSIRO, CRC Catchment Hydrology and other research organizations.

Target setting of any type can be a complex undertaking and water quality, which is impacted by many biophysical processes, is no different. An important aspect with target setting is the need for a transparent process to be developed so that ownership is achieved in the targets that are set. It is for this reason that the STM project placed a greater emphasis on the communication, engagement and scenario development than previous modelling projects.

SedNet/ANNEX was the model chosen to support the target setting process since it was used by the National Land Water Resources Audit) and for other modelling activities in GBR catchments (Prosser *et al.* 2001, Brodie *et al.* 2003, Bartley 2004a, 2005b). It is a respected model that can readily use updated base layer information and provide quantitative estimates of long-term average annual sediment and nutrient loads for a range of resource management scenarios. Importantly the underlying biophysical processes are easily and clearly presented.

Figure 1.1 illustrates the importance placed on communication and outlines the 5 interlocking project components and their source of funding, namely:

- Communication strategy for using models to assist in target setting
- Develop Contributor Module of SedNet
- Collation of Base Layers of Modelling information
- Regional Sediment Modelling
- Nutrient Modelling for GBR Catchments

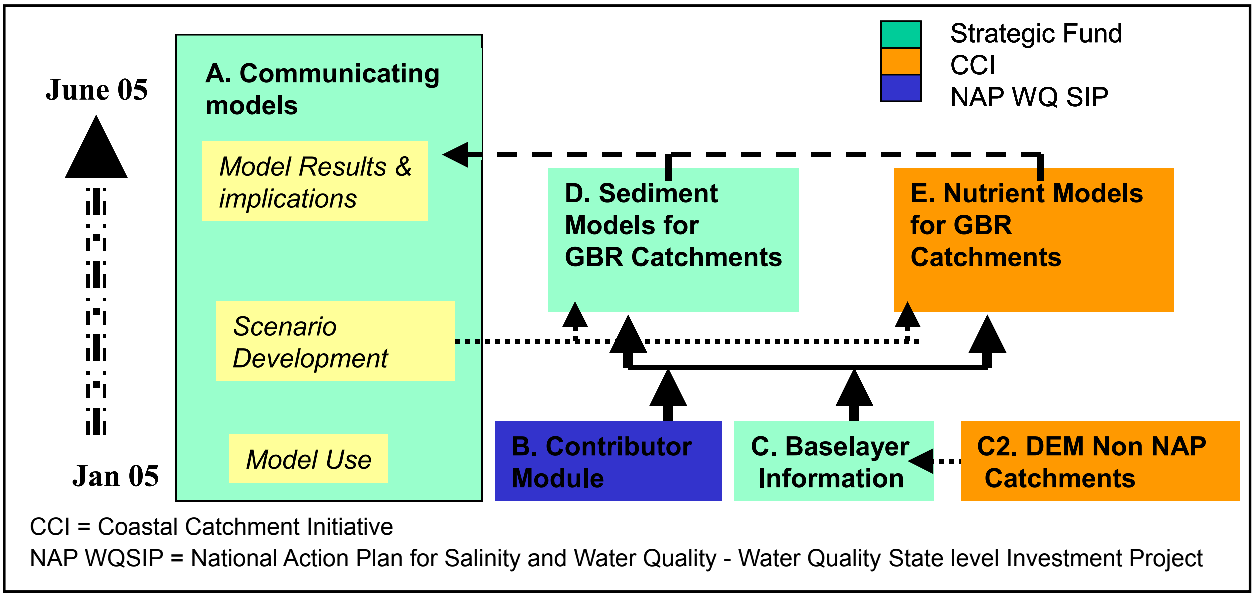

Figure 1.1 Short-term modelling project components with funding sources

Although contributing to the whole project, each of the components had their own set of following objectives and outcomes.

Communication strategy for using models to assist in target setting

Objective: To implement an effective communication strategy that informs stakeholders of the use and development of modelling activities in the GBR including:

a. dialogue with the Regions of what is currently being done in the short and longer term that will support the development of targets;
b. communicate the strengths, limitations and appropriate use of models;
c. review regional plans to identify which proposed management actions can be modelled and with what degree of accuracy; and
d. communicate findings of activities D and E to Regional Bodies.

Develop Contributor Module of SedNet

Objective: To develop the "Contributor" module for SedNet through the CRC Catchment Modelling Toolkit.

The 'Contributor' module is a software module of SedNet that calculates the spatial pattern of sediment contribution to export from the catchment. CSIRO rewrote the code to incorporate it into the new version of SedNet through the CRC Catchment Modelling Toolkit. The STM project applied this module to promote a better understanding of subcatchment sediment contributions.

Collation of Base-layers of Modelling information

Objective: To collate best available information needed to underpin model runs in activities D and E.

Best available data was collated to underpin both the sediment (D) and nutrient (E) models and included high-resolution digital elevation models, current landuse data, gully density and water quality information. Under the NAP Salinity SIP a high resolution 25 m DEM was completed by NRMW for NAP catchments. In order to have a common base layer framework across all GBR catchments a 25 m DEM was required in the non-NAP catchments of the Mackay-Whitsunday's and Far North Queensland.

Regional Sediment Modelling

Objective: To assemble regional catchment models and undertake scenario modelling to assess whether proposed management actions would deliver quantitatively significant reductions in sediment loss.

Nutrient Modelling for GBR Catchments

Objective: To predict spatial patterns of nutrient generation and transport in the GBR catchments by improved representation of a) nutrient sources and generation rates, and b) nutrient transformation and redistribution processes; and to assemble regional catchment models and undertake scenario modelling to assess whether proposed management actions would deliver quantitatively significant reductions in nutrient loads.

This report provides an overview of the SedNet/ANNEX results generated from the scenarios developed by the NRM Regional bodies, and identifies and discusses the implications for water quality target setting.

2 Methodology

This section summarises methods used for the STM project under the headings:

- Communication
- Input datasets
- SedNet modelling
- Nutrient modelling
- Limitations and uncertainty

As a great deal of this project builds on previous work with SedNet and ANNEX, this section will be summarised with appropriate references. Some of the project activities were also undertaken in other projects, an example being the DEM production under Component C2. This is reported elsewhere (Smith and Brough, 2005).

2.1 Communication Plan

(Carroll C. and Cogle A.L.)

A Communication Plan based on an approach used by CRC for Catchment Hydrology was developed for the project. This approach requires the identification of several components, viz Scoping, Implementation and Evaluation. These allowed a sequential approach to project communication. This plan was used to underpin communication in each NRM region, but it was applied flexibly to recognise the unique characteristics of each of the regions.

2.1.1 Scoping

The purpose of the project defined the communication plan, and this was to:

'Use catchment modelling in partnership with NRM regional Bodies, to build capacity and explore scenarios on the changes of land management practices on water quality.'

The overall objective of the Communication Plan was to implement an effective communication strategy that informed stakeholders of the use and development of modelling activities in the GBR, with the specific objectives to:

- Engage with Regional bodies in a dialogue on what modelling is currently being done and what can be undertaken in the future that will support the development of water quality targets;
- Communicate the strengths, limitations and appropriate use of models;
- Review regional plans to identify which proposed management actions can be modelled and with what degree of accuracy; and
- Communicate findings of sediment and nutrient modelling to Regional Bodies.

Proposed project outputs, which explicitly supported the communication strategy included:

- spatial patterns of hillslope, gully and streambank erosion and nutrient losses would be modelled and provided as maps, digital data and summary statistics.
- workshops were planned in each NRM region where a series of land management scenarios that lead to a positive change in water quality were identified.
- follow up workshops were planned to provide a detailed interpretation of the scenarios and where in each catchment, land and river management can have the most benefit for water quality.

To support the communication of these outputs a generic PowerPoint presentation was produced that described the value of catchment models for target setting and transparently outlined the strengths and weakness of the SedNet model. An aim was to 'demystify' the model. Another *PowerPoint* presentation was produced for each region that specifically described the outputs from the land management scenarios.

2.1.2 Implementation

Five categories of stakeholders that would use or support the model outputs were identified in each region. These were end-users, researchers, investors, beneficiaries and communicators.

- The 5 NRM regions were the key End-Users identified in the plan: Far North Queensland, Burdekin Dry Tropics, Mackay Whitsunday, Fitzroy, and Burnett Mary.
- CSIRO and CRC for Catchment Hydrology researchers who would support the training of the project team in the use of the SedNet model. Other regional researchers, who were associated with state agencies and universities, and involved reef modelling and monitoring activities were also identified.
- Investors who needed to be briefed on the project included the Joint Steering Committee and the GBR Water Quality Coordination Group. These groups included representatives from each of the NRM regional Groups adjacent to the Great Barrier Reef and state and Australian governments.
- Beneficiaries were identified as regional state agency staff, land and Waterwatch officers, integrated catchment management officers and extension officers.
- Landcare, Waterwatch, and extension officers were also identified as people who could support the communication of the projects approach and the model outputs. It was also recognised that the NAP Water Quality project officers in the Fitzroy, Burdekin and Burnett/Mary catchments had important communication roles in this project.

The adoption environment for the project had two risks that needed to be considered at all times. These were a) the mistrust and scepticism of catchment models and b) NRM groups being overwhelmed by the target setting task.

2.1.3 Evaluation

The primary purpose of the Evaluation component was to provide an opportunity for reflection and learning, to enable project closure and guide future action. A survey questionnaire was developed to canvass participant's views, observations and conclusions about the project. Particpants included both the members of regional NRM bodies (primarily CEOs and management staff) and the project staff (primarily agency and research organisation technical modelling officers, management, extension and communication staff). Dr Suzanne Hovermann (NRMW) undertook a questionnaire of project team members and the NRM regional CEO's to obtain feedback on how well the project had met its objectives and on the research and extension approach used (Appendix 1).

In an additional evaluation process, Professor Rodger Grayson (CRC for Catchment Hydrology CEO) and Dr Scott Wilkinson (CSIRO Land and Water) evaluated and reviewed the basic assumptions, data inputs and outputs and the rigour in which the modelling was undertaken by the project team.

2.2 Input Datasets

(Daly M., Searle R., Hateley L. and Pitt G.)

The application of the latest input datasets was an important and major component of the STM project. These datasets included new digital elevation models (DEM's), landuse coverages and hydrologic and soils information, amongst other layers. The purpose of this section is to show the input datasets that were used across all NRM regions. Unique datasets are reported in the regional volumes.

2.2.1 Digital elevation model

A digital elevation model (DEM) is a continuous surface representing terrain elevation as evenly-spaced grid cells. Several topographic attributes, including the stream network and subcatchment definition, are derived from a catchment's DEM by SedNet.

Different resolution DEM's were applied across the NRM regions (Table 1.1) due to a variety of factors. This was acceptable because the modelled outputs could still support target setting in that region, as long as a consistent DEM was applied to a region. The factors impacting on the DEM's included synchronisation with RWQPP timelines, availability of higher resolution DEM's and the impact of higher resolution DEM's on SedNet computational time, which meant that model runs could not be performed in a reasonable timeframe. A number of small coastal streams draining directly to the coast were not defined in the river network, because they were smaller than the model threshold, and therefore not modelled.

Table 1.1 Details of DEM's and catchment boundaries for each NRM region

NRM region	DEM Resolution	Catchment Boundary
Far North Queensland	100 m	FNQ NRMW Boundary
Burdekin	250 m	Burdekin NRMW Boundary
Fitzroy	250 m	Hydrologically derived from the 9 second v2 DEM
Mackay Whitsunday	25 m	Hydrologically derived from the NRMW 25 m Mackay Whitsunday Preliminary DEM
Burnett Mary (Burnett)	100 m	Hydrologically derived from the NRMW 25 m Burnett River Catchment DEM
Burnett Mary (Kolan, Baffle, Burrum)	25 m	Hydrologically derived from the NRMW 25 m South East Queensland DEM
Burnett Mary (Mary)	50 m	

Specific details for each of the NRM regions follows:

2.2.1.1 FNQ region

The region was modelled using the NRMW 25 m FNQ NRM region DEM. The DEM was generated using ANUDEM 4.6.2 from contour and drainage data scanned from AUSLIG 1:100,000 scale mapsheets, consisting of mostly 20 m contours, with 40 m contours covering the remainder. Due to SedNet input file size limitations, the 25 m DEM was resampled to 100 m cell size using ESRI ArcMap's Spatial Analyst extension.

2.2.1.2 Mackay Whitsunday region – Proserpine, O'Connell, Pioneer and Plane catchments

These were modelled using the NRMW 25 m Mackay Whitsunday DEM. The DEM was generated using ANUDEM 4.6.2 from contour and drainage data scanned from AUSLIG 1:100,000 scale mapsheets, consisting of mostly 20 m contours, with 40 m contours covering the remainder. Errors in drainage direction existed due to the DEM's preliminary nature.

2.2.1.3 Burdekin and Fitzroy NAP catchments

The GEODATA 9 Second DEM Version 2, produced under a co-operative effort by the (former) Australian Surveying and Land Information Group (AUSLIG), the Australian Geological Survey Organisation (AGSO) and the Australia National University's Centre for Resource and Environmental Studies (CRES), was used. The DEM was derived from a combination of spot heights from the AUSLIG GEODATA TOPO-250k Relief theme, watercourse features from the GEODATA TOPO-250k Hydrography theme, coastline from the GEODATA COAST-100k theme, coastal inlets from the GEODATA TOPO-250k theme, radar altimeter spot heights from the National Geodetic Data Base Spot Heights, and topographic information digitised from 1:100,000 scale map sheets. The DEM was generated using ANUDEM v5.0, developed by Dr Mike Hutchinson of CRES. The DEM was reprojected using ESRI ArcMap from GDA94 geographic coordinates to a GDA94 Albers conical equal area coordinate system. DEM cell size was resampled from 9 seconds to 250 metres during this process.

2.2.1.4 Burnett NAP catchment

The NRMW 25 m Burnett River Catchment DEM was utilised. The DEM was generated using ANUDEM v4.6.2 from contour and drainage data scanned from AUSLIG 1:100,000 scale mapsheets, consisting of mostly 20 m contours, with 40 m contours covering the remainder. Due to SedNet input file size limitations, the DEM was resampled to 100 m cell size using ESRI ArcMap's Spatial Analyst extension.

2.2.1.5 Burnett Mary region – Mary, Baffle, Kolan and Burrum catchments

The NRMW 25 m South East Queensland DEM was used. The DEM was generated using ANUDEM v4.6.2 from contour and drainage data scanned from AUSLIG 1:100,000 scale mapsheets, consisting of a mixture of 20 m and 40 m contours, with 5 m and 10 m contours utilised in some places. Due to SedNet input file size limitations, the DEM used for modelling the Mary catchment was resampled to 50 m cell size using ESRI ArcMap's Spatial Analyst extension.

2.2.2 Riparian vegetation

The proportion of riparian vegetation along each stream link affects the rate of bank erosion. SedNet calculates this proportion by averaging the amount of vegetation present in the riparian zone for each subcatchment. The Statewide Landcover and Trees Study (SLATS) Derived 2001 v8 25 m landcover dataset was used to generate riparian vegetation data. The data is derived from Landsat TM satellite imagery acquired by Geoscience Australia with a nominal ground resolution of 30 m. The dataset was re-projected and mosiacked from separate UTM Zone 54, 55 and 56 datasets to a single GDA94 Albers conical equal area projection. Foliage Projective Cover (FPC) was derived from the imagery (Goulevitch et. al., 2002) and image pixels with a FPC of greater than 20 percent were considered to be remnant vegetation. A buffer was applied either side of stream lines and the proportion of remnant riparian vegetation was calculated within the buffer. The landcover was then reclassified into a Boolean dataset representing the proportion of vegetation. Woody vegetation, regrowth and orchards was classified as one and pasture (<12% foliage percentage cover) crops, settlements, or bare areas were classified as zero (Table 1.2). Values of zero represented areas of degraded vegetation, with values of one representing healthy vegetation. Water and unclassified areas were represented by null values.

Table 1.2 Classification of riparian vegetation for different landuses in GBR catchments

SLATS 2001 Landcover Codes	SedNet Riparian Vegetation Reclass
1: Unclassified (cloud, fire, smoke, cloud shadow, smoke shadow, hill shadow)	NULL
2: Pasture (includes tree and shrub vegetation < 12% FPC)	0
3: Crop (irrigated pasture, forage crops, miscellaneous cropping fields)	0
4: Crop – Sugar	0
5: Crop – Broadacre: sorghum, wheat, cotton, etc	0
6: Crop – Horticulture	0
7: Settlement (> 200 population)	0
8: Bare	0
9: Bare – Mine	0
10: Bare – Scald	0
11: Bare – Rock	0
12: Bare – Infrastructure (roads, railways, isolated buildings)	0
13: Water	NULL
14: Woody Vegetation (WV)	1
15: WV – Plantation (Note! This category is not yet used)	0
16: WV – Orchard	0
17: WV – Native Vegetation	1
18: WV - Regrowth 88-91	1
19: WV – Regrowth 91-95	1
20: WV – Regrowth 95-97	1
21: WV – Regrowth 97-99	1
22: WV – Regrowth 99-01	1

2.2.3 Landuse

A state-wide landuse data set was obtained from NRMW, Queensland Land Use Mapping Project (QLUMP). The data set was classified using the Australian Land Use and Management classification (ALUM) Version 5 Feb 2002, and depicts 1999 landuse at nominal scales of 1:50,000 and 1:100,000, depending on the intensity of landuse. The ALUM classification emphasises delineation of the levels and types of landscape intervention, as opposed to landuse descriptions based on outputs. A three level classification hierarchy is employed (primary, secondary and tertiary). Primary and secondary classifications relate to the prime use of the land in terms of management objectives. Tertiary classifications may include data on commodities, land management practices or vegetation information (Bureau of Regional Sciences, 2002). The landuse data was used to derive separate C-factor layers for each catchment as part of the Revised Universal Soil Loss Equation (RUSLE) data set used to estimate the amount of hillslope erosion in the SedNet model. The application of landuse data in each region is further described in the regional chapters.

2.2.4 Potential evapo-transpiration (PET):Rainfall ratio

The PET-Rainfall ratio dataset is used by SedNet to calculate the mean upstream PET-Rainfall ratio upstream of each stream link. The PET-Rainfall layer from Brodie *et al.* (2003) was used. This dataset was derived from the Mean Annual Potential Evapo-Transpiration National Land and Water Resources Audit (NLWRA) dataset, created using the Priestly-Taylor method, and a 5 km resolution mean annual rainfall grid sourced from Bureau of Meteorology SILO data.

2.2.5 Gully density

Gully erosion was calculated from the gully density dataset from Brodie *et al.* (2003), sourced from the NLWRA dataset 'Erosion Gully Density'. Gully density was modelled using aerial photograph interpretation in combination with climatic, relief, soil and landuse variables. Detailed methods can be found in Hughes *et al.* (2001).

2.2.6 Mean annual rainfall

The mean annual rainfall data layer is used by SedNet to calculate the average rainfall over the catchment upstream of each link. The mean annual rainfall dataset from Brodie *et al.* (2003) was used, sourced from the NLWRA dataset 'Mean Annual Rainfall (mm)' for the period 1980 to 1999. The data was a temporal average over 20 years (1980 to 1999) of daily data at 0.05 degrees spatial resolution, supplied by Department of Natural Resources Mines and Water. Prior to temporal averaging, the data was resampled to 0.025 degrees resolution using a linear-weighted average of the surrounding four cells. A multiplier of 100, used to improve accuracy as an integer grid, was removed in order to ensure an input layer of mm/yr.

2.2.7 Lakes

The SedNet model uses shapefiles to represent lakes within the stream link network in order to model depositional processes. The lakes dataset from Brodie *et al.* (2003) was used for this modelling exercise.

2.2.8 Reservoirs

Similar to lake data, reservoir shapefiles are used to represent depositional processes within the stream link network. The reservoir dataset from Brodie *et al.* (2003) was used as a base dataset. Where further reservoir features were required, missing data was sourced from the NRMW 1:100,000 scale dataset 'QLD_DAMLAKE_100K'. This dataset stores the location of departmental dams and natural lakes. Capacity in gigalitres sourced from the Australian Water Resources Assessment (2000) national point coverage of flow control structures higher than 10 m, was appended to each reservoir. Where reservoir capacities were unavailable, the NRMW layer 'DAMWEIREXIST_100K_P' was used where possible. This dataset stores information regarding the location of existing dams, weirs and barrages controlled by NRMW.

2.2.9 Stream-flow time series

Stream-flow time series data was extracted from the NRMW Hydstra surface water database (NRMW 2005). Flow data for gauging stations with contiguous data for periods ten years and above was extracted on 26th April 2005. Flow data was extracted in megalitres per day.

2.2.10 Floodplain extent

Floodplain extent data originally created for the NLWRA, and as used in Brodie *et al.* (2003), was used by SedNet for the calculation of floodplain deposition. Floodplain extents were mapped from the GEODATA 9 Second DEM, and represent an assessment of floodplain extents at a discharge equivalent to the 1 in 25 year flood annual series. A detailed description of methodology is available in Pickup & Marks (2001).

2.2.11 Catchment boundaries

In each case, model input data was clipped to conform to an appropriate catchment boundary, based on the requirements of the catchment's modelling team). The majority of boundaries used were hydrological boundaries derived from the DEM using ArcINFO. The following procedure was used in this process:

- ArcINFO Fill command run to pitfill sinks in input DEM.
- ArcINFO FlowDirection command run on input depressionless DEM (obtained from first step) to obtain D8 flow direction raster.
- ArcINFO Basin command run on input flow direction raster (obtained from second step).
- The resulting basin grid converted to polygon shapefile.
- Spatial selection performed to group all basins where centroids fall within the specific drainage basin defined by the Australian Water Resources Management Committee (WRMC). WRMC drainage boundaries were captured at 1:100,000 scale and were supplied in the NRMW dataset 'Queensland Drainage Basins – QLD_DRNBASIN_100k'.
- The resulting collection of basins for each catchment merged and dissolved to define the modelling boundary for that catchment.

The remainder of the catchments used the Natural Resource Management regional boundaries, obtained from the NRMW dataset 'Queensland Natural Resource Management Regional Boundaries – QLD_NRMWREGBDY_100K'.

2.2.12 Projection information

All spatial datasets used in this modelling exercise used the GDA94 Albers conical equal area coordinate system. Datasets supplied in alternative co-ordinate systems were reprojected in ArcMap 9.0 using the following projection details:

Map Projection Name: Albers Conical Equal Area
Standard Parallel: -13.166667
Standard Parallel: -25.833333
Longitude of Central Meridian: 146.000000
Latitude of Projection Origin: 0.000000
False Easting: 0.000000
False Northing: 0.000000

Planar Coordinate Information
Planar Distance Units: meters
Coordinate Encoding Method: row and column

Geodetic Model
Horizontal Datum Name: D_GDA_1994
Ellipsoid Name: Geodetic Reference System 80
Semi-major Axis: 6378137.000000
Denominator of Flattening Ratio: 298.257222

Discrete grid data was resampled using the Nearest Neighbour assignment technique, while continuous grid data was resampled using the Cubic Convolution technique.

2.2.13 Data storage

All input datasets are stored on the Eclipse server at the NRMW, NRSc site in Brisbane.

All output datasets are stored on the Eclipse server at theNRMW, NRSc site in Brisbane.

2.3 Sediment Modelling

(Searle R., Hateley L., Sherman B.S. and Packett R.)

Sediment and nutrient budgets for the GBR catchments were modelled using the long term annual average SedNet model (Wilkinson *et al.*, 2004). SedNet was originally a set of routines that ran within a GIS program developed for the NLWRA (Prosser *et al.* 2001). In recent years these routines have been ported into The Invisible Modelling Framework (TIME) (Rahman *et al.* 2003, Murray *et al.*, 2004) and developed as a standalone executable program. This latter version was used for the STM project. Previous reports (e.g. Prosser *et al.* 2001, Brodie *et al.* 2003) have provided details on SedNet and we will summarise some of the methods from those reports for the project report. It is important to appreciate that SedNet provides long term annual average estimates and does not represent episodic or short term events.

For sediment budgets, the SedNet model (Fig. 1.2) requires mapping of soil erosion on land and the density of gullies in the landscape. The model calculates the rate of riverbank erosion. These three sediment sources are the inputs of sediment to the river network. Not all soil eroded on land is delivered to streams. Much of it travels only a few metres or is deposited on slopes, behind structures, or in areas of good vegetation (ground) cover. The reduction in soil erosion when moving from a plot-scale to small catchment scale is represented through a hillslope sediment delivery ratio. Once delivered to streams, sediment is routed through the river network accounting for losses to floodplain, riverbed and reservoir deposition along the way. A summary of the methods applied to the sediment budgets is given below and a discussion of assumptions and uncertainty is provided later in section 2.5. A comprehensive description of the modelling algorithms and concepts is available (Wilkinson *et al.* 2004).

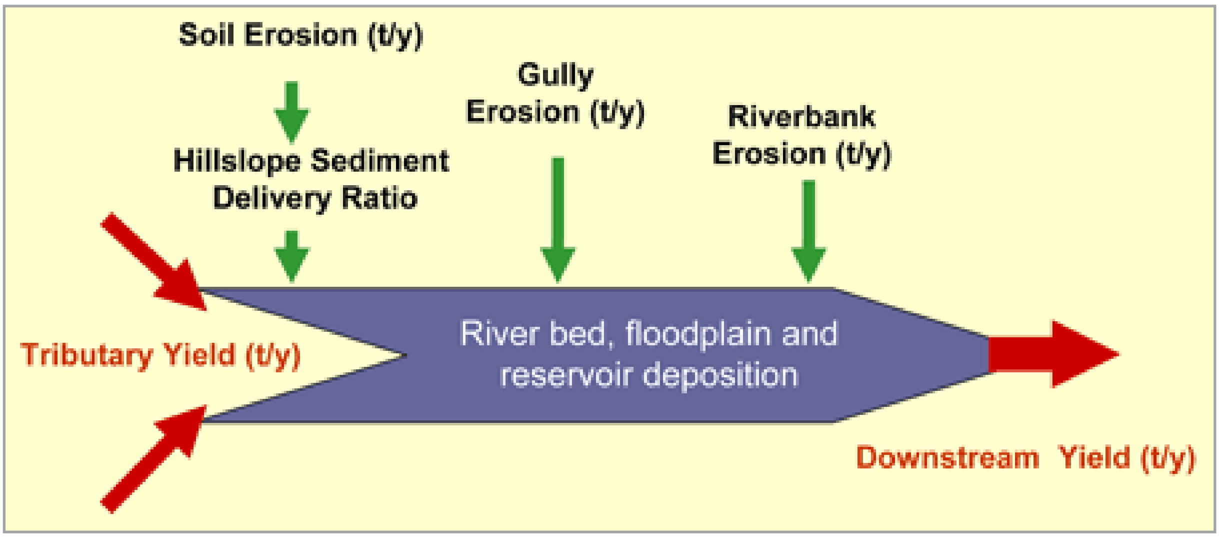

Figure 1.2 Conceptual diagram of the SedNet river sediment budget for one river link

2.3.1 Hillslope erosion

Hillslope erosion from sheet and rill erosion processes is estimated using the revised universal soil loss equation (RUSLE: Renard *et al.* 1997). A newer and more accurate method for calculating the effect of slope steepness and slope length devised by Rosewell (1993) is used in SedNet. The equation takes the form:

A = R x K x L x S x C x P

where,

A is the annual average soil loss (t/ha/yr),
R is the rainfall erosivity factor (MJ mm ha/hr/yr), a measure of the erosive power of the rain,
K is the soil erodibility factor, a measure of the resistance of soil to erosion,
L is the slope length factor,
S is the slope steepness factor,
C is the crop and cover management factor,
P is the support practice factor, a measure of the effect on erosion of soil conservation measures such as contour cultivation and bank systems (Rosewell, 1993).

In order to represent the model spatially, each of the terms in the equation is generated as a raster surface and combined in GIS. The method described by Lu *et al.* (2001) with a number of minor modifications, outlined below, was used to generate each of the component layers.

2.3.1.1 Rainfall erosivity (R)

Rainfall erosivity is defined as the mean annual sum of individual storm erosion index values, EI30, where E is the total storm kinetic energy and I30 is the maximum 30 minute rainfall intensity (Lu *et al.*, 2001).

This surface was generated using the methods described by Yu and Rosewell (1996), in a similar way to the National Land and Water Resource Audit. The rainfall erosivity was calculated at 0.05 degree (approx. 5 km) resolution using daily rainfall data obtained from the SILO database (NRMW) and the final result was re-gridded to 9" (approx 250 m) resolution. This R factor surface was calculated using rainfall data from 1915 to 2001, where-as the Audit used a much shorter period (1980 to 1999). The longer rainfall data set, along with incremental improvements the Silo daily rainfall product, should result in a rainfall erosivity surface which is more representative of Queensland climatology than the surface used in the Audit (pers comm. David Rayner, NRMW).

2.3.1.2 Soil erodibility (K)

Soil erodibility is the average soil loss per unit area for a particular soil in cultivated, continuous fallow with an arbitrarily selected slope length of 22 m and slope steepness of 9%. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute.

The K factor was estimated from an established relationship with A horizon soil texture, soil clay content and the saturated hydraulic conductivity of the A horizon (Lu *et al.*, 2001), as for the NLWRA. In some regions, a new K factor was used based on the latest information (see Regional Volumes)

These soil properties were derived from the mapping of the Australian Soil Resource Information System (Henderson *et al.*, 2001) using the best available soils mapping.

2.3.1.3 Slope steepness (S)

The slope steepness factor is defined as the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions. The slope steepness factor is calculated using the equations:

$$S = 10.8 \times \sin\theta + 0.03\sigma \leq 9\%$$
$$S = 16.8 \times \sin\theta + 0.03\sigma > 9\%$$

where θ is the angle of slope and is the slope gradient in percentage (McCool *et al.*, 1989).

The slope values are generated from the digital elevation models (DEMs) using the standard ArcGIS (ESRI, Redlands) algorithm. The finest scale DEM available in each region was used for slope calculation.

2.3.1.4 Slope length (L)

The slope length factor is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff water enters a well defined channel that may be part of a drainage network.

The slope length factor is evaluated using the equations in the RUSLE (McCool *et al.*, 1989). The slope length component of the slope length factor is calculated from the DEM using the drainage network as the slope length cut off point. The ArcGIS flow path length algorithm was used to generate the surface. The maximum flow length valid in the RUSLE is 300 metres. This was set as the upper limit for the flow length raster.

The slope length factor was set to 1 for all landuses except cropping as described in Lu *et al.* (2001).

2.3.1.5 Crop and cover management (C)

The crop and cover management factor is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land.

For this project the C factor was considered to be landuse specific. The Queensland Land Use Mapping Program (QLUMP, 2004) data was used as the basis for the landuse classification. Landuses were grouped up and C values assigned from a review of the literature, using locally determined values where possible, and also taking into account local land management techniques. Regionally specific C values are listed in each regional chapter.

2.3.1.6 Support practice factor (P)

The support practice factor reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. The most common locally used supporting cropland practices are cross slope cultivation, contour farming and contour banks.

It was considered that there was insufficient information available to apply P factors to within the study area. Therefore P was set to a standard value of 1 in all regions.

2.3.1.7 Annual average erosion surface

The final annual average erosion surface was generated by multiplying each of the individual raster input layers together as depicted in figure 1.3. The value generated for each cell is the expected long term annual average sheet and rill erosion rate in t/ha/yr). This surface is used as the hillslope erosion input for SedNet.

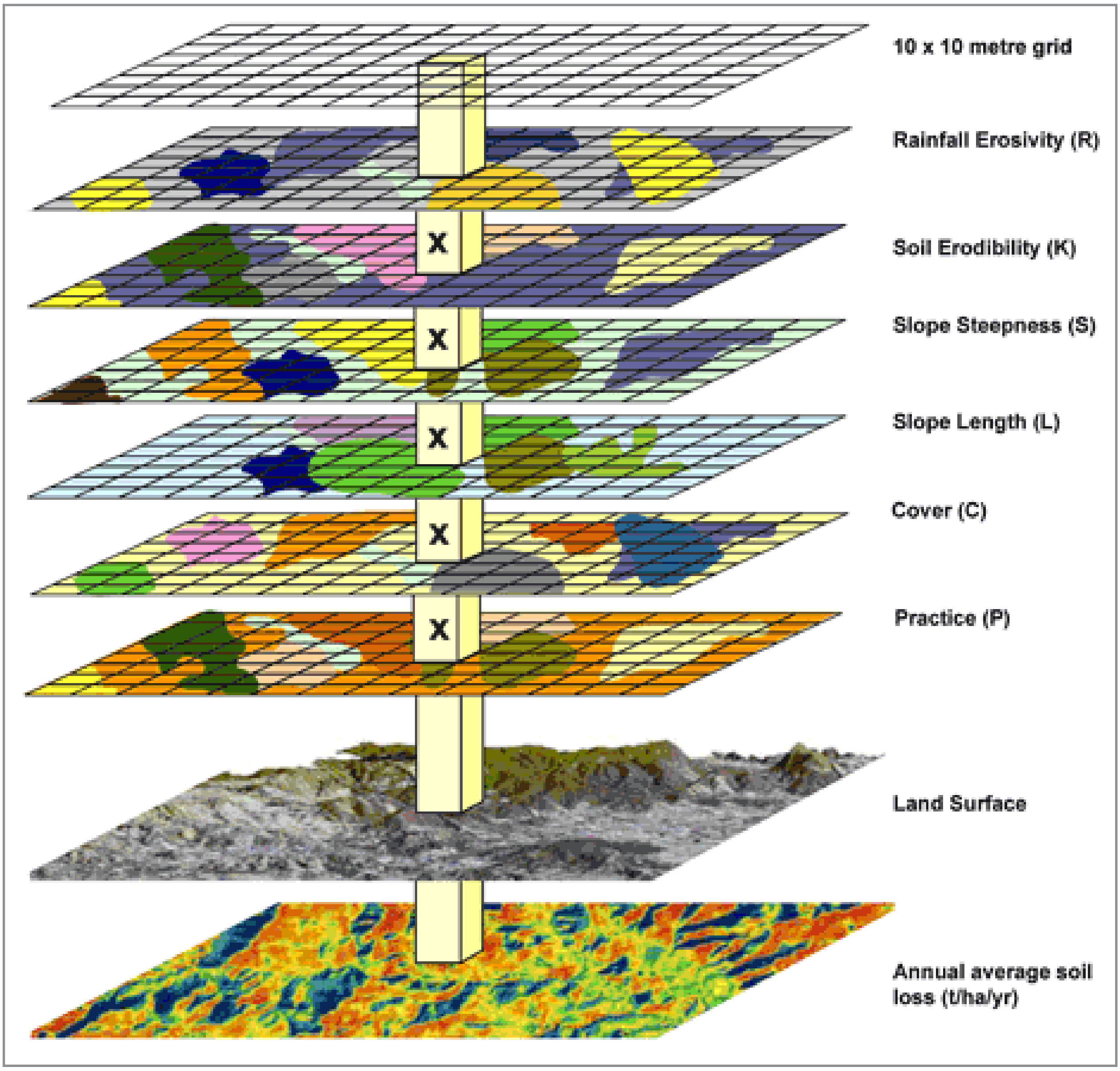

Figure 1.3 Schematic representation of how the annual average soil loss

2.3.2 Gully erosion

The gully erosion data used in this project was sourced from the NLWRA. A full description of the methods used to predict gully erosion can be found in Hughes *et al.* (2001). In brief, gully density (km of gully per km² of land) was determined by mapping the extent of gullies from a sample of aerial photographs. The data derived from the aerial photographs was then used in association with various environmental variables (e.g. landuse, soil texture, geology relief and various climatic indices) to construct a model of gully density for the entire region. The model was based on multivariate statistical analysis conducted using the Cubist data mining tool (version 1.08; Rulequest Research, 2002). Cubist generates models that are expressed as collections of rules, where each rule has an associated multivariate linear model. Whenever a situation matches a rule's conditions, the associated model is used to calculate a predicted value, thus a Cubist model resembles a piecewise linear regression model (except that the rules can overlap; Rulequest Research, 2002).

Gully density was converted into a soil erosion rate by considering the volume of soil removed to form a gully and its approximate age. From available studies it was found that gullies have an average cross-sectional area of 10 m². One kilometre of gully would then produce 10,000 cubic metres (approximately 15,000 t) of sediment per km² of land. If that was eroded over a typical gully age of 100 years, the mean annual rate of erosion would be 1.5 t/ha/yr.

2.3.3 Bank erosion

Bank erosion (BE) for a given link in the stream network (BEx) is calculated in SedNet using the equation;

$$BEx = \text{Coefficient} \times \text{BF} \times (1 - \text{PR}) \times (\text{Floodplain Factor})$$

where bank full stream power (BF) is calculated as,

$$\text{BF} = \rho \times g \times Q_{bf} \times S_x$$

where ρ is the density of water, g the acceleration due to gravity, Q_{bf} the bankfull discharge and S_x the slope of the channel. S_x is a topographic attribute derived from the DEM. PR is the proportion of remnant riparian vegetation and Floodplain Factor represents the floodplain width.

The mass of sediment supplied to the link B_x is the product of the bank erosion rate (m/yr), the length of the link (L_x, km), calculated from the DEM, bank height (h) with a minimum link length of 1 km, sediment bulk density (p_s, tm^3) set to the default 1.5 and P_b, the proportion of bank erosion that contributed to bedload set to the default 0.5.

The default setting for bank height is 3 m, which can be applied globally to the stream network. An option in the TIME version of SedNet is to apply a simulated variable bank height to the stream network based on a regression that relates observed bank heights to contributing area. The coefficient and exponent values are then used to generate a variable bank height for links in the stream network. Variable bank height simulations based on the above method were completed for a number of catchments (see regional volumes). Fixed bank heights for other catchments were either derived from the results of the simulations as described or were left with the default value.

2.3.4 Defining the river network and associated catchments

SedNet divides the river network into a set of links, which are the basic unit of calculation for the sediment and nutrient budgets. A link is the stretch of river between adjacent stream junctions (or nodes). Each link has an internal subcatchment, which is the catchment area added to the link between its upper and lower nodes (Fig. 1.4). For the purpose of the model, the internal catchment area of first order streams is the entire catchment area of the river link.

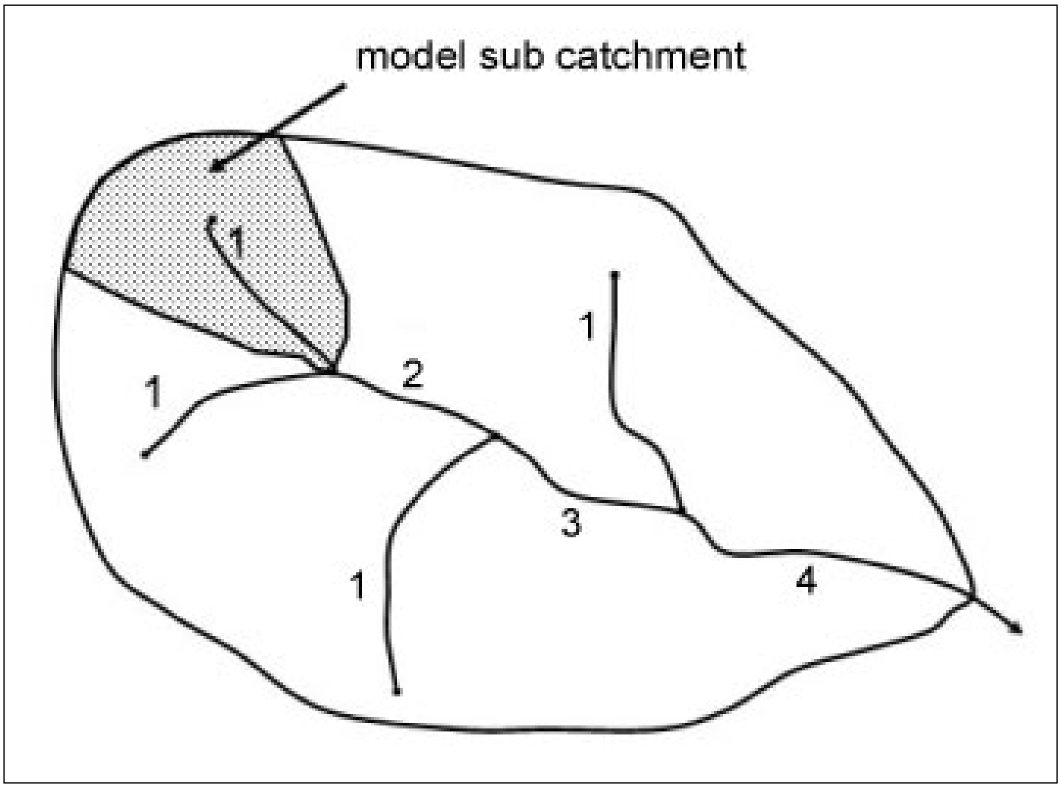

Figure 1.4 A river network showing links, nodes, stream ordering and internal catchment area of an order one and an order four link (from Wilkinson *et al.* 2004)

A DEM is used by SedNet to generate the node link network. The DEMs for the project were developed from digital contour mapping and drainage supplied by NRMW. Both contour and drainage vector coverages were originally digitised from aerial photography using standard photogrammetric techniques. Contour height attributes were checked and drainage lines were edited so that all arcs were pointing downstream. The drainage lines were also edited to produce a continuous network draining to a single outlet for each catchment.

2.3.5 River sediment budgets

Hillslope, gully and bank erosion supply sediment to each link of the river network. The RUSLE hillslope erosion surface predicts the amount of fine sediment that is mobilised from a hillslope but only a small proportion of this is actually delivered to the stream network. Much of the fine sediment moving across a hillslope is trapped by the landscape or redeposited before it reaches the stream network. This process is accounted for in the model by the application of a hillslope sediment delivery ratio (HSDR) to the RUSLE surface. A HSDR of 10% was used in this project.

Sediment supplied to the streams 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 mouth, 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 load sediment are dealt with separately in the model. Gully and bank erosion supply 50 % of their sediment to the bedload budget and 50 % to the suspended load budget. Soil erosion (Hillslope) is only supplied to the suspended load budget. The vast bulk of the bedload budget is typically deposited within river networks and is not exported. Bedload deposition is modelled by comparing load with sediment transport capacity (Prosser *et al.,* 2001).

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 so that sediment yields are limited by the amount of sediment delivered to the streams, not discharge of the river itself. Consequently, if sediment delivery increases, sediment yield increases proportionally.

Deposition of suspended sediment becomes significant when flows spread onto floodplains or enter reservoirs, both dramatically reducing the velocity of flow. 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 ample opportunity for deposition. It is assumed that suspended sediment is relatively evenly distributed through the water column. The precise equation for floodplain deposition is given by Prosser *et al.* (2001). 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).

2.3.6 Contribution of sediment to the coast

One of the main reasons for wanting to model sediment budgets in catchments is to determine what parts of the landscape are producing sediment that impacts coastal ecosystems. If these sediments are negatively affecting these ecosystems, it important to be able to implement management strategies to reduce these impacts. Understanding the spatial distribution of these source areas is critical in prioritising the application of limited resources to address these issues. Not all sediment that is generated within a catchment makes it to the coast. Depending on the characteristics of any given catchment, there is opportunity for deposition within the catchment and remobilisation over time. One of the strengths of the SedNet model is its ability to spatially describe where sediments affecting the coast are sourced.

The contribution of each subcatchment to the mean annual suspended sediment export from the river basin was calculated using the Contributor module. A major part of this particular project was the porting of the AML (ESRI, Redlands) version of the contributor module to the stand alone TIME version of SedNet.

2.3.7 Hydrology

SedNet incorporates a number of hydrological parameters into the calculation of river sediment budgets. These are used for calculations of patterns of deposition, river bank erosion, and denitrification. The parameters need to be predicted (interpolated) for each river link across the river basin, based upon observations at hydrological gauging stations within the region. The variables used are:

- the mean annual flow (Q_a)
- the bankfull flow (Q_{bf}); and
- a representative flood discharge for floodplain deposition (in this case median overbank flow – Q_{ob})

Values for these variables were derived from times series of daily flows at river gauging stations (NRMW, 2005) with more than 20 years of good quality flow record and no regulation. Details of the methods used to calculate these values are described in Wilkinson *et al.* (2004) and are summarised below.

The mean annual flow (MAF) is a function of catchment area (A, km^2), mean annual rainfall (RF, mm) and a mean annual runoff coefficient (ROC).

$$MAF = ROC \times RF \times A$$

The mean annual runoff coefficient (ROC) or "dryness index" is a function of the ratio of the potential evaporation (PET, mm) to the mean annual rainfall (RF, mm). The relationship derived from these values at the gauges is then used to calculate the MAF for each link in the model.

The bankfull flow is specified as the flow having a certain recurrence interval on the annual maximum series. This is the average interval between years in which a given discharge is exceeded (Wilkinson *et al.*, 2004). A default value of 2.5 years is used for the bankfull recurrence interval. Evidence suggests that for south eastern Australian coastal catchments a recurrence interval of 4 to 7 years is appropriate (Wilkinson *et al.*, 2004). Given the different hydrologic regimes experienced in coastal Queensland catchments an analysis of local data was undertaken. Recurrence intervals were calculated for representative catchments by inspecting cross section and discharge data at a number of gauging stations. Revised recurrence intervals were then applied using both local hydrological knowledge and historical data for the modelled catchments. Details of variable bank height simulations and recurrence intervals are given in the respective regional chapters.

Median overbank flow (Q_{ob}) is used to calculate floodplain sediment deposition and is the median of the time series of daily flows.

2.4 Nutrient Modelling

(Sherman B.S., Read A., Chen Y. and Brodie J.)

Nutrient loads can be calculated using the model ANNEX (Annual Nutrient Export). ANNEX calculates particulate and dissolved nutrients explicitly as they vary in their biological availability and according to different time scales. Particulate nutrient loads originate with hillslope, gully and bank erosion. Dissolved nutrient loads arise from both point sources such as sewage treatment plants and distributed sources such as fertilised croplands.

ANNEX is not a stand-alone nutrient model: it must be used in conjunction with SedNet, which provides estimates of suspended sediment loads. A basic conceptual model illustrating the linkages between SedNet and ANNEX is shown in figure 1.5. The following sections describe in greater detail how ANNEX computes these loads and highlights modifications made to the model for its implementation in this project.

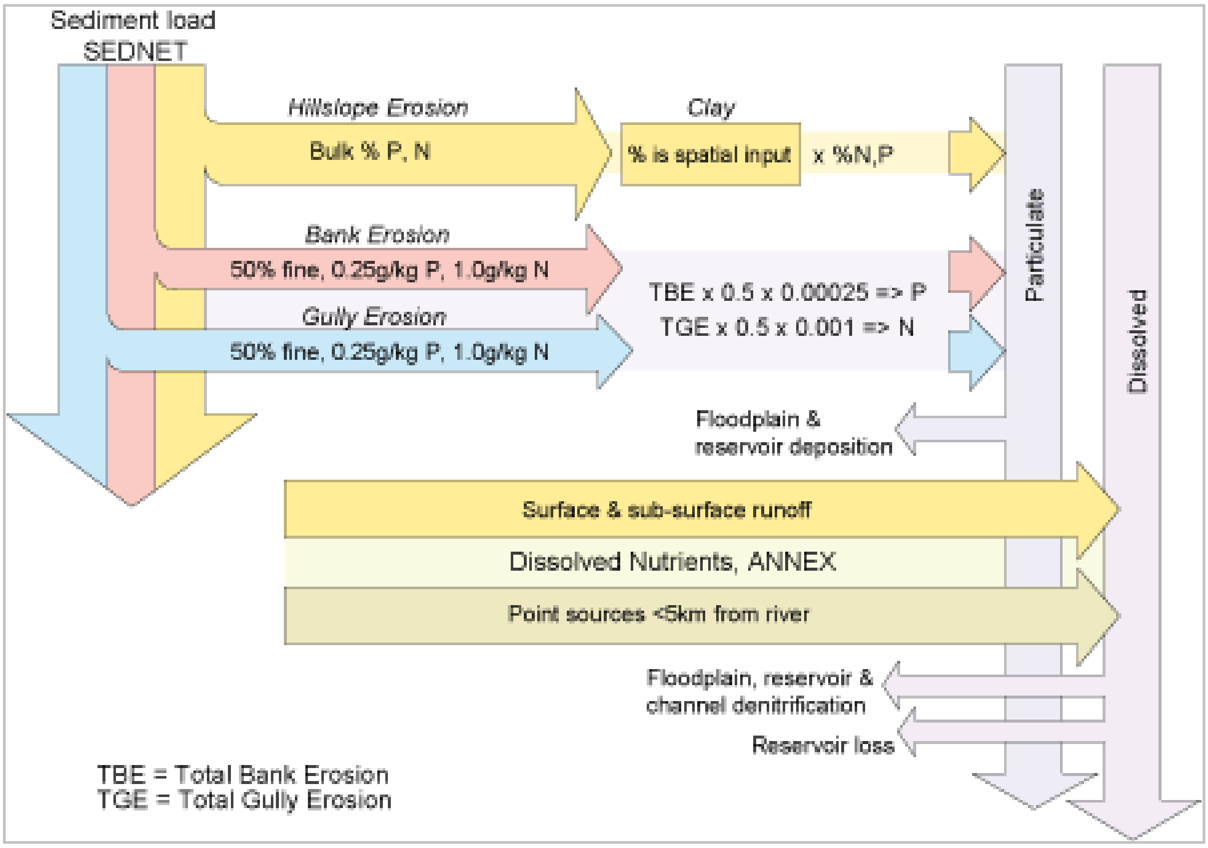

Figure 1.5 Conceptual model of ANNEX nutrient loads

2.4.1 Particulate nutrient loads – how sediment is mapped into nutrient loads

ANNEX maps the mean annual sediment loads predicted by SedNet into mean annual nutrient loads in two ways, depending on whether the sediment originates in topsoil due to hillslope erosion or subsoil due to bank and gully erosion. The basic concepts and equations used by ANNEX are described in detail by Young *et al.* (2001) and only a review of the methodology is presented here with attention

being drawn to modifications to the model introduced since 2001.
Bank and gully erosion are assumed to supply subsoils only. The subsoil is assumed to consist of 50% fine and 50% coarse material, and all nitrogen and phosphorus are assumed to be bound to the fine fraction. All previous applications of ANNEX have used the default assumption that the phosphorus content of subsoils is fixed at 0.25 g P kg^{-1} (0.025% P by weight) and nitrogen is fixed at 1 g N kg^{-1} (0.1% N by weight). Although it is possible to accommodate spatially variable subsoil nutrient contents in the model, in practice this has not been done due mainly to limited availability of field data to parameterise the model and the fact that, on average, the assumed concentrations are quite representative.

A check on the validity of the subsoil nutrient content assumption has been conducted recently for Queensland. Interrogation of more than 3000 soil profiles in the Queensland SALI database show TP content in samples below a depth of 0.3 m ranging from 0.001 - 0.72 % with a mean of 0.025%. Subsoil nitrogen content ranged from 0.007 - 0.16% with a mean of 0.032% over 211 profiles in the database. This suggests that applications in Queensland are expected to predict subsoil P loads well on average whereas they may overestimate the nitrogen load arising from bank and gully erosion (bearing in mind the limited spatial coverage afforded by such a small sample population).

The amount of particulate nutrient mobilised by erosion is equal to the total sediment generated multiplied by a spatially variable bulk soil nutrient concentration. The particulate nutrients are assumed to be bound exclusively to the clay fraction of the sediment. Both the bulk nutrient content and clay fraction are spatially variable soil properties and are taken from the mapping of Australia by Henderson *et al.* (2001) and contained in the ASRIS data base created for the Land and Water Resources Audit. The amount of nutrient delivered to the stream channel may differ from the amount initially mobilised should any of the fine particulate load be deposited during overland transport. Because it remains in suspension more easily than coarser sediments, the clay fraction is preferentially transported to the stream channel. The hillslope delivery ratio used by SedNet determines the fraction of the total eroded soil that reaches the stream channel and should it be less than the clay fraction, the nutrient content of the sediment reaching the channel is enriched.

Soil nutrient and clay content are among the most uncertain input data required by ANNEX (or any other catchment nutrient load model). Direct measurements of soil nutrient content are sparse throughout most of the GBR catchments. Most studies of soil properties have tended to be undertaken in regions subject to intensive agricultural development and vast tracts have never been measured. The ASRIS data base was derived from correlations between soil properties and other landscape and climate features and provides the uniform spatial coverage required by catchment models. The correlation coefficients, r^2, of the ASRIS relations for total phosphorus and clay content were 0.62 and 0.22, respectively (Henderson *et al.* 2001).

A comparison between the available observed surface soil nutrient data contained in SALI and the derived values in ASRIS revealed a low bias in the ASRIS data (Table 1.3). While median values of SALI:ASRIS nutrient contents compared reasonably well (P_{SALI}:P_{ASRIS} = 1.14, N_{SALI}:N_{ASRIS} = 1.04) the mean values and standard deviations of these ratios highlight the highly variable nature of the relation. A similar comparison was undertaken with roughly 100 soil samples collected by CSIRO (as part of another project) throughout the Fitzroy catchment with the result that the directly measured samples contained on average more than 2.4 times as much phosphorus as indicated by the ASRIS data base. No spatial trends in the ratios were evident. The implication of this finding is that spatial patterns of particulate nutrient load generation and export should be interpreted cautiously. Possible implications of the poor correlation for clay content are discussed further in section 2.4.9.

Table 1.3 Ratio of measured surface (A-horizon) soil P and N content in the SALI database to values for corresponding locations in the ASRIS database

	$P_{SALI}:P_{ASRIS}$	$N_{SALI}:N_{ASRIS}$
Minimum	0.01	0.05
Maximum	41	6
Points	2809	1962
Mean	1.88	1.21
Median	1.14	1.04
Std deviation	2.76	0.75

2.4.2 Dissolved nutrient loads

ANNEX simulates dissolved nutrient loads catchments by specifying mean annual concentrations of DIN, DIP, DON and DOP for different landuse classes, C (*landuse*). In the recent application of the model to GBR catchments (Brodie *et al.* 2003), 9 distinct landuses were specified.

The concentrations of dissolved nutrients in any link (stream section) in the model is a weighted mean value based on the areas of different landuses contributing to runoff for that link. For the ith internal subcatchment comprised of n cells contributing runoff, the equation for any of the four constituents, $\bar{C}_i$ is,

$$\bar{C}_i = \frac{\sum_{n=1}^{\#\text{ of cells}} C(\text{landuse})_n \, \text{Area}_n}{\sum_{n=1}^{\#\text{ of cells}} \text{Area}_n}$$

The dissolved nutrient load contributed by the *i*th subcatchment, Load_i, is simply

$$Load = MAF_i \, \bar{C}_i$$

where MAF_i is the mean annual flow contributed by the subcatchment.

Table 1.4 lists the concentrations of the four dissolved nutrient species assumed for the nine landuse classes for which adequate field data exist in Queensland. The values used by Brodie *et al.* (2003) were adopted except where more recent field data (Bartley *et al.* 2005; Brodie *et al.* 2004, 2005; Brode and Mitchell 2005; Cogle *et al.* in press; Faithfull *et al.* 2005a, 2005 b; Faithful and Finlayson 2004; Furnas 2003; McCulloch *et al.* 2003a, 2003b; McJannet *et al.* 2005; Mitchell *et al.* 2005; O'Reagain *et al.* 2005) indicated the values should be revised. The most significant changes in the current work were:

- A large increase in DIN for sugar cane and banana plantations
- A large decrease in DIN for urban landuses
- A decrease in DON for rainforest
- A decrease in FRP for sugar cane, bananas and rainforest
- A large increase in FRP for urban landuses
- A decrease in DOP for rainforest, sugar cane, bananas and urban landuses

Table 1.4 Dissolved nutrient concentrations (µg/L) for GBR catchment landuses used by Brodie *et al.* (2003) and for this project (STM). STM values are shown as the value used. Also shown are representative upper and lower bounds for the concentrations drawn from field experiments.

Landuse	DIN		DON		FRP		DOP	
	Brodie *et al.* 2003	STM	Brodie *et al.* 2003	STM	Brodie *et al.* 2003	STM	Brodie *et al.* 2003	STM
Savannah/ woodland grazing	100-200	160 ± 40	100-250	200 ± 50	20-50	20 ± 10	10-12	10 ± 5
Rainforest	40	40 ± 20	150	80 ± 40	10	6 ± 4	10	5 ± 3
Sugar cane	900	2000^{+2000}_{-1000}	250	250 ± 50	30	10 ± 5	25	15 ± 5
Bananas	700	1100 ± 300	250	250 ± 50	100	80 ± 20	20	14 ± 5
Horticulture	500	500	200	200	30	30	20	20
Cotton	700	700	200	200	80	80	20	20
Grain	500	500	300	300	60	60	20	20
Forestry	150	150 ± 75	150	150 ± 50	8	8 ± 2	8	8 ± 2
Urban	1650	200 ± 100	300	300 ± 50	120	230 ± 100	20	10 ± 5

2.4.3 Consolidation of landuse classes for use by ANNEX

In order to determine dissolved nutrient loads, it is necessary to map existing landuses into one of the classes for which nutrient concentrations are known. For example, the Queensland landuse data base (QLUMP) considers 94 different landuse classes. There are only sufficient field data to determine dissolved nutrient concentrations for 9 landuse classes. Because of the limited data set regarding water quality downstream of different landuses it was necessary to map the 94 different landuses into the closest of the 9 classes for which it was possible to specify DIN, DIP, DON and DOP concentrations. Figure 1.6 shows the mapping used for the GBR catchments.

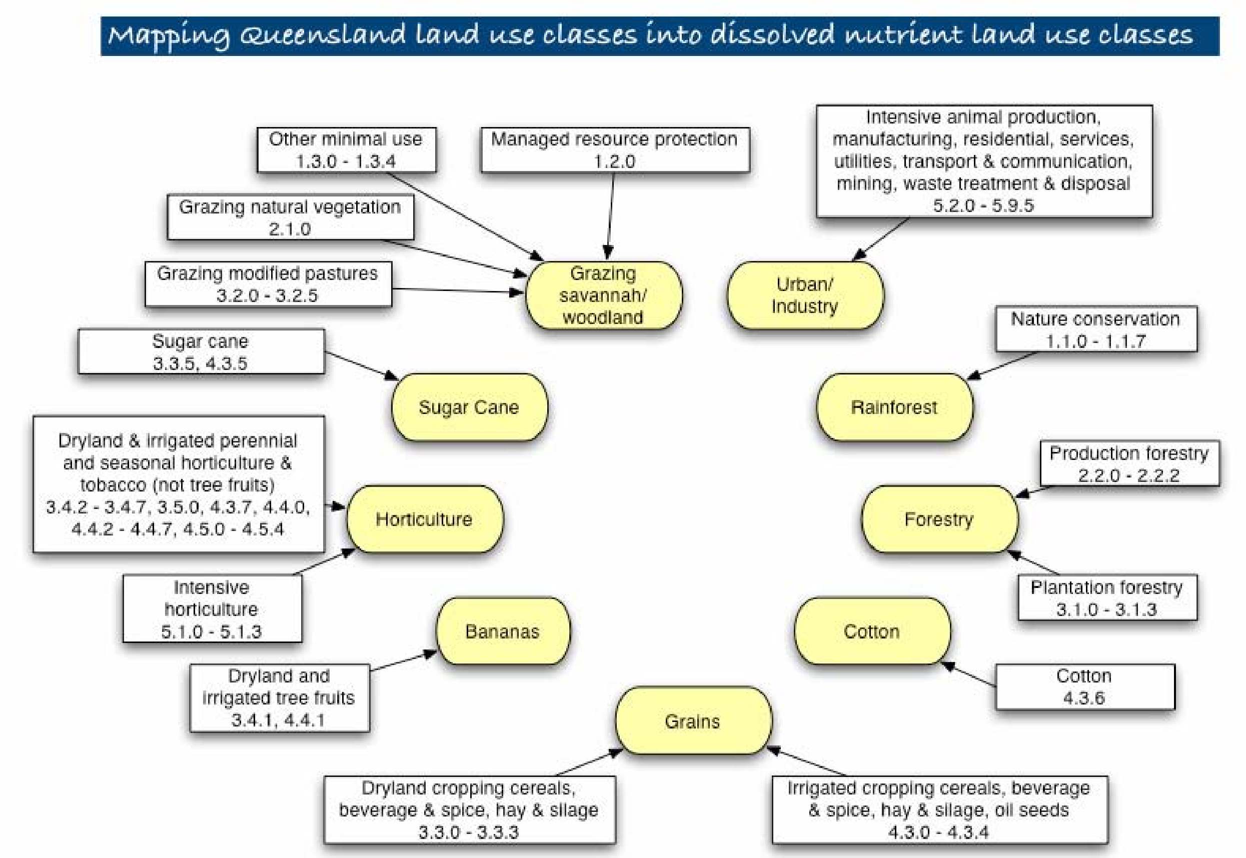

Figure 1.6 Mapping of the 94 QLUMP landuse classes into the 9 classes for which sufficient field data are available to allow specification of downstream nutrient concentrations

2.4.4 Nutrient sinks

Particulate and dissolved nutrients are lost from the system in different ways. Particulate nutrients are lost as a consequence of sediment deposition on the flood plain and in reservoirs. The amount of sediment deposited by each process is determined by SedNet for each link in the network. The amount of nutrient lost is simply the mean nutrient content of the $\overline{CP}_i$ sediment load multiplied by the amount of sediment deposited. The mean particulate nutrient concentration, , is continuously updated as one moves down the network to reflect the contributions of all upstream links to the total sediment load,

$$\overline{CP}_i = \frac{TSS_{i-1}\,CP_{i-1} + TSS_i CP_i}{TSS_{i-1} + TSS_i}$$

where i - 1 denotes the next upstream network link and TSS is the total fine suspended sediment.

A small proportion of dissolved N and P loads are lost in reservoirs. In addition, dissolved inorganic nitrogen is lost by denitrification in the river channel, on the flood plain and in reservoirs. The representation of these processes is described in more detail below.

2.4.5 Denitrification

As water moves along the river channel, over the flood plain and through reservoirs some of the dissolved inorganic nitrogen load will be lost mainly as N_2 gas due to denitrification in the sediments. Denitrification occurs in the water column as well but at a rate several orders of magnitude smaller than in the sediments (Wetzel 1983).

Strictly speaking, denitrification removes only nitrate whereas DIN includes both nitrate and ammonia. Ammonia may be lost from the water column through coupled nitrification-denitrification in which the nitrification step, which requires oxygen, converts the ammonia to nitrate which is subsequently denitrified to N_2 gas. Coupled nitrification-denitrification requires the presence of oxic and anoxic microhabitats in close proximity to one another in the sediments. Under anoxic conditions (DO < 0.3 mg L^{-1}) nitrification stops (Wetzel 1983).

ANNEX models the loss of DIN (kg) through coupled nitrification-denitrification in the river channel, on the flood plain and in reservoirs using the same functional relationship,

$$DIN_{out} = DIN_{in}\, e^{-k\,t}$$

where k is a mass transfer velocity [m s^{-1}] and t is a residence time [*s*]. The mass transfer velocity reflects the rate-limiting step (of which there are potentially many) in the coupled nitrification-denitrification process. For example, if transport across a diffusive boundary layer at the sediment-water interface was the rate-limiting step then $k = D/\delta$ where D is the diffusivity [m^2 s^{-1}] and δ is the boundary layer thickness [m]. This sort of control has been reported in systems with significant nitrate concentrations in the water overlying the sediments (Christensen *et al.* 1990).

The derivation of the denitrification equation is straightforward. For a control volume of area A and volume V and a discharge rate of Q the residence time is simply V/Q. Assuming a concentration of C in the water column and zero at the sediment sink the water sediment flux is:

$$F = kC \text{ [kg m}^{-2}\text{ s}^{-1}\text{]}$$

The change of solute mass, $V\,dC$, in the control volume during time interval dt is simply

$$V dC = AkCdt$$

where A is the surface area of the sediment. Rearranging gives

$$\frac{1}{C}\,dC = -k\,\frac{A}{V}\,dt$$

Finally, integrating and substituting V/Q for the residence time gives,

$$C = C_0\, e^{-k\frac{A}{Q}}$$

Inspection of this equation reveals that increasing the sediment area increases the denitrification loss whereas increase in discharge decreases the loss.

The mass transfer velocity is taken to be a function of mean annual air temperature calculated over all cells contributing to each link in the river network. The value of k depends also on the substrate. Denitrification is observed to act more quickly in mud than in sand possibly because the smaller particle size allows closer proximity between oxic and anoxic zones. ANNEX uses the following relations for the mass transfer velocity and residence times,

$$k = 1.16 \times 10^{-9}\, \overline{T}_{air} \qquad \textit{sand}$$

$$k = 2.32 \times 10^{-9}\, \overline{T}_{air} \qquad \textit{mud}$$

$$t = \frac{A_{channel}}{Q_{bankfull}} \qquad \textit{in - channel}$$

$$t = \frac{A_{floodplain}}{Q_{overbank}} \qquad \textit{flood plain}$$

$$t = \frac{A_{reservoir}}{Q_{overbank}} \qquad \textit{reservoir}$$

where the overbank and bank-full flows, $Q_{overbank}$ and Q_{bank} full, have been defined earlier in the section on SedNet.

2.4.6 Dissolved nutrient loss in reservoirs (sedimentation, other losses)

ANNEX assumes that a proportion of the dissolved nutrient loads are lost in reservoirs. The reduction in dissolved nutrient load is computed for each of the four species (DON, DIN, DOP, DIP) identically as a function of the residence time, τ , of the median flood,

$$t = \frac{V_{reservoir}}{Q_{median\ flood}}$$

where $V_{reservoir}$ is the reservoir volume [ML] and $Q_{median\ flood}$ is the median flood discharge [ML d^{-1}] determined as the median value of daily discharge for all days with overbank flow. If $\tau > 5$, i.e. the median flood takes 5 days to traverse the storage then 100% of the dissolved load is lost. For shorter residence times the loss varies linearly from 0 to 100% as residence time increases from 0 to 5 days. The underlying assumption here is that the majority of dissolved nutrients transport from a catchment occurs during flood events.

This feature of ANNEX was introduced by Brodie *et al.* (2003) and was based on the observation that labile nutrients are taken up rapidly by phytoplankton and bacteria. For example, phytoplankton can assimilate sufficient DIP for one cell doubling in about 8 minutes (Reynolds & Irish 1987) and they can store enough surplus nutrient to support 2 to 3 doublings. Measurements of phytoplankton population growth in a variety of Australian freshwater environments show typical populations double roughly every two days and that this growth rate is limited by the availability of light (Sherman *et al.* 1998, 2000). This implies that after 5 days a standing crop of phytoplankton could assimilate roughly 15 times its initial phosphorus and nitrogen content.

The absolute magnitude of this transformation of dissolved nutrients will depend on initial population abundance and the assumed value of 5 days for complete loss of dissolved nutrients is considered representative of the range of conditions experienced in the natural environment.

2.4.7 Changes since Brodie et al. 2003 – Adsorption-desorption of dissolved and particulate phosphorus

Only one significant change has been made to the ANNEX model since its previous application to GBR catchments by Brodie *et al.* (2003). The simulation of absorption/desorption of dissolved phosphorus onto suspended sediment particles was eliminated as recommended by Bormans *et al.* (2004). The reason for this modification is that the time scale for the reaction is very short, just a few hours (Payne *et al.* 1999), compared to the long term average annual time scale used in the SedNet/ANNEX model. The concentrations of DIP and TP measured in the field and used to configure the model already represent equilibrium conditions and little subsequent adjustment of concentrations is likely. Furthermore, the temptation to incorrectly use this process to 'tune' model predictions could potentially diminish the value of the output by concealing evidence of knowledge gaps, e.g. anomalous predicted DIP:TP ratios indicating a possible error in predicted sediment generation of dissolved phosphorus load.

2.4.8 Nutrient load point sources

Point sources of nutrient loads were taken from the National Pollutant Inventory (NPI) database. Only point sources located within 5 km of a stream channel were considered. More distant point sources are assumed to be disposed of on land and have no impact on stream water quality.

The NPI reports loads for total phosphorus, total nitrogen and ammonia. In some cases the NPI data are estimates rather than measured values where the estimates are computed following a procedure specified in the NPI documentation. A shortcoming of this approach is that the reported nitrogen loads are occasionally inconsistent, i.e. the ammonia load may exceed the total nitrogen load. Only total nitrogen and total phosphorus load data were used in the STM project.

NPI data for the previous 6 years (1999-2004) were assessed to identify conspicuous trends or step changes indicating the introduction of, for example, improved sewage treatment processes. In general, the average nutrient load over the 6 year period was used in ANNEX. In some circumstances the median or most recent reported load was used where it was judged to better represent the expected future contribution of the source.

It is envisioned that sometime during calendar year 2006 the Queensland EPA Point Source Database (PSD) will become available. This database will report measured loads (or concentrations) and will include smaller sources which are not included in the NPI. We recommend that in the future the PSD values be used in preference to NPI data.

All point source nutrient loads were assigned to the dissolved organic nitrogen (DON) and phosphorus (DOP) fractions. In fact most point sources consist of a mixture of organic and inorganic nitrogen and phosphorus. The main implication of this simplification is that point source contributions to the dissolved nitrogen load will not suffer any losses through denitrification. The significance of this simplification is discussed in each of the regional reports.

The point sources used in the current implementation of ANNEX are listed in table 1.5.

Table 1.5 Point source nutrient loads in the GBR catchments

Facility	Local government authority	Latitude	Longitude	Total Nitrogen Load (kg/yr)	Total Phosphorus Load (kg/yr)
Kingaroy Sewage Treatment Plant	Kingaroy (S)	-26.5525	151.818439	9490	3387
Murgon Leather	Murgon (S)	-26.23056	151.916667	73000	0
Gympie Eldorado Gold Mine	Cooloola (S)	-26.21997	152.642116	6000	0
Fairview Coal Seam Methane Field	Bungil (S)	-25.61637	148.924389	856	204
Maryborough Water	Maryborough (C)	-25.51871	152.72391	67024	16667
Maryborough Waste Water Treatment Plant	Maryborough (C)	-25.51133	152.70883	80000	21000
Millbank Wastewater Treatment Plant	Bundaberg (C)	-24.86897	152.318579	11186	9901
East Wastewater Treatment Plant	Bundaberg (C)	-24.8512	152.370524	29513	17823
Bundaberg City Council - Bundaberg East Wastewater Treatment	Bundaberg (C)	-24.85008	152.369691	32850	17520
Stanwell Corporation Limited - Stanwell Power Station	Fitzroy (S)	-23.49566	150.301083	0	3784
	Livingstone (S)	-23.41329	150.607782	3161	847
Rugby Park Landfill (closed)	Rockhampton (C)	-23.41066	150.494416	3686	132
Diggers Park Landfill (closed)	Rockhampton (C)	-23.4101	150.498027	322	23
South Rockhampton Sewage Treatment Plant	Rockhampton (C)	-23.39694	150.527778	33702	14871
Frank Ford Park Landfill (closed)	Rockhampton (C)	-23.38871	150.506083	55	2
Georgeson Oval Landfill (closed)	Rockhampton (C)	-23.38705	150.491083	683	24
Lakes Creek Road Landfill	Rockhampton (C)	-23.38177	150.46775	1032	37
Teys Bros (Lakes Creek)	Rockhampton (C)	-23.38	150.559722	60002	0
North Rockhampton Sewage Treatment Plant	Rockhampton (C)	-23.37639	150.525556	23232	29108
St John’s Ambulance Park Landfill (closed)	Rockhampton (C)	-23.37427	150.518861	273	10
Bawden Street Landfill (closed)	Rockhampton (C)	-23.3676	150.53275	91	3
Jardine Street Landfill (closed)	Rockhampton (C)	-23.36705	150.491361	27	1
Kershaw Gardens Landfill (closed)	Rockhampton (C)	-23.36566	150.532194	10240	366
Victoria Park Landfill (closed)	Rockhampton (C)	-23.36538	150.503305	910	33
Jardine Park Landfill (closed)	Rockhampton (C)	-23.36482	150.491361	2002	72
Ski Gardens Landfill (closed)	Rockhampton (C)	-23.36121	150.49275	80	3
West Rockhampton Sewage Treatment Plant	Fitzroy (S)	-23.36	150.489167	12040	3868
West Rockhampton Landfill (closed)	Fitzroy (S)	-23.35816	150.477472	853	30
Moores Creek Landfill (closed)	Rockhampton (C)	-23.35121	150.525805	3641	130

Table 1.5 Point source nutrient loads in the GBR catchments (Continued)

Facility	Local government authority	Latitude	Longitude	Total Nitrogen Load (kg/yr)	Total Phosphorus Load (kg/yr)
Belyando Shire Council - Clermont Sewage Treatment Plant	Belyando (S)	-22.82068	147.656933	11332	2914
Belyando Shire Council - Moranbah Sewage Treatment Plant	Belyando (S)	-21.99873	148.056926	18234	4689
Moranbah Sewage Treatment Plant	Belyando (S)	-21.99568	148.061093	0	3900
Racecourse Sugar Mill	Mackay (C)	-21.16484	149.134147	1103	1660
Mount Bassett Sewage Treatment Plant	Mackay (C)	-21.14694	149.162222	158128	49202
Mackay City Council - Mount Bassett Sewerage Treatment Plant	Mackay (C)	-21.14539	149.163314	219000	65700
Marian Sugar Mill	Mirani (S)	-21.1429	148.940535	685	93
Pleystowe Sugar Mill	Mackay (C)	-21.14234	149.039702	244	1672
Farleigh Sugar Mill	Mackay (C)	-21.10012	149.102481	263	276
Bucasia Sewage Treatment Plant	Mackay (C)	-21.03306	149.15	9286	7670
Mackay City Council - Bucasia Sewerage Treatment Plant	Mackay (C)	-21.03151	149.151092	0	6300
Xstrata Copper - Townsville Operations	Townsville (C)	-19.34013	146.85109	565	0
Condon Sewage Treatment Plant	Thuringowa (C)	-19.33347	146.709979	6955	2634
Cleveland Bay STP	Townsville (C)	-19.29028	146.845278	114491	32586
Mount St John STP	Townsville (C)	-19.25236	146.744423	107599	24485
Deeragun Sewage Treatment Plant	Thuringowa (C)	-19.24763	146.690812	5230	1502
QNI - Yabulu Refinery	Thuringowa (C)	-19.20181	146.626628	1059508	0
Mount Low Sewage Treatment Plant	Thuringowa (C)	-19.20069	146.661923	640	370
Innisfail Sewage Treatment Plant	Johnstone (S)	-17.53542	146.061087	29712	7504
Gordonvale Sewage Treatment Plant	Cairns (C)	-17.09264	145.786365	14325	3942
Edmonton Sewage Treatment Plant	Cairns (C)	-16.99153	145.762476	21979	10317
Mareeba Processing Plant	Mareeba (S)	-16.97986	145.416086	1501	0
Southern Water Pollution Control Plant	Cairns (C)	-16.95459	145.753587	91578	32382
Portsmith Landfill	Cairns (C)	-16.95153	145.762754	10	0
Northern Water Pollution Control Plant	Cairns (C)	-16.8707	145.742476	74981	27570
Marlin Coast Sewage Treatment Plant	Cairns (C)	-16.81736	145.688309	34366	10661

2.4.9 Adjustment to ANNEX predicted nutrient loads

In past ANNEX modelling in GBR catchments Brodie *et al.* (2003) found that the predicted particulate nutrient loads were too high; and noted that predicted particulate N and P concentrations were much higher than were observed in river sediment samples. Brodie *et al* (2003) reduced ANNEX predictions by, on average, a factor of two across the GBR. The over prediction of particulate nutrient loads was problematic because the sediment loads were reasonably accurately predicted. Either the assumed soil nutrient concentrations were lower than specified in the ASRIS database or there is some process (es) that reduces nutrient loads differentially to sediment loads.

We know by direct comparison of ASRIS (Australian Soil Resource Information System) and SALI databases that the ASRIS soil N and P concentration data are lower on average than measured values in the SALI database so the most likely explanation is either that the process by which nutrients travel from the landscape to the river channels is not correctly represented in the model, the assumed clay content of the soil is in error (see below), or most likely a combination of both. SedNet assumes that 10 per cent of sediment that is generated on the land makes its way to the channel network regardless of where the sediment is generated. Field data show that sediment generated more than a few hundred metres from a channel has little chance of reaching the channel during an event. It may be the case that assuming 10% of all sediment makes it to the channel biases the N and P content of the suspended sediment load should N and P concentrations increase systematically with distance from the river channel. *At this stage the mechanism is unknown and should be considered a significant knowledge gap that should be studied in much more detail.*

To compensate for the mismatch in predicted and observed sediment nutrient concentrations Brodie at al. (2003) introduced a ‘nutrient enrichment factor’ (although ‘nutrient reduction factor’ would be a more accurate name) to reduce the nutrient concentration of the sediment delivered to the river channel. The reduction in nutrient concentration was only applied to sediment generated in areas where the clay content of the bulk sediment exceed the hillslope delivery ratio. In GBR catchments the HSDR is assumed to be 10%, so for all locations where the ASRIS % clay exceeded 10% of the total soil mass, the concentration of N and P was reduced by a factor of 2. If a catchment consisted of soil with more than 10% clay everywhere then the particulate nutrient load was reduced by half. If the catchment had a mixture of soils with more or less than 10% clay then some lesser reduction would be the result. The poor correlation between ASRIS clay content (see section 2.4.1) and observed soil property values (Henderson *et al.* 2001) may bear directly on the spatial accuracy of the application of the nutrient reduction factor and its magnitude.

The introduction of the nutrient reduction factor was specific to the application of Brodie *et al.* (2003) and this factor is not included in the current Toolkit release (http://www.toolkit.net.au) to ensure consistency with other applications of the model. To facilitate comparison with the results of Brodie *et al* (2003) and ensure a more realistic distribution between dissolved and particulate nutrient loads, the particulate nutrient loads were adjusted as follows.

ANNEX was run twice. The first run included the nutrient reduction factor and the second run did not, i.e. the second run is the current Toolkit release of the model. The ratio of particulate nutrient loads with and without the factor was calculated once for each scenario considering the entire region only. The ratio for any particular scenario varied by less than 2% from the base scenario ratio. The base scenario ratio was then used to reduce the particulate nutrient loads and new total nutrient loads calculated as the sum of the dissolved inorganic + dissolved organic + adjusted particulate loads.

$$R = \frac{PN_{without\ factor}}{PN_{with\ factor}}$$

$$Load_{corrected} = \frac{Load_{ANNEX}}{R}$$

$$Total\ load = dissolved\ organic + dissolved\ inorganic + Load_{corrected}$$

R = ratio of unadjusted to adjusted load for base case

PN = particulate nutrient load

$Load_{corrected}$ = adjusted scenario particulate nutrient load

All values and plots in the body of this report are adjusted values. Appendix 2 presents tables with the actual ANNEX output to facilitate comparison with future applications of the model which do not include a nutrient enrichment factor. These tables differ from the tables and bar charts presented in the regional discussions in that the particulate nitrogen and phosphorus loads are typically twice as high (the actual factor varied).

2.5 Uncertainty and Limitations

(Dougall C., Searle R. and Sherman B.S.)

2.5.1 Why use models?

"All models are wrong but some are useful" (Anon 2005). This short statement provides a sound context for the application of biophysically based catchment models. The most complex of models can only ever be a simplified representation of our limited understanding of complex interrelated processes. Thus even with the best input data for our models they may struggle to provide simulations of the real world. Hence we should use models with the knowledge that they very rarely give us "the answer" to our questions. Models are often best used as one piece of the jigsaw puzzle, which can assist us in helping to understand and manage natural resource systems.

Given our limited understanding of system processes, most biophysical models require a range of assumptions to be made in order to describe the system. We cannot understand all aspects of a system, hence we are required to assume we know how things "should" function. It is critical for correct interpretation when applying models that we understand what these assumptions are and the impacts these assumptions may have.

With these limitations in mind one may then justifiably ask "why should we go to the expense and effort to develop and use models?" There are many benefits to be gained from utilising models. Our understanding of complex systems is generally gained from interpreting measured data that describes aspects of a system. We then take that data and try to extrapolate it over parts of the system we have not been able to measure via the use of models. Models provide a useful framework for combining, analysing and extrapolating our best available data. Models allow us to combine our data and understanding of systems in a consistent and repeatable manner. By using models we can combine our data and knowledge in a way that is transparent and open to critique. Models also provide a framework upon which stakeholders can come to a common and agreed understanding of how processes are operating.

If we accept that a given model provides a useful representation of a system, then we have the opportunity to use the model to explore the effect of changes within the system. Although a biophysical model rarely gives us an absolute answer to a question, it is often useful to use the model to explore the relative impact of changes within a system. It can be extremely useful to run a range of change scenarios and see the relative impact of these changes. Through this we can quickly gain an understanding of the likely impacts of changes to the system without the requirement to actually make the changes and then measure the results of this, be they beneficial or detrimental.

It is essential that when using models we are aware of both the limitations and the appropriate applications of models.

2.5.2 Considerations when using SedNet

To obtain the maximum benefit from catchment modelling tools, it is important to assess the uncertainty and limitations attached to the modelling process. From this assessment, we can develop rules for the correct interpretation of model outputs.

Unfortunately we don't have a full understanding of catchment behaviour. Therefore it is impossible to accurately assess our confidence in a formal scientific sense. Nonetheless, we can get a feel for correct interpretation through careful consideration of the underlying factors. A framework for the interpretation of SedNet requires an understanding of:

- How SedNet represents erosion processes,
- The accuracy and representativeness of input data used for these processes,
- The sensitivity of the SedNet to data changes,
- How the model correlates with the behaviour of the system under study.

In addition, it is important to assess the temporal and spatial scale of the model output. For example, one may have confidence in the representation of the erosion processes, data accuracy, and sensitivity at a basin scale for sediment load over decadal time period. But when one looks at results at a small catchment scale, or daily time period, the confidence levels may be much lower.

It is useful to note that where there is poor understanding of catchment behaviour, our confidence levels will naturally remain low. However a major output of the modelling process is the ability to formally identify these areas. To assess the level of confidence we should place on the models presented in this report, it is useful to break SedNet down into its main functional components of: generation, delivery and transport.

2.5.3 Generation

2.5.3.1 Hillslope

Process representation: Hillslope erosion (surface wash and rill) is generated using the Revised RUSLE equation (see Section 2.3 for details).

Input data: Regional scale data such as constant C factors, limited soil maps, and rainfall erosivity do not capture small scale variability.

Sensitivity: Changes in slope and cover can have significant impacts, on results.

Correlation: The equation was developed from empirical observations of erosion under cropping, and has been widely adopted and tested. The equation has not been adequately parameterised for rangelands and as such there is lower confidence in its application to these areas.

The level of interpretation is largely dependent of the input data, and the country type being modelled. The general consensus is that a regional scale is relevant, with the definition of regional being dependent on spatial inputs. As each GBR area (FNQ, Fitzroy, etc) have differing data inputs compositions a comment is made on interpretation, in each catchment.

2.5.3.2 Gully

Process representation: Gully erosion is generated using the SedNet gully equation (see Section 2.3). The use of a single gully cross sectional area for the entire catchment is a limitation.

Input data: The data used for gully mapping is particularly poor, as mapping was derived from national scale datasets and based on a relatively poor environmental correlation.

Sensitivity: Small perturbations in inputs such as cross sectional area, length and gully age can result in significantly different model outputs.

Correlation: There has been application in southern Australia, with reasonable results. However, the approach has not been significantly tested in northern Australia.

Due to the coarse level of gully mapping, and its high sensitivity, considerable care needs to be taken in the interpretation of results. At best, broad spatial patterns of erosion may only be applicable.

2.5.3.3 Bank

Process representation: Stream power, bank height, bank erosivity, stream slope and presence or absence of riparian cover is represented. (See Section 2.3 for details.)

Input data: Measurements of bank height are limited, however riparian coverage is considered to be well mapped.

Sensitivity: The modelled bank erosion is sensitive to changes in the specification of overbank flow.

Correlation: Bank Erosion at a basin scale is a poorly studied phenomenon. However, DeRose *et al.*, (2005) have described current uncertainty in bank erosion modelling. Model testing against tracer data indicates reasonable assessment of the total amount of sediment eroded from river banks across a region (e.g. Bartley *et al.*, 2003). There is some basis for using stream power to predict spatial variation in bank erosion rates across a region (Rutherfurd, 2000) and predicted spatial patterns match reasonably with expectations (DeRose *et al.*, 2005). However, the predicted regional spatial patterns have received much less testing against data than have the basin total yield from bank erosion, and confidence levels in regional patterns are consequently lower.

2.5.4 Delivery to the stream

Process representation:
Hill:
A Hillslope Sediment Delivery Ratio (HSDR) of 10% is applied i.e. 10% of hillslope erosion is assumed to be delivered to the stream regardless of distance from the channel. Field studies show that HSDR decreases with distance from the stream.
Gully: 100% delivery to streams. Not all sediment is delivered to streams.
Bank: 100% delivery to streams. This is reasonable.

Input data: Global variables (The values are constant over the entire catchment).

Sensitivity: High

Correlation: The HSDR is highly dependant on the individual landscapes being studied. For example, landscape with short steep slopes may have a high HSDR while ones with large areas of long flat slopes will allow more sediment to be deposited during transport resulting in low HSDRs. This variation in landscapes is not accounted for in the current models.

100% delivery of sediment from gullies and stream banks is probably a reasonable representation of these processes.

2.5.4.1 Transport to the coast

Process representation: Transport to the coast is controlled by floodplain size, overbank flow, and return periods. The presence of storages is also included:

Input Data: Currently limited and could improve using statewide geology and DEM derivatives.

Sensitivity: High

Correlation: Rates of vertical accretion on floodplains predicted by SedNet are generally reasonable (within an order of magnitude) when compared against rates expected from geomorphic analysis (Prosser *et al.*, 2001). Rates are also reasonable when considering that catchment sediment exports are generally reasonable in comparison with measured exports. Measurements of floodplain deposition rates, using sediment dating techniques, can considerably improve levels of confidence in predictions in particular catchments.

2.5.5 Some specific assumptions in SedNet to note

It is evident from this brief review of the components of SedNet that there are many potential sources of error and variance. It is therefore essential, that if SedNet is to be used appropriately, stakeholders have a good understanding of these issues and can apply the results of the modelling process with these limitations in mind.

The following section provides a brief and incomplete summary of some of the main assumptions used in the SedNet model. While on the one hand it is important to realise the consequences of these assumptions, it should be appreciated that the model is based on our best current understanding. Given the transparent nature of models, it would be expected that as better understanding comes to hand these assumptions could be refined.

Sediment is comprised of 50% fine and 50% coarse particles

Sediment generation of bank and gully erosion in the model assume that soil is composed of 50 percent fine particles and 50 percent coarse particles. Obviously these proportions vary greatly depending on soil type. This assumption is required given our lack of detailed knowledge of spatial soil type distributions.

All gullies have a 10 m^2 cross sectional area

A range of field measurements at a national scale have indicated that on average gullies have a 10 m^2 cross sectional area. Obviously this varies greatly within and between landscapes.

Gullies erode at a constant rate

It is assumed that over the model time period all the gullies in the catchment erode at the same rate every year. In reality, it is most often the case that immediately after clearing, gullies form and erode at a high rate. This rate generally decreases over time until a new lower equilibrium rate is reached as the gully matures. The constant erosion rate used by the model represents an assumed equilibrium between young and mature gully migration rates. If the model's default value is used without field confirmation, there is a potential for either a high or low bias in the model predictions.

Constant recurrence interval over whole catchment

SedNet uses a constant flood recurrence interval over the entire catchment being modelled. This value controls how often streams break their banks and deposit sediment on the floodplains. This means that the whole catchment will flood and sediment will be deposited over the all of the catchment's floodplains. This will not be the case, during any single year , especially in large catchments, but over a period of decades (the time scale considered by SedNet) this assumption is generally sound.

Bank height is constant over the entire catchment

The bank height is related to how often the streams break their banks. In some implementations of SedNet, all streams are given the same bank height regardless of the size or stream order. This is rarely the case in reality. However, some catchments have been mapped with variable bank height.

The Hillslope Sediment Delivery Ratio (HSDR) is constant over the entire catchment

The HSDR is highly dependant on the individual landscape being studied. For example, landscapes with short steep slopes may have a high HSDR, while ones with large areas of long flat slopes will allow more sediment to be deposited during transport, resulting in low HSDR's. HSDR has been observed to decrease exponentially with distance from the channel, and it is known that restoring riparian vegetation may also change HSDR. These variations across the landscape are not explicitly accounted for in the current models.

Stream bank erosion is directly proportional to riparian vegetation

It is assumed that there is a linear relationship between the total amount of riparian vegetation and the amount of sediment that is available to be eroded from the stream bank, i.e. 100 percent riparian vegetation means there will be no stream bank erosion and where there is no riparian vegetation all of the stream bank is able to be eroded. The ability of the stream vegetation species to provide stream bank stability is not considered.

Bank erosion is reduced where floodplain width is less than 100 m

Bank erosion is reduced where floodplain width is less than 100 m by a decaying exponential relationship. This is to account for there being exposure of rock such that only a proportion of the length of the channel link is erodible material, decaying to zero where the floodplain width is zero. (Wilkinson, 2004). Depending on the catchment this may or may not be the case.

Cover factor is constant for a landuse

The cover factor used in the hillslope erosion surface in this implementation of SedNet assumes that the ground cover is constant for a given landuse. In the case of grazing, it is known that cover varies spatially and seasonally. Cover is strongly influenced by the "country type" and the actual grazing pressure. The decadal time scale used by SedNet averages out seasonal variability. Although spatial variability due to country type and grazing pressure can theoretically be simulated in SedNet, in practice this is seldom done due to input data limitations and time constraints.

3 Whole of GBR and implications for water quality target setting

(Sherman B.S., Carroll C. and Cogle A.L.)

Target setting, of any type can be a complex undertaking and water quality target setting for the Reef Water Quality Protection Plan (RWQPP) is no different. An important component of all target setting activities is to implement a transparent development process. Previously, the SedNet/ANNEX model was used by the National Land Water Resources Audit (2001) to predict soil erosion and nutrient transport for continental Australia, and for other modelling activities in GBR catchments (Brodie *et al.* 2003, Bartley 2004). It is a respected model, which can readily use updated base layer information and provided long term average numerical outputs. Its underlying biophysical processes are also presented clearly. Hence it has significant value as a tool for use in the water quality target setting process.

The Short Term Modelling (STM) project used the SedNet model but with an increased emphasis on the communication, engagement and scenario development with the NRM regional bodies. These bodies are identified in the RWQPP as having responsibility for water quality target setting. The 5 interlocking project components were:

- Communication strategy for using models to assist in target setting
- Develop Contributor Module of SedNet
- Collation of Base layers of Modelling information
- Regional Sediment Modelling
- Nutrient Modelling for GBR Catchments

This chapter provides an overview of GBR wide results and communication. Detailed discussion of regional outputs, communication and the impacts of regionally derived scenarios are provided in the regional chapters.

3.1 Methodology

3.1.1 Communication

Communication within each NRM region aimed to progress the project in an open and fully consultative manner. Each region had unique arrangements, as discussed in the regional chapters. In summary, there were;

- presentations to the full NRM Boards of FNQ, Mackay Whitsunday and Burnett Mary and significant discussions with Board members of Burdekin Dry Tropics and Fitzroy Basin Association.
- workshops and informal discussions with Board nominees and sub-groups for all NRM regions and
- interactions with sub groups of some Boards eg for FNQ NRM these included the Industry Advisory Group, Cairns Landcare, TREAT and the Barron River ICM.

At the GBR level there were two formal reporting and communication forums. These were a) Water Quality Co-ordination Group (WQCG) and b) National Action Plan for Salinity and Water Quality Implementation Board.

The Water Quality Co-ordination Group consisted of:

- Chairs of regional bodies (Burnett Mary, Fitzroy Basin, Mackay Whitsunday, Burdekin Dry Tropics, Far North Queensland)
- CEO's or nominees of above Regional bodies
- Queensland State Government Representatives from NRMW (Tony Pressland), EPA (Andy Steven)
- Commonwealth Government Representatives from DEH (Veronica Blazely), GBRMPA (Hugh Yorkston)
- Noel Dawson, Independent Chair

The National Action Plan for Salinity and Water Quality Implementation Board met quarterly under the chair of NRMW (Chris Robson) and EPA (Bob Spiers) and consisted of representatives of NAP and non-NAP regions, Industry Groups and State and Commonwealth Departments.

In 2005, the STM project was communicated at GBR-level meetings as outlined in table 1.6

Table 1.6 Communication of the STM project at a whole of GBR level during 2005

Meeting	Date of meeting in 2005
NAPSWQ Implementation Board (Brisbane)	April 7th
WQCG (Townsville)	April 27th
NAPSWQ Implementation Board (Brisbane)	July 12th
NAPSWQ Implementation Board (Brisbane)	October 11th
WQCG (Townsville)	November 30th

3.1.2 Modelling

As previously explained in the Methodology chapter (2), input data was necessarily different for each region due to a number of constraints including; the project timeframe and practical matters related to RWQPP timelines and communication with regional bodies or their delegates, . The tables below summarise these differences, while further detail is provided in the individual regional chapters.

The STM project assembled the latest hydrologically valid DEM's, which had some differences in the spatial resolution for each region as shown in table 1.8. Input variables for bank height, reservoir volume and riparian width also varied across regions, as shown in table 1.9.

Landuse distribution is an important baselayer for any catchment modelling process. The whole of the Great Barrier Reef Lagoon catchment area is generally dominated, by grazing (Fig. 1.7). As rainfall increases closer both to the coast and to the equator the land supports a greater variety of agricultural applications, in particular the cultivation of sugar cane. This is apparent in the relatively smaller percentages of land area devoted to grazing and much larger proportions of landused for sugar cane in Far North Queensland (FNQ) and the Mackay Whitsunday region.

Scenarios to address water quality targets were developed in facilitated meetings with each of the Regional NRM bodies. The scenarios addressed a range of management actions including changed grazing land management, inter-row management of horticultural crops, fertiliser strategies, riparian management and are fully explained in each of the regional chapters.

Table 1.7 DEM resolution and catchment boundaries for each NRM region

NRM region	DEM resolution	Catchment Boundary
Far North Queensland	100 m	FNQ NRMW Boundary
Burdekin	250 m	Burdekin NRMW Boundary
Mackay Whitsunday	25 m	Hydrologically derived from the NRMW 25 m Mackay Whitsunday Preliminary DEM
Fitzroy	250 m	Hydrologically derived from the 9 second v2 DEM
Burnett Mary (Burnett)	100 m	Hydrologically derived from the NRMW 25 m Burnett River Catchment DEM
Burnett Mary (Kolan, Baffle, Burrum)	25 m	Hydrologically derived from the NRMW 25 m South East Queensland DEM
Burnett Mary (Mary)	50 m	

Table 1.8 SedNet parameter values that varied between NRM regions

NRM region	Bank Ht. (m)	Reservoir Volume Reduction Factor	Riparian Width (m)	Bankfull Recurrance Interval (y)
Far North Queensland	3	1	150	4
Burdekin	4	1	150	6
Mackay Whitsunday	variable	1	150	4
Fitzroy	4	0.5	150	6
Burnett Mary (Burnett)	4	1	variable	6
Burnett Mary (Kolan, Baffle, Burrum)	4	1	variable	6
Burnett Mary (Mary)	variable	1	variable	10

3.2 Results

Total exports of sediment were highest for the larger catchments of the Fitzroy and Burdekin NRM regions. Nutrient exports for total nitrogen were highest from the FNQ NRM region and for total phosphorus from the Fitzroy NRM region (Table 1.9).

These relative contributions are shown clearly in figure 1.8 to figure 1.10 for suspended sediment, Total N and Total P. In addition, estimates of the dissolved nitrogen and phosphorus loads contributed to the coast are shown in figures 1.11 and 1.12.

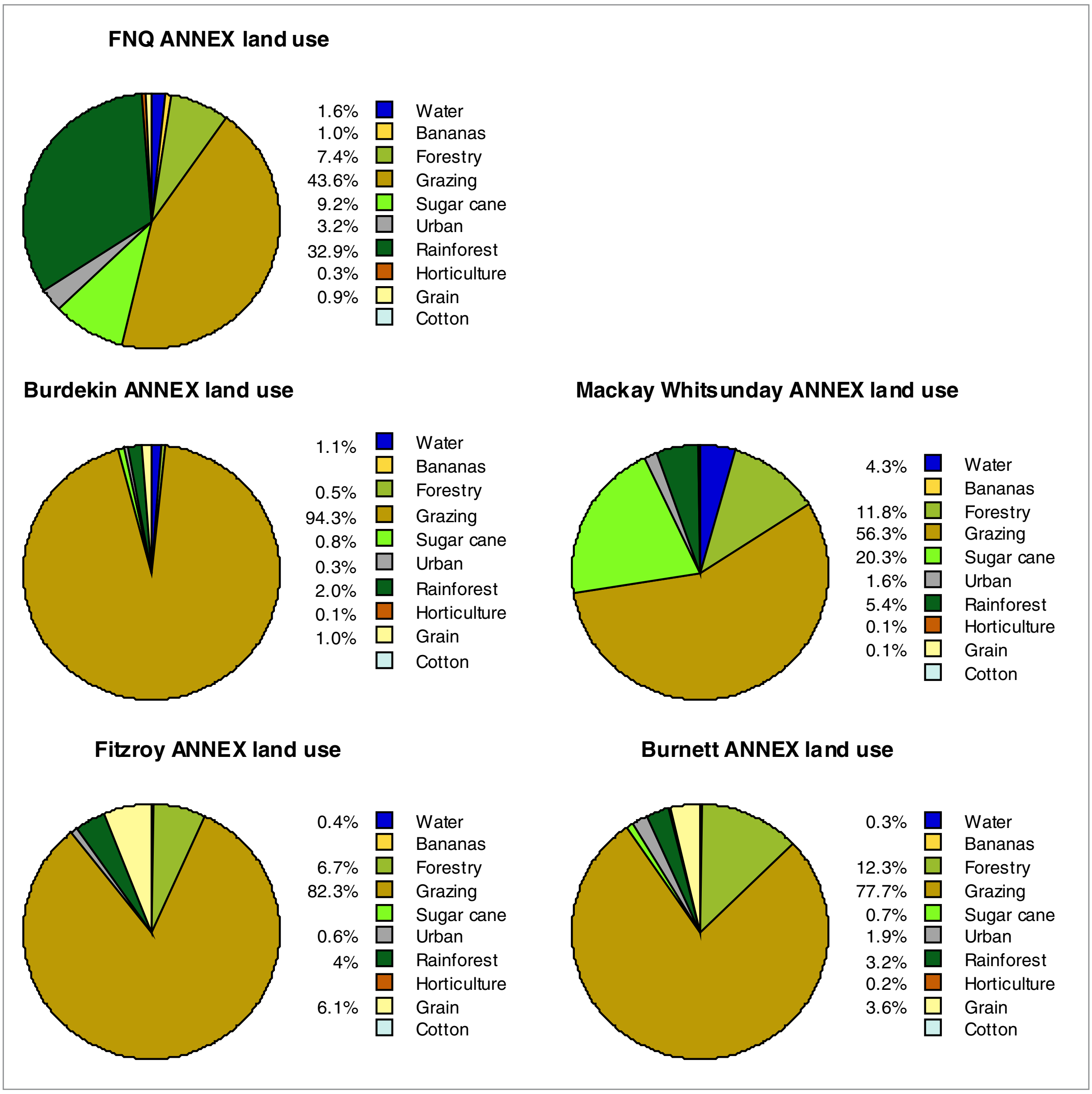

Figure 1.7 Distribution of landuse classes, as used by ANNEX to model nutrient loads in Great Barrier Reef catchments

Table 1.9 Total export (kt/yr) of sediment and nutrients from each NRM region in the GBR lagoon

NRM region	Suspended Sediment	DIN	Total N	DIP	Total P
	Export (kt/yr)				
FNQ NRM	1 479	9.1	18.3	0.4	2.4
Burdekin	4 473	2.3	14.3	0.2	2.4
Mackay Whitsunday	1 793	2.5	10.5	0.1	2.8
Fitzroy	4 575	1.0	11.1	0.1	3.2
Burnett Mary	1 421	0.4	4.1	0.04	1.1

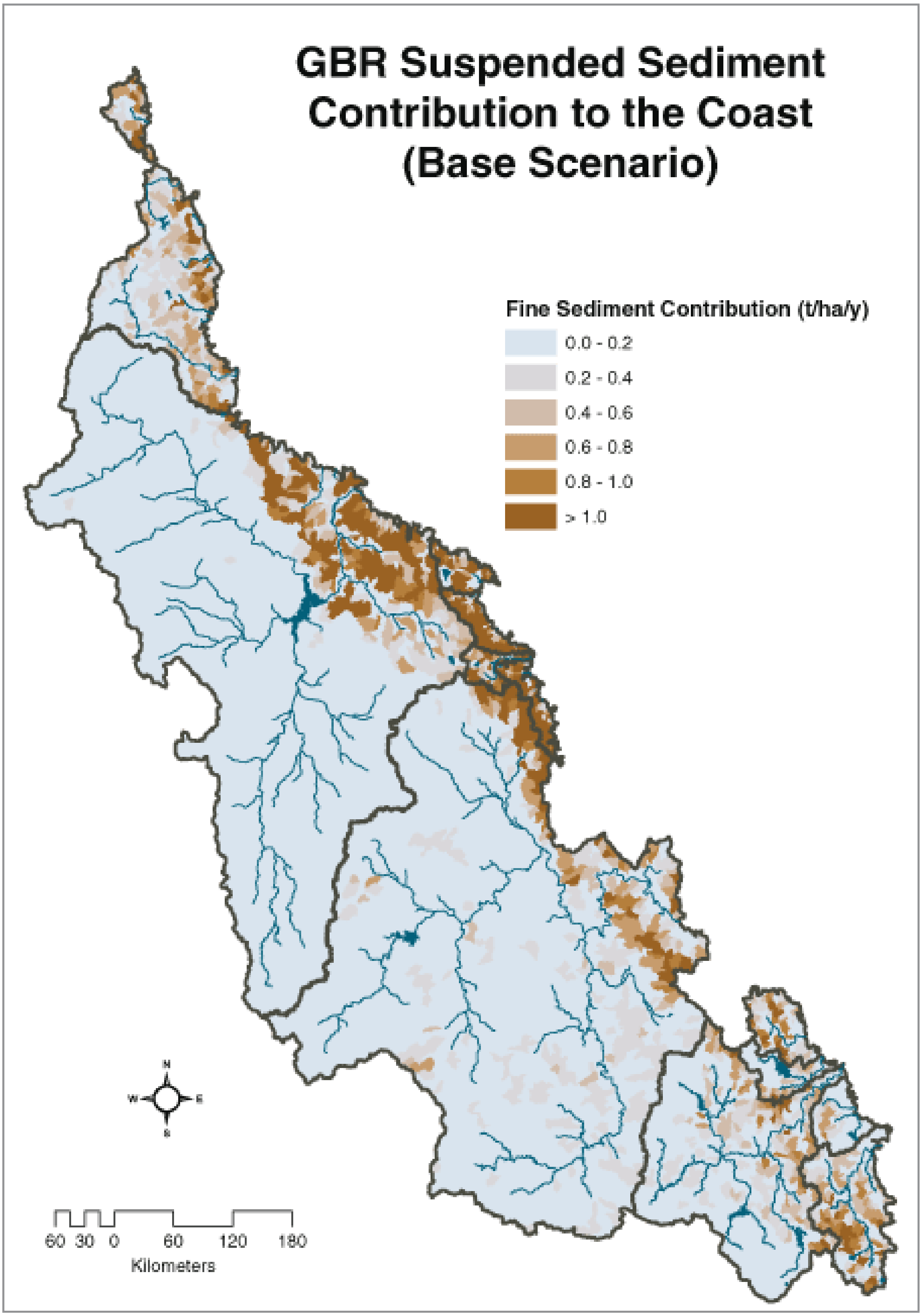

Figure 1.8 Contribution of fine sediment to the GBR lagoon (Base scenario)

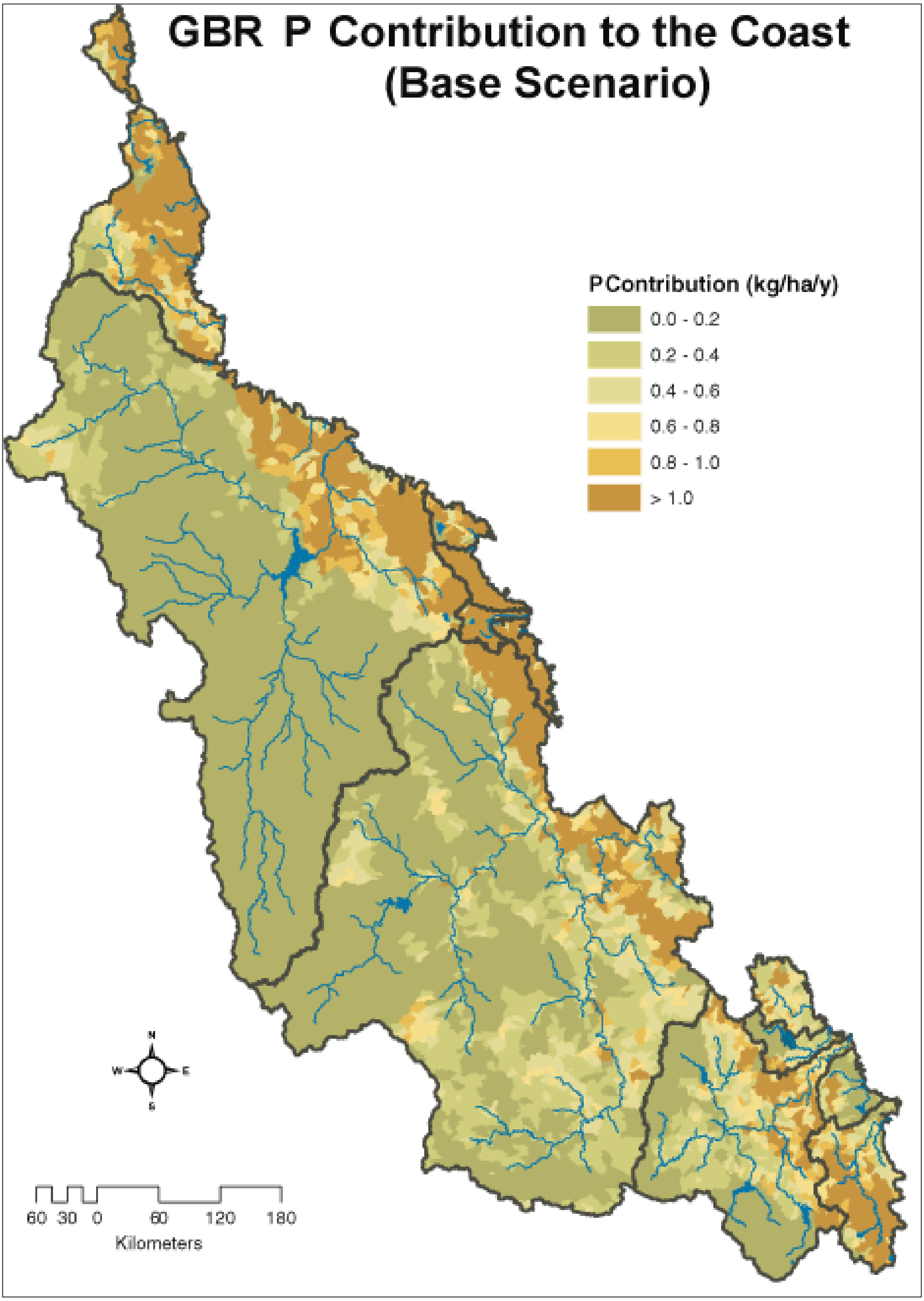

Figure 1.9 Total phosphorus load contributed to the coast (Base scenario)

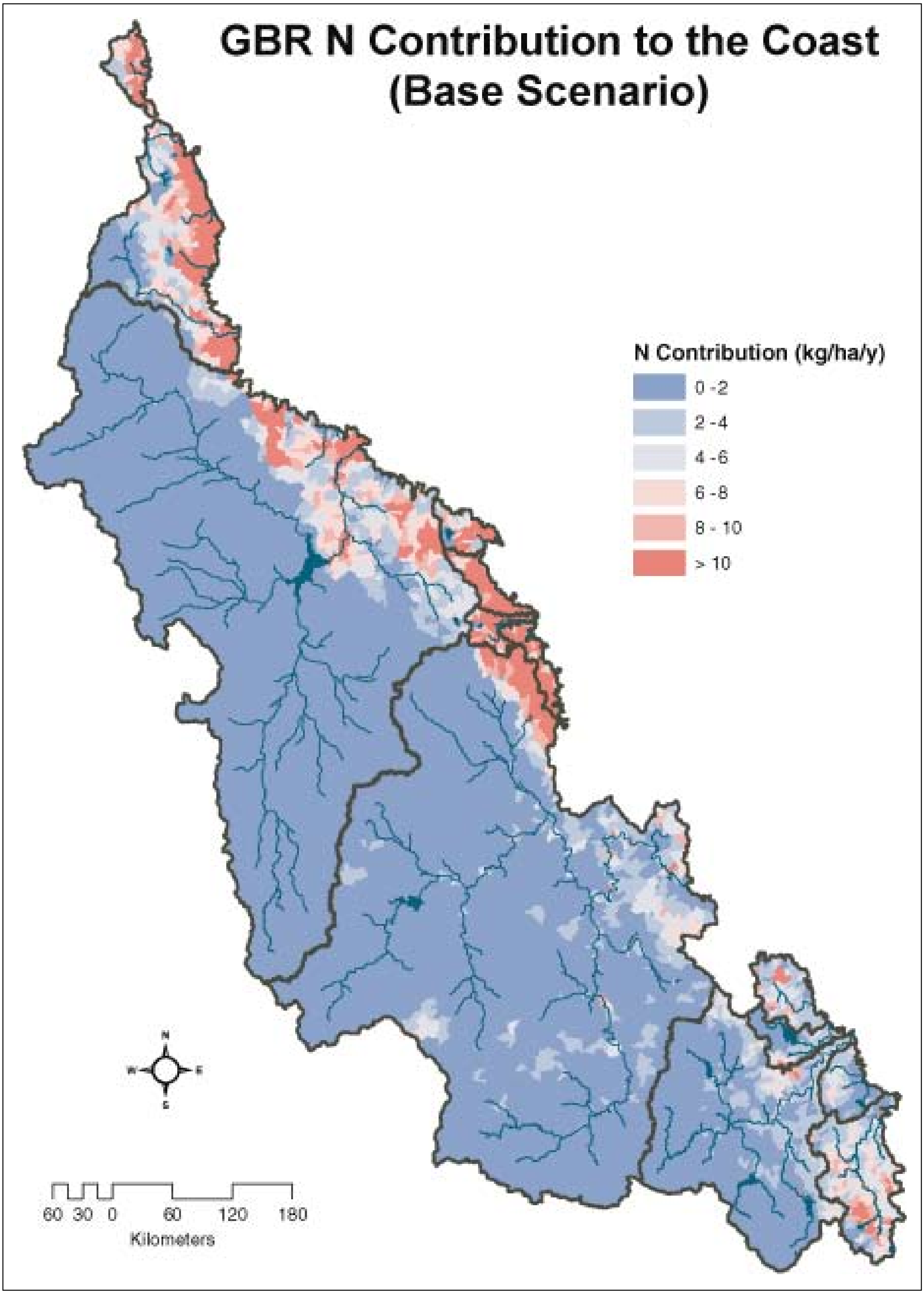

Figure 1.10 Total nitrogen load contributed to the coast (Base scenario)

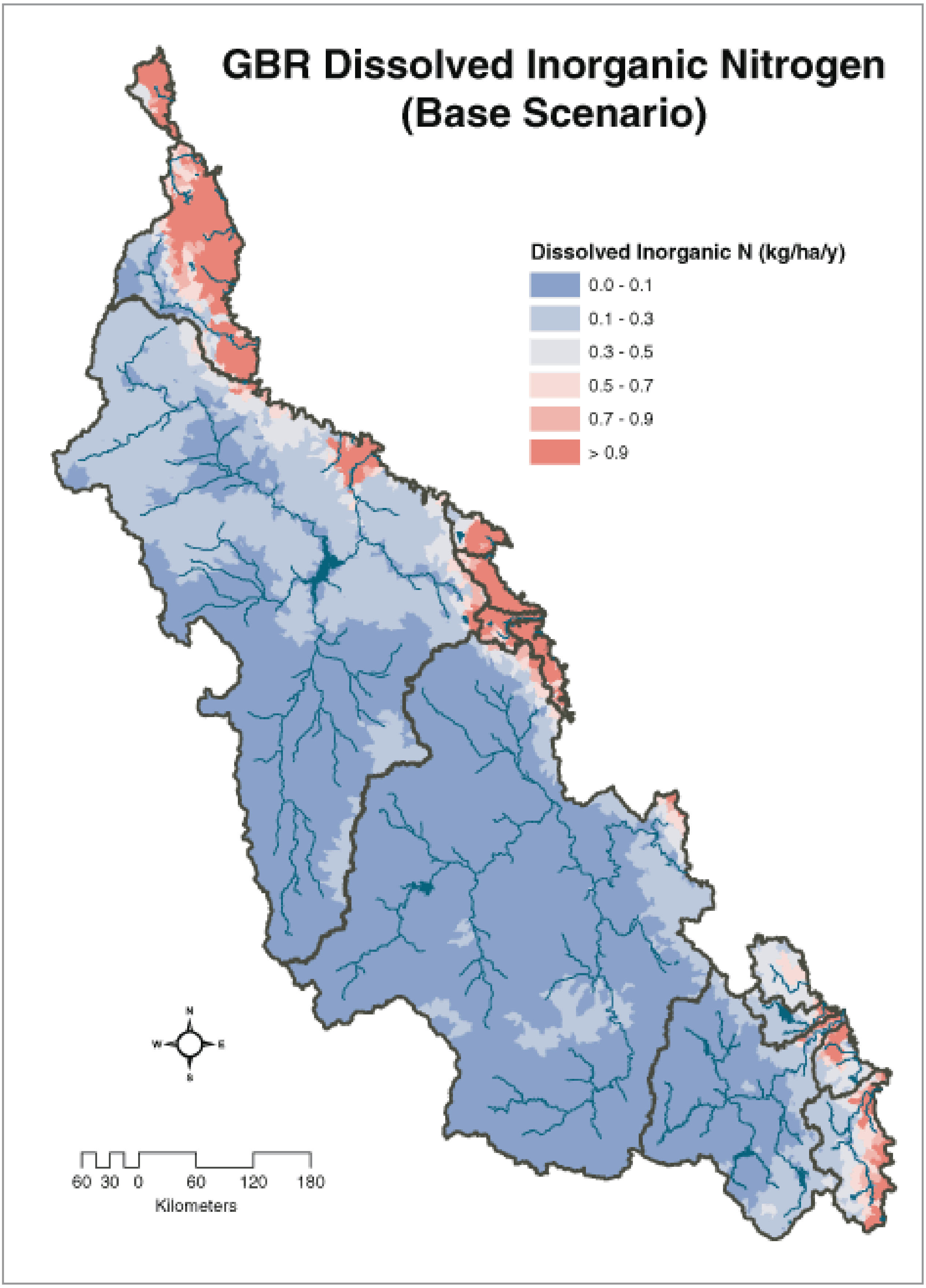

Figure 1.11 Dissolved inorganic nitrogen load delivered to the coast (Base scenario)

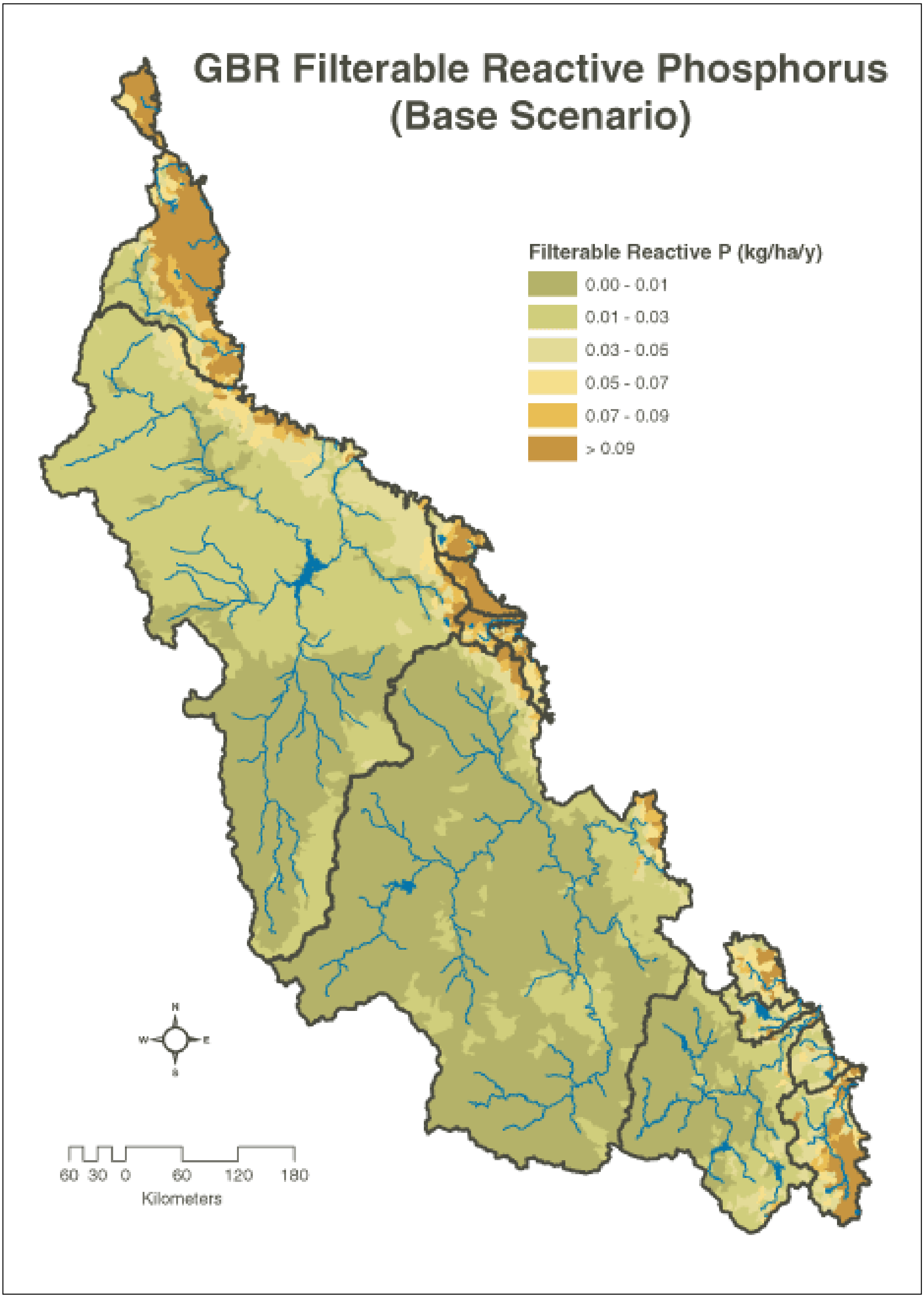

Figure 1.12 Filterable reactive phosphorus load delivered to the coast (Base scenario)

The generation of sediment and nutrients occurs from all land surfaces and while large areas may contribute the greatest total loads because of their size, high generation or export rates can occur from smaller areas and sometimes these high generation rates are the easiest to manage or reduce. Table 1.10 shows the export rate of suspended sediment, Total N and Total P from each of the NRM regions. The Mackay Whitsunday NRM region has the highest export rate of suspended sediment, Total N and Total P, while FNQ NRM region also has high export rates for these materials.

Table 1.10 Export rate (t/km²/yr) from each NRM region in the GBR catchment

NRM region	Export rate t/km²/yr				
	Suspended Sediment	TN	DIN	TP	DIP
FNQ NRM	69	0.89	0.44	0.11	0.02
Burdekin	34	0.11	0.03	0.02	0.002
Mackay Whitsunday	211	1.16	0.04	0.31	0.02
Fitzroy	32	0.08	0.004	0.02	0.0005
Burnett Mary	28	0.075	0.009	0.02	0.001

The individual impacts on sediment and nutrient loads of the scenarios, which were developed with each of the NRM regions, will be reported in the regional chapters.

3.3 General Discussion

3.3.1 Sediment and Nutrient Outputs

It is well understood that grazing increases erosion of top soil as a result of the loss of vegetation (ground) cover among other factors. Agricultural crops such as sugar cane and bananas require intensive use of smaller areas and application of fertilisers. Depending on the timing and amount of fertiliser applied, a proportion of the highly bioavailable nutrients used in fertiliser will wash off the landscape and be transported to the coast in dissolved inorganic forms. As the area of intensive agriculture increases, one expects a shift in dominance from particulate nutrient loads towards dissolved inorganic nutrient loads.

Dissolved inorganic nutrients are immediately bioavailable and allow near instantaneous algal bloom formation in receiving waters, provided adequate light is available for photosynthesis. Particulate nutrients are nutrients bound to sediment particles. These particles release a fraction of their attached nutrient when they encounter the marine environment. The remaining particle-bound nutrients require transformation, typically mediated by bacteria, before they become available to drive plant growth in the marine environment. As a consequence of this distinction, dissolved nutrients can be thought of as having the potential to cause acute symptoms such as phytoplankton blooms, whereas particulate nutrients pose a threat of relatively more chronic symptoms such as a progressive accumulation of attached algae (assuming such algae is not consumed by grazing marine animals).

The vast majority of strong sources of sediment were estimated by the long term annual average SedNet model to occur within 120 km of the coast, typically where rainfall is highest and slopes steepest. The strongest sources of sediment delivered to the GBR are the eastern Burdekin, Mackay Whitsunday and north-eastern Fitzroy catchments. Areas of high erosion in the western half of the GBR catchments (data not shown), do not have their sediment delivered efficiently to the coast. The sediment is either deposited in reservoirs located downstream or upon the flood plains of the various rivers.

SedNet/ANNEX modelling predicts that the delivery of phosphorus to the coast is dominated by an 80-90 km-wide band along the coastline. Reservoir trapping and flood plain deposition is apparent in the Burdekin, Fitzroy and Burnett catchments, which are dominated by grazing. The much wetter catchments of Mackay Whitsunday and Far North Queensland suffer greater erosion due to the higher rainfall and reduced opportunity for sediment deposition due to the relatively short distances travelled by the streams on their way to the ocean.

The situation is similar for total nitrogen as for total phosphorus. All of the high contribution areas are within the same 80-90 km-wide band along the coast, with especially high contributions from the northern edge of the Fitzroy up to the Daintree in FNQ. Total nitrogen delivery to the coast is relatively weaker in the Fitzroy (apart from the Isaacs River in the extreme northeast) and further south. Relatively high nitrogen and phosphorus contributions re-emerge at the extreme southeast end of the GBR in the Mary river catchment (Fig. 1.9 - 1.10).

The delivery of dissolved inorganic nutrients, both nitrogen and phosphorus (as filterable reactive phosphorus) was estimated to be greatest in areas with the most intensive agriculture. Far north Queensland, the mouth of the Burdekin, the Mackay Whitsunday and parts of the Burrum and Mary river catchments stand out as sources of dissolved inorganic nitrogen (Fig. 1.11). Relatively high delivery of filterable reactive phosphorus is sourced from the same areas as DIN with the exception of the mouth of the Burdekin and the Burrum where sugar cane is the dominant cultivated crop and other landuses associated with high FRP (such as bananas and urban) are less prevalent (Fig. 1.12).

ANNEX assigns a constant dissolved nutrient concentration for each particular landuse. Two identical farms, one located in a high rainfall-runoff region and one in a low rainfall-runoff region will have different predicted DIN and FRP loads with the high runoff farm producing the highest load. Areas of predicted high dissolved nutrient loads tend to be located in areas with relatively high rainfall so the patterns shown in figure 1.9 & figure 1.10 should not come as a surprise as they simply highlight the location of intensive agriculture in high rainfall areas of GBR catchments.

Model predictions of nutrient loads such as those presented here should be confirmed with water quality monitoring data because of uncertainty associated with time-dependent changes in dissolved nutrient concentration that are independent of discharge (e.g. exhaustion of accumulated groundwater nutrient stores), bulk soil nutrient concentrations, and seasonal changes in vegetation (ground) cover. These three factors are known to have relatively high intrinsic uncertainties and any conclusions drawn from the modelling exercise regarding differences in loads at small scales (say 100 km^2) must be considered with caution. Large scale annual average patterns are more reliably predicted because the uncertainties associated with the various model parameters will tend to cancel out as the area under consideration increases. It is important to remember that catchment models are better at illustrating relative differences over large scales than at accurate quantitative prediction due to the sparseness of data available to configure them.

Scenarios developed and modelled in each region showed their relative impacts at different scales and promoted dialogue about potential new management action to address water quality targets. Some scenarios had a very large impact at a subcatchment scale, but little at the larger GBR scale. The implication of the modelled results for water quality target setting is that management activities are likely to produce the greatest reduction in nutrient loads if they focus on the 80-90 km-wide belt of land adjacent to the coast. Broader catchment scale management is required to reduce sediment loads.

The targeting of particular areas for management intervention should be validated by water quality monitoring data to at least confirm or refute assumptions used in the modelling. However, this should be undertaken in an adaptive management framework whereby the results of the monitoring inform the modelling, which in turn informs the monitoring.

3.3.2 Summary of Model Results

There are two types of landuses that contribute significant amounts of sediment and nutrients to the GBR: low-intensity large-scale grazing and intensive agriculture. The former poses a risk for river health and may threaten near-shore sea grass beds and coral reefs with smothering. The latter contributes significantly more dissolved nutrients to the GBR which pose a greater risk of initiating algal blooms and potentially supporting crown-of-thorns starfish recruitment. These dissolved nutrients are transported farther offshore and directly threaten more of the GBR especially in the Mackay Whitsunday and Far North Queensland regions where the Reef is particularly close to the mainland.

The supplies of particulate (sediment) and dissolved nutrient loads originate overwhelmingly from within 120 and 90 km of the coast, respectively. Within this coastal band, management attention should be focused on areas with the highest rainfall and steepest terrain where grazing and intensive agriculture are significant landuses. High rainfall and steep terrain ensure high sediment generation rates and efficient transport of contaminants to the coast.

The contribution to sediment and nutrient loads of agriculture on the coastal flood plain was not considered in the present modelling exercise where these nutrients would enter the river system within the tidally-affected zone. It is likely that some nutrients either run off or move through the groundwater into the estuarine reaches at the downstream ends of river basins, e.g. the Daintree and Mossman, supplementing, in particular, the dissolved nutrient loads predicted by SedNet/ANNEX.

The uncertainty in the underlying data, e.g. soil nutrient content and vegetation (ground) cover, is sufficiently high that apparent strong pollutant sources suggested by the SedNet/ANNEX modelling should be further investigated. Comparison of measured soil nutrient content with the ASRIS data set showed a very high bias with observed total phosphorus content 88% higher than the ASRIS value used in SedNet/ANNEX (and in every catchment modelling application since the Land and Water Audit). Observed total nitrogen content is 21% higher than the ASRIS value. The need to reduce the modelled particulate nutrient loads to better match river water quality data by altering the assumed clay content of the soil further weakens our confidence in using catchment models to set quantitative river nutrient load targets.

3.3.3 Model Improvements

During the course of this project, the paucity of field data required to configure catchment models was identified, along with some improvements to the modelling procedures. Table 1.11 specifies actions that could be implemented in the near term which are likely to provide the greatest improvement in model accuracy and identify effective catchment management targets.

Table 1.11 Near term actions to improve model estimates

General	Sediment	Nutrient
In large catchments characterised by significant rainfall variability and/or uneven densities of stream flow gauging stations, (eg Fitzroy and Burdekin), hydrologic regionalisation should be performed on smaller subcatchments (e.g. Upper Burdekin, Belyando, Suttor) rather than on the whole catchment. The aim is to ensure the best possible hydrologic predictions. Accurate hydrologic modelling is essential to correct estimation of contaminant loads.	Empirically determine the true impact of dams on sediment deposition in the dry tropics, e.g. the impact of Burdekin Falls Dam, where sediment load has a very high proportion of fine particles and significant spill event occur intermittently. The effectiveness of dams as sediment traps has significant management implications.	Use spatially variable fertilizer management to discriminate between farms in the delivery of dissolved nutrients. (At present all farms are assumed to be managed identically).
Improve the hydrologic regionalisation by including variable bank heights, supported by field inspections.		Improve soil nutrient and clay content data sets. Incorporate observations (i.e. SALI) where available. This is perhaps the single greatest source of uncertainty in modelling particulate nutrient loads.
Include all small coastal subcatchments in future model runs. These are likely to be relatively strong contaminant sources.		Incorporate spatially variable hillslope delivery should current research conclude that this will lead to significant (> 10%) changes in predicted loads.
Include contaminant loads from coastal flood plain areas draining into tidally-driven river reaches.		Replace the National Pollutant Inventory point source nutrient load data from the proposed QEPA point source database when available. This will improve the accuracy of dissolved nutrient load predictions.
Use a spatially variable C-factor for grazing lands. At present all grazing land within a catchment is considered to have the same vegetation (ground) cover.		Support field studies to improve the mapping between landuse and dissolved nutrient concentrations in receiving water. Increase the number of landuse groups for better spatial resolution.

3.3.4 Implications for Water Quality Target Setting

Setting definitive pollutant emission targets is difficult given the limited water quality data that exists in the GBR catchments. The Productivity Commission (2003) suggested an alternative approach that targets inputs and practices that land mangers could readily change, and are correlated with pollution emissions. Hence, *'given the measurement problem in attributing diffuse pollution to individual landuser, it maybe more useful to state the objective as the adoption of specific management practices by landusers'* (Productivity Commission 2002, p147).

To achieve positive outcomes from target setting, targets need to be developed in a spirit of open and transparent dialogue with landholders. The GBR catchments comprise a wide diversity of landuses, soil types, topography and climate. Individual regions will need to take individual approaches to target setting that reflect their particular suite of management issues and opportunities. SMART targets (**S**pecific, **M**easurable, **A**chievable, **R**elevant, and **T**imed), as suggested by McDonald and Roberts (2004) offer a promising approach for application in the GBR catchments. SedNet/ANNEX is a useful tool for addressing SMART target setting because it provides an objective, transparent means to assess the relative changes that accrue from proposed management activities by providing:

- a framework to assemble catchment information and local knowledge,
- the ability to extrapolate available catchment and climate datasets, both spatially and temporally
- a framework to engage in a dialogue with the community on key catchment processes and behaviour, and
- a testable conceptual model and understanding of catchment processes and behaviour.

Some key components of any target setting approach are:

- Ownership and partnership; everyone (landholders, governments, regional bodies, industries, etc) needs to agree on the target setting process.
- Delivery; everyone needs to deliver their part, this may be a partnership or it may be achieved through coordinated but individual deliveries.
- Review: review of targets is essential, particularly as new information becomes available and review must occur in a timely manner. The review helps to improve the accuracy of the model, manage expectations and prioritise future actions.
- Consequences of non-delivery of targets need to be determined and barriers that constrain implementation regularly discussed and addressed.

SedNet was used to model the impact of specific management practices in specific locations that might lead to an improvement in water quality. Increasing vegetation (ground) cover in grazing lands was the most effective method to reduce sediment loads whereas implementation of best practice for fertiliser application was the most effective strategy for reducing dissolved nutrient loads. These management practices offer potentially measurable targets, such as increased ground cover and riparian vegetation, and modification of fertiliser application. Whether they are achievable needs further dialogue with land managers and industry. However, many management practices used in the modelled scenarios are relevant to industry guidelines, with the time period for adoption once again needing to be negotiated and agreed with land managers and industry.

The application of management actions to address water quality targets has been shown in the STM project at a catchment scale, but models do exist that address paddock scale processes (e.g. AGNPS, PERFECT, SWAT, EMSS). However, given that the input data requirements for high temporal and spatial resolution models are more demanding than that for SedNet/ANNEX, it seems unlikely that such an approach can provide relevant outputs at the GBR scale. Only areas with a high density of landscape data (eg. soil nutrient observations), would be suitable candidates for high-resolution models and these areas comprise a small proportion of the whole GBR catchment. The need for further landscape resource data capture can not be emphasised enough.

3.4 Conclusion

The project has demonstrated that SedNet is a particularly useful model for targeting catchment and river management actions and describing the relative impact on long-term average annual sediment and nutrient loads, and identifying their source and locations. The modelling identified two types of landuses that contribute significant amounts of sediment and nutrients to the GBR: low intensity large-scale grazing and intensive agriculture.

The implication of the project findings are that water quality target setting is possible using an adaptive management framework, which promotes an open and transparent approach. This approach should utilise improved management practice, various types and developments of models and an effective monitoring regime to identify the changes in water quality over time.

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Appendix 1

GBR Catchment Short Term modelling project. SW NRM01 Project Review

Appendix 1 - GBR Catchments short term modelling project

SW NRM01

Project Review

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December 2005

Introduction

The Short Term Modelling (STM) project is a collaborative package of catchment modelling and communication activity, intended to support regional bodies in the process of setting water quality targets under the Reef Water Quality Protection Plan by providing guidance on whether proposed management actions would deliver significant reductions in sediment and nutrient delivery.

Using the catchment model SedNet, five main tasks were to be delivered by science providers across State Agencies, CSIRO and CRC Catchment Hydrology and other research organisations. These tasks are categorised as:

- Produce and implement an effective communication strategy to inform stakeholders of the use and development of modelling activities in the GBR;
- Develop the "Contributor" Module of SedNet. Contributor is a software module that calculates the spatial pattern of sediment export from the catchment.
- Collate the base layers of modelling information, specifically high resolution digital elevation models, current land use data, gully density and water quality information, which are needed to underpin the sediment and nutrient models,
- Undertake regional sediment modelling through scenarios to assess whether proposed management actions will deliver significant reductions in sediment loss; and
- Refine nutrient modelling for GBR catchments, undertaking scenario modelling to test the effectiveness of proposed management actions in reducing nutrient loss.

The project is supported through a funding combination from the Australian Government's Coastal Catchments Initiative, the Water Quality State-level Investment Program (National Action Plan for Salinity and Water Quality (NAPSWQ)) and the Queensland Regional NAPSWQ Strategic Reserve.

The bulk of activities were undertaken between December 2004 and October 2005, with some extension of timelines to cater for difficulties in identifying suitable meeting dates with regional bodies following the scenario model runs. The final project report is due in February 2006.

Review Questionnaire

A survey questionnaire was developed in August 2005 to canvass participant's views, observations and conclusions about the project. The term *participants* is used here to refer to both the members of regional NRM bodies (primarily CEOs and management staff) and the project staff (primarily agency and research organisation technical modelling officers, management, extension and communication staff). In the remainder of this report, the terms "regional body staff" and "project staff" will be used to differentiate between these two groups of participants.

The survey asked for responses along several lines, to determine the regional body and project staff's views and interpretations on:

- the overall objectives and benefits of the project
- an assessment of the cross-regional, extension and scientific research aspects of the project, and
- overall conclusions and recommendations to guide similar projects in the future.

Survey Questionnaire Responses

The survey was sent to a total of 29 people including 22 government officers or CSIRO, 6 regional NRM body CEOs and one consultant. Respondents were initially given 2 weeks to respond, with a reminder sent out by email early on the day that survey returns were anticipated.

Twenty-one (21) responses were received within the requested timeframe: 16 from government officers or CSIRO, 4 from regional NRM body CEOs and one from the consultant. One additional response from an NRM body CEO was promised but never materialised. This gives an overall response rate of slightly better than 72%.

On average, project staff provided considered thoughtful responses to the survey questions; regional body staff responses, both supportive and not, were generally more cryptic. A few responses addressed only selected parts of the survey questionnaire; these responses were incorporated into the analysis where applicable.

Participants were not limited to one response per question and for some questions gave multiple comments so the total number of responses for any one question will not necessarily equal 21, the number of respondents.

A presentation of this summary analysis was made to the full project team at its project planning meeting at Natural Resources Sciences (NRSc), Indooroopilly on 27 September 2005.

This evaluation report summarises the aggregate response to the survey questions and makes recommendations based on these responses and on information provided at the NRSc presentation.

Survey Analysis

Overall Project Objectives and Benefits

Question 1 What do you see as the main purpose(s) of the Short Term Modeling Project?

The majority of respondents gave fairly general responses to the effect that the main purpose of the project is *to provide regional bodies with modelled water quality information* (15) specifically for decision-making (3) and/or for prioritisation (2). Alternatively, other general responses were that the main purpose was to *assist with water quality targets* (10).

Some respondents were more specific suggesting that the project's purpose was to:
- *develop updated modelling outputs (7);*
- *increase understanding of biophysical models in NR&M & regional bodies (6);*
- *build local expertise in modelling (3)*
- *Promote good uses of catchment modelling (2) or*
- *Guide investment in erosion mitigation (2)*

A final purpose which was mentioned by only a single person was an *improved understanding of sediment processes.*

Question 1.b
What do you see as the main outcome(s) of the project?

The most common response is that a main outcome of the project was *improved communication* (11) broken down more specifically to improved communication *within NR&M* (3), *between NR&M and regional bodies* including through science linkages (4), and *with other science providers* (2).

Eight (8) responses *identified increased capacity for modelling in NR&M* as the main outcome, with an additional four (4) responses focusing on the resulting *development of new data layers* as a main outcome.

Without specifying exactly who benefited but hypothesising that the main benefactors were regional body staff, *increased understanding of sediment processes* including the contributions of various land uses (5) was commonly identified as a main outcome of the project. Together with an *increased understanding of the appropriate use of models* (4) which appears to mean "understanding both the capabilities and limitations of modelling catchment processes", this implies significant learning for regional body staff from the project.

Also mentioned were the identification of major sources and/or relative contributions of sediment (3).

Finally, two respondents saw the main outcome of the project as being *to provide regional bodies with modelled scenarios* (2).

Figure 1 below compares the participants' responses concerning their understanding of Project Objectives with their assessment of Project Outcomes. Since the number of total responses varies between Question 1a and 1b, numbers of responses are represented in Figure 1 as percentages of total response for comparability.

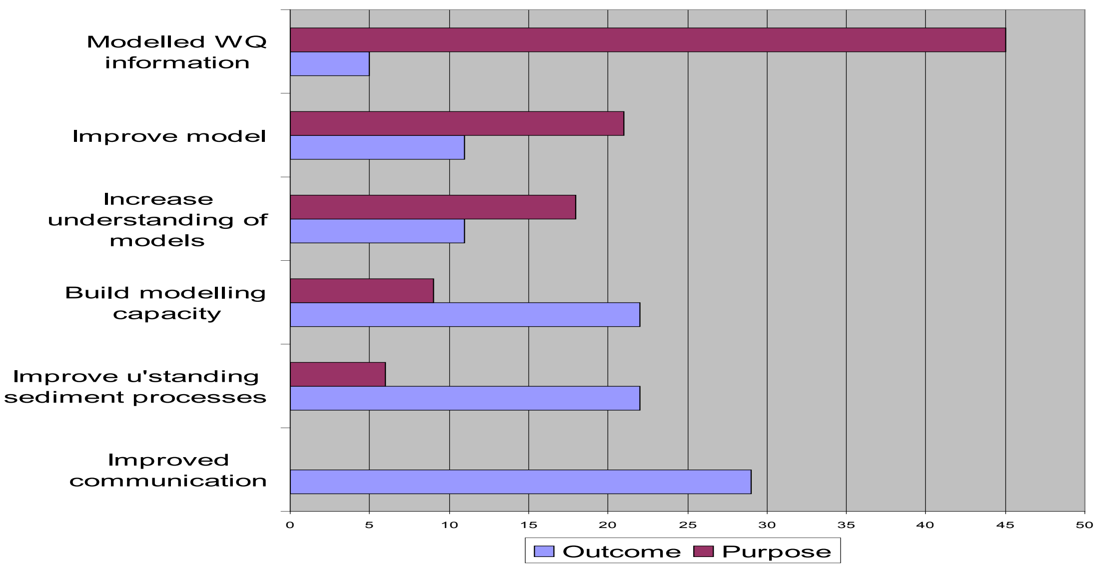

Figure A1. Comparison between Perceived Project Purpose/Objectives and Project Outcomes

Clearly there is a mismatch between the perceived project objectives (purpose) and the perceived project outcomes as reported through this survey questionnaire.

Improved communication, which was not identified as an objective in responses to Question 1, is nonetheless a clear objective and a major outcome of the project, featuring strongly and positively in the narrative responses of the project proponents in other questions. Its failure to be mentioned in Question 1a may be merely an oversight but its omission serves to remind us that information from this survey questionnaire represents participants' impressions which would benefit from being confirmed and verified by other methods of information gathering.

Modeled water quality information, which almost two-thirds of participants identified as a main purpose of the project, is identified by fewer than 5% of respondents as an actual outcome of the project.

Alignment between expected and delivered objectives was somewhat closer for *increased understanding of models* although still somewhat underachieved.

Improved understanding of sediment processes which was only mentioned by one person as a purpose of the project warrants 5 mentions as an outcome of the project. Out of 21 total responses, this variation is significant.

Question 2
How useful do you believe this project has been to the regional NRM bodies?

The general consensus to this question is that the project has had limited use for regional bodies, in that there has been some increase in understanding of landscape processes in their regions (3), some increased knowledge concerning sediment system and relative run-off differences between land uses (6), and good for identifying areas for better management (1).

In general individuals felt that achieving the project's objectives was hampered by regional body concerns over model uncertainties and/or limited data or indeed by a fear of what the model might tell land managers. Although not mentioned in responses here, it is well recognised that regional bodies were also under significant time pressures to complete their investment planning during the periods of main activity for the STM project which, as mentioned earlier, made even scheduling meetings with them quite challenging.

One respondent stated that the regional bodies were not interested in numerical WQ targets, while other individuals felt either that the usefulness to regional bodies was variable or that it was too early to tell or that there was a need to identify data and information gaps before the usefulness of the project would be determined.

Question 3 How would you characterise the main benefits of the project

Question 3 attempted, but did not succeed, in differentiating between the main benefits accruing to regional bodies and benefits accruing to the regional planning process, as in the 'cause' of regional planning.

In general however, it is believed that a major benefit of the project was to increase regional body awareness of modelling and modelling capacity (8) while developing new skills in NRM (4). The project is seen as bringing together lots of independent information (eg. from CSIRO scientists and modellers and NR&M scientists and modellers) (7) in what NR&M modellers generally consider an 'exciting' time which has also resulted in the identification of erosion hotspots (7) and improved spatial layers and data analysis (2).

Interestingly, the project is also seen as using discussions of sediment and nutrient flow modelling as a *good tool for discussing the actual physical processes which were occurring* (5) which perhaps accounts for the *increased understanding of sediment processes including the contributions of* *various land uses* identified in Question 2.

The Cross Regional Approach

Question 4a How would you describe the benefits, if any, of working on a cross-regional project?

The most frequent benefit was seen to be *the ability to share biophysical learnings – both similarities and differences* (10) between Queensland's regions. The project also provided a *larger context for interpretation* (4) of model outputs, which allowed model development which accommodated managing data for differences.

The STM project was applauded for bringing together a critical mass of modelling scientists and peers (7) which was large enough to develop a consistent approach amongst all involved, including stakeholders (6).

The cross regional approach was also credited with team building that broke down barriers (6) across the Department (3), the Department and external science providers and between NAP/non-NAP regions.

The opportunity to share social and extension type learnings (5) including sharing with regional bodies was seen as a benefit. The project provided a rewarding experience (3) of good people working together with the commendable result of building a collegiate science identify and spirit.

The cross regional approach also facilitated an efficient use of [modelling] resources (4).

Question 4b How would you describe the pitfalls, if any, of working on a cross-regional project?

As a cross-regional exercise, this project presented a significant challenge of organisation (4) involving the coordination and organisation of cross regional teams, meetings, and focus work groups. "The tyranny of distance" was used by two further respondents to signal the range of difficulties created by working across multiple locations.

The need to achieve consistency across very diverse regions with different needs (5) was seen as a potential pitfall of cross-regional projects, despite the earlier optimistic interpretation (see Question 4a) that regional diversity provided a *larger context for interpretation* (4) *of model outputs*, which allowed the development of a model that could handle data differences better.

Further difficulties attributable to the cross-regional nature of the project were the *development of data sets that were too large* and *hold ups associated with sorting out the logistics of data transfe*r. Additional issues raised by individuals were a concern that *expertise was thinly spread on the ground*; the proposed tasks were muddled by an *expectation of producing Reef targets*, early quandaries over the *appropriate mix of general versus particular models* and the extent to which the sum of regional products would give valid cross-regional comparisons.

Less related to the cross-regional nature of the project, and more to the short-term lead–in time for the project, were *hold ups* resulting from the lack of smooth sequencing where the development of basic data sets delayed the development of more complex dependent data sets (2), for example when the creation of new DEMs held up dependent modelling.

Of significant concern, but probably not directly attributable to the cross-regional nature of the project, was a sense that *the STM project pulled officers away from their other regional responsibilities* (5) and those who tried to do justice to their full range of work commitments ended up overcommitted, often with significant week-end and after hours work.

Question 4c Looking back over the past 6 months, have there been any processes that have specifically helped the project team to work more effectively as a cross-regional team? If so, please describe what they have been and how they have helped.

The majority of respondents agreed that regular workshops and teleconferences (16) were very helpful processes in the development of effective teams. These workshops both set aside time to work just on the project while also assisting each other with trouble shooting.

Good management (6) in the form of strong leadership, effective scoping and for the regular workshops and teleconferences, tight meeting structures and good agenda setting contributed to the project team working effectively.

Question 5a
Can you suggest any further ways to help the project team work more effectively and efficiently as a cross-regional team?

Some additional suggestions to improve effectiveness and efficiency are:

- Field trips to observe phenomenon first hand and to talk to experienced graziers so the entire team hears the same information,
- Inter-region attendance at workshops, and
- Exchange of participants between centres.

Question 5b Besides team effectiveness are there any other ways you can suggest that the cross-regional approach of the project could be improved in the future?

Improvements to the computing system could have improved the cross-regional approach. Suggested improvements included:

- centralised and efficient data storage, maintenance and control (2)
- no firewalls (use of Sharepoint).

An elaboration of the open atmosphere between lesser skilled and more expert model builders which developed within the project was suggested as an improvement. This would include *quick access to model builders and technical experts, including those previously involved* (5) as well as *access to outside professionals where needed.*

Greater lead-in time (7) to organise and coordinate which would have also provided the *opportunity at the project development phase to nurture wider involvement (3)* was also seen as a way to streamline and improve the cross-regional approach.

Question 5c
If you could choose one or two significant events in which you have been involved with the project team that influenced you in some way, what would they be and why?

NR&M and CSIRO project team meetings were held in Cairns, Mackay and Bundaberg while meetings with regional bodies were held in FNQ, Townsville, Mackay, Rockhampton, Emerald, and Burnett/Mary.

Mackay, Townsville & Rockhampton are mentioned as locations of discussions in workshops and regional body meetings which particularly stand out in respondents' memories.

Internal workshops featured widely (9) as significant and defining events in the project for many participants, mainly because there were seen to be so many experienced people in the room who participated in excellent group debates, informal discussions and workshop dinners to work through and resolve issues.

Also well regarded as significant and defining events were *the presentation of the project's results (6) to Board and industry representatives* because of the novel experience in hearing the Board and industry reps discussing NRM issues and in realising the diversity of expectations amongst stakeholders (including those of the Water Quality Coordination Group.)

For one respondent, there was also a genuine concern that the real community, landholders, were being left out of the consultation process.

Research Approach

Question 6a
How would you characterise the way in which research activities have been conducted over the past 6 months on the project?

The research activities have been characterised by sound management (7) which allowed the activities to be highly focused operating at a fast pace, and demonstrating a strong 'natural selection' of ideas.

The time pressures (5) were significant which meant that people worked more than required (2) and on occasion had to make decisions based on limited information. Overall there was good collaboration (4) with community and between agencies which demonstrated good will and made for an enjoyable and generally empowering experience.

Two respondents queried calling the activities of collation and summarising known information as "research".

Question 6b
What would you see as the main research success(es), if any, of the project?

Having a model running in all regions with the best available base layer information (2) *in the time allotted* was seen as the main research success though in the process the identification of the original SedNet model's shortcomings and clarification of existing knowledge gaps while improving the understanding of catchment processes generally (3) were seen as significant research successes.

Individuals stated that developing a DEM for the non-NAP Reef regions was a main research success, while another felt that conquering the challenges of data management was a research success.

Question 6c
What would you see as the main research principles the project has tried to uphold? (Please describe what each of these principles means.)

Overall it appears this is a project that the participants and project management can take pride in.

The project was characterized by good communication and community engagement (6) (although see below in the Extension Approach for some caveats), intellectual honesty and openness (4) to opinions and ideas. The project maintained regard for data quality and encouraged vigorous debate in an atmosphere of researchers willing to share knowledge which also permitted the less experienced researcher/modeller to ask for help.

The project is characterised as good science research (5) which produced new data, not a rehash of old, delivered reproducible findings and promoted landscape process understanding. The research component of the project was seen to be collaborative and supportive.

Question 6d
Can you suggest any way(s) in which the research approach could be improved in the future?

Again the issue of *time*, specifically *more realistic timeframes* (5), especially in providing more lead time, would have supported better research outcomes and better extension.

Efforts to improve data quality before modelling (3) including water quality events-based monitoring data and DEM, would have improved the research approach.

It was also seen as important to build on what has been accomplished (5) and extend the research, eg. by improving the development of floodplain models, seeking external verification of results through coral cores, and by publishing the results for peer review, especially the regional variations to modelling.

Extension Approach

Question 7a
How would you characterise the way in which extension/communication has been conducted over the past 6 months on the project?

This set of questions produced the most equivocal responses, with a general assessment that the extension component was characterised by good intentions which were not as good in delivery (7). For some respondents this was an issue of considerable concern.

Most of the project time was spent in model development and preparation, and dependent on the region, delivery of the extension component was quite variable --excellent in some regions, but heavily dependent on skills and availability of the staff (full-time/part time on project) and the regional body receptivity. Some regional bodies felt they were too busy with other pressing commitments to engage with the STM project.

A regular series of presentations and engagements (3) were delivered to time but called for significant (and rushed) efforts.

Question 7b
What would you see as the main extension/communication success(es), if any, of the project ?

Despite regrets over what was not accomplished, there was a general sense that the project had successfully *educated the community with regard to the appropriate use of models,* both of the benefits and limitations of what models can do (7). The outcomes of the project were characterised as *preliminary but useful.*

The project was also seen to exhibit a *great willingness to engage* (5), to use collaborative approaches (4) with regions determining the scenarios to be modelled, with NR&M and the modellers listening to Boards and understanding Board needs in the production of useful management scenarios (2).

Question 7c What would you see as the main extension/communication principles the project has tried to uphold?

The collaboration was seen to employ an open and transparent process (7) in which involvement increases understanding and employing good two-way communication and a collaborative approach.

Question 7d Can you suggest any way in which the extension/communication approach could be improved in the future?

Again more time (15) (especially lead-in time to build partnerships) was suggested. Related to time, but slightly different, was the need to be able to make a full time commitment to the collaborative process.

Improved communication to a broader audience (5) was seen to increase data validity & usefulness and to develop 'ownership'.

The suggestion was made that one possible way to progress the extension component of STM would be employing the SIP WQ03 project[1] which still has a year to go.

1 **WQ03: Modeling landscape processes, management impacts and catchment loads**
Using spatial and temporal models to provide regions with user-friendly outputs related to landscape processes and their impacts on water quality, the effect of management practices and estimates and predictions of catchment loads. Enhancement of selected monitoring sites in each catchment will provide better temporal resolution of key water quality indicators as well as the ability to measure export loads.

Overall Looking Back on the Project

Question 8
If there were three successes you could identify, what would they be?

Responses to this question were very clear, centering around three main and two ancillary responses:

- Regional agency capacity building (7)
- Team development (8)between regional scientists and also within the catchment modelling network in NR&M
- Enhanced relationships with regional boards (6)
- Slightly improved understanding of catchment models (3), and
- Further research into the information needs for modelling, including major bugs in modelling software.

Question 9
If there were three suggestions you could make to improve the project, what would they be?

Almost unanimously respondents see *more time* (15) as delivering the greatest improvements to the STM project.

The *acknowledgement of modelling as part of a longer term commitment to regional NRM* (3) was also seen as one way to make improvements in the project.

At the time of this project review, there appears to be a feeling that the project is yet unfinished and that there is a need to formally complete the project. Two aspects of this completion were highlighted in responses:

- There remains a need to do the engagement and/or extension process better. This might entail the modelling team returning to do more one-to-one work with the regional bodies, focusing on the regions which express an interest to progress the collaboration. The project has resulted in significant advancement of modelling capabilities within the Department and the benefits of that advancement need to be shared by interested regional bodies.

- The project must be formally written up, both for the professional development of staff and because (at least some of) the relevant regional bodies are awaiting an official report with recommendations in order to develop an implementation plan.

Question 10
(Optional) -- Any concerns with the project to date? (e.g. project management, project intent, project approach, relationships, etc.) and how could these concerns be addressed?

There were no responses to this (optional) question.

Summary and Recommendations

The Short-Term Modelling (STM) Project set out to *support* regional bodies in the process of setting water quality targets, by providing guidance on whether proposed management actions would deliver significant reductions in sediment and nutrient delivery. Five main tasks were to be delivered by science providers across State agencies, CSIRO and CRC for Catchment Hydrology between January and June 2005. Project delivery was made more challenging by the project design which integrated research and extension activities, in some areas coming close to a co-learning approach, within a cross-regional project with project officers/ researchers and modelers drawn from a number of organizations.

The project succeeded admirably in some areas of achievement and in others, less well. There was also variability across geographical areas. Good progress appears to have been made in utilizing the "Contributor" Module of SedNet. Digital elevation models were developed where none had existed before. Base layers of modeling information, including current land use data, gully and water quality information were produced and were collated to underpin the sediment and nutrient transport models.

Regional sediment and nutrient modeling through scenarios was undertaken in collaboration with regional body board members in most regions to assist regional bodies in determining whether particular proposed management actions would deliver reductions in sediment transport and nutrient loss. In some regions, information from the STM project has been used to determine the most efficient and effective management action targets to deliver set reductions in sediment and nutrient transport but in all regions, the project has been responsible for clarifying the community's understanding of the appropriate use of models, both of the benefits and limitations of what models can do. It has become clear that models are most appropriately used to deliver a comparative analysis, in this case of the various levels of sediment and nutrient flow for a catchment under different management regimes. Modelling is therefore capable of informing regional bodies of the most appropriate management actions to be put in place; modelling is less able to support the setting of definitive targets, without significant and repeated "ground truthing" efforts.

As a result of the project there has been a clarification of knowledge gaps while improving the understanding of catchment processes generally. There has been significant progress in identifying major bugs in modeling software and in learning how to meet the challenges of data management across multiple modelers and regions.

In less tangible outcomes, this cross-regional has been characterized by good communication, intellectual honesty and openness providing regional scientists and modelers with a memorable experience of vigorous debate in a supportive and inquiring research atmosphere. It has helped to develop a team approach between regional scientists and also within the catchment modeling network of NR&M.

The project has been less successful in its extension efforts, as the majority of project time was devoted to developing and preparing the model itself to the regional context, leaving less time than expected for interacting with the regional body staff and boards. Then too, delivery of the extension component was quite variable --excellent in some regions, but heavily dependent on skills and availability of the staff (full-time or part time on the project) and the regional body receptivity. Some regional bodies felt they were too busy with other pressing commitments to engage with the STM project. Presentations and engagements were more abbreviated and rushed than desired. Nevertheless, the project was seen to exhibit a willingness to engage and to use collaborative approaches with regions to understand regional information needs and use these as a basis for the development of management scenarios.

This has left several of the regional bodies in some quandary, still awaiting the completion of the project and its formal recommendations before the scenarios developed can be acted upon.

Recommendations therefore are that:

- There remains a need to finalise the pre-existing extension work in a more comprehensive way, particularly with those regional bodies who have demonstrated a receptiveness to collaboration. This might entail the modelling team returning to do more one-on-one work with interested regional bodies.

- Developed with the assistance of NAPSWQ SIP funds and Strategic Reserve regional funds, the project has resulted in significant advancement of modelling capabilities within the Department and the benefits of that advancement need to be shared by interested regional bodies. Some consideration needs to be given to the arrangements under which regional bodies who wish to engage in continued testing of selected management actions and their targets in the future, are to be supported.

- The project must be formally written up, both for the professional development of staff and because at least some of the relevant regional bodies are awaiting an official report with recommendations in order to develop an implementation plan.

Appendix 1 - Attachment 1

GBR Catchments
Short-term Modelling Project
SW NRM01

Survey

Please tick where you are from:

____	State Government agency
____	Federal government
____	Peak Industry body
____	Regional Body CEO
____	Regional Body Planning Officer
____	Regional Body Scientific Coordinator

Overall Project Objectives and Benefits

1a What do you see as the main purpose(s) of the Short Term Modelling Project?

1b What do you see as the main outcome(s) of the project?

2 How useful do you believe this project has been to the regional NRM bodies?

3 How would you characterise the main benefits of the project

a. to the regional NRM bodies
b. to the regional planning process

The Cross Regional Approach

4a How would you describe the benefits, if any, of working on a cross-regional project?

4b How would you describe the pitfalls, if any, of working on a cross-regional project?

4c Looking back over the past 6 months, have there been any specific approaches or processes that have specifically helped the project team to work more effectively as a cross-regional team? If so, please describe what they have been and how they have helped.

5a Can you suggest any ways to help the project team work more effectively and efficiently as a cross-regional team?

5b Are there any other ways you can suggest, besides team effectiveness, that the cross-regional approach of the project could be improved in the future?

5c If you could choose one or two significant events in which you have been involved with the project team that influenced you in some way, what would they be and why?

Research Approach

6a How would you characterise the way in which research activities have been conducted over the past 6 months on the project?

6b What would you see as the main research success(es), if any, of the project ?

6c What would you see as the main principles the Project has tried to uphold? (Please describe what each of these principles means.)

6d Can you suggest any way(s) in which the research approach could be improved in the future?

Extension Approach

7a. How would you characterise the way in which extension/communication has been conducted over the past 6 months on the project?

7b. What would you see as the main extension/communication success(es), if any, of the project ?

7c. What would you see as the main extension/communication principles the project has tried to uphold?

7d. Can you suggest any way in which the extension/communication approach could be improved in the future?

Overall Looking Back on the Project

8. If there were three successes you could identify, what would they be?

-
-
-

9. If there were three suggestions you could make to improve the project, what would they be?

-
-
-

10. (Optional) -- Any concerns with the project to date? (e.g. project management, project intent, project approach, relationships, etc.) and how could these concerns be addressed?

Thank you for your participation in this end-of-project survey.

Appendix 2

ANNEX unadjusted results for the Far North Queensland, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary NRM region scenarios

ANNEX unadjusted nutrient loads for Far North Queensland

EXP TO COAST (T/Y)	Suspended Sediment	DIN	DON	PN	TOTAL N	DOP	FRP	PP	TOTAL P
Brodie	1 890 000	5 357	4 344	4 555	14 256	358	120	1 530	2 008
Base	1 404 826	9 069	3 314	8 478	20 860	259	396	2 539	3 194
Sugar current	1 260 905	9 069	3 314	7 385	19 768	259	396	2 211	2 866
Sugar recommended	1 260 905	7 814	3 314	7 385	18 513	259	396	2 211	2 866
Sugar BMP	1 260 905	6 296	3 314	7 385	16 995	259	396	2 211	2 866
Banana BMP	1 260 905	8 839	3 314	7 385	19 538	259	396	2 211	2 866
Cane to cow 100%	1 268 309	2 676	3 167	7 453	13 297	244	425	2 249	2 918
Riparian 30%	1 331 787	9 069	3 314	8 329	20 712	259	396	2 501	3 156
Riparian 50%	1 280 370	9 069	3 314	8 226	20 609	259	396	2 476	3 131
Riparian 100%	1 224 964	9 069	3 314	8 115	20 497	259	396	2 448	3 103
Cane to cow top 20% USLE	1 356 456	6 629	3 278	8 083	17 990	255	402	2 379	3 037
3% to natural	1 356 456	7 092	3 209	8 083	18 384	253	381	2 379	3 014

ANNEX unadjusted nutrient loads for Burdekin region

EXP TO COAST (T/Y)	Suspended Sediment	DIN	DON	PN	TOTAL N	DOP	FRP	PP	TOTAL P
Brodie	3 743 000	2 249	1 350	8 763	12 362	75	35	2 314	2 424
Base	4 472 811	2 257	3 434	16 735	22 426	170	228	4 000	4 398
export10	11 909 089	2 257	3 434	53 775	59 466	170	228	13 100	13 498
export20	9 203 899	2 257	3 434	40 346	46 037	170	228	9 811	10 208
export30	7 321 639	2 257	3 434	30 987	36 678	170	228	7 515	7 912
export40	6 013 931	2 257	3 434	24 468	30 158	170	228	5 912	6 309
export50	5 104 222	2 257	3 434	19 914	25 605	170	228	4 788	5 186
export60	4 472 811	2 257	3 434	16 735	22 426	170	228	4 000	4 398
export70	4 032 919	2 257	3 434	14 505	20 195	170	228	3 444	3 841
export80	3 727 688	2 257	3 434	12 944	18 635	170	228	3 052	3 449
export90	3 515 222	2 257	3 434	11 848	17 539	170	228	2 774	3 172
export100	3 365 599	2 257	3 434	11 070	16 760	170	228	2 576	2 974
gully_2	4 003 504	2 257	3 434	15 763	21 453	170	228	3 751	4 148
ripveg_2	4 163 538	2 257	3 434	16 116	21 807	170	228	3 845	4 243
without_dam	6 992 227	2 302	3 619	25 922	31 843	179	245	7 045	7 470

ANNEX unadjusted nutrient loads for Mackay Whitsunday region

EXP TO COAST (T/Y)	Suspended Sediment	DIN	DON	PN	TOTAL N	DOP	FRP	PP	TOTAL P
Brodie	2 143 000	1 489	886	3 784	6 159	130	24	1 467	1 621
base	1 792 931	2 497	1 609	6 400	10 506	294	83	2 394	2 771
graz40	2 348 727	2 499	1 609	8 494	12 602	294	83	3 184	3 561
graz80	951 380	2 499	1 609	3 167	7 274	294	83	1 141	1 518
ripveg75	1 732 980	2 499	1 609	6 278	10 385	294	83	2 350	2 727
cane0tb	1 891 432	2 499	1 609	6 733	10 840	294	83	2 514	2 891
cane100tb	1 639 222	2 499	1 609	5 892	10 000	294	83	2 214	2 591
canecc	2 679 879	2 499	1 609	9 372	13 480	294	83	3 457	3 834
hsdr05	1 001 442	2 499	1 609	3 451	7 559	294	83	1 275	1 652
cane_din500	1 792 931	1 001	1 609	6 408	9 017	294	83	2 387	2 764

ANNEX unadjusted nutrient loads for Fitzroy scenarios

EXP TO COAST (T/Y)	Suspended Sediment	DIN	DON	PN	TOTAL N	DOP	FRP	PP	TOTAL P
Brodie	2 911 000	1 251	1 314	5 506	8 071	66	17	2 057	2 140
Base	4 575 202	972	1 293	17 507	19 772	122	119	5 809	6 050
Graz30	8 716 399	972	1 293	35 893	38 157	122	119	12 224	12 465
Graz40	6 747 945	972	1 293	27 254	29 519	122	119	9 205	9 446
Graz50	5 180 912	972	1 293	20 257	22 522	122	119	6 764	7 005
Isaac800_30%	5 516 909	972	1 293	22 360	24 624	122	119	7 627	7 868
Boomer96_gully	5 626 304	972	1 293	22 688	24 952	122	119	7 710	7 950
Graz60	3 989 170	972	1 293	14 825	17 090	122	119	4 878	5 119
Graz70	3 121 873	972	1 293	10 838	13 102	122	119	3 489	3 730
Conventional tillage	4 797 020	972	1 293	18 020	20 285	122	119	6 020	6 261
Zero tillage	4 488 994	972	1 293	17 307	19 571	122	119	5 726	5 967
Riparian 100%	4 157 460	972	1 293	16 671	18 936	122	119	5 600	5 841

ANNEX unadjusted nutrient loads for the Burnett River catchment

EXP TO COAST (T/Y)	Suspended Sediment	DIN	DON	PN	TOTAL N	DOP	FRP	PP	TOTAL P
Brodie	471 000	470	447	977	1 894	70	6	336	412
Base	1 007 950	340	406	4 416	5 161	59	30	1 399	1 487
60percent	919 044	340	406	3 985	4 731	59	30	1 248	1 336
80percent	522 544	340	406	1 950	2 696	59	30	592	681
peanut2grazing	1 026 945	328	405	4 540	5 274	58	30	1 426	1 514
urbanisation	1 022 651	340	406	4 523	5 269	59	30	1 421	1 509
156km_bank_reveg	1 000 307	340	406	4 394	5 140	59	30	1 393	1 482
194km_bank_reveg	998 823	340	406	4 391	5 137	59	30	1 393	1 481
352km_bank_reveg	995 370	340	406	4 384	5 130	59	30	1 391	1 479
583km_bank_reveg	992 425	340	406	4 378	5 124	59	30	1 389	1 478
1113km_bank_reveg	990 101	340	406	4 373	5 119	59	30	1 388	1 477
10km_gull_rstabilised	1 007 702	340	406	4 409	5 155	59	30	1 397	1 486
53km_gull_rstabilised	1 006 685	340	406	4 407	5 153	59	30	1 397	1 485
273km_gull_rstabilised	1 001 282	340	406	4 396	5 142	59	30	1 394	1 482
1383km_gull_rstabilised	974 089	340	406	4 341	5 087	59	30	1 380	1 469
2978km_gull_rstabilised	939 771	340	406	4 273	5 019	59	30	1 363	1 451