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

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Executive Summary

Overview
1. This report describes results and conclusions from the monitoring component of the Douglas Shire Council (DSC) water quality project. The components of this project that this report addresses are:

- Site selection and installation of in-stream and off-paddock automatic water quality monitoring equipment in the Douglas Shire
- Design of appropriate sampling strategies for automatic stations
- Estimation of loads of suspended sediment, total nitrogen and total phosphorus in rivers and also estimation of the changes in nutrient loads from sugar cane under different fertilizer application rates.
- Development of a community-based water quality sampling program to complement the automatic sampling efforts.
- Design of an optimised, long-term water quality monitoring strategy

The report also makes recommendations for the refinement and development of future water quality monitoring strategies. These recommendations are particularly applicable to other Queensland catchments draining into the Great Barrier Reef (GBR) lagoon.

2. The monitoring component of the DSC water quality project aimed to establish the infrastructure and methodologies necessary for estimating: (1) the long-term trends in loads of sediments and nutrients being discharged into estuaries from three major rivers (Daintree, Mossman, Saltwater Creek); and (2) the impacts of adoption of best management practices and changes in land use on trends in water quality of rivers and streams in the Shire. The loads of sediments and nutrients have the potential to adversely affect the ecosystem processes operating within streams and the GBR lagoon and so this project aims to quantify how land use can be changed to reduce sediment and nutrient loads.

Performance Of Automatic And Community Monitoring During 2003/2004
3. The automatic monitoring infrastructure for collecting water quality samples worked very well. Careful choice of instruments and appropriately designed installation techniques ensured the collection of quality data from both in-stream stations and off-paddock flume systems. The ability to deliver up-to-date data to DSC water quality staff and CSIRO officers was a major contributor to the successful operation of these stations. There was, however, some data loss due to a combination of problems resulting from faulty sensors, vandalism, extreme conditions and operator error.

4. The rate-of-rise algorithm developed as a means to trigger sample collection for both the in-stream and flume stations performed particularly well. This strategy gives a good temporal representation of flow events and could prove useful for developing sampling strategies for similar ungauged locations around Australia.

5. Community collected samples from sixteen different sites across the Douglas Shire were used to assess baseflow water quality condition in relation to Queensland EPA guidelines and to raise awareness of water quality issues. If the community are to be used to collect water quality samples for loads estimation then the best use of their time and available resources is collection of baseflow samples from each of the automatic station sites. These samples will be used in loads calculations for times when river levels are below the level of the automatic sample off-take.

Timing Of Delivery Of Sediments And Nutrients
6. Baseflow sampling shows that concentrations of nutrients and sediments are relatively constant and considerably lower than during the large flow events. Hence, baseflow can be adequately represented by once monthly grab samples.
7. There was a general tendency for sediment and nutrient concentrations during peak flow events to fall and to become less variable as the wet season progressed. This is likely to be caused by the depletion of nutrient and sediment stores which accumulated over the dry season.

8. Although the concentration of nutrients and sediments peaks early in the wet season, the proportion of total load moved is still greater during the later part of the wet season when prolonged monsoonal events and tropical depressions result in high discharges.

9. The concentration data from the two Mossman River stations (upper and lower positions in the catchment) indicate that there is a source of phosphorus between the two stations. The mean total nitrogen and organic nitrogen concentrations decrease between the two stations as a result of dilution but the concentration of dissolved forms increases. These findings are consistent with nutrients entering the river from the agricultural region on the coastal floodplain. The data also indicate that the agricultural lands of the coastal floodplains and tributary streams are a sediment source.

10. The best use of community collected data was in the comparison of sediment and nutrient concentrations to Queensland EPA water quality guidelines. Samples collected in the four major catchments showed that dry season water quality in the Douglas Shire streams was generally below recommended maximum levels.

**Sediment And Nutrient Loads**

11. Nutrient and sediment loads could not be calculated at the Saltwater Creek, Lower Daintree and Lower Mossman sites because instrumentation and resources necessary for determining discharge at tidally affected sites was beyond the available budget. Estimates of loads delivered during 2003/2004 at the Upper Daintree and Upper Mossman sites are given in the table below. It must be remembered that these load estimates are considered to be only preliminary estimates because of gaps in the data (primarily at the Upper Daintree site), the short duration of the monitoring period (7 months) and the sensitivity of the estimates to the method used to calculate loads.

<table>
<thead>
<tr>
<th></th>
<th>Upper Mossman</th>
<th>Upper Daintree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream contributing area</td>
<td>8,677 ha</td>
<td>90,865 ha</td>
</tr>
<tr>
<td>Total Discharge (01/12/03 – 30/06/04)</td>
<td>280,895 ML</td>
<td>1,530,000 ML</td>
</tr>
<tr>
<td>Load (tonnes)</td>
<td>delivery rate (kg/ha)</td>
<td>load (tonnes)</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>151</td>
<td>17.4</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>4.48</td>
<td>0.52</td>
</tr>
<tr>
<td>Total suspended sediment</td>
<td>2902</td>
<td>334</td>
</tr>
</tbody>
</table>

12. An analysis of the data suggests that the total phosphorus load estimate at the Upper Mossman site is likely to be slightly underestimated (2-8%), while the total nitrogen load is likely to be underestimated by 12 to 25%. The accuracy of the other loads could not be established from the available data.

13. The delivery rates (kg/ha/yr) of nitrogen, phosphorus and sediment were much higher at the Upper Daintree than at the Upper Mossman site although both drain from undeveloped forest. This may be related to differences in vegetation cover, slope and/or soil types, or could be related to uncertainty in load estimates based on the small number of samples available at Upper Daintree. The Upper Mossman catchment is completely covered by dense rainforest, while about 50% of the Upper Daintree catchment is open Eucalypt woodland.
Sugarcane Nutrient Trials

14. Nitrogen fertilizer was applied at rates of 190 kgN/ha (traditional rate) and 98 kgN/ha (recommended rate) to establish whether the reduced application rate affected production as well as nutrient loss from the trial sites. There was a reduction in the average concentration of nutrients in runoff from storm flows as the wet season progressed – similar to the progression seen in the river data.

15. The calculated loads of total nitrogen, total phosphorus and total suspended sediment from the high and low fertiliser plots are shown in the table below. They show that higher loads of sediments and nutrients were lost from the plot with the higher fertilization rate. The table below also shows the sugar production and final income from the two flume plots. These results show that sugar production is approximately 10% higher for the higher N application, however, total income, adjusted for N application cost, is only marginally less (3.5%) for the lower N application rate. The results suggest that N application rates can be reduced significantly, thus greatly reducing environmental impacts with only minor reductions to farm income. Higher sediment loss from Flume 2 is unexpected and the mechanisms for this are unclear. Consequently, these results need to be treated with caution and we recommend that further work be done on the effects of fertiliser application rate.

<table>
<thead>
<tr>
<th></th>
<th>Flume 1</th>
<th>Flume 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contributing area</td>
<td>0.33 ha</td>
<td>0.26 ha</td>
</tr>
<tr>
<td>Nitrogen fertiliser application rate</td>
<td>98 kg N/ha</td>
<td>190 kg N/ha</td>
</tr>
<tr>
<td>Total rainfall (01/12/03 – 30/06/04)</td>
<td>9.77 ML (2960 mm)</td>
<td>7.70 ML (2962 mm)</td>
</tr>
<tr>
<td>Total surface runoff</td>
<td>3.3 ML (1000 mm)</td>
<td>2.53 ML (973 mm)</td>
</tr>
<tr>
<td>Total nitrogen delivery rate</td>
<td>9.54 kg/ha/yr</td>
<td>11.58 kg/ha/yr</td>
</tr>
<tr>
<td>Total phosphorus delivery rate</td>
<td>1.58 kg/ha/yr</td>
<td>2.46 kg/ha/yr</td>
</tr>
<tr>
<td>Total suspended sediment delivery rate</td>
<td>174 kg/ha/yr</td>
<td>534 kg/ha/yr</td>
</tr>
<tr>
<td>Sugar Production</td>
<td>10.19 t/ha</td>
<td>11.24 t/ha</td>
</tr>
<tr>
<td>Income (adjusted for N inputs)</td>
<td>$1054 /ha</td>
<td>$1093 /ha</td>
</tr>
</tbody>
</table>

16. Significant loads of nitrogen, mainly as NOX, were lost via sub-surface pathways. There were higher sub-surface nitrogen loads from the higher application rate plots. Subsurface phosphorus loads were very low.

17. Overall, there was 44% more nitrogen being lost to water (both surface and sub-surface) from Flume 2 than Flume 1. Therefore, as long as the plant is receiving sufficient nitrogen for growth, it appears that the Flume 2 fertiliser application rate is too high and results in higher environmental losses of nitrogen for a very small financial gain.

Recommendations For Future Water Quality Monitoring

18. The main features of the Douglas Shire catchments identified in the interim monitoring, which must be recognised and addressed in the future monitoring strategy, are:

- The need to focus loads based sampling on events as this is when the most variation in sediment and nutrient concentrations occurs and this is when the vast majority of loads are moved.
- The occurrence of strong seasonal flow changes, not just between the wet and dry season, but also during the wet where there is a marked change in inter-event flow.
- The importance of the ‘first flushes’ of sediment and nutrient at the start of the wet season and the subsequent exhaustion of sediment and nutrient supplies as the wet season progresses.
- The need to invest resources in the development of reliable discharge estimates.
- The need to deal with the influence of tidal incursions on the lower catchment sites.
19. The sampling requirements for calculating loads at all stations are summarised in the following table. The sampling strategy for upper stations and flumes was developed from statistical analysis of loads calculated from discharge and concentration data collected during the 2003/2004 monitoring period. The strategy for the lower stations, which are tidal, first requires the determination of discharge and, hence, loads, followed by application of the statistical techniques used to refine sampling at the upper and flume stations.

<table>
<thead>
<tr>
<th>Target number of samples per year</th>
<th>Event Sampling Strategy</th>
<th>Non-event sampling strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Stations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Rate-of-rise</td>
<td>Monthly grab</td>
</tr>
<tr>
<td><strong>Lower Stations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Salinity &amp; Rate-of-rise</td>
<td>Monthly grab</td>
</tr>
<tr>
<td><strong>Flume Stations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 (70 + 30 lysimeter)</td>
<td>Rate-of-rise</td>
<td>NA</td>
</tr>
</tbody>
</table>
Acknowledgements

This study was commissioned by the Douglas Shire Council using funds obtained from the Coastal Catchments Initiative Program within the Australian Government's Natural Heritage Trust Program. This study presents the results of the water quality monitoring component of the Douglas Shire Water Quality Improvement Plan. This monitoring program would not have been possible without the efforts of a number of people from many different organizations.

Installation and maintenance of the automatic stations would not have been possible without the hard work and technical expertise provided by Dave Fanning, Mark Disher, Aaron Hawdon, Rex Keen and Joseph Kemei (CSIRO). We also acknowledge the assistance provided by Neale Searle, Gary Drake and Darren Alston of the Queensland Department of Natural Resources and Mines in supplying hydrological data for various aspects of the project. Andrew Moss and Andy Steven of the Queensland Environmental Protection Agency provided valuable historic water quality data. Anne Henderson (CSIRO) provided assistance with map production. We would also like to thank Kit Rutherfurd (CSIRO, Canberra) and David Fox (CSIRO and Melbourne University) for their valuable comments on the draft document.

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Table of Contents

Executive Summary.............................................................................................................ii
Acknowledgements............................................................................................................vi
Table of Contents...............................................................................................................vii
List Of Appendices ...........................................................................................................viii
Associated Reports ..........................................................................................................viii
Section 1. Introduction........................................................................................................1
Section 2. Water Quality Monitoring Programs: Development And Management
Considerations.....................................................................................................................3
  2.1 Overview......................................................................................................................3
  2.2 Defining The Question And Timeline.......................................................................3
  2.3 Clearly Assigning Budgets And Timelines ...............................................................3
  2.4 Communication .........................................................................................................4
  2.5 Sample Site Selection ...............................................................................................4
  2.6 Equipment Selection And Installation .....................................................................4
  2.7 Automatic Sampling Strategy ..................................................................................5
  2.8 Community Sampling Strategy ...............................................................................5
  2.9 Sample Processing Storage And Analysis ...............................................................6
  2.10 Data Storage, Analysis And Interpretation .............................................................6
  2.11 Detecting Trends In Sediment And Nutrient Loads ...............................................7
Section 3. Water Quality Monitoring In Douglas Shire During The 2003/2004 Wet
Season: Performance And Findings.................................................................................8
  3.1 Project Objectives ......................................................................................................8
  3.2 Automatic Sampling Overview ...............................................................................8
  3.3 Community Sampling Overview ............................................................................9
  3.4 Performance Of Automatic Monitoring During 2003/2004 ....................................9
  3.5 Findings From Automatic Sampling During 2003/2004 .........................................10
  3.6 Performance Of Community Monitoring During 2003/2004 ...............................18
  3.7 Findings From Community Monitoring During 2003/2004 .....................................19
Section 4. Recommendations For Future Development Of The Douglas Shire
Council Water Quality Monitoring Program ..............................................................20
  4.1 Overview ....................................................................................................................20
  4.2 What Was Learnt From The Interim Douglas Shire Study? .....................................20
  4.3 Future Water Quality Monitoring In Douglas Shire .................................................20
  4.4 Requirements For Refining The Loads-Based Monitoring Program ....................22
Section 5. Conclusions ......................................................................................................27
List Of Appendices

Appendix A Selection Of Douglas Shire Automatic Water Quality Monitoring Sites

Appendix B An Automatic Load Based Monitoring System For Douglas Shire

Appendix C Development Of Automatic Water Quality Sampling Strategies For The 2003/04 Wet Season

Appendix D Discharge Calculation At The Upper Mossman And Upper Daintree Stations

Appendix E Presentation And Interpretation Of Water Quality Data From Automatic Monitoring Stations For The 2003/2004 Wet Season

Appendix F Adequately Representing Water Quality Condition With Automatic Monitoring Stations: Sampling Design And Initial Analysis

Appendix G Load Calculations For Upper Mossman And Upper Daintree Automatic Monitoring Stations For The 2003/2004 Wet Season

Appendix H Reducing Loads Through Management Interventions: Results From Douglas Shire Water Quality Monitoring Flume Experiments

Appendix I Analysis Of Community Collected Water Quality Data For The 2003/2004 Wet Season

Appendix J A Future Loads-Based Monitoring Program For The Douglas Shire Catchments

Associated Reports


Section 1. Introduction

Monitoring Strategy Goals
A major component of the Douglas Shire Council (DSC) water quality project has involved measuring the concentration and loads of sediment and nutrients in the four major river systems in the shire (Daintree, Mossman, Saltwater and Mowbray). Water quality samples were collected through a combination of community based monitoring and automated water quality monitoring stations.

The methodologies employed, data collected, and research findings will be incorporated into the DSC water quality improvement plan and will be used to demonstrate progress towards, and compliance with, water quality targets for sediment and nutrient loads that have been set by external regulatory agencies. The infrastructure installed for this project is owned by DSC and the associated monitoring systems, data delivery technology, and sampling strategies developed are designed to be scientifically rigorous and defensible. The automatic stations are designed to allow robust, reliable and cost-effective measurement, documentation and reporting of:

- Long-term trends in loads of sediments and nutrients being discharged into estuaries from three major rivers (Daintree, Mossman, Saltwater Creek); and,
- The impacts of adoption in the Shire of best management practices and changes in land use on trends in water quality of adjacent rivers and streams.

A further objective of this project was to ensure that approaches, methods and results generated in developing this monitoring strategy will have, with appropriate modification, broad potential application in other Queensland catchments draining into the GBR lagoon.

This document represents the final report for the monitoring component of Project 5 in the DSC water quality monitoring project. The monitoring component has included:

- purchase assembly, testing and field installation of automatic monitoring stations (Milestones 5.1 and 5.2)
- initial development and subsequent refinement of the sampling strategies for each automatic station (Milestones 5.4 and 5.11)
- selection of samples for analysis (Milestone 5.14)
- desktop system for delivery and integration of monitoring data (Milestone 5.12)
- analysis of water quality and hydrologic data and subsequent interpretation of results (DSC funded extra component)
- QA/QC program for community monitoring (Milestone 5.7)

Report Structure
Due to the technical content and volume of much of the background work in this project we have decided to present the detailed background work to the project findings in appendices. In this way we are able to communicate our findings and recommendations in a far clearer and succinct manner.

The main body of this report consists of three sections. Section 2 covers the development and management considerations for water quality monitoring projects. This section includes a number of recommendations developed from our experiences in the Douglas Shire catchments. These recommendations are put forward to both DSC and others considering similar projects. Section 3 provides an overview of the performance of the water quality monitoring systems, a description of the timing and delivery of sediment and nutrients, and estimates of loads for the 2003/2004 phase of the Douglas Shire interim monitoring strategy. Section 4 details our recommendations to DSC for future development of sampling strategies and load estimation techniques.

Catchment Overview
The Douglas Shire is made up of a number of sub-catchments including those of the Daintree River, Saltwater Creek, Mossman River and Mowbray River (Figure 1). The total catchment area
for the four catchments sums to 186,000 ha. The Daintree River catchment is the largest catchment with an area of 133,000 ha. Ninety-five percent of the catchment is undeveloped forest or wetland, 87% of which is within the World Heritage Area. Saltwater Creek has a catchment area of 14,000 ha, of which 70% is forested, and 30% is under intensive farming (predominantly sugar cane). Mossman River catchment, with an area of 21,000 ha, includes the largest area of sugar cane in the Shire (4000 ha), encompassing 20% of the catchment while another 78% is forested. Mowbray River catchment, with an area of 18,000 ha, is the driest catchment in the Shire, and much of the water flowing in this catchment moves within small coastal streams rather than in the Mowbray River itself. Most of the Mowbray catchment is forested (72%) with only small areas allocated for sugar cane and grazing. Overall, 78% of the Shire is included within the internationally renowned Wet Tropics World Heritage.

Figure 1. Location of the catchments, rivers, land uses and water quality monitoring sites in the Douglas Shire catchments.
Section 2. Water Quality Monitoring Programs: Development And Management Considerations

2.1 Overview
In the following sections we outline the factors that we believe to be important in each stage of a water quality monitoring project from defining the original question to analysing the data. These recommendations arose through reflecting on the processes that worked well in the DSC project and thinking about what we would do differently if we undertook a project like this again. Of course, each water quality project will be unique, but we believe all will face similar issues which will be much easier to tackle with appropriate planning and resources. The information that we provide below is relevant not only to the DSC in its planning for subsequent water quality monitoring, but also applies to those planning to develop water quality monitoring projects into the future.

2.2 Defining The Question And Timeline
This is by far the most important stage of any water quality monitoring strategy, and as such sufficient time needs to be allocated to it to allow comment and modifications from all involved. The following steps should be undertaken:

- Well before any other part of the strategy is defined, the organizing body, including funding representatives, needs to clearly define the questions to be answered. All involved parties should agree on the questions and have a clear understanding of what is involved.
- The organizing body should arrange an independent review of the proposed questions and methodologies to ensure that they are practical and that sufficient resources are available.
- The questions to be answered and the methodology to be used should be incorporated into a clear plain worded document, with sufficient detail that all involved parties review and agree too. The document needs to explicitly detail each task in the project, the person responsible, time for completion, and the budget allocated. Tasks should be clearly linked to aims and objectives.
- The project specification document produced can then form the basis of the contract which all parties can then comment on and sign before commencement of any further work. This document needs to remain flexible and may need to be changed and updated as the project progresses, however, it is vital that the aims of the project are clearly stated ‘on paper’ at the beginning of the project.
- The time line of the project should be outlined early as this will define what can be achieved. The objectives set, need to match closely with the timeline. The timeline also needs to clearly show how each task feeds into the next.
- The initial planning phase is also an ideal time to start thinking ahead and planning for the future. For any major water quality monitoring effort we would recommend a project duration of at least 3 years. The first season of measurements should include a larger proportion of the resources as this is when a considerable amount of ‘over sampling’ should take place so that sampling strategies can be tested. During the first collection period there will inevitably be equipment and operator errors that need to be sorted out.

2.3 Clearly Assigning Budgets And Timelines
Sorting out project budgets is dependent on correct definition of the objectives and timelines. Budgets and timelines are generally detailed in both the project specification and the project plan and should be based on the following recommendations:

- The quality of equipment purchased and the number of samples that can be potentially analysed should be established and agreed on early in the project.
- Analysis of water quality samples needs to be accurately costed well in advance and all involved should be kept informed as to the status of the sample analysis budget as the project progresses.
- If a large number of samples are to be collected and stored, budgets should be assigned for storage fees or freezer rental. We believe that better decisions about which samples
need to be analysed can be made at the end of the collection period (e.g. end of wet season), when all samples collected can be taken into account. Such a procedure requires sample storage, however, this ensures that available funds are spent on the whole seasons data rather than being used up on the first few events.

Clear objectives will make the distribution of resources much easier. For example, if the emphasis of the study is on loads then money needs to be invested in rating curves for streams and development of sampling strategies. If the emphasis is on community awareness then recruitment of community members, education of collectors, and feedback of results is a priority. If the objective is to look at land use impacts on water quality then flumes rather than river stations should be resourced.

2.4 Communication

The need to communicate effectively cannot be stressed enough. Any water quality monitoring project must have clear lines of communication between the different parties involved. Our recommendations for communication are as follows:

- Due to the importance of communication we would recommend that a reasonable proportion of the total budget (i.e. at least 5%) should be assigned specifically to interaction between staff members.
- Email is an ideal means of communication which provides staff with a record of past transactions, however, acknowledgement of receipt of emails is essential if this means of communication is to be successful.
- Phone conversations are also an effective means of interacting although notes of discussions should be recorded for future reference and distribution to other staff.
- Regular monthly update emails and newsletters are also recommended to let people know how the project is travelling and where the project tasks are in relation to timelines and budgets.
- Document sharing can be made possible across organisations using one of a number of internet based file sharing applications. The webpage created using these applications allows multiple users to access files and provides a central repository for storing documentation. However, these types of systems must be resourced and allocated for in the budget.

2.5 Sample Site Selection

Selection of sample site locations needs to be allotted sufficient time so that well informed and discussed decisions can be made. The following recommendations should be followed:

- All parties involved need to agree on the location of sample sites so that they are located in positions where the questions being asked can be answered.
- Sample sites should be accessible in all but the most extreme conditions and the safety of staff members and/or community collectors should not have to be jeopardised to collect samples.
- Where possible, sample sites should be located as near as possible to sites where long term or additional water quality data are available. Data analysis and sampling strategy design both benefitted greatly in the Douglas Shire project from available NRM stream discharge and EPA water quality data.
- Tidal fluctuations in stream levels greatly complicate discharge measurements and the estuarine mixing process distorts the water quality picture. If load estimates are required at the end of such catchments, significant additional resources and expertise needs to be assigned to the task.

2.6 Equipment Selection And Installation

Equipment selection and installation needs to be made with consideration of the project objectives. Long term projects will benefit from high quality instruments which cost considerably more and which will be much more reliable. The following recommendation are offered for the equipment selection and installation phase:
• Equipment installed in the field, such as automatic samplers, should be made secure and theft proof. As we found in the Douglas Shire project, solar panels can be very attractive to certain members of the community.

• Budgets for equipment should also include a component for equipment maintenance, servicing and replacement.

• Instruments and samplers should be able to be accessed throughout the year. We found that some of our sensors (e.g. Upper Daintree) failed early in the season but we were unable to repair the sensors for many months because the instrument housing was underwater in a crocodile infested river.

• Field based equipment should be serviced at regular intervals and those responsible should follow detailed checklists to prevent problems occurring.

• Automatic sampler stations should be fitted with telemetry devices. These devices allow remote access to stations for changing sampling strategies, monitoring ambient conditions and determining the number of samples collected. The telemetry system also allows sending of SMS alerts to staff members responsible for emptying samplers.

• In designing automatic sampling stations and costing installation, it must be kept in mind that all station installations will be different. The most appropriate way to cost station installation is to prepare the budgets after final site selection. This way the project specification will include the site selection and project plan. Alternatively, a contingency budget needs to be included to cover the unexpected costs that will invariably arise.

2.7 Automatic Sampling Strategy

In designing the sampling strategy a number of issues need to be taken into account:

• The sampling strategy needs to be practical and fit in with the aims and objectives of project.

• The sampling strategy should be based on the budget available and, early in the planning phase, those responsible need to make judgements as to how many samples will potentially be collected.

• The first season’s sample collection would ideally include over-sampling so as to provide good coverage of all events and conditions, and to enable refined sampling strategies to be thoroughly investigated for future years. An estimate of 100 samples per station for the first year would be a reasonable start. In this way the first year of collection would be a preliminary strategy with subsequent years incorporating a refined data collection methodology and testing of the sampling strategy.

• The development of the sampling strategy will be an iterative process. Team members responsible for developing sampling strategies need to draw upon historic data and local knowledge where possible and should have a good understanding of the statistical and analysis techniques which will be applied to the data further down the track.

• Any automatic sampling strategy should include a representativeness study to ensure that samples collected from the fixed point in the stream are representative of the stream cross section. Having data to address and answer these questions of representativeness are critically important for forming the foundation of a robust monitoring design that incorporates automatic monitoring stations. A proposed representativeness study is detailed in Appendix F of this report.

2.8 Community Sampling Strategy

The objectives of a community based sampling strategy will determine the way in which samples will be collected. The following points should be considered in designing a community sampling strategy:

• If the objective of the study is to compare loads coming from different land uses then serious thought needs to be given to requirements for load estimation. An automated measure of discharge is necessary and this demands the commitment of significant time and resources (by water quality staff NOT community volunteers). This is not something
that can be easily done during one year, but rather is a process started during the first year with continual improvements coming over subsequent years.

- The sampling strategy for community sampling needs to also recognise that collection will be more erratic due to a combination of safety issues, and conditions not conducive to collecting (i.e. night, holidays, working hours).
- Whatever sampling strategy is chosen one of the most important things that staff need to keep in mind is that it is essential to keep detailed field notes and that samples should be numbered and dated according to a predefined system. Inconsistent labelling and can cause much frustration and wasted time during data processing.
- We recommend that community sampling be employed for ambient water quality monitoring studies and to conduct additional sampling for load based event studies. The infilling would be at existing monitoring stations where additional grab samples at low discharges allow a more complete assessment of loads.
- Studies using community members to collect samples need to also include a means by which to feed results back to the collectors and the community. Without this, collectors may soon lose interest and data quality will suffer.

### 2.9 Sample Processing Storage And Analysis

After all the effort that has gone into collecting samples, significant time and effort needs to be allocated to maintaining field records and processing samples. The following procedures are recommended:

- Staff processing samples should use standard lab sheets made well in advance of sample collection to record sample details. We recommend that a sample management system be used for future studies that eases the burden of managing and tracking samples.
- The host organisation needs to be aware of the potential volume and intensity of samples and the required processing time and costs.
- Staff responsible for sample collection should be fully trained.
- Thought needs to be given to sample storage well in advance. As already mentioned, significant freezer storage will be required to preserve samples until decisions about which samples to analyse are made.
- The storage and selection of samples needs to be made locally, and only samples to be analysed should be transported to the laboratory.
- Staff will need to be fully trained in sample analysis and backup staff may be needed in the event of particularly intense collection periods.
- Staff will also need to be aware that sample collection will often require out of hours work when conditions are likely to be less than favourable.

### 2.10 Data Storage, Analysis And Interpretation

After all the effort that has gone into sample collection, and processing, equal effort is needed to store, analyse and interpret the results. The following procedures are recommended:

- In the Douglas Shire project an online web based system was used to store and deliver the data to all parties involved ([www.data-tv.csiro.au/DSCDDD](http://www.data-tv.csiro.au/DSCDDD)). This system is currently maintained by CSIRO but management responsibilities will be handed to DSC in March 2005. This type of system allows central storage of data and enables everybody to access the same data. The web based system can be used to restrict permissions and access to certain levels of data.
- Analysing the data returned from the water quality laboratory to form an interpretation of the results is an important part of the whole process. The first step is to have one or more staff members perform quality control checks on the data to find any errors or omissions. This process needs to be undertaken before any in depth analysis and should involve somebody with intimate knowledge of the equipment so that the cause of errors can be ascertained quickly.
- Once data is quality checked, staff with a detailed knowledge of analysis and statistical techniques should undertake interpretation and presentation of results. If sample data is to
be used to calculate loads then those responsible should have a good understanding of the
different flow and load estimation techniques available and the problems associated with
many of the methods.
- Any analysis should also involve some discussion about the robustness of load estimates
  and should preferably include analysis of potential error, precision and bias in the results.

2.11 Detecting Trends In Sediment And Nutrient Loads
Design of a water quality project for detecting trends in sediment and nutrient loads over long time
periods should include consideration of the following:

- Precise load estimates will more readily enable detection of trends in sediment and nutrient
  loads because any change is more likely to stand out over and above natural variability in
  loads and the uncertainty associated with the load estimates.
- The need to identify any significant trends in sediment and nutrient loads may have
  implications for the preferred load estimation method. While it is important that the load
  estimation method has low bias so that loads are on average neither under or over-
  estimated, it may be more important that it has high precision if the focus is on establishing
  changes to the load. For instance, we may be willing to trade off some consistent bias for
  higher precision if that enables us to more easily identify trends.
- In the 2003/2004 DSC study, results show that loads decreased, even in storms of similar
  size, as the wet season progressed, indicating depletion of sediment and nutrient stores.
  This further complicates trend detection and requires methods to account for within-year
  variability.
- One way to establish changes in load over multiple years/seasons is through a regression
  approach that incorporates seasonal and trend terms in time. If, after accounting for
  changes to discharge, season and within-year variability, the trend is still significant then
  this is indicative of some real change to the load being carried.
- A substantial number of years may be required to confidently detect a trend in sediment
  and nutrient loads given the large natural variability in load and the difficulty in measuring
  loads with precision.
- It important that consistent methods are used for estimating loads so as to enable fair
  comparisons to be made. For example, we want to avoid the danger of comparing an
  unbiased estimate of load with one that is knowingly biased but more precise. It is also
  important that any changes to the sampling regime be recorded and accounted for in
  assessing trends in order to avoid confounding a potential trend with some other change.

3.1 Project Objectives
The DSC water quality monitoring strategy was established with a number of key objectives. These objectives were:

- Installation of in-stream and off-paddock automatic water quality monitoring equipment in the Douglas Shire.
- Design of appropriate sampling strategies for automatic stations.
- Estimation of loads of total suspended sediment (TSS), total nitrogen (TN) and total phosphorus (TP) in rivers and also estimation of the changes in nutrient loads from sugar cane under different fertilizer application rates.
- Development of a community-based water quality sampling program to complement the automatic sampling efforts.
- Design of an optimised, long-term water quality monitoring strategy (This component is detailed in Section 4 of this report).

3.2 Automatic Sampling Overview
Five automatic water quality monitoring stations were installed at locations on the Mossman River, Saltwater Creek, and Daintree River (Figure 1). The remaining two automatic stations were used in flume experiments to monitor differences in nutrient loads from sugar cane under different fertilizer application rates. The site selection process was a crucial stage in the project and involved extensive field reconnaissance, analysis of aerial photography, location of existing NRM infrastructure, negotiation with land holders and consultation with water quality officers and councillors in the DSC. A full description of the site selection process is given in Appendix A.

Three of the in-stream monitoring stations were used to measure river depth and collect samples at the end of the three major rivers in the shire (Daintree, Saltwater and Mossman Rivers). However, reliable rating curves between depth and flow could not be developed for these sites because they were affected by tides, hence, load estimates were not possible. The remaining two stations were reserved for assessing sediment and nutrient loads coming from the natural forested systems which dominate the upper part of all catchments in the Douglas Shire (Upper Daintree and Upper Mossman). The information from these two stations is essential in the calculation of targets for the region and in the assessment of the effectiveness of management practices in achieving desired outcomes. The location of the automatic sampling stations throughout the Douglas Shire are shown in Figure 1.

In-stream monitoring stations were designed to sample water quality only when river levels rose in response to rainfall events. In doing this we assume that the vast majority of sediment and nutrient movement takes place during large events (This assumption has since been proven to be correct – see below). This design keeps the sensors and pumps away from the stream bed where turbulence and mixing may affect sample concentrations. Baseflow water quality was determined using a complementary community collecting strategy managed by DSC. Each of the monitoring stations was fitted with telemetry equipment which enabled remote data access, and modification of control programs. This system allowed for automated data collection and real time delivery of water level and sample collection data via the internet. Automatic sampling stations were self powered using solar panels and battery banks. The technical details of the automatic stations and the materials, sensors, and installation techniques used can be found in Appendix B.

The design of appropriate sampling strategies for automatic stations (both in-stream and off-paddock) was a complicated process involving extensive consultation of historic data sets, incorporation of local and expert knowledge, testing of methodologies and some trial and error. A detailed description of the process is given in Appendix C.
Flow measurement at tidally affected sites could have been possible in Douglas Shire through the use of automatic flow measurement instrumentation based on Doppler technology (see Section 4 for more details), however, this was beyond the budget available for the 2003/2004 season. Clearly, if end of catchment loads are the goal of water monitoring then such equipment is essential and should be budgeted for in future years.

3.3 Community Sampling Overview

The DSC water quality project community monitoring program included the following specific objectives:

- Collection of ambient and event flow data.
- Identification of various land uses' contributions of sediments and nutrients to receiving waters.
- Commencement of a long-term (5 to 10 years) water sampling program to identify trends in sediment and nutrient concentrations.
- Provision of knowledge for assessing the ability of the shire to meet water quality targets.
- To provide a mechanism for community ownership of information generated in the shire.
- To provide the community with an understanding of the information collected from water quality monitoring.

Staff from DSC, Queensland EPA, and CSIRO contributed to selection of monitoring sites to meet the objectives of the community monitoring strategy for the Douglas Shire catchments. Those sites visited during the 2003/2004 season are located on the map in Figure 1. A review of historical water quality data collected in the shire (Dobbie and Harch, 2004) was used to determine the degree of spatial variation within Douglas Shire catchments. DSC staff organised community volunteers and arranged monthly grab sampling in base flow conditions between January 2004 and June 2004. In addition, community volunteers also collected event based samples as frequently as conditions were safe and practical.

3.4 Performance Of Automatic Monitoring During 2003/2004

Overall, the automatic monitoring infrastructure for collecting samples from Douglas Shire streams worked very well. Careful choice of instruments and appropriately designed installation techniques ensured the collection of quality data from both the in-stream stations and the off-paddock flume systems. One of the most impressive aspects of the system design was the ability to deliver up-to-date data (stream depth, number of samples collected, turbidity and salinity) to DSC water quality staff and CSIRO officers. This data delivery was made possible through the use of satellite and mobile phone telemetry which enabled diagnosis of problems, modifications to sampling strategies, access to data at regular intervals and information regarding sample collection status. Data from stations was regularly updated on the internet allowing river conditions and sample collection to be carefully monitored.

The in-stream infrastructure proved to be robust and reliable at all sites with the exception of Upper Daintree. At Upper Daintree the third biggest flood on record scoured away material from around the sample intake causing the sample intake structure (anchored with 9 t of concrete) to topple resulting in damage to pump and sensors. At all of the stations, the data loggers, telemetry and power systems worked well. Unfortunately some of the automatic samplers and sensors were faulty and were recalled by the manufacturers. This resulted in some downtime of the systems and loss of data. These types of issues and occasional vandalism were out of our control and are likely to plague any project of this type and scale. Some periods of lost data were preventable and as a result we recommend that equipment maintenance, servicing and data checks be given a high priority so that response times to problems can be improved. A full description of the equipment installed at each site, wiring diagrams, installation techniques, and the performance system components is given in Appendix B.

We were impressed with the performance of the rate-of-rise algorithm we developed as a means to trigger sample collection for both the in-stream and flume stations. This algorithm performed particularly well considering the lack of prior knowledge regarding the flow conditions at these
ungauged locations. With this in mind we believe we have a powerful method for developing sampling strategies for similar ungauged locations around Australia. This strategy gives a good temporal representation of flow events and should continue to be used to trigger the auto-samplers. The ability of the sampling strategy to respond to changes in rates of change in river depth, in both tidal and non-tidal locations is illustrated in Figure 2. Further enhancement of the sample triggering mechanisms in tidal sites could be gained through the refinement of salinity triggers.

**Figure 2. River depth and triggered samples at the Upper Mossman (A) and Saltwater Creek (B) sites.**

### 3.5 Findings From Automatic Sampling During 2003/2004

#### 3.5.1 Timing Of Delivery Of Sediments And Nutrients

Techniques used to estimate stream discharge are presented in Appendix D. Full details of the results presented in this section are given in Appendix E summarised findings are presented here:

- There was a general tendency for sediment and nutrient concentrations during peak flow events to fall and to become less variable as the wet season progressed. Presumably nutrients and sediments that accumulated during the dry season were progressively washed out of the catchment. The decline in concentration of sediment and nutrients over the duration of the wet season is illustrated in Figure 3.

- Although the concentration of nutrients and sediments peaks early in the wet season, the proportion of total load moved is still greater during the later part of the wet season when prolonged monsoonal events and tropical depressions result in high discharges. Thus, during March discharge at the Upper Mossman station was eight times higher than in January and 48% of the total suspended sediment load was moved during this month, even though the March average concentration was 0.03 tonnes/ML compared to 0.09 tonnes/ML in January. This finding is illustrated in Figure 4.
Figure 3. Concentration of total nitrogen and phosphorus (A) and suspended sediment (B) over the 2003/2004 season at Upper Mossman.

Figure 4. Fraction of total load of suspended sediment for each month from December 2003 until April 2004 and corresponding fraction of total discharge for the same months.
• Comparison of nutrient and turbidity measurements taken during baseflow and event conditions show that a much larger variation in measurements is experienced during the events. The results suggest that dry season baseflow could be represented by less frequent sampling while event (storm) conditions require many more samples so that the variation in the flows is more adequately represented. This is illustrated by the box plots in Figure 5 which show the range of sample concentrations measured.

Figure 5. Box plot comparison of concentrations of TN, TP, turbidity and for baseflow and event conditions on the Mossman River¹

• The concentration data from the two Mossman stations indicate that there is a significant source of soluble phosphorus (TDP and FRP) between the two stations which is likely to come from the agricultural region on the coastal flood plain (Figure 6). They also suggest that there are two processes in action affecting the nitrogen concentrations. The total nitrogen concentration decreases between the two stations but TDN, NO₃ and NH₃ concentrations increase. This suggests inflows low in TN but high in the other forms. The data also indicate a significant increase in suspended sediment concentration. Overall, there is evidence of sources of soluble nutrient and sediment in the agricultural lands of the coastal floodplains and tributary streams.

¹ The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Lines above and below the box indicate the 90th and 10th percentiles. Outlying data is plotted as points.
3.5.2 Representativeness Of Automatically Collected Samples

Collecting samples using an automatic station makes the assumption that the sample collection point is representative of the conditions found across the stream. In order to test this assumption a representativeness study was designed for the 2004/2005 season (Appendix F). Analysis of the results collected for the Lower Daintree and Saltwater Creek sites are also presented in Appendix F. A summary of the findings is provided here:

- Due to a combination of sampling errors and a lack of samples, conclusions about the representativeness of automatically collected samples were hard to develop.

- Results for the falling event stage at Saltwater Creek suggest that there is homogeneity (or little difference) across the cross-sectional profile for the water quality parameters considered. This suggests that during this sampling occasion, the reach was well mixed and that the samples collected automatically are representative of the stream conditions.
• Results for the Lower Daintree provide conflicting evidence as to representativeness of automatically collected samples. Of the limited number of samples collected some indicate well mixed conditions while others show distinct changes in water quality parameter concentrations.

• As the limited data collected (as a result of time and financial constraints) prohibits a statistically sound analysis of representativeness, it is strongly recommended that the results of this initial representativeness study be used to implement a future study that more fully addresses the representativeness of the automatic monitoring stations. Having this knowledge is imperative for making inferences based on any of the automatic monitoring station data both now and in the future and ensuring a robust monitoring design is implemented.

3.5.3 Turbidity As A Surrogate For Nutrient And Sediment Concentrations

A number of studies have shown that the concentration of various water quality parameters is closely related to the turbidity of the water. The opportunity then exists to develop relationships between continuously measured turbidity and nutrient and sediment concentrations at a site which can then be applied into the future to greatly reduce the number of water quality samples that need to be analysed. Each of the in-stream automatic water quality station in the Douglas Shire was fitted with a turbidity sensor for this purpose. Some of the sensors were continuously plagued by malfunction and have since been recalled by the manufacturer. Sensors at Upper Mossman, Upper Daintree and Saltwater Creek worked for at least part of the wet season and measurements from these stations will be discussed below, full details are given in Appendix E.

• In general, good relationships were observed between turbidity and TP and TSS during all seasons, while poor relationships were observed between turbidity and TN regardless of the season. An example of the types of relationships observed at Upper Mossman is given in Figure 7.

• Analysis of data from different automatic stations showed that the relationships between continuous turbidity and sediment and nutrient concentrations are likely to vary from site to site and between seasons. Hence, before this technique can be applied with any confidence further sample comparison is needed.

• Because of the uncertainty involved in inferring sediment and nutrient concentrations from continuous turbidity measurements at the automatic sampling stations in Douglas Shire, the technique has not been applied to the collected data for any analysis purposes. The comparison does, however, show the potential for using continuous turbidity to estimate other water quality parameters if data integrity and relationships with nutrients and sediments can be improved.

• Further data and more regular maintenance of equipment is necessary before continuous turbidity can be used as a surrogate for water quality samples.
Figure 7. Relationships between sensor turbidity, total nitrogen (TN), total phosphorus (TP), total suspended sediment (TSS) and laboratory turbidity at Upper Mossman.

3.5.4 Sediment And Nutrient Loads
Full details of the loads calculation methods are presented in Appendix G. A summary of results is presented here:

- Nutrient and sediment loads could not be calculated from the available data at the Saltwater Creek, Lower Daintree and Lower Mossman sites because these sites were tidal. Techniques which account for tidal fluctuations need to be developed for these sites.

- Loads estimated at the Upper Daintree and Upper Mossman sites are given in Table 1. Loads for Upper Daintree are calculated using the Beale ratio estimator, while loads at Upper Mossman are calculated using linear interpolation. It must be remembered that these load estimates are considered to be only preliminary estimates because of gaps in the data (primarily at the Upper Daintree site), the short duration of the monitoring period (7 months) and the sensitivity of the estimates to the method used to calculate loads.
Table 1. Discharge, loads and delivery rates of TN, TP and TSS at Upper Mossman and Upper Daintree for the seven month study period.

<table>
<thead>
<tr>
<th></th>
<th>Upper Mossman</th>
<th>Upper Daintree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream contributing area</td>
<td>8,677 ha</td>
<td>90,865 ha</td>
</tr>
<tr>
<td>Total Discharge</td>
<td>280,895 ML</td>
<td>1,530,000 ML</td>
</tr>
<tr>
<td>load (tonnes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>delivery rate (kg/ha)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>151</td>
<td>3,581</td>
</tr>
<tr>
<td></td>
<td>17.4</td>
<td>39.4</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>4.48</td>
<td>241</td>
</tr>
<tr>
<td></td>
<td>0.52</td>
<td>2.65</td>
</tr>
<tr>
<td>Total suspended sediment</td>
<td>2902</td>
<td>225,200</td>
</tr>
<tr>
<td></td>
<td>334</td>
<td>2478</td>
</tr>
</tbody>
</table>

In order to assess the potential error in our load estimates two modelling techniques were used. The models used were a stratified regression model and the USGS 7 parameter model, both of which are based on flow and concentration data (for full details see Appendix G). Following the procedures in Figure 8, the models produced a continuous time series of concentration and flow for the Upper Daintree and Upper Mossman sites for the 2003/2004 collection period from which a ‘modelled’ load could be determined. We then extracted concentration data from the continuous time series for the actual sample collection times at each site for the 2003/2004 period and used this data to estimate a ‘sample’ load. Comparison of ‘modelled’ and ‘sample’ loads reveals the ability of the samples collected and load estimation technique to produce a reliable estimate of modelled load.

![Flow diagram of procedures followed to assess potential error in load estimates](Image)

- Results suggest that at Upper Mossman our loads of TN underestimate by between 12 to 25%, while TP loads are underestimated by between 2 to 8%. TSS load calculations were harder to test because of poor model performance, however, results suggest that the load is slightly over-estimated. The small number of samples collected at the Upper Daintree and the weak relationships between variables limited our ability to estimate loads and assess load calculation techniques at this site. Further data collection in future years will help clarify these issues.

- The delivery rates (kg/ha/yr) of nitrogen, phosphorus and sediment were much higher at the Upper Daintree than at the Upper Mossman site although both drain from undeveloped forest. This may be related to differences in vegetation cover, slope and/or soil types, or could be related to uncertainty in load estimates based on the small number of samples available at Upper Daintree. The Upper Mossman catchment is completely covered by dense rainforest, while about 50% of the Upper Daintree catchment is open Eucalypt woodland.
3.5.5 Sugarcane Nutrient Trials

In the sugar cane nutrient trials, nitrogen fertilizer was applied at rates of 190 kgN/ha (traditional rate) and 98 kgN/ha (recommended rate) to establish whether the reduced application rate affected production as well as nutrient loss from the trial sites. A full description of the nutrient loss trials is given in Appendix H. The main findings are presented here:

- The samples collected showed that there was a reduction in the average concentration of nutrients in runoff from storm flows as the wet season progressed. As with the river data a ‘first flush’ of nutrients and sediment was observed (Figure 9).

- The calculated loads of TN, TP and TSS from the high and low fertiliser plots are shown in Table 2. They show that higher loads of sediments and nutrients were lost from the plot with the higher fertilization rate. Table 2 also shows the sugar production and final income from the two flume plots. These results show that sugar production is approximately 10% higher for the higher N application, however, total income, adjusted for N application cost, is only marginally less for the lower N application rate. The results suggest that N application rates can be reduced significantly, thus greatly reducing environmental impacts with only minor reductions to farm income. Higher sediment loss from Flume 2 is unexpected and the mechanisms for this are unclear. Consequently, these results need to be treated with caution and we recommend that further work be done on the effects of fertiliser application rate.

![Figure 9. Discharge TN, TP (A) and TSS (B) for Flume 2 showing the decline in concentrations over the wet season.](image-url)
Table 2. Flume discharge, load and delivery rate information for TN, TP and TSS, and sugar production and income.

<table>
<thead>
<tr>
<th></th>
<th>Flume 1</th>
<th>Flume 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contributing area</td>
<td>0.33 ha</td>
<td>0.26 ha</td>
</tr>
<tr>
<td>Nitrogen Fertiliser application rate</td>
<td>98 kg N/ha</td>
<td>190 kg N/ha</td>
</tr>
<tr>
<td>Total rainfall (01/12/03 – 30/06/04)</td>
<td>9.77 ML (2960 mm)</td>
<td>7.70 ML (2962 mm)</td>
</tr>
<tr>
<td>Total surface runoff</td>
<td>3.3 ML (1000 mm)</td>
<td>2.53 ML (973 mm)</td>
</tr>
<tr>
<td>Total nitrogen delivery rate</td>
<td>9.54 kg/ha/yr</td>
<td>11.58 kg/ha/yr</td>
</tr>
<tr>
<td>Total phosphorus delivery rate</td>
<td>1.58 kg/ha/yr</td>
<td>2.46 kg/ha/yr</td>
</tr>
<tr>
<td>Total suspended sediment delivery rate</td>
<td>174 kg/ha/yr</td>
<td>534 kg/ha/yr</td>
</tr>
<tr>
<td>Sugar Production(^1)</td>
<td>10.19 t/ha</td>
<td>11.24 t/ha</td>
</tr>
<tr>
<td>Income (adjusted for N inputs)(^1)</td>
<td>$1054 /ha</td>
<td>$1093 /ha</td>
</tr>
</tbody>
</table>

\(^1\) Tony Webster (unpublished data)

- Significant loads of N, mainly as NO\(_x\), were lost via sub-surface pathways. There were higher sub-surface nitrogen loads from the higher application rate plots (Figure 10). Over the 5 week period for which analytical data are available, leaching losses of N (and standard errors) were 5 ± 1.7 kg/ha for the low application rate and 13 ± 5.1 kg/ha for the high application rate. Subsurface phosphorus loads were very low.

![Figure 10. Comparison between nitrate concentrations for Flume 1 and 2 between early and mid wet season events.](image)

- An attempt was made to optimize the sampling strategy for future detection of differences in nitrogen application trials. The statistical analysis suggests that between 70 and 100 samples are required from both flumes in the upcoming wet season so that a 25% detectable difference in the level of nitrate removed in runoff between the two flumes can be measured.

### 3.6 Performance Of Community Monitoring During 2003/2004

The community monitoring program involved the collection of water quality samples from sixteen different sites across all four of the major catchments in Douglas Shire (Figure 1). 135 baseflow samples were collected between September 2003 to June 2004. The community volunteers also collected 109 samples in events during the 2003/2004 wet season. Volunteers are to be commended for their efforts in collecting samples in a safe and enthusiastic manner.

It is essential to keep detailed field notes and to follow a predefined sample collection and numbering system. Inconsistent labelling and sample collection records caused much frustration and wasted time in the Douglas Shire project.
One of the most valuable outcomes from the community monitoring came from raising the awareness of community collectors to water quality issues and the illustrating to them that changes in on-farm practices can influence water quality.

3.7 Findings From Community Monitoring During 2003/2004

A full site by site description of the results from the community monitoring is given in Appendix I. The main findings are highlighted below.

The best use of community collected data was in the comparison of baseflow sediment and nutrient concentrations to Queensland EPA baseflow water quality guidelines. Analysis of samples collected in the four major catchment showed that dry season water quality in the Douglas Shire streams was generally below recommended maximum levels. Findings from base flow samples in each catchment are as follows:

- Mowbray catchment – The community monitoring shows that, under baseflow conditions, the concentrations of TN and TP in the Mowbray River are within the Queensland EPA guidelines for the lower catchments but are above the guidelines for upper catchments. Under peak flows, both parameters are well above the guidelines.

- Mossman Catchment – In the main channel of the Upper Mossman River, both TN and TP were within, or close to, the water quality guidelines during base flows. However, both TN and TP are well above the guidelines standards in Cassowary Creek during base flows.

- Saltwater Catchment – All parameters were within the guidelines for baseflow condition at all community monitored sites in Saltwater Creek. Event samples were generally well above Queensland EPA guidelines.

- Daintree Catchment – At all five community monitoring sites in the Daintree River and its tributaries, TP and turbidity concentrations were within the guideline range for base flow conditions. However, the TN concentrations were occasionally above guideline values, though this may have been a result of tidal processes.

Baseflow concentrations were shown to be relatively similar across the dry season suggesting that less regular sampling could be used to represent base flow conditions. During events there was generally a considerable amount of variability amongst the parameters and across the sites with concentrations commonly exceeding Queensland EPA guidelines.

Calculation of event loads from the grab samples that were collected by the community is not achievable. Concentration and discharge data are required to calculate loads and this information is not available for community grab sample sites.

We suggest that community sampling efforts would be better directed towards sampling of baseflow water quality at the automatic stations. This would remove safety issues around sampling during flood events and would strengthen load estimations for these stations. Baseflow samples are crucial to loads calculations at the automatic stations, however, the design of the current automatic stations allows for sampling only during event conditions.
Section 4. Recommendations For Future Development Of The Douglas Shire Council Water Quality Monitoring Program

4.1 Overview
The aim of this section is to outline the development of a future loads-based water quality monitoring strategy for the Douglas Shire catchments. The recommendations outlined in this sectioned have been developed from the data collected during the 2003/2004 season. It should be recognised that the development of a load based monitoring program is an iterative process where sampling, processing and analysis techniques are gradually improved. The water quality stations in the Douglas Shire were installed at previously ungauged locations. This meant that the first season’s monitoring involved testing of instrumentation and sampling techniques, and the development of discharge and loads estimation techniques. The aim is to improve these methodologies into the future.

4.2 What Was Learnt From The Interim Douglas Shire Study?
The data collected during 2003/2004 wet season in the Douglas Shire (Section 2) has greatly improved our understanding of the hydrological behaviour and water quality characteristics in the region. The knowledge gathered from this process must now be coupled with existing knowledge from other catchments and the literature to develop an improved water quality monitoring strategy for the future.

The main features of the Douglas Shire catchments identified in the interim monitoring, which must be recognised and addressed in the future monitoring strategy, are:

- The need to focus loads based sampling on events as this is when the most variation in sediment and nutrient concentrations occurs and this is when the vast majority of loads are moved.
- The occurrence of strong seasonal flow changes, not just between the wet and dry season, but also during the wet where there is a marked change in inter-event flow.
- The importance of the ‘first flushes’ of sediment and nutrient at the start of the wet season and the subsequent exhaustion of sediment and nutrient supplies as the wet season progresses.
- The need to deal with the influence of tidal incursions on the lower catchment sites.

These features are likely to apply to all Great Barrier Reef catchments and as a result the establishment of a ‘working group’, consisting of participants from all interested agencies, is recommended so as to formalise standard methodologies for dealing with these issues. Other features that are specific to individual catchments may also need to be recognized for an optimal program. Some of the issues encountered and lessons learnt from the interim monitoring in the Douglas Shire are discussed in more detail below.

4.3 Future Water Quality Monitoring In Douglas Shire
The Douglas Shire Water Quality Improvement Plan aims to develop a long-term monitoring strategy to enable the measurement of sediment and nutrient loads from the rivers and streams in the Douglas Shire. This section centres on the development of the future loads-based monitoring strategy for the Shire. It focuses on the Upper Mossman and Saltwater Creek as being indicative of the upper and lower catchment sites respectively. The monitoring program is constructed around total suspended sediment (TSS) as that is widely considered the most difficult water constituent to represent reliably because of its greater variability. A monitoring program that performs well for TSS will invariably cope with constituents that are not as variable. The statistical methodology used to arrive at the recommended sampling strategies is detailed in Appendix J.
4.3.1 Future Sampling Regime For Upper Mossman Automatic Station

- Aim to take at least 100 samples per year.
- Aim to place 75-80% of the effort into high-flow, or event, conditions. The parameters underlying the rate-of-rise algorithm (Appendix C) should drive this allocation. The automatic sampler should also record the event status.
- Inter-event samples should be automatically triggered during the wet season using a time based methodology. While these time periods do not represent a major proportion of the total load, these samples are necessary for reliable load estimation.
- Reduce unnecessary over-sampling caused by fluctuations around predefined sample depth by employing a minimum time interval before sampling re-occurs at the same depth trigger.
- Use community volunteers or DSC water quality staff to take monthly samples at each of the stations during the dry season. These samples are necessary for load calculations during periods when river levels are below the depth of the sampler intake.
- If too many samples are triggered, or if a strategy of over-sampling is adopted, and the sample number must be reduced prior to laboratory analysis seek to (i) maintain 75-80% high-flow sampling effort, (ii) represent all flow conditions and, (iii) choose samples from throughout the year.
- It is important to explore the collected data for structure and insight into the processes that are operating so that the sampling regime can continue to be improved.
- Use the Beale ratio estimator, with bias correction, to estimate load. It is important to assess whether the underlying assumptions for the Beale estimator are met. It is strongly encouraged that other load estimation also be investigated in the future. If different methods are giving consistent load estimates greater confidence can be given to estimates.

4.3.2 Future Sampling Regime For Upper Daintree Automatic Station

- The Upper Daintree site was plagued by equipment issues during the 2003/04 wet season and only a modest amount of data is available to guide the future load monitoring strategy. The Upper Daintree does, however, closely follow the characteristics of Upper Mossman. It is thus recommended that an identical overall load-based monitoring strategy be employed at the two upper catchment sites.

4.3.3 Future Sampling Regime For Saltwater Creek Automatic Station

A sampling strategy for determining loads at Saltwater Creek and the other lower catchment sites cannot be reliably developed because of the lack of flow data from the 2003/2004 season. As a way to move forward in the development of a loads based sampling strategy for these stations we recommend the following steps be taken.

- It is critical that continuous stream discharge be determined at each site and it is recommended that Doppler velocity techniques be used to account for tidal influences.
- Continue to use the salinity trigger in combination with the rate of rise algorithm and continuous average 24 hourly depth to avoid taking samples when conditions are affected by tidal incursions.
- Initially aim to take the same number of samples as that recommended for the upper stations (i.e. 100 per year).
- Use community volunteers or DSC water quality staff to take monthly samples during baseflow and inter-event conditions. These samples should be collected during low tide conditions.
- Use the Beale ratio estimator, with bias correction, to estimate load.
- Undertake the same statistical analysis used for Upper Mossman station (Appendix J) to arrive at an improved sampling strategy for the site.
Collection of concentration data in the absence of flow data has relatively little application and is not recommended, however, if DSC see merit in collecting samples that characterise TSS, TN and TP concentrations then the following strategy should be followed.

- Aim to take around 60 samples per year
- Place approximately 60% of the sampling effort into event conditions.
- In the absence of discharge information, the focus of the monitoring regime should be on characterizing TSS, TN & TP concentrations. It is critical that solutions to the current lack of discharge information be investigated as soon as possible.
- Continue to use the salinity trigger in combination with the rate of rise algorithm to avoid taking samples when conditions are affected by tidal incursions.
- Use the average depth over 24 hours, calculated continuously, to adjust for the tidal influence on the site depth. Alter the sampling intensity according to this average depth, with samples taken more regularly when the average depth is high and the site is in event conditions and less frequently during inter-event conditions.

4.3.4 Future Sampling Regime For Lower Mossman And Lower Daintree Automatic Stations
- As with Saltwater Creek, load calculations are not possible at Lower Mossman and Lower Daintree sites because of the lack of discharge information for these tidally affected sites. The number one priority at these sites if loads are to be calculated is to reliably measure discharge. The same recommendations made at Saltwater Creek for measuring loads and subsequently improving the sampling strategy apply to Lower Mossman and Lower Daintree.
- Use of the stations to collect concentration data alone is not recommended, however, if DSC see merit in such measurements then it is recommended that an identical strategy as that developed for Saltwater Creek be employed at all lower catchment sites.

4.3.5 Future Sampling Regime For Flume Based Studies
- Aim to take around 70 samples from each flume system per year.
- It is particularly important to capture the first events of the wet season as this is when applied nitrogen is first mobilised by surface waters.
- Use the rate of rise algorithm to control sampling (Appendix C).
- Aim to take 30 samples from lysimeters for each trial as results suggest that more than 60% of the applied nitrogen moves through sub-surface pathways. The first 10-15 samples should be collected after the first substantial rain following fertiliser application.
- Re-assess sampling regime when more data becomes available.

4.3.6 Future Sampling Regime For Community Based Sampling In Douglas Shire
- If the community are to be used to collect water quality samples for loads estimation then the best use of their time and available resources is collection of baseflow samples from each of the automatic station sites. These samples will be used in loads calculations for times when river levels are below the level of the automatic sample off-take. The samples from each site should be collected on a monthly basis following a strict sample collection, storage and labelling system. Collection of samples from ungauged locations does not allow loads to be calculated.
- Community collected samples can also be used to assess baseflow water quality condition in relation to Queensland EPA guidelines and raise awareness of water quality issues.

4.4 Requirements For Refining The Loads-Based Monitoring Program
As the DSC continues to develop its loads-based monitoring program, water quality officers or suitable scientific advisors will have to continually refine the sampling, measurement and analysis techniques that have been developed from the interim monitoring program. The number of
samples that need to be collected, the sampling strategy to be employed, and loads estimation
techniques used will need to be re-assessed over the first few years of operation until a final
strategy is developed. This is a process that is applicable to DSC and all other catchments
contemplating a loads-based monitoring program.

The water quality improvement plans being developed for catchments draining to the Great Barrier
Reef lagoon will require the development of sediment, nitrogen and phosphorus load targets.
These plans will involve the implementation of abatement actions that will lead to a reduction in
loads of the contaminants being delivered. In order to assess compliance with these targets, the
development, and refinement, of load estimation and monitoring techniques is essential.

Methodologies available for developing sampling strategies, calculating discharge, estimating
loads and assessing the number of samples required for monitoring are discussed below as a
reference for those responsible for refining the monitoring strategy. Further details and references
are given in Henderson and Harch (2005).

4.4.1 How Many Samples Are Needed?
One of the first questions asked in the development and refinement of monitoring projects for
determining loads is ‘how many samples are needed?’ The answer to this question is necessarily
a balance between having enough samples to reliably estimate the sediment and nutrients loads
and the cost of sampling. As more samples are taken the precision of the load estimates will
invariably improve, but at the expense of a more costly sampling regime. In practice we tend to
seek the smallest possible sample size that will deliver a desired load precision.

The decision on the sample size required to estimate load with a desired precision is a non-trivial
task. It depends on the data collected, the variability of the flux for different water quality parameter
of interest and the nature of the rainfall over the load estimation period. The required sampling
frequency will be determined by the variability of system. For example, unregulated tropical
systems, will require more samples than a regulated temperate catchment. Some techniques for
assessing the precision of load estimates based in sample size are outlined in Appendix J.

It is impossible to provide universally appropriate sample numbers. They are invariably intimately
tied to the variability of the flux for different water quality parameters of interest, the nature of the
rainfall and the desired precision for each river. Sample numbers must be seen as catchment-
specific.

One method for maximising the possibility of collecting appropriate samples is to trigger more
samples than might end up being analysed. This provides something of a contingency against
unexpected equipment or collection problems that may otherwise result in an inadequate number
of samples. Furthermore, it means that additional samples may be available if retrospective
analyses are required to provide supporting evidence for any trends identified after the
interpretation of the laboratory analysed data. This does, however, require additional funding for
sample storage costs.

If there are more samples collected than can be analysed, it is important to select samples from
across dry season, event and inter-event times. The number of samples from each time period
should reflect the variation expected during that period i.e. sampling should be more heavily
weighted towards events than baseflow. Sample collection requirements can be expected to be
largest during the first few years, however, as information for each station builds it is expected that
sample numbers will be able to be reduced.

4.4.2 Sampling Strategy
Resource and other constraints invariably mean that a limited number of samples can be collected
for subsequent laboratory analysis. It is important that those samples be selected so as to facilitate
the reliable estimation of sediment and nutrient loads. The interim rate-of-rise sampling strategy
used in Douglas Shire performed particularly well, however, if new advancements in sampling
strategies occur DSC water quality staff may wish to modify the type of sampling employed. There
are a variety of strategies available. The most appropriate for a given catchment requires careful consideration of:

- The resources and budget available for sampling
- The hydrologic characteristics of the catchment
- The characteristics of the load delivery process in that catchment
- The availability of historical records
- The method and equipment available for collection
- The technique that will be used to estimate sediment and nutrients loads
- The water constituent(s) of interest

There are a variety of sampling strategies used in practice. To highlight the range of techniques available and the importance of choosing an appropriate sampling strategy a brief summary is provided below, more detail including recommended references is given in Henderson and Harch (2005).

**Simple Systematic Or Random Sampling**

One of the most widespread sampling approaches is to sample at regular time intervals, e.g. every day or every fortnight. While the more widespread use of automatic sampling stations have enabled more sophisticated sampling strategies to become more popular, systematic strategies are still commonly used. Systematic sampling routines are good for controlling the sampling effort as the number of samples required for a fixed time interval is known at the start of the monitoring period. It is also usually more efficient than randomly allocating the sampling points in time. Simple random sampling is, however, known to deliver estimates of load that are unbiased (on average equal to the true value) of load. As neither simple systematic or random sampling makes any account of the flow or depth information the load estimates can often be imprecise.

**Stratified Sampling**

The variability of the sediment and nutrient loads delivered can change considerably depending on the depth or flow and the time of the year. In order to improve the precision of the load estimates it is sensible to direct more of the sampling effort to those periods contributing the most to the total loads. By allocating more effort to them we help ensure they are estimated better and thus the overall load is more precise.

Stratification may be based on time (e.g. summer and winter) or depth (high and low depth) or a combination of both. More sophisticated stratifications may also be considered. For example, different amounts of sampling effort could be allocated to the rising and falling stages of the hydrograph. A sampling strategy based on river depth fluctuations (rising and falling), time and depth was used in the DSC monitoring program.

**Flow Proportional Sampling**

In flow-proportional sampling, the sampling is continuous and in proportion to the instantaneous discharge. This is typically achieved by varying the pumping rate of the automatic station in accordance with the flow. An alternative procedure is to take a sub-sample every time a fixed amount of water passes the sampling point. In both approaches an integrated or aggregated sample results. The analysed concentration data thus applies to the integrated sample and therefore the entire interval over which it was collected. It can be viewed as a flow weighted concentration.

**Flow Proportional Composite Sampling**

This sampling is similar to flow proportional sampling, in that a sub-sample is taken once a fixed amount of water has passed the sampling point, but differs in that the sub-samples are aggregated. The sampling decision relies on accurate flow information being available to the sampling system in real time. The aggregation “bulking”, can be event based, allowing an event mean concentration to be obtained or by fixed quantity aggregation where a number of sub samples are “bulked” together. Once the sub-samples are aggregated the “bulked” sample is sub-
sampled and the resulting flow proportional composite sub-sample sent for analysis. This sampling strategy has the advantage of a significant reduction in analytical costs and allows for easy calculation of loads.

Flow proportional sampling is problematic to use where the difference between base and event flows is high, as this can result in under sampling during low flows and over sampling in high flows. This technique can deliver an unbiased estimate of loads at an efficient cost. Because of the un-gauged nature of the sites under study, this sampling strategy was not considered, but if good flow measurements were available it would definitely warrant further investigation.

**Automated Probability Sampling**

Under simple random sampling the probability of selecting each monitoring time in the sample is equal. Stratification is one way to vary the sampling intensity in response to likely flow patterns. An alternative is to sample with a probability proportional to an auxiliary variable (e.g. flow) that is known to be strongly related to the flux. This enables us to focus the sampling effort on those periods with the greatest flux. The most natural auxiliary variables are the flow or the flux as estimated by a regression model or rating curve.

The performance of such a strategy is dependent on how well the auxiliary variable is related to the true flux. If they are indeed proportional then the loads may be estimated accurately with fairly high precision. Probabilistic methods are likely to develop further and become more common in the future as they have the advantage of being able to produce reliable estimates of uncertainty in load calculations. A prototype system has been developed by the Australian Centre for Environmetrics.

**4.4.3 Discharge Calculation**

Development of reliable discharge estimates for facilitating calculations of loads is a continuing process that needs to be given sufficient resources. Estimations of discharge from the interim monitoring period in Douglas Shire are either very coarse or non-existent. Some progress towards discharge estimates has been made but these needs to be refined and improved over the next few years.

If the loads of streams need to monitored in order to demonstrate compliance with targets then accurate estimates of discharge are essential and, hence, significant time and resources need to be assigned to this task. Discharge estimation techniques often require development and refinement over a number of years and flow events. A brief over view of some of the techniques commonly used is given below.

**Manning’s Equation**

This is a simple deterministic equation that relates discharge to several hydrologically important features that may be estimated during a survey of the site. These features include the slope, hydraulic radius, cross-sectional area and the roughness of the bed. Several alternative formulations are possible. Depth is then related to the discharge through the relationship between depth and cross-sectional area so that given a depth, an estimate of the discharge is available. Such estimates are very subjective and should be applied only by those with a sound hydrological understanding of the processes involved.

**Rating Curves**

If a site has simultaneous discharge and stream depth values measured over a range of event sizes, then it is possible to generate a stage-discharge relationship. The rating curve for a specific stream location is developed by making successive discharge measurements at many different stream stages to define and maintain a stage-discharge relation. Discharge can be measured based on a cross sectional assessment using velocity meters or can be determined using boat-mounted Doppler techniques (see below). Once this stage-discharge relationship is developed, it is possible to obtain estimates of discharge simply by obtaining stream depth data. A number of years of data is required to produce accurate rating curves.
**Doppler Velocity**
The discharge of a stream can also be measured using an instrument known as a monostatic Doppler current meter. This instrument is mounted underwater and ‘looks’ sideways across the stream channel to take measurements of cross sectional velocity and direction. Techniques such as this, although expensive, may provide the means by which to continuously monitor discharge from tidal reaches of streams which is currently impossible to do by traditional rating curve techniques.

**4.4.4 Load Estimation Methods**
The loads estimation techniques employed in the DSC monitoring program are the best suited to the limited datasets available. As datasets of discharge and concentration grow and the true characteristics of the catchments being monitored emerge then the choice of appropriate estimation technique is likely to change. The choice of technique to use must be made by staff who have a thorough understanding of the conditions under which certain techniques will be best suited. Load estimation methods broadly fall under four main categories: 1) interpolation, 2) averaging methods, 3) ratio, and 4) regression methods. An overview of load estimation techniques and relevant literature review is given in Henderson and Harch (2005) a brief overview is given below.

**Interpolation Methods**
These methods overcome the infrequent concentration data by assuming that concentrations between observed sample points change smoothly with time and estimate them by their interpolated values. If it is reasonable to assume that concentration and discharge in an interval of time are well represented by the sample values, then reliable estimates are likely. If however the time interval is wide and concentration and discharge is variable, then the ensuing load estimate is typically subject to much greater uncertainty.

**Averaging Methods**
These methods seek to represent concentrations over an interval of time by the average concentration in that interval. If a stratified sampling strategy is employed the average estimator may be employed in each stratum and the total load estimated by the weighted sum of average stratum loads, where the weights are determined by the length of the strata.

**Ratio Methods**
These methods try to improve on the information contained in the observed discharge and concentration pairs by using the exhaustively available discharge information. The estimator centres on the assumption that the ratio of the average load to the total load is the same as the average discharge to the total discharge. A bias-corrected ratio estimator, known as the Beale Estimator, is widely used.

**Regression Methods**
These methods attempt to ‘infill’ concentration data by using regression techniques to predict concentration from the observed discharge. Load can subsequently be estimated by treating the predicted concentration data as if it was observed and using the linear interpolation method or something similar.
Section 5. Conclusions

Development And Management Of Water Quality Projects

All water quality projects should involve regular review and continual improvement. Mistakes should be learnt from, and recommendations for improvements should be made and implemented. Through this open process, the future development of water quality projects should become better informed and water quality issues will become better understood.

The key messages that we want to pass on to others planning water quality projects are, in order of importance:

- Clearly define the question before proceeding to other steps
- Involve all relevant parties
- Continually communicate between parties
- Select appropriate sites and discuss issues associated with each
- Assign appropriate timelines and budgets
- Fit the sampling strategy to the objectives of the study
- Develop a thorough plan for sample collection, storage, and records management
- Consider options for data storage, delivery, statistical analysis and interpretation.

Findings From The Interim Monitoring Strategy

The following conclusions can be made from the interim monitoring strategy:

- The automatic monitoring infrastructure installed in Douglas Shire worked very well. Careful choice of instruments and appropriately designed installation techniques ensured the collection of quality data from both the in-stream stations and the off-paddock flume systems. The ability of the stations to deliver up-to-date data to DSC water quality staff and CSIRO officers was particularly useful.

- The performance of the rate-of-rise algorithm developed to trigger sample collection for both the in-stream and flume stations worked well. This algorithm performed particularly well considering the lack of prior knowledge regarding the flow conditions at these ungauged locations. This methodology also has potential for developing sampling strategies for similar ungauged locations around Australia.

- A representativeness study, designed to assess the ability of the automatic samplers to represent stream water quality conditions, was designed but was not fully implemented. Further implementation is necessary in future years.

- A comparison of continuous measured turbidity with laboratory analysed TP and TSS samples showed the potential for decreasing the number of samples required to be analysed. The relationship between turbidity and TN was poor. Further data is required to develop stronger relationships or to conclude that this technique is suitable or otherwise.

- The variability of water quality constituents was found be to much more variable during events than during baseflow conditions. Baseflow conditions can, therefore, be represented by fewer samples.

- There was a general tendency at all stations and flumes for sediment and nutrient concentrations during peak flow events to fall and to become less variable as the wet season progressed. This is likely to be caused by the depletion of nutrient and sediment stores which accumulated over the dry season.

- The concentration data from the Upper and Lower Mossman stations indicate that there is a significant source of phosphorus and readily dissolved forms of nitrogen which is likely to come from the agricultural region between the two stations.
Estimates of loads delivered during the interim monitoring period were made for the Upper Daintree and Upper Mossman sites. Load estimates for these sites are subject to considerable uncertainty as a result of gaps in the data (primarily at the Upper Daintree site), short duration of the monitoring period, the approximate nature of discharge calculations and the sensitivity of the estimates to the algorithm used to calculate loads. Future sample collection will help to reduce uncertainty in load estimates for these stations.

The flume systems showed that higher loads of sediments and nutrients are lost from the plot with the higher fertilization rate. However, these results need to be treated with caution because of the sparse data sets available.

**Recommended Future Monitoring Strategy**

The main features of the Douglas Shire catchments identified in the interim monitoring, which must be recognised and addressed in the future monitoring strategy, are:

- The need to focus loads based sampling on events as this is when the most variation in sediment and nutrient concentrations occurs and this is when the vast majority of loads are moved.
- The occurrence of strong seasonal flow changes, not just between the wet and dry season, but also during the wet where there is a marked change in ‘baseflow’.
- The importance of the ‘first flushes’ of sediment and nutrient at the start of the wet season and the subsequent exhaustion of sediment and nutrient supplies as the wet season progresses.
- The need to invest resources in the development of reliable discharge estimates.
- The need to deal with the influence of tidal incursions on the lower catchment sites.

The sampling requirements for all stations are summarised in Table 3.

**Table 3. Recommended future sampling strategies for determining loads in Douglas Shire**

<table>
<thead>
<tr>
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<th>Target number of samples per year</th>
<th>Event Sampling Strategy</th>
<th>Non-event sampling strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Stations</td>
<td>100</td>
<td>Rate-of-rise</td>
<td>Monthly grab</td>
</tr>
<tr>
<td>Lower Stations</td>
<td>100</td>
<td>Salinity &amp; Rate-of-rise</td>
<td>Monthly grab</td>
</tr>
<tr>
<td>Flume Stations</td>
<td>100 (70 + 30 lysimeter)</td>
<td>Rate-of-rise</td>
<td>NA</td>
</tr>
</tbody>
</table>

Appendices

Appendix A  Selection Of Douglas Shire Automatic Water Quality Monitoring Sites

Appendix B  An Automatic Load Based Monitoring System For Douglas Shire

Appendix C  Development Of Automatic Water Quality Sampling Strategies For The 2003/04 Wet Season

Appendix D  Discharge Calculation At The Upper Mossman And Upper Daintree Stations

Appendix E  Presentation And Interpretation Of Water Quality Data From Automatic Monitoring Stations For The 2003/2004 Wet Season

Appendix F  Adequately Representing Water Quality Condition With Automatic Monitoring Stations: Sampling Design And Initial Analysis

Appendix G  Load Calculations For Upper Mossman And Upper Daintree Automatic Monitoring Stations For The 2003/2004 Wet Season

Appendix H  Reducing Loads Through Management Interventions: Results From Douglas Shire Water Quality Monitoring Flume Experiments

Appendix I  Analysis Of Community Collected Water Quality Data For The 2003/2004 Wet Season

Appendix J  A Future Loads-Based Monitoring Program For The Douglas Shire Catchments