
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>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>load (tonnes)</th>
<th>delivery rate (kg/ha)</th>
<th>load (tonnes)</th>
<th>delivery rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total nitrogen</td>
<td>151</td>
<td>17.4</td>
<td>3,581</td>
<td>39.4</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>4.48</td>
<td>0.52</td>
<td>241</td>
<td>2.65</td>
</tr>
<tr>
<td>Total suspended sediment</td>
<td>2902</td>
<td>334</td>
<td>225,200</td>
<td>2478</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.
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></th>
<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>100</td>
<td>Rate-of-rise</td>
<td>Monthly grab</td>
</tr>
<tr>
<td><strong>Lower Stations</strong></td>
<td>100</td>
<td>Salinity &amp; Rate-of-rise</td>
<td>Monthly grab</td>
</tr>
<tr>
<td><strong>Flume Stations</strong></td>
<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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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 in 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 timeline 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 benefited 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). 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.](image)

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.

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.

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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.
Figure 6. Comparison of mean sample concentration at Upper and Lower Mossman for the period 4-5 February 2004. A) Mean Concentration of total phosphorus (TP), total dissolved phosphorus (TDP) and filterable reactive phosphorus (FRP). B) Mean concentration of total nitrogen (TN), total dissolved nitrogen (TDN), nitrites plus nitrates (NO$_x$, N) and ammonium (NH$_3$). C) Mean concentration of total suspended sediments (TSS). Error bars are one standard error.

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 (01/12/03 – 30/06/04)</td>
<td>280,895 ML</td>
<td>1,530,000 ML</td>
</tr>
<tr>
<td>Total nitrogen load (tonnes)</td>
<td>151</td>
<td>3,581</td>
</tr>
<tr>
<td>delivery rate (kg/ha)</td>
<td>17.4</td>
<td>39.4</td>
</tr>
<tr>
<td>Total phosphorus load (tonnes)</td>
<td>4.48</td>
<td>241</td>
</tr>
<tr>
<td>delivery rate (kg/ha)</td>
<td>0.52</td>
<td>2.65</td>
</tr>
<tr>
<td>Total suspended sediment load (tonnes)</td>
<td>2902</td>
<td>225,200</td>
</tr>
<tr>
<td>delivery rate (kg/ha)</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)

Figure 8. Flow diagram of procedures followed to assess potential error in load estimates

- 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.

![Graph of Discharge and Nutrients](image)

Figure 9. Discharge TN, TP (A) and TSS (B) for Flume 2 showing the decline in concentrations over the wet season.
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 Production¹</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 NO₃, 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 section 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 be 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 overview 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 to be 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>
<th>Station Type</th>
<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
Appendix A - Selection Of Douglas Shire Automatic Water Quality Monitoring Sites

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1. Introduction
There is increased concern amongst scientists and natural resource managers regarding the impact of agricultural land use on the sediment and nutrient loads entering the coastal waters adjacent to the Great Barrier Reef World Heritage Area. The impact of terrestrial runoff on the Great Barrier Reef is associated with it a number of potential ecological, economic and social impacts. Catchments with the Douglas Shire lie on the wet tropical coast that drains to the Great Barrier Reef and as such there is a need to identify the major sources of sediments and nutrients so that appropriate management action can be taken to reduce the impact to the reef.

Potential degradation of the Great Barrier Reef has given rise to the development of water quality targets for catchments draining to the coast. Despite this, there is currently a lack of monitoring sites with sufficient precision in streamflow and water quality measurements to report on changes in sediment and nutrient loads to the reef. This makes it particularly hard to assess the effect of management interventions on loads from these catchments. Douglas Shire council are beginning to address this issue through successful bidding for funding to establish automatic water quality monitoring sites for Daintree River, Mossman River, Saltwater Creek and Mowbray River.

The purpose of this Appendix is to outline the location of automatic water quality monitoring sites installed as part of the Douglas Shire Water Quality Monitoring project. The site selection process will be outlined, and the instrumentation involved and data to be collected will be described.

2. Automatic Sampling Stations
Funding for seven automatic water quality monitoring sites was obtained by Douglas Shire from Environment Australia. It was decided to put five of these water quality monitoring sites in the major rivers in the area and to use two to assess the sediment and nutrient loads leaving sugar cane paddocks under different fertiliser strategies in the Shire. CSIRO was contracted to undertake site selection, purchasing, installation and data delivery for the automatic sampling stations. A full description of the automatic water quality sampling stations in given in Appendix B.

Each of the automatic water quality 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 data via the internet as well as alerting staff when water quality samples were collected. All automatic sampling stations were self powered using solar panels and battery banks.

Consultation between Douglas Shire and CSIRO resulted in the decision to use three of the in-stream monitoring stations to measure discharge and sediment and nutrient loads at the end of the three of the major rivers in the shire. The remaining two 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. Very little is known about loads coming from the natural forested systems in the Wet Tropics but this knowledge is essential in calculation of targets for the region and in the assessment of the effectiveness of management practices in achieving desired outcomes.

In-stream monitoring stations were designed to sample water quality only when river levels rise in response to rainfall events. In doing this we are assuming that the vast majority of sediment and nutrient movement takes place during large events, particularly those which occur at the start of the wet season. This design reduces the number of automatically collected samples and also keeps the sensors and pumps away from the stream bed where turbulence and mixing may affect sample concentrations. Baseflow water quality will be determined using a complementary community based collecting strategy that was run by Douglas Shire Council.

Programming the automatic stations to collect samples at pre-defined thresholds or time intervals is a complex process which is not helped by the lack of comparable data in the shire. The automatic samplers have 24 collection bottles which can be triggered to fill at predefined intervals,
but the problem is knowing how big an event is going to be and how long it will last. The most important time to collect samples will be at the start of an event in the initial flush but the trick will be to ensure that all bottles are not filled too quickly, especially in the event of a prolonged or multi-staged event. The other sampling issue involves the tidal cycle and tidal range which is big in the lower reaches of rivers in the Douglas Shire. Samples in the lower reaches will need to be triggered based on a combination of river height and salinity measurements because at certain times water will be moving upstream with incoming tide instead of downstream. This is in issue at all of our lower in-stream stations. A full description of the methodology used to trigger automated sampling is given in Appendix C.

Automatic monitoring stations and collection flumes for assessing the sediment and nutrient loads leaving sugar cane paddocks with different fertiliser application practices were installed in the Saltwater Creek catchment. These stations enable comparison of nutrient loads in runoff from sugar cane using existing fertiliser strategies, with those from cane using newly developed ‘fertiliser replacement’ strategies.

3. Site Selection

The site selection process involved extensive investigations by CSIRO staff combined with close consultation with Douglas Shire employees. Initial site selection involved analysis of topographic maps, aerial photos, and existing NRM stations. This was followed up with extensive on ground field investigations involving CSIRO scientists and technical instrumentation team. A number of potential sites were located and the feasibility of installation for all sites was assessed. Feasibility of sites was based on their suitability for measurements, access for sample collection, safety for staff, and cooperation from landholders and infrastructure owners. A description of the selected sites, instrumentation and property owners on a river by river basis is given below.

4. Mossman Catchment

4.1 Upper Mossman

The Upper Mossman River site needed to be positioned in order to be able to analyse flow and quality of water coming from the forested section of the upper part of the Mossman River. Rainforest dominates the Mossman catchment making up 70% of the total area. The rainforest covers the upper part of the catchment which is steep and mountainous with some peaks exceeding 1300m in altitude. The geology of the Upper Mossman river is granitic and the river in the upper part of the Mossman catchment flows in a distinct gorge.

The ideal location for the Upper Mossman site would be in the Mossman Gorge national park but this was not feasible for a number of reasons. Firstly, the gorge is one of the most visited tourist locations in the Wet Tropics. Installation of infrastructure in this World Heritage Area would be out of the question. Secondly, this area is the traditional land of the Kuku Yalanji Aboriginal people and we need to respect the fact that this is the home of their story places, sacred sites and Dreamtime legends. Thirdly, the river at this section is full of massive boulders and swift currents which would make installation at this site particularly difficult and unsafe. A number of drownings have occurred in the area over the years.

With these factors in mind the search for a site moved to the area downstream where the river flows out of the Mossman Gorge. As it leaves the gorge the Mossman River splits into three distinct channels as demonstrated by Figure 1. The smallest channel (yellow) flows through the Aboriginal Mission which runs a septic tank system. Clearly point source input from the Mission could severely compromise measurement integrity so this channel is not an option. The most northerly channel (red) flows through the Silky Oaks resort so again point source inputs could be an issue. Establishment of a gauging station in a holiday resort could also be problematic. The remaining channel (blue) flows directly from the rainforest without any anthropogenic input.
became the desired installation location despite the fact that not all of the river flow comes through this channel.

Although capturing all of the river flow is the desirable option, alternatives upstream are not viable. The purpose of the Upper Mossman River monitoring site is to determine water quality from the forested system. The middle channel below the gorge offers the only opportunity to do this.

The selected site is located on the property of Don Murday who is a cane and papaw farmer. The location of the site is shown in Figure 2. This site was fully instrumented with an automatic water sample collector, a depth sensor, and a turbidity sensor.

Figure 1. Aerial view of Mossman river showing area where river splits into three channels.

Figure 2. Aerial photo showing Upper Mossman monitoring site location.
4.2 Lower Mossman

The Lower Mossman River site needed to be positioned in order to be able to analyse flow and quality of water as low as possible in the Mossman Catchment. At this measurement point the monitoring station will take samples which, when compared to those taken at the Upper Mossman site, will help to determine the loads of sediment and nutrient coming from agricultural land.

Agriculture in the lower part of the Mossman catchment is dominated by cane (20% of catchment area) with some minor area of horticulture. The lower part of the catchment includes the town of Mossman which will also have an impact on water quality. The Lower Mossman is characterised by flat coastal plains well suited to agriculture, but with a lower rainfall that the upper part of the catchment. The site selected for the Lower Mossman Automatic monitoring station is shown in Figure 3.

![Aerial photo showing Lower Mossman monitoring site location](image)

The key siting criteria for the Lower Mossman monitoring station were easy access in all weather for installation and so that samples can be collected for rapid analysis, a cooperative landholder, and a position away from the estuary where complex mixing processes occur. Below this site, extensive bank rehabilitation and stabilisation are being undertaken. Earth moving activities in this region excluded it as a sampling point. A photo of the selected site is shown in Figure 4.

The selected site is located on the property of Doug Crees who owns an extensive area of cane paddock adjacent to the Mossman River. Access to this site is possible through Doug’s paddocks by vehicle or foot in all weather. This site was instrumented with an automatic water sample collector, a depth sensor, a salinity and temperature sensor, and a turbidity sensor. Salinity measurements will be used to manage sampling during high tide.
5. Daintree River

5.1 Upper Daintree

The upper Daintree river water quality sampling site will be used to measure the quality of water coming from the large area of natural forest which dominates the upper part of the Daintree catchment. This site will provide valuable information about the types of loads coming from natural forested systems which area unaffected by agriculture.

After in depth site assessment CSIRO have decided to locate the Upper Daintree water quality monitoring site at a location about 250m upstream of the CREB track crossing. This site is located in an area where forest gives way to grazing land. The reasons for choosing this site location are outlined below. An Aerial photo of the selected site is shown below in Figure 5.
This site is located a bit over 1 km downstream of the existing NRM river gauging site which was initially considered for water quality monitoring. The decision to locate the water quality sampling site downstream of the existing NRM infrastructure was based mainly on access issues.

Local farmers informed CSIRO that the water depth at the ford is too deep for vehicles to cross for 6 months of the year. This creates a number of logistical issues because water quality samples need to be collected as soon as possible after events (when the river will be at its highest). Access is not an issue for NRM hydrographers because they access their data using satellite phone telemetry and have no need to collect samples.

Locating the water quality monitoring station on the opposite side of the river to the NRM infrastructure was also considered but was deemed to be inappropriate because of the very steep banks, dense rainforest, and long distance over which samples would need to be pumped. Access on the opposite bank improves downstream slightly but the stream splits into 3 or 4 channels which become active during different size events. This would make stream gauging and sample collection impossible. With no other alternative CSIRO were forced to start looking downstream for suitable sites.

A suitable site where the river is straight and all of the flow is confined to one channel (i.e. ideal for gauging) was located about 1 km downstream in an area where land cover changes to grazed pasture. There were some initial concerns that moving the site downstream would mean that water samples would be influenced by runoff from grazing land but some simple calculations and observations have completely eliminated these concerns.

![Figure 6. Annotated aerial view of the site illustrating site location and natural drainage lines.](image)

Firstly, the area of forest upstream of the selected sampling site is roughly 38,000ha. By locating our sampling site about 1000m downstream of the NRM sampling site we are including a grazing area of less than 100ha which is equivalent to 0.25% of the contributing area. Obviously, this small contribution is not of a concern. To further back up these calculations, aerial photography and maps have been studied to look at the local topography. This revealed that the area of grazing influence is, in fact, much less than 0.25%. This is illustrated in Figure 6 which shows a small
natural drainage channel that takes most of the water from the grazing land and pipes it into the Daintree river below the selected monitoring site.

Concerns about bank and sheet erosion from the grazing lands contributing to the river loads from the very small remaining area of grazing upstream of the monitoring site were also raised but site assessment ruled these out as a problem too. Figure 7 shows the pasture cover at the selected water quality monitoring site in the middle of the Dry Season. Lush grass cover and no signs of bank erosion can be seen in this figure. Bank erosion does become an issue further downstream as the grazing country opens up, but upstream of this site, ground cover is very high and most banks are inaccessible to cattle.

![Figure 7. Monitoring site during the dry season with lush pasture and no bank erosion.](image)

The extremely low percentage of grazing area relative to forest area upstream of the monitoring site combined with the excellent condition of the tiny area of pasture upstream and the easy access in all weather conditions make this site an ideal location for water quality monitoring.

The selected site is located on the property of Craig Pocock who owns the grazing property adjacent to the Daintree River. Access to this site is possible all weather except the biggest floods. This site will be fully instrumented with an automatic water sample collector, a depth sensor, a turbidity sensor. The completed automatic water quality station at Upper Daintree is shown in Figure 8.

![Figure 8. Upper Daintree automatic water quality monitoring station.](image)
5.2 Lower Daintree

The Lower Daintree River site needed to be positioned in order to be able to analyse flow and quality of water as low as possible in the Daintree Catchment. At this measurement point the monitoring station will take samples which, when compared to those taken from the upper catchment, will help to determine the loads of sediment and nutrient coming from agricultural land. Agriculture is concentrated on the coastal lowlands and is dominated by sugar cane (1% of catchment) and grazing (3% of catchment).

The key siting criteria for the Lower Daintree monitoring station, as with the other lower sites, are easy access in all weather for installation and so that samples can be collected for rapid analysis, a cooperative landholder, and a position away from the estuary where complex mixing processes occur. Locations downstream of the ferry crossing (Figure 9) were eliminated because beyond this point the Daintree River flows through a large wetland and estuary system dominated by mangroves. This area is completely inaccessible by vehicle or on foot and is, therefore, not suitable for the monitoring station.

The selected location is slightly upstream from the busy Daintree River Ferry. At the selected location a pontoon has been constructed for the use of crocodile tour operators (Figure 10). The pontoon rises and falls with the river level and allowed samples to be taken well off the river bed where turbulence and mixing occur.

Figure 9. Aerial photo showing Lower Daintree River monitoring site location

Figure 10. Lower Daintree pontoon
The pontoon is owned by Queensland Transport who gave permission for the installation and the Douglas Shire Engineer was consulted about the siting of remaining infrastructure on the river banks. This site was be fully instrumented with an automatic water sample collector, a depth sensor, a salinity and temperature sensor, and a turbidity sensor. Salinity measurements will be used to manage sampling during high tide.

6. Saltwater Creek

6.1 Lower Saltwater Creek

The Lower Saltwater Creek site need to be positioned in order to be able to analyse flow and quality of water as low as possible in the Saltwater Creek Catchment. At this measurement point the monitoring station will take samples which, when compared to those taken from the upper catchment as part of a the community sampling strategy, will help to determine the loads of sediment and nutrient coming from agricultural land. Agriculture, mainly cane (25% of catchment) is concentrated on the coastal lowlands. This station will also be used to determine total loads from the Saltwater Creek Catchment.

Potential sites for this installation are limited because of the existence of a coastal estuary/mangrove swamp at the end of the creek. At the top of this swamp area the Captain Cook Highway crosses the Saltwater Creek and next to the highway there is a bridge used by sugar cane trains. This bridge is ideal for the establishment of a water quality monitoring site and as such it was been selected as the desired location (Figure 11).

The train bridge (Figure 12) is owned by the Mossman Mill who gave permission for the bridge to be used for the monitoring. Access to this site for the collection of samples and equipment maintenance can be gained easily and safely from the highway. The completed automatic sampling station is shown in Figure 13.

Figure 11. Aerial photo showing Saltwater Creek monitoring site location
To be able to reliably evaluate the sediment and nutrient losses from sugar cane (the main land use in the catchment), two smaller scale automatic water quality stations were established in the Saltwater Creek Catchment. The two smaller scale stations are installed in cane paddocks to look at the effect of reduced fertiliser application on the water quality leaving cane lands. There are two flumes installed on the same property so that all the conditions (e.g. soil type, cane type, rainfall, slope etc) are as similar as possible. Each flume drains roughly 12 rows of cane. One flume received the ‘business as usual’ level of fertiliser application and the second flume will received the Thorburn ‘replacement method’ of fertiliser application. These smaller plot scale studies were designed to look specifically at the difference between nitrate losses between the two application rates, although the loss of sediment (fine sediment load only) and runoff from cane paddocks can also be evaluated. As part of this experiment, the sugar cane at both sites was also assessed for sugar cane condition, growth and yield, to assess whether the reduced level of fertiliser has had an impact on cane productivity. The sites have been surveyed usual total station surveying gear to determine the total contributing area to each flume.

The property chosen is Sandy MacDonald’s property adjacent to Saltwater Creek and the Bruce Highway (Figure 14). The two flumes were installed following the last cane harvest and fertiliser application which were at the end of October 2003. The installation includes two cut throat flumes equipped with a monitoring station which includes an automatic water sampler, stage recorder.
located in stilling well, rain gauge and solar panel. The cane runoff automatic monitoring station is shown in Figure 15.

Figure 14. Aerial view of fertiliser/runoff trial site location.

Figure 15. Cane runoff automatic monitoring station in Saltwater Creek Catchment
Appendix B – An Automatic Load Based Monitoring System For Douglas Shire

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CSIRO Land and Water, Davies Laboratory, Townsville

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1. Introduction
The purpose of this appendix is to record the specifications, components and installation methods for the automatic water quality load monitoring stations installed as part of the Douglas Shire Water Quality Monitoring project. The design of the system will be detailed and, where in-house components are used, drawings are presented. A justification is given for the selection of the various components used and the overall performance of the system is assessed.

It is hoped that this document, which is developed out of experiences in Douglas Shire, will provide a guide and recommendations for future load monitoring station design.

2. Background
The objective of the automatic water sampling station design was to acquire water samples from the rivers and creeks of Douglas Shire during event conditions. These samples are then to be used for the determination of loads of nutrient and sediments exported from the rivers to the near shore.

In Tropical Queensland, it is thought in that 90-95% of the sediment and nutrients transported to the inner GBR are transported during events. A system designed to sample during these episodic events is necessary if a good estimate of transported loads is required. System design needs to keep in mind the harsh climate conditions of tropical Queensland which include high intensity rainfall events, sometimes with long duration, which result in significant runoff and sometimes flooding. These conditions with the addition of heat, humidity and salt are very harsh for structures and equipment.

To ensure success of the project a couple general of guidelines were followed.

- Ensure that the equipment box is located above the 1 in 100 year flood event high water mark.
- Bury or cover all exposed cables.
- Use corrosion resistant materials for all external surfaces or equipment.
- Select tried and tested equipment.

2.1 Specifications:
The specification for the monitoring stations was only loosely defined in the contract for installation, between Douglas Shire Council and CSIRO. The main requirements specified for design of the system are:

- Able to survive a 1 in 100 year event
- Solar powered (with enough capacity to run 10 days without charge)
- Refrigerated auto-sampler with a temperature set to 4°C for storing and preserving water samples to be analysed for:
  - Total Nitrogen (TN).
  - Total Phosphorus (TP).
  - Nitrate.
  - Ammonia.
  - Total Suspended Solids.
- Sampler to have capability to take discrete samples (not just composite).
- Continuous level, Turbidity and Electrical Conductivity measurements.
- Connection to real-time telemetry.
3. Site Selection For Installation
On the 15th and 16th of April 2003, a team consisting of 3 scientists and 1 technician from CSIRO Land and Water conducted a qualitative field survey of potential sites through the Douglas Shire. The report from this survey can be found in Appendix A of the Douglas Shire Water Quality Monitoring Plan Oct 2004. This report collates notes, photographs and details specifications for the required infrastructure necessary to successfully establish each of these potential sites.

Of the initial nine sites, four were finally selected as being suitable based on scientific, logistical and budgetary constraints. One further site was selected in the Upper Daintree region to include loads from the naturally vegetated catchment of this significant river and a further two were selected as small scale, paddock runoff experiments to specifically examine water quality in flows over sugar cane fields under 2 different fertiliser treatments. Completing a final suite of seven sites to install, monitor and maintain.

Stream sites were selected to satisfy various criteria including:
- Section of river required (i.e. area of human impact in catchment or area of natural impact in catchment) on scientific merit.
- Most representative samples possible (within budget).
- Logistically possible to install infrastructure to protect electronic instruments to minimise damage and loss due to flooding.
- Access to sites for machinery and equipment to install equipment.
- Wet season access to sites for sample collection and maintenance.
- Safety considerations for installation, maintenance and monitoring.

The final stream monitoring sites selected were at:
- Upper Mossman River
- Lower Mossman River
- Lower Saltwater Creek
- Upper Daintree River
- Lower Daintree River

Two flume sites were selected on a sugarcane paddock adjacent to Saltwater Creek.
4. Station Platform

4.1 Design

The platforms for the stream gauging sites (Figure 1 and Figure 2) were based on the design of the Bureau of Meteorology flood alert stations with various amendments to accommodate space and power requirements. Four platforms at 3 m high and one at 2.5 m high were used to make every effort to remain above flood levels.

The design is simple with a single pole supporting a floor frame with handrails attached. A large stainless steel enclosure was used to house the refrigerated sampler, logger, gas bottle and batteries. Solar panels were set on a pole mounted at the back of the platform with the entire set up bolted to deep concrete footings.

![Figure 1. Platform at upper Daintree](image1)

![Figure 2. Platform at lower Mossman](image2)

The Platforms at the two flume sites (Figure 3) were fabricated from angle iron then hot dip galvanised. The floor is 6 mm checker plate aluminium, 1800 mm x 1200 mm surface area, with holes to mount the standard enclosure used for the stream monitoring sites. At the base of each leg of the platforms is a plate (200 mm x 200 mm x 6 mm) with four 14 mm holes to facilitate 12 mm pegs to hold the platform in place. There are also steps built in and facility for U-bolts to support the solar panel (pole).

The 4.5 m high solar panel poles for the flume sites were 100 mm diameter aluminium with 3 mm thick walls. It was fastened at the bottom plate with 12 mm pegs, and at the platform with 90 mm nominal bore U-bolts. Three stays positioned from lug on the pole to star pickets in the ground. Aluminium brackets at the top of the pole support the two 80-watt solar panels and a tipping bucket rain gauge is attached to the pole with an appropriate bracket (Figure 3).
4.2 Installation Methods

The platforms were prefabricated and delivered in sections, with the final assembly being completed before trucking to the sites for erection. All components were hot-dip galvanised steel, stainless steel or aluminium to prevent corrosion.

1 m deep 1.8 m x 1.8 m footings were excavated using a small excavator (Figure 4). Three layers of F92 reinforcement mesh were inserted horizontally and welded together with vertically placed rod to form a single cubic mesh with cut-outs to facilitate the bolt cage and cable tube (Figure 5). While the specifications indicated a hole depth of 750 mm with 2 layers of reinforcement mesh for a wet foundation condition, it was decided to increase this depth to 1000 mm and use 3 layers of mesh. This was mainly in response to a need for a larger platform than originally designed for use by the Bureau of Meteorology and the extra weight on the platform of the six batteries and the refrigerated ISCO sampler.

The top of the hole was then framed with 150 mm x 25 mm timbers and the bolt cage and hidden pipe work held in the correct horizontal and vertical position via a timber template (Figure 5). All reinforcement had a minimum cover of 50 mm.

All concrete was N50 (50 MPa) with a 20 mm maximum aggregate and 80 mm nominal slump. Each site had 3.6 to 4 cubic meters of concrete poured and was evenly distributed with the aid of a vibrator (Figure 6).
Figure 4. Excavating the footings

Figure 5. Formwork, mesh and piping completed, ready to pour concrete

Figure 6. Pouring concrete, note the skilled use of the vibrator.

Figure 7. Completed slab
Once the completed slabs (Figure 7) had cured they were stripped of the formwork, and the assembled platforms put in place using a crane (Figure 8). The platforms were levelled and secured using the ground bolts then lifted into position using a crane (Figure 9). The enclosures were bolted to the platforms and the other heavy components (fridge and batteries) were lifted and placed in the enclosure.

Figure 8. Positioning platform (lower Mossman River site)

Figure 9. Positioning enclosure (Upper Mossman River site)

The solar panel poles were lifted into place with the crane and secured to the platform handrails with a prefabricated bracket. They were then dynabolted to the slab through an offset base plate.
At a later date, the solar panel poles were welded to the platform base (Figure 10) with a series of plates for greater security after three sets were stolen. The two 80 watt solar panels were assembled onto a frame, which included a sleeve to slip over the solar panel pole for through-bolting. This prevented dislodging and spinning.

Figure 10. Welding solar panel pole to platform base.

4.3 Problems And Improvements

The manufacture of the platforms was contracted out for a number of reasons.

Firstly, the company used produces standard platforms complete with engineering certificates. Their flood rating and demonstrated compliance with standards was viewed favourably by a shire council.

Secondly, with such tight timelines it was necessary to outsource as much of the manufacturing as possible.

Thirdly, also as a result of the timelines, the order of the designing was disruptive. For example, the fridge size was yet unknown and the enclosure needed to house this, in addition, the platform then needed to be the correct size to support the enclosure. The solar panels and associated infrastructure also needed to be integrated into this system.

To address these design problems Greenspan Technology Technical services was selected to design and build all four components to ensure each would fit properly during assembly and installation.

Unfortunately there was a design flaw that which was not realised until the platforms were delivered onsite. It became clear that the base area was too small and, hence, the enclosure door could not be opened while standing on the platform. Furthermore, the safety chains could not be closed while the enclosure door was open, and the safety rails were fully open at the approach end. There was also no space to remove the fridge to service the batteries let alone space to
actually lift the fridge onto the platform in the first place. It was also discovered that the safety rails were in fact lower than the legal height of 1000 mm.

Clearly, there were very serious safety implications and the system was unworkable. To address these problems a local (Mossman) engineering firm extended platform base by 600 mm. The handrails were modified to the correct height and an extra platform was added.

Further modifications were made to the solar panel mounting system so they could be lowered onto the poles with ease and safety. Following security issues, solar panel poles were extended to decrease accessibility for thieves, unfortunately, making cleaning and maintenance difficult.

Other than this the design has proved to be robust and reliable.
5. In-Stream Infrastructure

At each of the five stream monitoring sites there were different installation challenges. Each design needed to allow representative sample to be collected, whilst being able to fully protect electronic instruments from harsh environmental conditions and vandalism. The following section of this report examines the methods used to solve this problem at each site, including unique difficulties associated with them and possible improvements to the systems where appropriate.

5.1 Upper Mossman River

The upper Mossman River site had a relatively simple set of in-stream instruments to install, consisting of a depth transducer, turbidity meter and sample intake hose. In this instance an extra river pump was not required for the ISCO sampler since the lift was only about 5 m, well within the capabilities of the sampler pump (7 m limit). Being a freshwater stream with no tidal influence an EC meter was not required at this site.

Two marine grade (316) stainless steel, 2 inch medium wall, pipes were used to house the instruments, with a series of 13 mm holes drilled right around both pipes to ensure adequate flow through of fresh water. These were fixed to stable rocks at the rivers edge by means of stainless steel plates with bolts chemset in the rocks at suitable depth. As shown in Figure 9 the pipes were welded in situ to these plates with a series of stainless bars and straps to form a robust and rigid sampling point.

Figure 11. Sampling tubes at upper Mossman

Cables were run underground up the bank to the platform (Figure 12). A lockable stainless steel box (Figure 13) allows access to the instruments for cleaning, maintenance and calibration.
5.2 Lower Mossman River

At the lower Mossman River site a monitoring tube was driven into the riverbed to form the infrastructure to house the sensors and river pump. The monitoring tube was 4 inch light wall 316 (marine grade) stainless steel pipe with a series of 13 mm holes drilled through it, again to allow free flow of water. It was driven into the riverbed with a custom-made hand driver similar to a large fence picket driver.

Three 2 inch, medium wall, galvanised pipes were also driven in to surround monitoring tube for extra support and protection. The driving method consisted of anchoring a boat in an appropriate position and driving the first 2 m section of pipe in to a level above the water. A 1 m section of pipe was the butt welded to the top of this (Figure 14), allowed to cool, then driven in to an accessible level just above the water for the next section to be welded. This method was repeated for all pipes until a maximum depth was reached, that is, no further depth could be gained. It should be noted that a crocodile lookout was on duty during all these proceeding since the area is a known crocodile habitat.
These four vertical pipes were later welded together to form a single solid infrastructure. For access and extra support two lengths of 75 x 75 x 4 mm, galvanised RHS were welded to the two downstream vertical pipes and run back to the groyne. The area of contact on the groyne was then formed up with plywood and some reinforcement bar was welded to the RHS in preparation for cementing. Cement was carried in steel buckets down the bank and poured into the formwork to fashion a concrete step that would anchor the RHS, as well as increase accessibility to the instruments via a jetty (Figure 15).

After completion of the framework, a custom stainless steel access box was added to the monitoring tube and galvanised grid-mesh was welded to the access jetty for a safe and robust installation (Figure 16). The cables were run above ground through stainless steel pipe until they were out of the water, then underground through poly-pipe up to the platform.
5.3 **Lower Saltwater Creek**

The sampling station at lower Saltwater Creek was sited at the railway bridge adjacent to the highway. The bridge is for cane haulage and owned by the Mossman sugar mill. Permission was granted to attach sampling equipment to the bridge.

The monitoring tube was 4 inch light wall 316 (marine grade) stainless steel pipe with a series of 13 mm holes drilled through, similar to that used at the lower Mossman River site. The tube ran the full depth of the bridge (4 m) with a half-inch pipe covered by stainless steel angle stitch welded at the front for extra strength and facilitation of bubbler tube installation.

The monitoring tube was attached to the bridge with chemset attached plates top and bottom, and brackets around the pylons (Figure 17). The brackets were welded to the tube on site ensuring a robust installation. Two hook style brackets were chemset in place next to the tube to safely support a ladder for access to the tube for installation and maintenance. This area is also a known saltwater crocodile habitat so due care was taken.

At a later stage a stainless steel access box was welded to the top of the monitoring tube and cables were run through PVC pipe on the downstream under side of the railway sleepers (Figure 18). At the bank they crossed under the line and into a deep trench up to the platform.

The instrument cluster, as shown in Figure 32, was suspended inside the tube by a stainless steel cable secured inside the access box at the appropriate sampling depth.
5.4 Upper Daintree River

The Upper Daintree River in-stream infrastructure was the most difficult installation. There was no existing infrastructure at the site selected and the riverbed consisted of a highly mobile sand and gravel mix. Initial thoughts of siting the monitoring station along side the DNR&M gauging site at “Bairds Crossing” were abandoned due to its inaccessibility during the wet season for sample collection and maintenance.

The final design involved inserting a 300 mm nominal bore (NB) pipe into the bed adjacent to the base flow of the river with a box attached to house the turbidity meter and sampling pump. The pipe and box were fabricated in one piece (Figure 19) at the Davies Laboratories workshop then hot-dip galvanised. A 50 mm NB pipe for cables was attached at the downstream end and an “anchor”, consisting of a 400 mm x 400 mm plate and a length of heavy steel strap, was attached to the upstream end via a lug welded to the 300 mm pipe.

An access road was constructed so cement trucks could drive into the riverbed to deliver 6.8 cubic meters of 30 mpa concrete (Figure 20 and Figure 21).

Figure 22 shows the position of the sampling structure in relation to the base flow of the river. At this site the only practical and affordable installation method was to be adjacent to the base flow and wait for a significant rainfall event and, hence, river rise to commence sampling. The base flow sampling was to be completed by grab sampling.
The bubbler tube for depth measurements was run past the sampling point and buried in a trench so the outlet was underwater during baseflow. The bubbler tube, along with other data cables, power and sample hose were run through a deep trench up to the platform (Figure 22).
5.5 Lower Daintree River

The lower end of the Daintree River is a large (crocodile infested) estuary. A floating public pontoon was selected as the only suitable monitoring point considering budgetary constraints. The pontoon (Figure 26) is constantly used by tour operators and instrumentation was installed so as not to interfere with boating operations or be damaged by any knocks from boats. Working around the boats and tourists was another issue in the installation of the equipment.

The final design involved the fabrication of an aluminium enclosure (Figure 25) which allowed access from the pontoon with the instruments extending into the water. This box was then welded to the front side of the pontoon with a hole drilled through the pontoon to pass the wiring (with appropriate permissions granted). A hole was also drilled on the other side under the walkway and a length (approx. 5 m) of 50 mm polypipe was placed inside the pontoon with bulkhead fittings at each end to seal the holes. The wiring for the instruments was run through this polypipe, then under the walkway up to the bank, around the concrete slab (pontoon anchor) and underground up to the platform. Specialists certified to work in confined spaces were called in to work inside the pontoon (Figure 28).
Since the pontoon is floating the depth could not be monitored from the pontoon. This was done by forming a concrete block with an anchoring point for the attaching a heavy chain (Figure 26). The bubbler tube was attached to the chain with cable ties, and the chain was dragged from the bank to the pontoon (Figure 27). The concrete block was then thrown from the pontoon and the extra chain dragged back up the bank and secured to the pontoons concrete slab. This method allowed a consistent water level monitoring point where the outlet of the bubbler tube remained underwater even in the lowest tides, while being out of the way of the working boats in the area. The bubbler tube was run back up the bank to meet the other cables, before being directed underground to the platform.
5.6 **Flume Sites**

Nine inch Parshall Flumes were selected for measuring discharge at the nutrient runoff trial sites. The flumes were manufactured in aluminium to standard specifications (Figure 29). The flumes were wet set, in level position, at the end of the sugarcane rows. Galvanised steel sheet was used as bunding to collect runoff contributed by eleven inter-rows and direct the water into the flume for discharge measurement and sample collection.

A depth transducer with a 1 m range was secured in the stilling well at the front section of the flume, and an intake for the auto sampler placed in the hydraulic dip at the rear section of the flume (Figure 30).
5.7 **Site Selection In The Wet Tropics**

This paragraph gives some advice on selecting sites for load based monitoring stations in the wet tropics.

1. Select sites to take advantage as much as possible of existing infrastructure such as NR&M gauging sites. This allows easy measurement of discharge and there is likely to be historical data and other benefits such as easy access.

2. Use bridges where possible as these make ideal fixing points for sample river pumps.

3. Do not locate in-stream infrastructure on loose river beds if at all possible. The intensity of the flows is amazing, and the amount of scouring and re-deposition is significant.

4. If locating the site in a tidally affected reach, some thought MUST be given to how discharge will be measured.

5. For large rivers, like the Daintree, take advantage of structures placed on the bank of the river for access and security.
6. Sampling System
The sampling system consisted of a combination of a 24-volt Shurflo submersible river pump and the ISCO automatic water sampler. As mentioned in section 4.1, the pump was required when a high lift or a long distance existed between the sample intake point and the ISCO sampler. At four out of the five river monitoring sites the submersible pump was required. At these sites the logger activated the pump so the sample was pushed through a 13 mm hose up to the platform (Figure 31). After a period long enough to ensure that lines were purged, the peristaltic pump was activated to extract a 1 L sample from this hose.

![Sampling System Schematic](image)

The sampling trigger could be an increase or decrease in water height in the river, a change in turbidity, or for estuarine reaches, a significant decrease in EC (i.e. freshwater).

At the Upper Mossman River site and the two flume sites the submersible pump was not required since the peristaltic pump in the ISCO sampler was adequate to draw the samples. In these instances the end of the hose had a small strainer to prevent blockage from debris.

At each site the pump (or hose intake) was set as close as possible the same or to the same height as the other instruments to maintain consistent measurements.
The instrument cluster for the lower Mossman River and Saltwater Creek sites (Figure 32) were constructed of stainless angle and flat bar. The cluster housed the pump, turbidity and EC meters and was suspended on stainless steel cable at the appropriate depths. At the upper and lower Daintree River sites enclosures with specific internal frames were designed and manufactured to house and protect the instruments, pump and associated cables and hose.

![Figure 32. Instrument cluster for lower Mossman River site (the same was used for the Saltwater Creek site). The Shurflo pump is at the base with its intake at the top mesh section. The silver instrument is the turbidity meter with a copper shroud over the end to physically protect the wiper and act as a sacrificial anode in the saltwater environment. The longer black instrument is the EC meter.](image-url)
7. Instrumentation

7.1 Selection Of Instrumentation

In this section we look at the complement of instruments and electronic components used. As mentioned previously, the equipment was selected based on meeting the criteria of ability to do the job and experience with that instrument. The full complement of instruments used can be seen in Table 1.

Table 1 List of Instruments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Level (River Stations)</td>
<td>Hydrological Services HS23 Dry Bubble unit, size D gas bottle.</td>
</tr>
<tr>
<td></td>
<td>Greenspan PS700 10m Full Scale pressure transducer.</td>
</tr>
<tr>
<td>Water Level (Upper Mossman)</td>
<td>Greenspan PS700 5m Full Scale pressure transducer.</td>
</tr>
<tr>
<td>Water Level (Flumes)</td>
<td>Greenspan PS700 1m Full Scale pressure transducer.</td>
</tr>
<tr>
<td>Turbidity</td>
<td>McVan Instruments NEP395 3000NTU Full Scale.</td>
</tr>
<tr>
<td>Electrical Conductivity</td>
<td>Greenspan EC1200 60mS Full Scale</td>
</tr>
<tr>
<td>Data Logger</td>
<td>Campbell Scientific CR10X + 2MB memory.</td>
</tr>
<tr>
<td>Cell Phone Telemetry</td>
<td>Campbell Scientific SC932 interface plus GIGA GPM3000 CDMA Modem</td>
</tr>
<tr>
<td>Satellite Phone telemetry</td>
<td>Campbell Scientific SC932 interface plus Thrane&amp;Thrane Inmarsat TT3060A Mini-M satellite transceiver.</td>
</tr>
<tr>
<td>Refrigerated Auto Sampler</td>
<td>ISCO¹ 3700 controller and mechanism, placed in a Barron Refrigeration enclosure.</td>
</tr>
<tr>
<td>River Pump</td>
<td>Shurflo 9300 24v pump</td>
</tr>
<tr>
<td>Solar Power</td>
<td>2 60W solarex solar panels</td>
</tr>
<tr>
<td></td>
<td>6 100A/h 12v Hoepecke Deep Cycle Batteries</td>
</tr>
<tr>
<td></td>
<td>Regulator Plasmatronics PL20 Controller</td>
</tr>
</tbody>
</table>

7.2 Instrument Descriptions

7.2.1. Water Level

The dry bubbler system is widely used in hydrography, mainly for the advantage of placing the pressure transducer in the instrument hut. A plastic gas tube is run from the hut to the measurement point in the river. This gas tube is pressurised by the bubbler system and transfers the water pressure from the measurement point to the sensor. With the sensor in the hut, it is easy to test and calibrate. With the installation at the Lower Daintree tourist pontoon, the gas tube was tied to a concrete block and placed adjacent to the platform which housed the remainder of the instruments. This made the installation simple.

One of the recommendations that has come out of this work is that all instruments should be deployed with good quality water proof connectors. The connectors allow for easy removal of the sensors for repair or calibration. The water level pressure transducer is the only exception to this as it has a venting tube to equalise the sensor for changes in atmospheric pressure. This venting
tube makes it almost impossible to purchase a vented sensor with a connector. The use of a bubbler system overcomes this problem for water level measurements. The disadvantage is the additional cost of the hardware and the ongoing maintenance required in replacing the gas bottle. In this system the size D nitrogen gas bottle would last around 2-3 months. The layout of the water level system can be seen below in Figure 33.

Figure 33. Gas Bubbler Regulator, Gas Bottle and Sensor.

7.2.2. Turbidity
Good relationships between turbidity and Total Phosphorus and Total Suspended Sediment (TSS) can be expected in the Douglas Shire. The continuous record of turbidity with a good relationship to TSS will provide an additional tool in estimating loads, so the value of a good turbidity sensor is high. The import aspects of turbidity sensor choice are that it covers the range of turbidities expected and that the sensor has an integral wiper to minimise fouling effects. The McVan 395 is the sensor that covers both those requirements at the most favourable cost. As we were unsure of the range of turbidity that would be observed, the additional advantage of having 3 programmable ranges was useful.
Another feature that makes the McVan sensor attractive is that it uses the SDI-12 communication interface. SDI-12 is a digital serial communication standard used by environmental sensors to communicate with dataloggers. This interface greatly simplifies the connection of equipment to dataloggers.

7.2.3. Electrical Conductivity (EC)
The Greenspan Technology EC sensor was selected for use as it is a non media contact sensor. This means that there are no electrodes in direct contact with the water so fouling is far less of a problem. The sensing is performed by way of inductive coupling between two torroidal transformers with the linkage between the two being the water under observation. More detail of the sensing method can be found on the Greenspan Technology web site. This type of sensor is particularly suited to long term low maintenance installations.

7.2.4. Data Logger
The datalogger used is the Campbell Scientific CR10x with a 2MB memory expansion. This logger was chosen because we use it extensively in other work and it is widely used for environmental monitoring. The CR10x is the standard logger utilised by Department of Land and Water Conservation (DLWC) in NSW. One of the features that makes this datalogger attractive is flexibility. It is easy to:

- Add additional Sensors.
- Change sampling strategy.
- Connect to telemetry.

The 2MB expansion was added in case the telemetry failed there would be sufficient capacity within the logger to store up to 6 months worth of data.

7.2.5. Telemetry
This section describes the two types of telemetry used in this project. We have found telemetry on monitoring systems to be very useful. The telemetry is used to alert operators that samples have been taken and that the samplers need to be unloaded and reset. This was very helpful in planning efficient use of limited personnel in maintaining the samplers during the wet season. Aside from this, the most beneficial aspect of telemetry is receiving frequent information on the system performance allowing operators to have confidence that the system is working properly. With automatic sampling systems technical problems can be a frequent occurrence, but with telemetry the operator can have confidence that the system is operating correctly. The cost of telemetry is a small additional investment when considering the overall cost of a monitoring project.

Cell-Phone
Prior to installation of the equipment a site selection study was done and as part of this cell phone coverage in the region was assessed. At the sites where there was cell phone coverage, there was both CDMA and GSM access; we selected to use the CDMA network. In our experience the CDMA network with the GIGA CDMA modem from Maxon has a better data recovery rate than the GSM network. The GPM3000 has been superseded by the GPM5000 which we would recommend for new installations. The GPM5000 has internal reset capability as well as non volatile memory for saving settings (this is not available on the GPM3000). The inability of the GPM3000 to store settings made interfacing to it a little difficult as the settings had to be programmed into the CR10x and sent to the modem by the CR10x after each reset. The modem was reset once a day under control from the CR10x.
Satellite Phone
The satellite terminal selected was the Thrane & Thrane TT3060A Inmarsat Mini-M terminal. This unit is supplied in Australia by Electrotech Australiavi. Inmarsat is a geostationary satellite system primarily used by marine vessels as a marine communication network and emergency system. The network has had reasonable use in terrestrial applications and was once thought to be superseded when the Iridium system was activated. This has not been the case as this system has a number of advantages. The primary advantage of this system is that the antenna once located in position, is always aligned with the satellite. This is more important than it seems in tropical regions, where canopy cover is often high and satellite visibility is, therefore, a problem. With the Iridium network, which is a low earth orbiting system, the constellation of satellites is in constant movement in relation to a fixed position on the earth. This means that if you only have a small window through the canopy, the satellites will only be visible to the transceiver from time to time. This limits the opportunities that you have to gather data.

The main disadvantage of the Inmarsat system is that the hardware is more expensive than Iridium and the power consumption is greater as the distance to the satellites is greater.

7.2.6. Refrigerated Auto-Sampler
The refrigerated auto-sampler used in this project is based on an ISCO 3700 sampler. We have widely used the ISCO 3700 control unit and have had extremely good results in many sampling projects. Typically in our sampling installations, the ISCO is controlled by a data logger (in this case the Campbell scientific CR10x). The control unit from the 3700 is mounted on a refrigeration unit manufactured by Barron Refrigeration and can be seen below in Figure 34.
The refrigerator has a Danfoss 24V compressor which is controlled by a Danfoss electronic temperature controller which is preset to 4 degrees Celsius.

Figure 35. Sampler Mechanism

7.3 Layout Of Instrument Box

The instrument box was assembled with the batteries located on the base (floor) with a wooden floor placed above them. On this floor, which was made of marine plywood, was placed the auto-sampler and gas bottle. On the rear of the box, above the sampler, the electronics panel was mounted (Figure 36). The electronic panel is where the datalogger, modem interface, cell phone and electrical distribution bus were fixed. The panels were prefabricated and placed into position during the installation. Placement of the panel at the rear of the box meant that the in situ wiring was easy and that the electronics is easily accessible and easy to maintain.

Cable trunking was used on the electronics panel to provide channels for the cables, which keeps everything neat and tidy and easy to work with. The gas bubbler regulator is mounted on the side of the enclosure (see Figure 33) with the gas cylinder towards the front for easy replacement. The major disadvantage of this layout is the inaccessibility of the batteries (being under the wooden floor Figure 37).
Figure 36. Electronics Panel

Figure 37. Battery compartment underneath sampler.
8. Electrical Wiring
The various components were wired together using WAGO 260 series DIN rail terminal blocks. These terminal blocks have the advantage of allowing quick installation and maintenance in the field. The solid state relays used to activate the river pump, refrigerator and modem were of plug in type OMRON G3FD-X03SN available through RS part number 386-0085. The relays have an indicator light that is activated when the relay is on and can be driven directly by the CR10x control ports. The indicator light has been a great help in assisting with remote trouble shooting. The system wiring diagram can be seen in Technical Note 1.

8.1 INITIAL SAMPLING STRATEGY AND PROGRAMMING THE DATA LOGGER.
The initial sampling strategy was determined on a philosophy of over sampling. For determination of an optimized long term monitoring strategy an over sampled data set is required. The initial strategy is detailed in Appendix C of the Douglas Shire Water Quality Monitoring strategy and will not be fully covered here, rather we give a brief summary of the algorithms and present the flow chart used to implement those algorithms in the CR10x logger.

8.2 Upper Stations And Flumes
The algorithm used for the upper stations and the flumes follows this format:
If the hydrograph is rising and if the water level is above the current Rising hydrograph Trigger level (RisSample) then take a sample if the level is above the event level threshold. Conversely if the hydrograph is falling and if the water level is below the current Falling hydrograph Trigger level (FalSample) then take a sample if the level is above the event level threshold (EThresh). In both cases, then update the rising and falling hydrograph trigger levels. If the hydrograph is steady, and it has been greater than the sample period between samples (SPeriod), take a sample. This algorithm can be seen in Tech Note 2. This type of sampling strategy is commonly known as systematic stratified sampling.

8.3 Lower Stations
Initially the lower stations, which are tidally affected, were programmed with the algorithm detailed above. It was found that this did not work very well for low to medium level events as the necessary event threshold condition (which was set to be just above the highest tidal excursion was ever met. So to fix this an Electrical Conductivity trigger was implemented with a time based sampling.

The algorithm used is of this format:
If Electrical Conductivity (EC) is below EC trigger level and if it has been SPeriod minutes since the last sample is taken and that the water level is above EThresh, take a sample. The flowchart for this can be seen in Tech Note 2.

8.4 Rate Of Rise Trigger
To account for the different stages of the wet season where the baseflow changes i.e. early, middle and late wet season, it became clear that a trigger based on level was not ideal. So a rate of rise algorithm was developed where to put the system into event (sampling) mode a pre-defined rate of rise of water level had to be exceeded. In this system it was 20mm in an hour. A second difference is then used to set the system back into standby mode.
The algorithm used is of the following format:
if the rate of rise is greater than rate of rise trigger level, go into event mode. If in event mode apply algorithm 8.2. If the rate of rise is negative and less than the tolerance (TOL) and the second difference is positive and less than TOL revert to standby mode. The algorithm worked extremely well. The flow chart can be seen in Tech Note 2.

The performances of the various components of the system are assessed in this section. This information can be used in designing future water quality monitoring stations by learning from the results presented here. Generally the auto-station has worked well but there have been a number of technical problems. The infrastructure apart from the instream infrastructure at the upper Daintree has proved to be robust and reliable. At the upper Daintree during a significant event on 4 Feb 2004, the scouring from the high flows removed material from underneath the instream structure which consequently moved and slumped. This meant that the cables to the turbidity sensor snapped and that the gas bubbler tube became dislodged and free to move around in the river. The intake for the river pump was also partially covered in bedload and sediment causing it to fail. It later came to life again when some of the bedload and sediment was shifted away.

The dataloggers, telemetry and power systems have all worked well. Some specific components of the system will now be looked at in a bit more detail.

9.1 Refrigerator Performance

An example of the performance of the unit can be see in Figure 38. The set point as mentioned was 4 degrees C but the average for this period is 8.5 deg C. This performance is typical of all the units installed.

The design of the fridge is worth commenting on. The refrigeration coil is located at the rear of the insulated chamber with the fridge control temperature sensor located on the coil. The logged temperature sensor in the fridge is located in the centre near the top of the chamber. The samples bottles are arranged in a circular holder centrally located in the box. One explanation for this difference in measured to set point difference is that the controller temperature sensor is measuring a non representative temperature being located on the cooling coil. Also it is likely that the convection relied upon with the box to transfer the heat is insufficient and so there is a temperature gradient within the box. This could be improved significantly by the inclusion of a small circulation fan within the box to improve the circulation.

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**Figure 38. Example of Refrigerator Performance**
9.2 Auto-sampler Performance
Generally the auto-samplers performed well. There were two failures though of the ISCO controller unit. The fault was identical in both controller units. The symptoms were that the sampler would not take samples and would report that the pump was jammed. The first station to be affected was Flume one which failed on 21/12/2003 and was not successfully repaired until 16/2/2004. The controller failed again on the 12/3/2004. The fault was diagnosed as a misaligned opto-encoder which was rectified by the agents. This fault a manufacturing fault that ISCO say affected a small batch of samplers. All the samplers used in this project have been returned for a check to ensure that this fault does not re-occur. The other failure (identical fault) was at the Lower Daintree auto-station and this fault was rectified by a CSIRO technician. CSIRO Land and Water has used ISCO 3700 sampler with great success over 8 years and we have been very disappointed with this problem.

9.3 River Pump
The combination of a Shurflo 9300 series river pump and the ISCO 3700 worked well. The pump had no difficulty in pumping the sample over 100m with a 5m head to the sampler. The standard Surflo fine mesh filter screen had been replaced with a course mesh to allow sampling of the coarser bedload fraction of the suspended sediments. This proved to be a bit of a problem as the river pump at the Saltwater Creek auto-station failed due to ingesting sand. Once the river level had fallen the pump was easily cleaned and put back in action. In future it would be desirable to keep the fine mesh screen for protection of the pump. This would mean that only suspended sediment finer than .2mm would be sampled.

9.4 Continuous Sensors
This section looks at the performance of the continuous sensors.

9.4.1 Water Level
The water level system used was a combination of the HS23 dry bubble system with a Greenspan Technology PS700 10m pressure transducer. The dry bubble system is the standard installation method used by QNRM&E for their stream gauging stations. The advantage of this technique is that the transducer is not located in the river or stream but safely in the protection of the instrument enclosure. This means that it can be easily tested and calibrated as well as being protected.

Generally the sensors have worked well at the river stations with the major problem being small gas cylinder (D size) that required regular replacement. At the Upper Daintree site, gas consumption was considerably greater than at the other sites which became inconvenient as this required even more frequent replacement. Also, the gas line at the Upper Daintree became dislodged during the large event on 4th Feb 2004, resulting in large variations in the measurements. From this time onwards the Upper Daintree water level measurement has had differences to the NRM gauging station at Bairds. This is most likely due to the gas line drifting in the water and floating upwards causing an error in measurement as mentioned previously. The differences can be seen in Figure 39.
9.4.2. Turbidity

The McVan turbidity sensors NEP395 performed variably. At the upper Mossman, and saltwater creek they performed well but required more frequent servicing (Figure 40). The comparison between the lab and in-situ measurements can be seen in Figure 41.
The sensor at lower Mossman has not worked properly at all, and the manufacturers suggest that an upgrade to the firmware might rectify the problem. This problem still needs to be resolved at the time of writing.

The sensor at the lower Daintree platform became fouled and required additional maintenance, while the sensor at the upper Daintree failed due to the in stream infrastructure being under cut and moved. This stretched and broke the cable.

9.4.3. Electrical Conductivity

The electrical conductivity sensors have performed well at all stations with no failures.

9.4.4. Power System

In the wet tropics, solar powered installations are quite tricky. This is because even though the solar insolation is high, the persistence of wet periods becomes a problem. For this design we allowed for 10 days with little or no solar insolation. Despite this, there were a number of occasions where the battery voltage was lower than desirable. The variation in battery voltage for saltwater creek can be seen in Figure 42. The system, therefore, would benefit from some added solar panel capacity and additional battery storage. We would recommend an additional 100A/hr of battery capacity with an additional 40W of solar panels. A more cost effective option might be to look at the use of a micro hydro generator used in conjunction with the solar system to form a hybrid solar hydro system. Micro turbines such as the Aquair\textsuperscript{\textregistered} U.W. Water Turbine ($\textdollarUS980), which has an output of up to 8 Amps, could be a better solution. This would provide good power when the rivers are flowing, which is exactly when the solar system power output drops. Other than that the power system has worked very well.
9.5 Maintenance

For any monitoring program that uses automatic and in-situ equipment the maintenance is very important if the equipment is to be operated reliably. A maintenance schedule for this equipment is listed in Tech Note 3.

The major items requiring ongoing maintenance are the turbidity sensors which need to have a clear optical surface to make accurate measurements. In waters that are high in turbidity or have high growth rates of aquatic organisms the fouling of the sensor occurs quite rapidly. McVan Instruments recommends that service interval for the NEP395 probe be 8 weeks, for the Douglas Shire, with reference to Figure 41, it need to occur more frequently. We would recommend cleaning the surfaces every two weeks.
10. Improvements And Discussion
Although there have been some niggling technical problems with the equipment, particularly the samplers, overall the design and equipment has proved to be robust and suitable for the water quality monitoring program. We cannot stress enough the quantity of effort required to design and deploy such monitoring stations as described in this report. It is hoped by including a large number of pictures that the reader gains an appreciation of the effort involved. Coupling this with the conditions in tropical North Queensland makes this installation even more notable. Even though on the whole the automatic stations have worked well, a number of suggested improvements can be made.

We make the following recommendations for future water quality monitoring programs:

- The station platform, boxes, in-stream infrastructure and system design presented here are a suitable design basis for a long term water quality monitoring projects.
- Given the theft of the solar panels, all solar panels and power generation equipment should be secured (either by height or otherwise) against theft.
- An additional set of in-situ instruments should be purchased to be used as change out units should any sensors fail
- All in-situ instruments should be fitted with good quality water proof connectors. The connectors will add about $600 to the purchase price of the instruments. This will allow the instruments to be interchanged easily. The spare set would be calibrated in the office and then taken to the field to be placed into service. The other advantage of the spare set is that if there is a failure in one of the instruments, they could be changed out easily allowing greater reliability with the data capture.
- The ISCO avalanche refrigerated sampler be evaluated. ISCO have a new refrigerated 12V auto-sampler called the Avalanche. Details can be found on the ISCO web site, but this might have better temperature control than the Barron refrigerated system. The only disadvantage of the ISCO Avalanche is that it has a reduced sample capacity of 14 by 950mL samples compared to the 3700 system which has 24 by 1000 mL samples.
- For the wet tropics, greater than 10 days spare battery capacity is warranted and in this system an additional 100 Ahr of capacity would be desirable. The power supply could be augmented by use of a micro turbine which would provide good power when the solar system is reducing power due to cloud cover and rain.

One of the other difficult aspects of this deployment was the very tight timeframe. This tight delivery put significant pressure on the manufactures, suppliers and on our team. We suggest that for future installation of this type that more consideration is given to the quantity of work involved.
Technical Notes

Tech Note 1. Wiring Diagram

Figure 43. Wiring Diagram for Auto-Stations
Tech Note 2. Programming Flow Charts

This section contains the programming flow charts for the software algorithms for the Auto-Stations.

![Flowchart for EC triggered stations.](image)

**Definition of Parameters**

**Level:** The water level or depth or water above the water level sensor.

**Ethresh:** The event threshold water level, below which is thought of as baseflow. This parameter is also used to set a minimum level below which the system does not sample. This is used to prevent sampling in the tidal reaches when the level is below the sample intake.

**EC:** Electrical Conductivity (EC) of the stream.

**ECthresh:** EC below which indicates freshwater flows from upstream.

**ECRen:** EC Re-enable, the EC value above which the system stops sampling.

**Speriod:** The period between samples, once the system is in event mode.

**Timer:** The system timer used for timing between samples.

Figure 44. Flowchart for EC triggered stations.
**Lower Mossman:**
ECThresh: 100uS/cm  
Ethresh: 700mm  
ECRen: 1000uS/cm  
Speriod: 360min

**Saltwater Creek:**
ECThresh: 100uS/cm  
Ethresh: 1100mm  
ECRen: 1000uS/cm  
Speriod: 360min

**Lower Mossman:**
ECThresh: 1000uS/cm  
Ethresh: 1000mm  
ECRen: 5000uS/cm  
Speriod: 360min

Figure 45. Initial programming parameters for Lower Stations
Start Do every Minute

Level > RisSample

Yes → Hydrograph is Rising

RisSample = RisSample + DeltaHRis

No → Level < FallSample

Yes → Hydrograph is Falling

FallSample = FallSample - DeltaHFal

No → Hydrograph is Steady

Is Level > Ethresh

Yes → Take a sample

No → Finish

Is Timer > Speriod?

Yes → No

No → Yes

FallSample = FallSample - DeltaHFal

RisSample = FallSample

Is Level > Ethresh

Yes → No

No → Yes

RisSample = RisSample + DeltaHRis

FallSample = FallSample - DeltaHFal

Figure 46. Flowchart for Upper Stations and Flumes.
Definition of Parameters

**Level:** The water level or depth or water above the water level sensor.

**Ethresh:** The event threshold water level, below which is thought of as baseflow. This parameter is also used to set a minimum level below which the system does not sample. This is used to prevent sampling in the tidal reaches when the level is below the sample intake.

**RisSample:** Higher level of the level window used to determine hydrograph state. This is not a settable parameter, but rather a variable initially = 0 on first run.

**FallSample:** Lower level of the level window used to determine hydrograph state. This is not a settable parameter, but rather a variable initially = 0 on first run.

**DeltaHRis:** Change in height on the rising hydrograph since last sample that will cause a sample to be taken

**DeltaHFal:** Change in height on the falling hydrograph since last sample that will cause a sample to be taken

**Speriod:** The period between samples, once the system is in event mode and the hydrograph is steady.

Note: FallSample must be an even multiple of RisSample

**Upper Daintree:**
Ethresh: 2200mm
DeltaHRis: 400mm, original setting 100mm changed 21/1/2004
DeltaHFal: 400mm original setting 100mm changed 21/1/2004
Speriod: 1440min

**Upper Mossman:**
Ethresh: 500mm
DeltaHRis: 100mm
DeltaHFal: 100mm
Speriod: 1440min

**Flume 1:**
Ethresh: 5mm
DeltaHRis: 100mm
DeltaHFal: 100mm
Speriod: 1440min

**Flume 2:**
Ethresh: 5mm
DeltaHRis: 10mm
DeltaHFal: 10mm
Speriod: 1440min

Figure 47. Initial parameters for Upper Stations and Flumes.
Is it 0 minutes into an hour?

FirstDiff = level - LastLevel

2ndDiff = FirstDiff - LastFirstDiff

If FirstDiff > TriggerRateRise
Set EventFlag = true

If 2ndDiff > 0 and abs(FirstDiff) < TOL and abs(2ndDiff) < TOL
Set EventFlag = false

Calculate Trigger Levels

If 1st Diff > 0
SampleTrigger = LastLevel - mod(DeltaHFall)

SampleTrigger = LastLevel - mod(DeltaHRis) + DeltaHRis

Determine if in event mode

Determine if end of event mode condition met

Do Every hour

Calculate Differences

Start

Yes

Yes

No

Yes

No

Figure 48. Flowchart for Rate of Rise trigger for Upper Mossman (part 1).
If \( \text{FirstDiff} > 0 \) and \( \text{Level} > \text{SampleTrigger} \), then \( \text{SampleFlag} = \text{true} \).

If \( \text{Level} < \text{SampleTrigger} \), then \( \text{SampleFlag} = \text{true} \).

If \( \text{EventFlag} = \text{true} \), then \( \text{LastFirstDiff} = \text{FirstDiff} \)

\( \text{LastSecDiff} = \text{SecDiff} \)

\( \text{LastLevel} = \text{Level} \)

If \( \text{Timer} > \text{Speriod} \), then \( \text{SampleFlag} = \text{true} \).

Determine if we need to take a level change sample

Update Values for next iteration

Determine if we need to take a timed sample

Take Sample and reset Timer

Goto Start

Figure 49. Flowchart for Rate of Rise trigger for Upper Mossman (part 2).
Definition of Parameters

**Level:** The water level or depth or water above the water level sensor.

**Ethresh:** The event threshold water level, below which is thought of as baseflow. This parameter is also used to set a minimum level below which the system does not sample. This is used to prevent sampling in the tidal reaches when the level is below the sample intake.

**TriggerRateRise:** The rate of rise in water level in one hour that will set the system in event mode.

**TOL:** The maximum difference which the first and second differences are compared to to determine of the stop condition has been met.

**DeltaHRis:** Change in height on the rising hydrograph since last sample that will cause a sample to be taken.

**DeltaHFal:** Change in height on the falling hydrograph since last sample that will cause a sample to be taken.

**Speriod:** The period between samples, once the system is in event mode and the hydrograph is steady.

**EventFlag:** System flag used to keep event state

**SampleFlag:** System flag used to keep sample state

---

**Upper Mossman:**
Ethresh: 100mm  
DeltaHRis: 100mm  
DeltaHFal: 100mm  
Speriod: 360 min  
TriggerRateRise: 20mm in an hour  
TOL: 1.2mm

---

Figure 50. Initial parameters for Upper Mossman Rate of Rise.
Tech Note 3. Monitoring Station Maintenance Schedule

This section details the recommended maintenance schedule for the automatic water quality stations.

Event Maintenance
Event maintenance is the tasks that need to be done when an event has occurred at any of the water quality stations. An event will cause the automatic sampler to commence taking water samples. These samples need to be removed from the samplers within 24-48 hours of acquisition and the bottles replaced with empty bottles.

Tasks
1. Unload sampler, capping and labelling sample bottles and placing into portable fridge or esky for return to base.
2. Refill sampler with empty bottles
3. Record sample times from ISCO sampler
4. Check fridge temperature
5. Restart Sampler
6. Take grab samples from waterbody
7. Take spot readings with portable instruments: turbidity, EC
8. Compare spot readings to those on the automatic station to gain confidence that the sensors are working properly.
9. Back at base decant samples into bottles for transportation to laboratory
10. Organise transportation of samples.
11. Organise for acid washing of ISCO sample bottle

Three monthly preventative maintenance
These maintenance tasks are to ensure that the stations are operational and ready for the next event.
1. Check operation of fridge
2. Withdraw in-stream pump and check condition of stainless steel mesh, if needed clean or replace. Ensure that the pump lines and cable are in good condition, by visual inspection
3. Withdraw in-stream turbidity meter and replace wiper rubber if required. Ensure that the optical surface is in good condition and clean. Check condition of sacrificial anode, if required replace
4. Withdraw in-stream EC sensor and clean build up of algae or bio-film.
5. Check condition of either pressure transducer of gas bubbler capillary line
6. Check contents of gas for gas bubbler system Check operation of sampler
7. Check battery voltage to check the charging system.
8. Download charging profile from power management module to PC for reference and examination if required.
9. Clean rain-gauge collector (flume sites)
10. General visual inspection of the station looking for anomalies.

Twelve Monthly Maintenance
These maintenance tasks are more laborious and would be undertaken prior to the wet season ensuring the system is in good condition. This maintenance is in addition to the 3 monthly schedule.
1. Clean Solar Panel surfaces
2. Calibrate Pressure, turbidity and EC sensors

Twenty Four Monthly Maintenance
This maintenance is in addition to the 12 monthly schedule.
3. **Check condition of batteries, if required replace. (will require a battery tester)**

**Equipment and consumables required.**

1. ISCO bottles for change out. Initially 7 spare sets will be required.
2. Sample bottles (500mL and 250mL)
3. Multi-parameter dip and read EC/Turbidity/pH meter
5. In field pressure calibrator.

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2 SDI-12: [www.sdi12.org](http://www.sdi12.org)
7 Available from [www.absak.com](http://www.absak.com)
Appendix C – Development Of Automatic Water Quality Sampling Strategies For The 2003/04 Wet Season

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1. Introduction
The current monitoring strategy for the automated sampling stations during the 2003/04 wet season has been based on analysis of relevant historical data, local landscape and hydrologic knowledge, and instrumentation capabilities and limitations. Since the initial setting of parameters in December 2003, and subsequent analysis of collected data, ongoing refinement of the monitoring strategy has taken place.

2. Historical Data Sets
Of the six historical data sets available for analysis, the QNRM discharge and stage height data was considered the most relevant for providing input for the monitoring strategy. It should also be noted that the historic data was collected at different sites than those being monitored in the current study and thus will only provide a rough guide for the monitoring strategy as the current sites will behave differently during both ambient and event conditions because of differences in channel shape and increasing discharge as we move downstream. Table 1 outlines the matching of the automatic monitoring stations with the most relevant historical sites with flow data. The other historical data sets from both QNRM and QDPI will be analysed in terms of characterising ambient condition in the catchments and will be used to inform the ambient manual sampling program.

Table 1: Matching of automatic monitoring stations with relevant historical sites with flow data.

<table>
<thead>
<tr>
<th>Automatic Monitoring Site</th>
<th>Relevan Historical Site Having Similar Characteristics to the Automatic Monitoring Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Daintree</td>
<td>Daintree at Baird’s</td>
</tr>
<tr>
<td>Salt Water Creek</td>
<td>Saltwater Creek Upper at O’Donoghue Rd</td>
</tr>
<tr>
<td>Upper Mossman</td>
<td>Mossman at Highway Bridge</td>
</tr>
<tr>
<td>Lower Mossman</td>
<td>Mossman at Highway Bridge</td>
</tr>
<tr>
<td>Lower Daintree</td>
<td>Daintree at Baird’s</td>
</tr>
</tbody>
</table>

3. Initial Setting Of Parameter Values
Previous expertise with establishing automatic stations for monitoring storm events along with analysis of the historical record were used to establish initial parameter setting values for controlling the automatic monitoring stations. These parameters were used to set the conditions required to start sampling an event, conditions to sample on both the rising and falling stages of the hydrograph and conditions to stop sampling the event.

Following is an outline of the eight parameters used, the reason why these parameters have been used and comments on initial values set at each of the automatic monitoring stations. Table 2 provides a summary of the parameters used and the initial values set on each of the automatic monitoring stations.

Table 2: Initial set of parameters specified for Douglas Shire Automatic Monitoring Stations.

<table>
<thead>
<tr>
<th>Site</th>
<th>Parameters</th>
<th>ETHRESH (mm) – Event threshold – this value tells the automatic sampler at which depth it can start sample collection.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Daintree</td>
<td>Ethresh</td>
<td>2200 ATL(^1) 0 200 200 1440 20 0.002 (^2\text{rd}) Difference tolerance</td>
</tr>
<tr>
<td>Saltwater Creek</td>
<td>Ethresh</td>
<td>1900 60000 0 100 100 1440 20 0.002 (^2\text{rd}) Difference tolerance</td>
</tr>
<tr>
<td>Upper Mossman</td>
<td>Ethresh</td>
<td>500 ATL(^1) 0 100 100 1440 none none (^2\text{rd}) Difference tolerance</td>
</tr>
<tr>
<td>Lower Mossman</td>
<td>Ethresh</td>
<td>2300 60000 0 100 100 1440 20 0.002 (^2\text{rd}) Difference tolerance</td>
</tr>
<tr>
<td>Lower Daintree</td>
<td>Ethresh</td>
<td>4000 60000 0 100 100 1440 20 0.002 (^2\text{rd}) Difference tolerance</td>
</tr>
<tr>
<td>Flume 1</td>
<td>Ethresh</td>
<td>5 none none 10 10 480 none none (^2\text{rd}) Difference tolerance</td>
</tr>
<tr>
<td>Flume 2</td>
<td>Ethresh</td>
<td>5 none none 10 10 480 none none (^2\text{rd}) Difference tolerance</td>
</tr>
</tbody>
</table>

\(^1\) ATL refers to above tidal limit and hence an EC threshold value is irrelevant for this site.

\(^2\) The \(^2\text{nd}\) difference tolerance is a measure of how much the \(\text{Delta } H\) values change over a certain period of time.
- Values are selected to ensure sample intakes at all stations are in the water.
- Values for the tidally affected sites (Saltwater Creek, Lower Daintree & Lower Mossman) set to be above the high tide mark. It was noted that consideration of using Electrical Conductivity (EC) as an event threshold parameters in conjunction with Depth should also be made. As data is collated over December/January 2004 this will be investigated and further sophistication into the parameter set used will be considered.
- Value for flumes the event threshold was set to 5 mm so that the ‘first flush’ off the paddock would be captured. Following analysis of water quality data, this value may be increased in the future.

ECTHRESH – Electrical Conductivity (EC) threshold – this value can be used at tidal sites to tell the automatic sampler that to start sampling. Low EC readings indicate that the system is dominated by freshwater flow and that tidal influences have been reduced/mitigated.
- ECTHRESH were initially deactivated at tidal sites by using a high EC threshold, however, subsequent data analysis has shown the potential usefulness of this parameter and future sampling strategies at tidal sites are currently being programmed to include this measurement.

TTHRESH (NTU) – Turbidity event threshold – this value can be used to tell the automatic sampler at which turbidity to change into sampling mode.
- At this stage turbidity has been effectively deactivated by using 0 as the Turbidity threshold. Subsequent analysis of data already collected shows that this parameter is unlikely to be useful for initiating measurements by automatic stations.

DELTA H RIS & DELTA H FALL (mm) – these values are depth change thresholds for rising & falling stages of the hydrograph
- These predetermined depth tell the automatic sampler at which depth samples should be taken on the rising and falling river/flume depths.

DELTA T (min) – Time based sampling – these values control the number of samples that the automatic station takes when river/flume depths are falling. Experience has shown that depths fall at a much slower rate than they rise. This means that a falling river/flume depth situation may persist for days. Delta T values are used to collect time based samples that are taken regardless of whether a Delta H fall value has been achieved.

RATE OF RISE (mm/hr) – Rate of depth change over an hour- Rates of depth change from QNRM depth data were considered and developed for use as parameters for the automatic monitoring stations.
- Initial thoughts of using three different sets of parameters to characterise base flow conditions and event types (events during dry weather, wet season and cyclonic events) were replaced by jointly using first and second differences as a more objective method for setting the parameters.
- A rate of rise of 20mm/hr was assigned as the relevant parameter for all sites. This value was based on historical records and instrumentation limitations. This value is initially set quite low so that over sampling takes place. Statistical analysis of initial samples will be undertaken to adapt these parameters in the future.

CONDITION SET FOR STOPPING EVENT SAMPLING
- To stop sampling an event (i.e. on the falling stage of the hydrograph) at time t, the preceding 1st difference (t-60 mins) must be negative and the preceding 2nd difference (t-60 mins) must be positive and the 2nd difference at time t be less than the 0.002 (tolerance). These sets of conditions will be used to characterise the end of the effects of an event.
- Flumes are stopped when depth falls below 0mm
4. Validation Of Monitoring Regime Using The Historical Data Sets

The sampling regime based on these set of parameters were validated using historical data from a three sites (Daintree@Bairds, Mossman@Bridge and Saltwater@O'Donohue's). The regime was found to capture all events that would be expected to be identified in the monthly time series record of depth data. Figure 1 highlights the implementation of the above monitoring strategy for the Daintree@Bairds site, which is indicative of the Upper Daintree monitoring station (Table 1). Figure 2 provides the implementation at Mossman@Bridge, which is indicative of the Upper and Lower Mossman and Figure 5 Saltwater@O'Donohues for Salt Water Creek. While these historical data have a coarser temporal frequency than the frequency that will be logged by the automated monitoring stations, the data is still adequate for validating the monitoring strategy.

![Daintree@Bairds](image1.png)

Figure 1: Monthly depth record for Daintree@Bairds site from 30/11/2000 to 31/01/2001. Superimposed is the initial monitoring strategy for this automated monitoring station.

![Mossman@Bridge](image2.png)

Figure 2: Monthly depth record for Mossman@Bridge site from 01/12/2000 to 31/01/2001. Superimposed is the initial monitoring strategy for this automated monitoring station.
5. First Review Of Parameters Values

The set of parameters given in Table 2 above were implemented during December 2003/January 2004 and in mid January 2004 these values were reviewed based on the monitoring data collected during that period. Here, each monitoring station is considered separately and comments about the relative success and/or adaptation of the parameters used initially are outlined.

**Upper Mossman**: Overall the monitoring strategy has been very effective for this station with the majority of events being sampled adequately (Figure 4). One issue that was identified was the taking of multiple samples at the one depth which occurred on the falling stage of the hydrograph (Table 3). This phenomenon occurs when the depth measurement hovers around a predefined sample collection depth. This results in unwanted sample collection. All stations are now being reprogrammed so that sample collection at each depth only takes place if the previous sample was not at the same depth.
Figure 4  Record of depth data (-) and automatic sampling points (•) during the period 29/12/2003 to 20/01/2004 for the Upper Mossman station.

Table 3: Depth (mm) record for the Upper Mossman automatic monitoring station during the period 29/12/2003 to 20/01/2004 for the Upper Mossman station. The coloured sections highlight time of the falling stage of the hydrograph where replicate depth samples have been taken.

<table>
<thead>
<tr>
<th>Date &amp; Time</th>
<th>Depth (mm)</th>
<th>Date &amp; Time</th>
<th>Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29/12/2003 7:21</td>
<td>503</td>
<td>12/01/2004 15:26</td>
<td>602.1</td>
</tr>
<tr>
<td>29/12/2003 8:14</td>
<td>617.1</td>
<td>12/01/2004 17:08</td>
<td>596.6</td>
</tr>
<tr>
<td><strong>29/12/2003 13:18</strong></td>
<td><strong>601.6</strong></td>
<td>12/01/2004 17:55</td>
<td>1008</td>
</tr>
<tr>
<td>29/12/2003 13:22</td>
<td>600</td>
<td>12/01/2004 17:59</td>
<td>1114</td>
</tr>
<tr>
<td>29/12/2003 13:26</td>
<td>598.9</td>
<td>12/01/2004 18:03</td>
<td>1135</td>
</tr>
<tr>
<td>30/12/2003 0:05</td>
<td>611.3</td>
<td>12/01/2004 18:07</td>
<td>1216</td>
</tr>
<tr>
<td>30/12/2003 0:26</td>
<td>711</td>
<td>12/01/2004 18:11</td>
<td>1246</td>
</tr>
<tr>
<td>30/12/2003 3:37</td>
<td>806</td>
<td>12/01/2004 18:15</td>
<td>1250</td>
</tr>
<tr>
<td>30/12/2003 4:45</td>
<td>905</td>
<td>12/01/2004 18:19</td>
<td>1238</td>
</tr>
<tr>
<td>30/12/2003 7:33</td>
<td>898</td>
<td>12/01/2004 18:33</td>
<td>1187</td>
</tr>
<tr>
<td>30/12/2003 8:22</td>
<td>901</td>
<td>12/01/2004 19:01</td>
<td>1089</td>
</tr>
<tr>
<td>30/12/2003 9:09</td>
<td>1007</td>
<td>12/01/2004 19:44</td>
<td>996</td>
</tr>
<tr>
<td>30/12/2003 11:44</td>
<td>999</td>
<td>12/01/2004 20:33</td>
<td>893</td>
</tr>
<tr>
<td><strong>31/12/2003 3:38</strong></td>
<td><strong>699.9</strong></td>
<td>12/01/2004 22:54</td>
<td>696.6</td>
</tr>
<tr>
<td><strong>31/12/2003 3:43</strong></td>
<td><strong>698.3</strong></td>
<td>13/01/2004 1:26</td>
<td>598.2</td>
</tr>
<tr>
<td><strong>31/12/2003 3:47</strong></td>
<td><strong>697.3</strong></td>
<td>13/01/2004 4:00</td>
<td>600.4</td>
</tr>
<tr>
<td><strong>31/12/2003 23:53</strong></td>
<td><strong>600.1</strong></td>
<td>13/01/2004 4:14</td>
<td>599.3</td>
</tr>
<tr>
<td>1/01/2004 0:01</td>
<td>598.1</td>
<td>13/01/2004 10:53</td>
<td>499</td>
</tr>
<tr>
<td>1/01/2004 0:05</td>
<td>597.5</td>
<td>14/01/2004 19:48</td>
<td>499.9</td>
</tr>
<tr>
<td>2/01/2004 0:06</td>
<td>503.8</td>
<td>15/01/2004 10:03</td>
<td>500.9</td>
</tr>
<tr>
<td>2/01/2004 1:34</td>
<td>499.4</td>
<td>15/01/2004 11:14</td>
<td>622</td>
</tr>
<tr>
<td>2/01/2004 1:48</td>
<td>500.4</td>
<td>15/01/2004 15:16</td>
<td>599</td>
</tr>
<tr>
<td><strong>12/01/2004 14:49</strong></td>
<td><strong>504.2</strong></td>
<td>16/01/2004 6:36</td>
<td>499.4</td>
</tr>
</tbody>
</table>
**Upper Daintree:** At the time of writing no event data has been sampled at the Upper Daintree monitoring station as river levels are yet to reach ETthresh.

**Salt Water Creek, Lower Mossman and Lower Daintree:** The tidal influence each of these monitoring stations was very clear (e.g. Salt Water Creek in Figure 5). Generally for each of the monitoring stations samples were taken where it is possible to see the higher depth record which goes beyond the tidal depth range during high tides. In the case of the Lower Daintree, a pulse of freshwater, indicated by the EC values during this time period, was not sampled. It should be noted that up until this time, only small rainfall events have been experienced. The full set of implications of this initial monitoring strategy in tidally influenced areas would require the inclusion of a large event during the data record.

Nonetheless, the preliminary analysis of the data record suggests that the monitoring strategy for these tidally influenced sites needs adapted to include EC trigger values in conjunction with depth thresholds. An appropriate strategy including both EC and depth is currently being considered.

---

**Figure 5:** Record of depth data (−) and automatic sampling points (●) during the period 28/12/2003 to 20/01/2004 for the Salt Water Creek station.

**Flume 1 and 2:** The sampling record highlights the gross level of over-sampling when the depth is around 5mm, where 5mm is the event threshold depth for both flumes. This over-sampling is particularly evident for Flume 1 (Figure 6). Note also the lack of rising stage samples taken, with the majority of samples taken in the falling stages of the hydrograph. As a consequence the depth change thresholds on both the rising and falling stages have been reduced from 50mm to 15mm. At this review point the time change threshold remains unchanged. Over sampling will now be eliminated by reprogramming.
Figure 6 Record of depth data (--) and automatic sampling points (●) during the period 26/12/2003 to 2/01/2004 for Flume 1.

Table 4: First review of parameters specified for Douglas Shire Automatic Monitoring Stations. Note parameters in bold blue type are those parameters that have changed or are currently being considered in terms of ways to incorporate them into the monitoring strategy.

<table>
<thead>
<tr>
<th>Site</th>
<th>Ethresh</th>
<th>ECThresh</th>
<th>Tthresh</th>
<th>Delta H Rise (mm)</th>
<th>Delta H Fall (mm)</th>
<th>Delta t (min)</th>
<th>Rate of Rise (mm/hr)</th>
<th>2nd Difference tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Daintree</td>
<td>2200</td>
<td>ATL 1</td>
<td>0</td>
<td>200</td>
<td>200</td>
<td>1440</td>
<td>20</td>
<td>0.002</td>
</tr>
<tr>
<td>Saltwater Creek</td>
<td>1900</td>
<td>in revision</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>1440</td>
<td>20</td>
<td>0.002</td>
</tr>
<tr>
<td>Upper Mossman</td>
<td>500</td>
<td>ATL 1</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>1440</td>
<td>20</td>
<td>0.002</td>
</tr>
<tr>
<td>Lower Mossman</td>
<td>2300</td>
<td>in revision</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>1440</td>
<td>20</td>
<td>0.002</td>
</tr>
<tr>
<td>Lower Daintree</td>
<td>4000</td>
<td>in revision</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>1440</td>
<td>20</td>
<td>0.002</td>
</tr>
<tr>
<td>Flume 1</td>
<td>5</td>
<td>None</td>
<td>none</td>
<td>10</td>
<td>10</td>
<td>240</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Flume 2</td>
<td>5</td>
<td>None</td>
<td>none</td>
<td>10</td>
<td>10</td>
<td>240</td>
<td>none</td>
<td>none</td>
</tr>
</tbody>
</table>

1 ATL refers to above tidal limit and hence an EC threshold value is irrelevant for this site

6. Future Reviews Of Parameters Values

With ongoing data collection through the wet season, regular review of the monitoring strategy at each of the stations will be undertaken to continually adapt and optimise the strategy to minimise sampling requirement. The final synthesis of the entire data record for each of the automatic monitoring stations will be conducted by simulating different sampling regimes from the over-sampled record. This will involve a process of dropping off sampling points using specific scenarios to determine the information loss/economic gains from various monitoring strategies. This will enable the most optimal monitoring strategy to be developed.
Appendix D – Discharge Calculation At The Upper Mossman And Upper Daintree Automatic Water Quality Monitoring Stations

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1. Introduction
In order to calculate the mass of materials carried by a river (known as its ‘load’) it is necessary to have reliable measurements of the flow of water discharged past a point in combination with regular measurements of the concentration of water quality constituents. There are a number of techniques available for determining discharge of a river and these will be discussed below.

In the Douglas Shire catchments, discharge measurements are available from a number of DNR&M stations, however, the sites selected for water quality sampling in the DSC water quality project are not at the same location and, hence, new discharge relationships need to be developed for the automatic monitoring locations. This study has covered a seven month period and, as a result, very little data is available for producing reliable estimates of discharge.

It should be noted that there is an ongoing need for refinement and improvement of discharge calculation for each of the DSC automatic station. Being based on such a short period of data, the techniques presented in this appendix are by no means final and will require significant refinement and improvement as more data becomes available. What we present here is a first cut at discharge measurements so that we could produce estimates of loads for the first season of automatic station data.

2. Potential Methods For Calculating Discharge
A number of different techniques exist for calculating discharge from a stream and these are detailed below. Techniques range from those that directly measure discharge to those that estimate discharge based on river depths and relationships derived from river hydraulic properties.

2.1 Rating Curve
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. Stream discharge is the rate at which a volume of water passes through a cross-section per unit of time. It is usually expressed as cubic metres per second (m³/s) or megalitres per day (ML/day). 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 Section 2.3). The stage-discharge relationship is expressed as a rating curve, a rating table or rating equation (Gordon et al., 1992). Once this stage-discharge relationship is developed, it is possible to obtain estimates of discharge simply by obtaining stream depth data.

Rating curves are not static and they occasionally must be recalculated due to changes in the factors that determine the relation between stream stage and streamflow. These factors include the slope of the water surface and bed (affects velocity), the roughness of the channel, the area of the channel at each stream stage, backwater effects (when a tributary enters a larger river) and filling in and scouring out after large floods. For these reasons rating curves are not appropriate for estimating loads in tidal or estuarine areas.

2.2 Manning Equation
At ungauged sites, discharges are often estimated using indirect methods based on knowledge of the height of the water. Manning’s equation (Equation 1) is probably the widely used uniform flow equation for open channel flow calculations (Gordon et al., 1992).

$$Q = rac{1}{n} AR^{2/3} S^{1/2}$$  

Equation 1

Where $Q =$ discharge (m³/s), $S =$ the slope of the energy line equal to the bed or water surface, $A =$ the cross-sectional area of the flow (m²), $R =$ the hydraulic radius (m) and $n =$ a coefficient referred
to as ‘Manning’s n and represents the roughness of the channel. One of the greatest difficulties in using the Manning equation is estimating an accurate value of \( n \). This is because \( n \) increases as turbulence and flow retardance effects increase, and in natural channels \( n \) can vary with depth. However, for this study, \( n \) is going to be considered constant and will be estimated using the methods outlined in Chow (1959).

To obtain estimates of \( S \), \( A \) and \( R \) the channel of interest must be surveyed. This data can then be used to develop a stage discharge curve, similar to a rating curve. It must be remembered that this method is approximate only and a rating curve still needs to be developed for this site in the longer term. This method assumes uniform flow (i.e. the depth and velocity are constant along the channel) and therefore this approach is not applicable in tidal areas.

### 2.3 Doppler Velocity

The discharge of a stream can also be measured using an instrument known as a monostatic Doppler current meter. Monostatic refers to the fact that the same transducer is used as transmitter and receiver. This instrument is mounted underwater and ‘looks’ sideways across the stream channel to take measurements of cross sectional velocity. A monostatic Doppler uses a set of acoustic transducers with precisely known relative orientations. During operation, each transducer produces a short pulse of sound at a known frequency that propagates along the axis of the acoustic beam. Sound from the outgoing pulse is reflected (“scattered”) in all directions by particulate matter in the water. Some portion of the scattered energy travels back along the beam axis to the transducer. This return signal has a frequency shift proportional to the velocity of the scattering material. This frequency change (Doppler shift) is proportional to the projection of the water velocity onto the axis of the acoustic beam. Techniques such as this, although expensive, may provide the means by which to continuously monitor discharge from tidal reaches of streams which is current impossible to do by traditional rating curve techniques.

### 2.4 Other/Modelling

In the absence of data collected from the field, nutrient and sediment loads can be predicted using relationships generated using data from other catchments either nearly or in other parts of the world (Letcher et al., 1999). There are a number of publications that describe the range of methods and models that can be used to predict sediment and nutrient loads (see Letcher et al., 1999; Letcher et al., 2002; Merritt et al., 2003).

In the Douglas Shire Water Quality Project two models were used to estimate sediment and nutrient loads: SedNet and EMSS. Details regarding the application of these models are documented in other reports (see Bartley et al., 2004a and b; Ellis et al., In Prep). These models are useful for estimating whole of catchment exports, however, they have limited application at the sub-catchment or paddock scale. Models such as SedNet and EMSS also have a number of limitations as many of the processes that they model are not yet well understood for tropical systems such as the Daintree Catchment (e.g. generation of sediments and nutrients from forest systems). Nonetheless, these models are useful for providing an estimate of the sediment and nutrient loads in the catchment, and they will be improved with verification from data collected in the field.

### 3. Methods Used In The Douglas Shire To Calculate Discharge

#### 3.1 Upper Mossman

The Upper Mossman site presented an interesting challenge for developing a rating curve. At the Upper Mossman site the river has is split into three channels which each carry a different amounts of water. Samples and stage measurements for the 2003/04 wet season were taken from the middle channel (CH2). Cross sections through the three channels are shown in Figure 1. These cross sections and channel slopes were determined using total station surveying.
A rating curve for Channel 2 was developed using WinXSPro software (USDA Forest Service). This software takes the surveyed data and channel slope and calculates cross sectional areas at variable heights. This information is then used with a user defined Manning’s n to calculate the relationship between stage and discharge. Manning’s n for Channel 2 was set at 0.065 because of the very rough bed of the stream which consists predominantly of boulders larger than 20cm diameter.

The rating curve was then applied to the depth measurements at Upper Mossman to estimate discharge for Channel 2. The discharge in Channels 1 and 3 was calculated by scaling the discharge for Channel 2 based at the ratio of their cross sectional areas. Using this method the discharge at Upper Mossman has been calculated (Figure 2). Total discharge for the Upper Mossman station for the measurement period (1/12/03 – 30/6/04) was 280,895 ML. To check whether our estimates of discharge for Upper Mossman were reasonable we compared the total discharge at Upper Mossman to the total discharge for the NRM Mossman gauge (109001) which is 7 km downstream. We found that our estimate for Upper Mossman was 6% less than the discharge at the NRM Mossman gauge (297,710 ML). This comparison provides confidence in the discharge estimates because there are only a couple of small creeks that enter the Mossman river between the Upper Mossman site and the NRM Mossman gauge. NRM Mossman data was at the highest standard available at the time of analysis. However final checks and analysis of this data have not been undertaken by NRM.
3.2 Upper Daintree

There is no rating curve available for the Upper Daintree gauging station, however, the NRM Bairds gauge (108002) is located about 1km upstream and it has been rated. The NRM Bairds gauge was established on the 25/09/68 and has rating and cross-sectional details. Both sites have very similar morphological characteristics. The width:depth ratio values for the cross-sections of the two sites are 0.069 and 0.068 for the DSC and NRM stations, respectively. Both sites also have a confined bedrock wall on one bank and a terraced alluvial floodplain on the other. A comparison of the depth changes for the Upper Daintree and NRM Bairds station for the 2003/2004 wet season (Figure 3) shows that depth changes at these two sites are well matched. The close match of the two sites, combined with the small distance between them and the lack of any major water input between the two stations, meant that the NRM Bairds gauge rating curve could also be used at the Upper Daintree gauging station.

![Figure 3. Comparison of depth changes at the NRM Bairds station and the Upper Daintree automatic station.](image)

![Figure 4: Hydrograph for the Upper Daintree station](image)

Failures of the Upper Daintree system during some of the major events led to the decision to use the Bairds stage data for analysis of flow at Upper Daintree. NRM Bairds data was at the highest standard available at the time of analysis. However final checks and analysis of this data have not been undertaken by NRM. Discharge at the Upper Daintree station was calculated using the NRM Bairds rating curve and the resulting hydrograph is shown in Figure 4. Total discharge for the study
period (1/12/03 – 30/6/04) was 1,658,780 ML. Although this is not a full years measurement, discharge over this period is about the fifth highest since records began at NRM Bairds station in 1969. Average annual discharge is 1,033,600 ML.

3.3 Lower Daintree, Lower Mossman And Saltwater Creek

Due to the tidal influence at the three lower stations, it was not possible to calculate discharge using the conventional methods mentioned in Section 2. It may be possible to measure the discharge at these lower stations using a Doppler velocity metre (Section 2.3) or similar approach. These techniques are, however, expensive and will require the knowledge of skilled practitioners that are familiar with measuring discharge in tidal areas. If load calculations are required by DSC at these lower stations in the future, then the cost of such equipment will need to be incorporated into any future planning.

An alternative method for calculation of loads in tidal areas is presented in Webster et al. (In press) who worked in the Fitzroy estuary in Queensland, Australia. This paper presents a method for calculating nutrient loads in tidal estuaries. The method utilises a simple hydrodynamic transport model that is calibrated using measured salinities and which is used to describe the transport properties of the estuary as they respond to river discharge. Using this transport model, the temporal variation in nutrient concentrations within the estuary can be resolved between sampling surveys even when the discharge events are of short duration. An inverse method is then applied to calculate internal fluxes of nutrients from measurements obtained on successive sampling surveys.

4. Discussion

If estimates of loads are to improve we need to have a strong methodology for determining flow from our catchments. In non-tidal areas rating curves need to be developed over a number of seasons. In tidal areas, where rating curve techniques do not work, a completely new set of techniques to determine flow is needed. These techniques could include use of Doppler based flow meters which ‘look’ at direction and rate of flow in cells across the river channel, or could include estuarine modelling techniques which separate tidal and river flows. Research in this area is very limited and requires a lot more work before confidence in flow estimates can be achieved. Bearing in mind that many rivers in Australia experience large tidal fluctuations (e.g. The entire wet tropics region) which push many kilometres inland, issues to do with tidal influences on load estimates are not insignificant. Special attention needs to be given to developing an agreed method for obtaining load estimates in tidal regions – this is vital since water quality improvement plans are written in terms of loads delivered to coastal areas.

References


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

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1. Introduction
In the following sections basic interpretation of the water quality data collected for each automatic
station during the 2003/2004 wet season will be presented. For Upper Mossman and Upper
Daintree stations, where rating curves have been developed, discharge and concentration data will
be presented. For the other sites concentration data will be plotted against stream depth.

This appendix also includes a section relating to the use of continuous sensor measurements of
turbidity and how these measurements may be able to be used as surrogates for different water
quality parameters.

2. Sample Collection Overview
A breakdown of the number of samples collected during the study period is given in Table 1. In
total over 600 samples were analysed, with the vast majority of those coming from the automatic
stations. Results from the flume stations will be dealt with in Appendix H of this report.
“Representativeness” samples were collected to analyse how representative samples drawn by the
automatic stations were of samples taken across the stream channel.

Table 1. Total number of samples analysed for the 2003/04 wet season

<table>
<thead>
<tr>
<th>Collection type</th>
<th>Samples analysed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic Stations</td>
<td>425</td>
</tr>
<tr>
<td>Flume Stations</td>
<td>54</td>
</tr>
<tr>
<td>Community grab samples</td>
<td>99</td>
</tr>
<tr>
<td>Representativeness</td>
<td>36</td>
</tr>
<tr>
<td>Total</td>
<td>614</td>
</tr>
</tbody>
</table>

Table 2 shows the breakdown of the sampling collection characteristics of each of the in stream
automatic stations. Triggered samples are those which the automatic sampling stations attempted
to collect in response to the programmed sampling strategy for each site. Of course not all samples
triggered to be collected were. Samples often failed to be collected when the full rack of 24 sample
bottles for each station was not offloaded before all were full. This occurred in large events when
roads were cut and conditions were too hazardous for staff to travel. Sample collection also failed
when sample bottles did not fill properly or when equipment malfunctioned. Of all the samples
collected only about a third were actually sent for analysis due to budgetary constraints.

Overall, the total number of samples analysed from each of the five stream based automatic
stations is 425 (Table 2). The best set of samples was collected for the Upper Mossman station
which had 173 samples. Low numbers of samples at some sites reflect continuous equipment
problems and field operator error which are likely to occur in all studies of this type. Nevertheless,
enough samples were analysed from the Upper Daintree site to allow loads to be estimated, and
for an efficient sampling program to be designed at all sites.

Table 2. Total number of samples, triggered, collected and analysed at each automatic station

<table>
<thead>
<tr>
<th>SITE NAME:</th>
<th>Number of samples triggered</th>
<th>Number of samples collected</th>
<th>Number of samples analysed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Daintree</td>
<td>499</td>
<td>57</td>
<td>43</td>
</tr>
<tr>
<td>Lower Daintree</td>
<td>868</td>
<td>240</td>
<td>46</td>
</tr>
<tr>
<td>Saltwater Creek</td>
<td>400</td>
<td>208</td>
<td>105</td>
</tr>
<tr>
<td>Upper Mossman</td>
<td>653</td>
<td>429</td>
<td>173</td>
</tr>
<tr>
<td>Lower Mossman</td>
<td>474</td>
<td>286</td>
<td>58</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2894</strong></td>
<td><strong>1220</strong></td>
<td><strong>425</strong></td>
</tr>
</tbody>
</table>
3. Baseflow And Event Concentrations

The automatic water quality stations were designed to collect samples only during events to keep the water pump intakes away from the stream bed where turbulent mixing can create unrepresentative samples. Although this means that baseflow conditions are not sampled, experience in many tropical catchments shows that the majority of the sediment and nutrient load moves during big events when the entire catchment is hydrologically active. The assumption in this design is that the concentrations of nutrients in baseflow is relatively stable over time so monthly grab samples during the dry season is all that is needed to represent the baseflow component of the total stream load.

EPA water quality data collected between May and November at NRM Mossman station (109001) from 1994 to 1999 were used for the baseflow conditions in the Mossman River. Event samples are taken from the Upper Mossman automatic station for the 2003/2004 wet season. The automatic station is 7 km upstream from the NRM Mossman station (109001). For the Daintree River, data collected at the QEPA historical sampling location on the Daintree (164101) between May and November from 1994 to 1999 were used for the baseflow data. Event data is from the nearby Upper Daintree automatic station for the 2003/2004 wet season. The results for total nitrogen, total phosphorus, turbidity and total suspended solids concentrations at Upper Mossman are shown in box plots in Figure 1 and at Upper Daintree in Figure 2.

Box plots graph data as a box depicting various statistical characteristics of the data. 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. Whiskers above and below the box indicate the 90th and 10th percentiles. In addition, outlying data is plotted as points. The width of the box is proportional to the number of samples (specifically √n) represented by each individual box plot.

Figure 1. Comparison of concentrations of TN, TP, turbidity and TSS for baseflow and event conditions on the Mossman River. Baseflow concentrations are from EPA water quality data from 34 sampling campaigns for the months May until November for the period 1994 to 1999. Baseflow data for TSS was only recorded on three occasions, with each value being below the detection limit (< 2mg/L) and has been recorded on the box plot as a single point at 2mg/L. Note that QEPA data recorded at a station 14.35km from the Mossman River mouth also had below detection limit values on three occasions for TSS. Event concentrations are from the Upper Mossman site for the 2003/2004 wet season.
Figure 1 and Figure 2 show for both the Upper Mossman and Upper Daintree (respectively) the difference between sample concentrations during baseflow and event conditions. The range of concentrations is much greater during events and in general the median concentrations are greater, particularly for the Upper Daintree site. These figures also clearly indicate that concentrations during baseflow are far less variable, supporting our assumption that baseflow conditions can be adequately represented by occasional grab samples.

Figure 2. Comparison of concentrations of TN, TP, turbidity and TSS for baseflow and event conditions on the Daintree River. Baseflow concentrations are from EPA water quality data from 29 sampling campaigns for the months May until November for the period 1994 to 1999. Baseflow data for TSS was only recorded on three occasions, each being below the detection limit (< 2mg/L) and has been recorded on the box plot as a single point at 2mg/L. Event concentrations are from the Upper Daintree site for the 2003/2004 wet season.

The variability in the wet season data was further explored by dividing the data into those collected during the early stages of the wet season (December 2003 to January 2004), during the mid stages of the wet season (February 2004 to March 2004) and during the late stages of the wet season (April 2004 to May 2004). The reason for dividing the data was to ascertain if there were different median and ranges of values within each of the stages of the wet season – that is, to better characterise the variability being seen in the wet season. Note, however, that the size and duration of storm flows varied between these three periods, with flows generally smaller and of shorter duration early in the wet season. Figure 3 and Figure 4 show the distribution of data when divided into the additional categories of early, mid and late wet stages of the wet season for Upper Mossman and Upper Daintree. For total nitrogen at Upper Mossman, and all the parameters for the Upper Daintree, there were decreasing median values as the wet season progressed and interestingly the variability of the values also decreased as the wet season progressed. For total phosphorus, turbidity and total suspended solids at Upper Mossman the median values generally stayed constant and the variability decreased as the wet season progressed.
Figure 3. Comparison of concentrations of TN, TP, turbidity and TSS for baseflow and event conditions on the Mossman River, with event condition further divided into early (December 2003 to January 2004), mid (February to March 2004) and later (April to May 2004) stages of the wet season. Baseflow concentrations are from EPA water quality data from 34 sampling campaigns for the months May until November for the period 1994 to 1999. Baseflow data for TSS was only recorded on three occasions, each being below the detection limit (< 2mg/L) and has been recorded on the box plot as a single point at 2mg/L. Note that QEPA data recorded at a station 14.35km from the Mossman River mouth also had below detection limit values on three occasions for TSS. Event concentrations are from the Upper Mossman site for the 2003/2004 wet season.
Figure 4. Comparison of concentrations of TN, TP, turbidity and TSS for baseflow and event conditions on the Daintree River, with event condition further divided into early (December 2003 to January 2004), mid (February to March 2004) and later (April to May 2004) stages of the wet season. Baseflow concentrations are from EPA water quality data from 29 sampling campaigns for the months May until November for the period 1994 to 1999. Baseflow data for TSS was only recorded on three occasions, each being below the detection limit (< 2mg/L) and has been recorded on the box plot as a single point at 2mg/L.

Investigation of concentrations in the lower reaches of the Daintree River also confirmed that during baseflow conditions there were considerably lower medians values and less variation for total nitrogen, total phosphorus and turbidity than those found during the 2003/2004 wet season (Figure 5). The evidence here strongly suggests that baseflow conditions can be adequately represented by monthly grab samples. A better use of resources for the automatic sampler is to focus on event based concentrations when timing of sample collection is crucial and access to the site is often unsafe.
4. Concentration And Depth/Discharge Data From Automatic River Stations

In this section, the salient features of the nutrient and sediment concentration data will be presented. For the Upper Daintree and Upper Mossman stations, which both have rating curves, concentration data will be presented against continuous discharge. The concentration data from the other sites, Saltwater Creek, Lower Daintree, and Lower Mossman will be presented against depth.

4.1 Upper Mossman

Upper Mossman site has the best dataset of discharge and sediment and nutrient concentrations. The most striking characteristic of the data collected at this station is the decline in concentration of total nitrogen, total phosphorus and total suspended sediment as the wet season progressed (Figure 6). The first few events occurred between mid-December and mid-January. Although these events were very small in comparison to events later in the season, they have the highest concentration of sediment and nutrients. It is believed that this effect is due to a process known as “first flush”. Throughout the dry season the reserves of nutrients accumulate as leaf litter accumulates and decays but this pool is not mobilised until rains arrive. Similarly, the supply of sediment that can be moved by the river builds over the dry season, as banks slump following the
previous wet season’s high flows and animals disturb the soil surrounding streams. This supply of nutrient and sediment is flushed through the system during the first elevated flows. This process is particularly pronounced as streams rise to greater heights, thereby, flushing sediments and nutrients not reached in previous events. Eventually, most of the pools of accumulated sediment and nutrient are exhausted and concentrations reduce.

![Discharge against sample concentrations of total nitrogen, total phosphorus (A) and total suspended sediment (B) at Upper Mossman.](image)

Figure 6. Discharge against sample concentrations of total nitrogen, total phosphorus (A) and total suspended sediment (B) at Upper Mossman.

The correlation amongst discharge, total nitrogen, total phosphorus and total suspended solids at Upper Mossman is depicted in Figure 7 and quantified using Spearman Rank correlations in Table 10. The strongest positive correlation is between total phosphorus and total suspended solids ($r = 0.93$), with the correlation between total nitrogen and total phosphorus being relatively high as well (0.72). It is interesting to note that the correlation between total nitrogen and total phosphorus was weakened by high total nitrogen, and corresponding low total phosphorus, concentrations early in the wet season. Total suspended solids concentrations were low early in the wet season, presumably because there was little erosion. Total phosphorus concentrations were also low presumably because phosphorus is often adsorbed to sediment particles. The likely reason for the high total nitrogen is that TDN was high early in the wet season, presumably because soluble nitrogen compounds were flushed from the catchment. The relatively weak association of discharge with the other parameters potentially reflects the change in sources, and exhaustion of pools of nutrients and sediments as the wet season progressed.
Figure 7 Bivariate plots depicting correlation of discharge, total nitrogen, total phosphorus and total suspended solids at Upper Mossman during the 2003/2004 wet season.

Table 3 Spearman rank correlations quantifying the correlation of discharge, total nitrogen, total phosphorus and total suspended solids at Upper Mossman during the 2003/2004 wet season.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total Phosphorus</th>
<th>Total Suspended Solids</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Nitrogen</td>
<td>0.72</td>
<td>0.62</td>
<td>-0.22</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>0.93</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td></td>
<td></td>
<td>0.45</td>
</tr>
</tbody>
</table>

Although the concentration of nutrients and sediments may peak 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. Although concentrations may be low, the volume of water moving down the stream is very high resulting in a considerable total load. Loads are discussed fully in Appendix G and Appendix J. However, it is worth briefly looking at some results here to illustrate the point. Figure 8 shows the 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. From this figure we can see that during January a disproportionately large amount of load was moved for the amount of discharge that occurred during this month. Average concentration of suspended sediment was 0.09 tonnes/ML. During March discharge was eight times higher than January and 48% of the total
suspended sediment load was moved but average concentration was much lower at 0.03 tonnes/ML.

These results highlight the importance of defining the question when undertaking a monitoring program to assess stream water quality. If in-stream water quality is being measured for looking at impacts on stream biota then concentrations are of interest and, therefore, the early part of the season is most important for monitoring, but if offshore effects are of interest (e.g. impacts on offshore reefs) then total loads are important.

![Figure 8. 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.](image)

4.2 **Lower Mossman**

At the Lower Mossman automatic station the collected data are much sparser mainly due to the combination of insufficient funds to analyse samples and equipment failure. Lower Mossman site is subjected to tidal influences which complicate the triggering of sample collection based on river depth. Separating in-stream events from tidal influences is difficult. Despite this, distinct events can be seen clearly in Figure 9. Maximum suspended sediment concentrations and total phosphorus concentrations at this station are higher than at the Upper Mossman station.
Figure 9. River depth against sample concentrations of total nitrogen, total phosphorus (A) and total suspended sediment (B) at Lower Mossman.

4.3 Upper Daintree

The concentration of total nitrogen, total phosphorus and total suspended sediment for samples from the Upper Daintree site are shown in Figure 10. As with Upper Mossman the interesting characteristic of the samples from Upper Daintree is the high concentrations early in the wet season, particularly for the first events. Peak sediment concentrations are much higher for this catchment, which is not too surprising considering the size of the upstream contributing area (908 km²) and the fact that a large proportion of the upper catchment is sparse eucalypt woodland unlike the upper part of the other catchments which is dense tropical rainforest. Discharges at Upper Daintree were amongst the highest on record during March 2004 when compared to discharges for NRM Bairds station which is 1 km upstream. Unfortunately these high flows toppled the in-stream sampling pylon which was anchored with 9 tonnes of concrete. This meant that no samples were collected for this large event.
Figure 10. Discharge against sample concentrations of total nitrogen, total phosphorus (A) and total suspended sediment (B) at Upper Daintree.

4.4 Lower Daintree

Unfortunately, the depth and sample data at Lower Daintree are very sparse (Figure 11). The large gap in depth data during March was caused by an incorrect setting of a gas valve which controls depth measurement. As a result depth readings were false and samples were not triggered properly. This meant that a large proportion of the wet season was not monitored at this site. Some of the samples collected during this March period were analysed to look at concentrations of sediments and nutrients and, as with other sites, these samples show a decline in concentration as the wet season progressed.
Figure 11. River depth against sample concentrations of total nitrogen, total phosphorus (A) and total suspended sediment (B) at Lower Daintree.

### 4.5 Lower Saltwater Creek

Figure 12 shows the stream depth, and concentrations of suspended sediment and total nitrogen and phosphorus for the Saltwater Creek automatic station. A good selection of water quality data has been collected for this stream covering most of the major events that occurred. This site is influenced by tidal fluctuations but during large events the tidal influence is largely dissipated by the large body of water pushing seawards. The concentration data again clearly shows the reduction in sample concentrations as the wet season progresses.
5. Upper vs Lower Stations

Due to a number of factors including, equipment malfunction, operator error, and sample problems, there are few data to compare sediment and nutrient concentrations from upper and lower stations on the one stream. On the Daintree River, there are no overlapping sample periods, so comparison of these two stations is not possible. For the Mossman River system the upper and lower stations have 2 days of sample overlap for the 4th and 5th of February 2004 only. This study period was selected because a number of samples were collected at both the upper and lower sites during this event; 11 samples for the upper site and only 8 samples for the lower. Consequently, Upper Mossman data only will be discussed in this section and interpretations of the findings reported here should consider the limited nature of these data.

Figure 13A shows the average phosphorus concentration and standard error of the mean from Upper and Lower Mossman. TP is total phosphorus, TDP is total dissolved phosphorus, and FRP is filterable reactive phosphorus. Only TDP and FRP both show an increase in mean concentration from the upper to the lower station (p<0.001). However, mean TP does not increase by the same amount as TDP. One possible explanation is that some particulate phosphorus has settled between sites, but the resulting decrease in TP has been offset by inflows of TDP and FRP. The most likely source of such TDP and FRP is the agricultural region on the coastal flood plain. The mean TSS concentration has increased between sites. This rules out net deposition although it is conceivable some deposition occurs which is offset by inflows (e.g., from the South Mossman River) that have a different chemical composition from the upper site.

Total suspended sediment (TSS) concentrations at the lower station are roughly double those at the upper station (p<0.05; Figure 13C). This indicates that there is a significant source of sediment from the agricultural lands of the coastal floodplains and the other sub-catchments (e.g., South Mossman River) that feed into the Mossman River below the Upper Mossman Station.
Figure 13B shows the nitrogen concentration data from Upper and Lower Mossman. This figure shows the average concentration of the various forms of nitrogen over the two day period and the standard error of the mean. TN is total nitrogen, TDN is total dissolved nitrogen, NO\textsubscript{x} is nitrate plus nitrite and NH\textsubscript{3} is ammonium. This figure shows that there might be a slight reduction, but more likely there is no change, in TN concentration between the upper and lower Mossman sites (p>0.2) whereas there is a significant increase in TDN, NH\textsubscript{3} and NO\textsubscript{x} concentration (p<0.01). As discussed previously, the mean TSS concentration has increased which rules out net deposition between sites. Several unmonitored tributaries enter between sampling sites. The observed concentration changes are consistent with these inflows having slightly lower TN, but higher TDN and NH\textsubscript{3} concentrations than the upper site. In addition there may be transformations (e.g., particulate settling or scour, soluble to particulate nitrogen and vice versa) between sites. The overall effect is that the proportion of total nitrogen present as dissolved nitrogen has almost doubled between the upper and lower stations.

Overall the observed increases in soluble phosphorus and nitrogen are consistent with inputs of these forms of nutrient from agricultural activities between the two sampling sites. While the concentrations of total nitrogen and phosphorus do not change between sites during the event studied, the increase in the proportion that is soluble has important implications for the availability of these nutrients to plants in the lower river, estuary and GBR region.

![Figure 13](image-url)
6. Continuous Turbidity As A Surrogate For Water Quality Samples

In water quality studies researchers are sometimes able to fill gaps in concentration data sets by using previously established modelled relationships between concentration and flow parameters (e.g. Letcher et al., 1999). In other studies the timing of dominant flux pathways during events produces characteristic cyclical shapes in relationships between discharge and concentration (Degens and Donohue, 2002). The cyclic variation is usually caused by changes in the dominant source (i.e. groundwater v surface water) of nutrients and sediments during an event. This cyclic variation in concentration and discharge, known as hysteresis, occurs in Douglas Shire streams and is clearly illustrated for Upper Mossman in Figure 14. The shape and direction of the flow pathways of this hysteresis are often indicative of the flow pathways during individual storm events (i.e. changes from groundwater source to surface water) (Evans and Davis, 1998, Johnson and East, 1982). These cyclic relationships between concentration and flow vary from storm to storm and also across seasons, therefore, to fill gaps in water quality data in the Douglas Shire, an alternative means is needed.

![Graph](image)

Figure 14. Temporal variation in discharge and turbidity (A) and corresponding hysteresis in turbidity measurements during an event (B) at Upper Mossman. The red arrow represents the start of the event and subsequent arrows indicate the direction of hysteresis over time.

A number of studies have shown that the concentration of various water quality parameters is closely related to the turbidity of the water (e.g. Letcher et al., 1999). Electronic sensors are available that enable turbidity to be monitored continuously, therefore, the opportunity exists to develop relationships between 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. This technique has the benefit of greatly reducing the cost of sample analysis while also providing a much clearer temporal picture of sediment and nutrient fluctuations. Each of the in-stream automatic water quality station in the Douglas Shire was fitted with a turbidity sensor for this purpose. The turbidity sensors used were fitted with automatic wipers to keep the optical surfaces clean, however, periodic servicing is required in order to prevent the accumulation of bio-film on the sensor which affects readings.
Unfortunately the turbidity sensors for the Lower Mossman and Lower Daintree sites 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.

6.1 Upper Mossman

The Upper Mossman site provides the best data for comparing nutrient and sediment concentrations to continuously measured turbidity. Three statistical modelling methods were used to establish the most suitable relationship between sensor turbidity and the various sediment and nutrient parameters (total nitrogen, total phosphorus and total suspended solids). Out of interest the relationship between sensor and laboratory turbidity was also determined. With power curves (non-linear modelling) being commonly employed in the hydrological literature, the results of these model fits have been presented here.

Note: The $r^2$ value provides an indication of the model fit to the observed data. $r^2$ values range between 0 and 100%; when there is no relationship the value is near zero; for a strong relationship the magnitude of the value is closer to 100%. An $r^2$ value of say 85% can be interpreted as 85% of the variation being explained by the power curve relationship between the water quality parameter and turbidity.

Figure 15 provides the relationship between total nitrogen and turbidity ($r^2<15\%$), with the relationship being particularly poor for low turbidity and high total nitrogen values. The wet season is divided into the early, middle and late and can be identified by separate plotting characters.

The relationship between turbidity and both total phosphorus and total suspended sediment is much stronger regardless of time during the wet season and shows the potential for using continuously monitored turbidity as a surrogate for water samples ($r^2 = 88\%$; Figure 15). The concentrations of phosphorus and suspended sediment concentrations are often similar in water quality samples because the phosphorus is often bound to the suspended sediment particles. Unfortunately the Upper Mossman continuous turbidity sensor experienced a period where field servicing was neglected therefore a large section of data had to be removed from the analysis preventing the prediction of continuous nitrogen, phosphorus and suspended sediment concentrations throughout the entire study period.
Figure 15 Power curve (or non linear) relationships between sensor turbidity, total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS) at Upper Mossman. Based on auto-station collected water samples during 18/12/2003 to 7/5/2004. For completeness a plot of sensor turbidity versus laboratory turbidity has been given here with a simple linear model fitted (being the most appropriate model to fit).

6.2 Upper Daintree

The relationship between continuous turbidity and suspended sediment, nitrogen and phosphorus was much less obvious at Upper Daintree (Figure 16). Damage to the turbidity sensor during the large event in March 2004 meant that available data for comparison was very sparse. Some resemblance of a relationship can be seen for total phosphorus and total suspended sediment but without further data this cannot be verified. As the turbidity sensor at this site was mounted mid-stream it could not be accessed for repair or replacement during the high flows experienced. It is also worth mentioning that this would also have meant that the sensor could not have been serviced to remove bio-film and as a result results would be expected to drift over time.
6.3 Saltwater Creek

The dataset comparing continuously measured turbidity against total nitrogen, phosphorus and suspended sediment at Saltwater Creek was reasonably extensive (Figure 17). Saltwater Creek was the only station with a continuous record of turbidity for the whole study period. Unfortunately the usefulness of this data in predicting continuous nutrients and sediment concentration is limited because this tidal stream reach is yet to be rated so that discharge can be determined. The relationship between turbidity and total nitrogen is weak, and while the relationship with total phosphorus and total suspended sediment appears stronger, further samples are required to ascertain whether it is real. A couple of data points in this figure show very high turbidity levels but low concentrations, it is likely that these points are outliers and may in fact be attributed to the blocking of the optical sensor by debris. As with the other sites, the Saltwater Creek station could benefit from more water quality samples by which to improve the relationship with continuous turbidity.

Figure 16. Relationship between Continuous turbidity, total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS) at Upper Daintree.
Figure 17. Relationship between Continuous turbidity, total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS) at Saltwater Creek.

7. Overview
There is a general tendency for sediment and nutrient concentrations during peak flow events to fall and to become less variable as the wet season progresses. Presumably nutrients and sediments that have accumulated during the dry season are being progressively washed out of the catchment.

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.

The concentration data from the two Mossman stations indicate that there is a significant source of phosphorus between the two stations which is likely to come from the agricultural region on the coastal flood plain. They also suggest that there are two processes in action affecting the nitrogen concentrations. The total nitrogen load gets diluted between the two stations, and there is a change in the source of nitrogen as one moves down the river from organic to readily dissolved forms. The data also indicate a significant source of sediment from the agricultural lands of the coastal floodplains and tributary streams.
Comparing the relationship between turbidity and sediment and nutrient concentrations for these three sites has highlighted the need for a both a good set of water quality samples and a good record of accurate continuous turbidity measurements. It could be seen from this analysis that the relationships between continuous turbidity and sediment and nutrient concentrations is likely to vary from site to site. 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 purpose.

This comparison has highlighted the need for a regular field maintenance regime in order to keep sensors in optimal condition. It has also highlighted the need to be able to access the turbidity sensor throughout the year. The Upper Daintree sensor, for example, once immersed, could not be retrieved for servicing, meaning that readings would begin to gradually drift. Further data and more regular maintenance of equipment is necessary before continuous turbidity can be used as a surrogate for water quality samples. 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.

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1. Background
The development of a strategy for monitoring sediment and nutrient concentrations in the rivers and streams of Douglas Shire requires consideration of the representativeness of the samples taken by the automatic sampling stations. Characterising the representativeness of the automatic sampling stations in relation to both within site spatial variation and within event temporal variation is an integral part of designing the sampling program.

With the automatic samplers being the main means of monitoring data during events, it is critical to understand how representative these samplers are of stream cross section concentration during event conditions. The following section outlines a sampling study designed to specifically investigate the representativeness of samples taken by automatic samplers during event conditions. This type of focused sampling study is imperative for developing a robust and scientifically defensible monitoring program for Douglas Shire that is relevant for the hydrological features of its catchments.

The final representativeness sampling design (see end of this Appendix) was provided to water quality monitoring staff at Douglas Shire Council for implementation during the 2003/2004 wet season. Unfortunately, the full recommended sampling design could not be undertaken in 2003/2004 due to logistical and budgetary problems and time constraints.

2. Design
The design and implementation of the interim monitoring strategy for intensive collection of water samples is currently focused on 1) gathering baseline sediment and nutrient load data, 2) determining spatial and temporal variability in sediment and nutrient concentrations, 3) determining the representativeness of samples taken by automatic samplers during event conditions, and 4) understanding the likely sources and magnitudes of error in estimation of loads.

This document outlines a sampling study to specifically investigate the representativeness of samples taken by automatic samplers during event conditions (point 3 above). This type of focused sampling study is imperative for developing a robust and scientifically defensible monitoring program for Douglas Shire that is relevant for the hydrological features of its catchments.

The process that has been undertaken to develop this study on representativeness has involved various iterations and adaptations of a sampling design initially focusing on the statistical requirements for a robust design. Subsequent iterations focused on both the logistics and costs associated with the sampling design and the final sampling design presented here is the result of these various deliberations.

3. Defining Representativeness
Three main aspects of representativeness considered in this study included:

Grab Sampling Study
- How representative were sediment and nutrient concentrations in relation to the cross-sectional profile of the creek river during an event?

Study Comparing Grab Sampling and Automatic Sampling
- How representative were event sediment and nutrient concentrations for samples taken by the automatic samplers compared to grab samples?

To address these three aspects of representativeness the sources of variation contributing towards each of these has been considered and used as design factors in the sampling study.
It is beyond the scope of this pilot study to address representativeness through investigating the sampling variability associated with laboratory analysis, sample handling and transport. This would involve a level of replication that would require a considerable budget for processing samples.

Consequently, this initial study focused on the field sampling components of:
- large scale spatial variation (sites at Saltwater Creek and Lower Daintree)
- within site spatial variation which may be caused by stratification (i.e. variation in two dimensions - across a river/stream channel and down the depth profile at a sampling site)
- variation during an event (i.e. over the rising, peak and falling stages of the hydrograph)

By understanding the magnitude of variation associated with each of these spatial and temporal scales during event conditions, we will subsequently be able to make more definitive statements about the representativeness of samples taken by automatic samplers during event conditions.

4. Methods

4.1 Overview

A multi-factored sampling design that encompasses all the identified field components of variation is outlined below. Multi-factored sampling designs enable optimisation of resources, and the amount of information obtained. Consequently, the ability of the design to detect a certain level of precision for assessing representativeness of water samples taken by automatic monitoring stations during event conditions is made possible.

The sampling proposed for Douglas Shire required that cross sectional samples be collected by grab sampling across the stream in combination with simultaneous triggering of the automatic stations. Unfortunately, triggering of the automatic monitoring stations and simultaneous collection of samples near intake points were rarely achieved.

4.2 Sampling Design

4.2.1. Large Scale Spatial Variation (ie Sites)

Two sites have been chosen for conducting the sampling project – Saltwater Creek and Daintree River at the ferry crossing. These two sites were chosen with the aim to represent different environmental conditions, with a particular focus on position in catchment – a smaller creek system versus a larger estuarine system. Note that the sampling study on the Daintree River was not carried out at the position of the automatic monitoring station. For convenience during events, sampling was undertaken from the ferry as it crossed the Daintree River.

4.2.2. Within Site Two–Dimensional Spatial Variation

The main focus of this initial sampling study was to understand the spatial variability inherent during event conditions. It is often assumed that during an event stratification of the water body does not occur and that the water is well mixed, representing a homogenous system. Consequently, this would suggest that sediment and nutrient concentrations within a site at a particular time point during an event would be very similar and, hence, a single sample point would be sufficient.

Horizontal Spatial Dimension

The focus on the horizontal dimension for within site spatial variation is to enable information about the representativeness of a river edge sample in relation to the rest of the river reach to be obtained. Stratification across a water body is well known hydrological phenomena in base flow conditions.
Logistically, the automatic samplers can only sample from a single designated point in the waterway, with that point limited by the profile of the sampling site. Consequently, the automatic samplers generally require the sampling point to be relatively close to the waterway’s edge.

A transect across the waterway at regular intervals, with five separate grab samples along the transect, should be taken. In general, there should be a grab sample taken close to each bank of the water course (relatively close to the automatic station’s sampling point on the relevant edge the station is located at), a grab sample in the middle of the water course and samples taken either side of the mid point. The edge sample closest to the sample intake for the automatic station would be used as the point of reference for subsequent statistical analysis.

**Vertical Spatial Dimension**

Stratification of the water body with depth is another source of variation to be considered in the sampling design. As mentioned for the horizontal spatial dimension, the point the automatic sampler takes a water sample is dictated by the profile of the sampling site.

At least two different sampling depths (surface and subsurface) should be taken at each of the five sampling points along the transect, excepting points close to either bank where only one depth may be appropriate.

**For Further Consideration Post This Initial Sampling Study**

Ideally, investigation of small scale spatial variation would involve obtaining grab samples from a fine resolution grid using a two-dimensional cross section across the water course. The number of samples to be taken from both the horizontal and spatial dimensions, as listed above, provides a compromise to this fine resolution grid. Fewer samples are taken than the statistical ideal, but we believe the numbers of samples suggested is an adequate trade-off between having too fine a resolution, having enough samples and subsequently obtaining adequate samples to represent the variability in the water course.

**4.2.3. Variation During An Event**

To characterise the variation in sediment and nutrient concentrations during an event is it necessary to sample at various points during the event (i.e. rising, peak and falling stages). However, it is difficult to appropriately identify these stages during an event when taking grab samples. The best that can be achieved is taking grab samples at three time points ascertained by the sampling staff as those that would adequately correspond to the rising, peak and falling phases of the hydrograph.

For Saltwater Creek one event was sampled on two different days; 15\(^{th}\) March, designated by the sampling team as peak stage (4.15m), and 16\(^{th}\) March, designated as falling stage (2.3m). The record of the nearby automatic monitoring station was also used to verify their designation.

For Daintree River (at ferry crossing) three events were sampled across four different days. The first event was sampled on 4-5\(^{th}\) February, the second on 11\(^{th}\) February and the third on 3\(^{rd}\) March. All transect samples were taken in the north to south direction during the ferry’s normal traverse of the river, apart from those taken on 11\(^{th}\) February which were taken in the south to north direction. The automatic monitoring station was not working during this time period due to the bubbler value not being turned on, so no information was available about the event stage (rising, peak or falling). An approximate indication of the event stage was not recorded by the sampling team.
4.2.4. Sampling Methods

Sampling methods for this project will mainly involve grab sampling and will require consultation with relevant staff from Qld EPA and Qld NRME to adopt appropriate sampling methodology to ensure data with a high standard of QA/QC is collected to consider the issues surrounding representativeness. Note that the documentation of the sampling methods used in this sampling study will be an important component of the monitoring strategy delivered to Environment Australia. We also require this documentation to be provided to CSIRO for their information and potential comment.

It is also imperative that samples are also collected by the automatic samplers at the approximately the same time points the grab samples are taken during an event. This will allow the representativeness of the automatic samplers to be established. Apart from the 8 grab samples taken at any one time during an event at a site, and additional grab sample taken at precisely the same time point the automatic sample is triggered is needed. Thus at any one sampling time point there should be:

- 8 grab samples (with one sample assigned as being representative of the position the automatic station samples from)
- 2 distinct automatic samples (2 separate water bottle samples – true replicates and no composite samples)
- 2 replicate grab samples at precisely the same time the automatic sample is taken

4.3 Statistical Analysis Of The Collated Data

The collated data for each of the water quality variates should be statistically analysed address the three questions posed in section 2. outlined below are some suggested forms of statistical analysis for these data. These may require modifications after the data has been received and reviewed for statistical analysis.

- How representative are sediment and nutrient concentrations in relation to the cross-sectional profile of the creek river during an event?
- How representative are sediment and nutrient concentrations when the value is characterised by a single sample rather than an aggregate from replicate samples during an event?
- How representative are event sediment and nutrient concentrations for samples taken by the automatic samplers compared to grab samples?

If the statistical analyses for the above two questions find that the water body is relatively well mixed, the 8 grab samples + the 2 replicate grab samples specifically taken near the sampling intake at each site for each time point will be able to be compared to the 2 replicate automatic sample taken.

The comparison of automatic samplers and grab sampling will be considered by using a two-factor repeated measures analysis of variance model, including site and sampling method as factors and considering the time points over the hydrograph as the repeated measures.

If the analyses find that the water body is not well mixed, there will be two replicate samples each for the automatic sampler and the grab samples. These will be compared by using an appropriate analysis of variance model.
Importantly, graphical diagnostics to support the findings should also be used. Tables of means and coefficients of variation (%) for each of the water quality variates should also be provided as a summary of the sampling project results.

5. Recommendations For Implementation Of Sampling Project
In summary the following design points need to be considered to implement this sampling project:

Grab Sampling Study
- Large scale spatial variability: 2 sites (Saltwater Creek and Lower Daintree)
- Within site variability: 5 points along a horizontal transect (left bank/mid left/middle/ mid right/right bank) and 2 depths (surface vs subsurface) excepting those at the banks where one depth sample is taken. This constitutes 8 sampling points in the site's 2D space. 5 at the surface and 3 subsurface.
- Variation during an event: 3 time points during an event (preferably as close as possible to the rising, peak and falling stages of the event)

Study Comparing Grab Sampling and Automatic Sampling
- Large scale spatial variability: 2 sites (Saltwater Creek and Lower Daintree)
- Variation during an event: 3 time points during an event (preferably as close as possible to the rising, peak and falling stages of the event)
- Sampling method: 2 methods – grab sampling versus automatic sampling
- Replication: 2 replicates for both the automatic sampler and the grab sample taken at precisely the same time the automatic sample is taken

In total, there will be 72 samples with:

- the study comparing grab sampling and automatic sampling having 24 samples (2 sites * 3 sampling points during the event (rising/peak/falling) * sampling method (auto/grab) * 2 replicates), and
- the grab sampling study having 48 samples (2 sites * 8 spatial sampling points * 3 sampling points during the event [rising/peak/falling])

6. Samples Collected
Of the 72 samples recommended in the representativeness study design, only 25 were collected in total. Specifically, samples were collected as follows:

Saltwater Creek
The total number of samples taken for the representativeness study conducted at Saltwater Creek was 12:
- a single event
- 2 stages of the hydrograph sampled (peak & falling)
- 5 positions across the waterway
- 1 triggered auto station sample during falling event stage
- 2 auto station samples matched to peak stage of event
- 1 sample taken near the automatic monitoring station intake during falling event stage
Daintree River (ferry crossing)
The total number of samples taken for the representativeness study at Daintree River (ferry crossing) was 13:
- 5 sampling occasions representing three events (unknown stages of the hydrograph sampled)
- 3 positions across the waterway (with only 1 position for one sampling occasion)
- 2 auto station samples matched to sampling period
- no samples taken near the automatic monitoring station intake

While this very small set of data will not adequately address all the questions posed by the original study, or provide the ability to make definitive statements about the representativeness of the automatic monitoring stations, a basic analysis of the features of the data has been provided. Rather than detail all aspects of data analysis in the main body of the report, a synthesis of the results for each site is provided below.

7. Results

7.1 Saltwater Creek

7.1.1 Turbidity

Figure 1A depicts the single event sampled at Saltwater Creek with the two sampling occasions representing peak and falling event stages. The most obvious feature in the plots is large differences in the median and range of turbidity values (both laboratory (Figure 1A) and electronically measured (Figure 1B)) during the peak and falling stages of the event. Unfortunately, the laboratory turbidity values during the peak stage of the event are difficult to interpret for the decrease across the transect can either be attributable to spatial differences – which would indicate that there is a lack of homogeneity in turbidity across the creek during this event – or it could be attributable to time differences as there is an approximate 20-25 minute lag between samples being taken across the transect. If it is attributable to time differences – which is more likely – this decrease is depicting gradual fall off in turbidity during an event (Figure 1A).

Interestingly the laboratory turbidity measurements across the transect during the falling stage of the event do not change significantly and are very close to the ambient guideline value for laboratory turbidity (Figure 1A). In contrast to the event samples taken during 2003/2004 by the automatic monitoring station, the event sampled here for the representativeness study represents one of the larger events ((Figure 1C; peaking around 150 NTU).

The automatic monitoring station sample during the falling event stage was actually triggered to be taken at the time of the representativeness sampling and it is slightly higher than the range of the turbidity values taken across the transect suggesting that the automatic monitoring station sample was essentially representativeness of conditions in the waterway at that time and spatial extent (Figure 1A). It is difficult to provide any definitive statement for the automatic monitoring station samples taken during the peak event stage as these were not triggered but were matched to samples taken close to the time the representativeness samples were collected.

The turbidity value for the grab sample taken close to the intake of the automatic monitoring station (during the falling event stage) was within the range of values for the entire transect and the automatic monitoring station, providing further evidence of the representativeness of the automatic monitoring station at that time and across the spatial extent of the creek.
Figure 1 Turbidity (both laboratory and electronically measured) values for representativeness study undertaken at Saltwater Creek during 2003/2004 wet season. A) Depiction of a single event at two event stages (peak and falling) including the ambient water quality guideline value, and automatic monitoring station samples collected at approximately the same time during the event. B) Boxplots representing distribution of values for peak and falling stages of the event. C) Boxplot representing distribution of values for the entire 2003/2004 wet season.
7.1.2. **Total Suspended Solids, Total Nitrogen And Total Phosphorus**

Similar results to those found for turbidity were found for total suspended solids (Figure 2), total nitrogen (Figure 3) and total phosphorus (Figure 4). The peak event stage results are confounding spatial extent of the transect with time since sampling began. As a result it is difficult to provide a definitive statement explaining the decrease in values across the transect (or with sampling time lapsed). The automatic monitoring station samples for both the peak and falling event stages are showing that they indicative of conditions at the site during the event. The intake grab sample is also within the range of the values sampled during the falling event stage and similar to that taken by the automatic monitoring station (Graph A, Figure 2, Figure 3 and Figure 4). The total suspended solid values during the peak of this event were at the higher extreme of values found for the entire 2003/2004 wet season (Graph B, Figure 2, Figure 3 and Figure 4).

![Graph A](image1.png)  ![Graph B](image2.png)

Figure 2 Total suspended solids values for representativeness study undertaken at Saltwater Creek during 2003/2004 wet season. A) Depiction of a single event at two event stages (peak and falling) including automatic monitoring station samples collected at approximately the same time during the event. B) Boxplot representing distribution of values for the entire 2003/2004 wet season.
Figure 3 Total nitrogen values for representativeness study undertaken at Saltwater Creek during 2003/2004 wet season. A) Depiction of a single event at two event stages (peak and falling) including automatic monitoring station samples collected at approximately the same time during the event. B) Boxplot representing distribution of values for peak and falling stages of the event and for the entire 2003/2004 wet season.

Figure 4 Total phosphorus values for representativeness study undertaken at Saltwater Creek during 2003/2004 wet season. A) Depiction of a single event at two event stages (peak and falling) including automatic monitoring station samples collected at approximately the same time during the event. B) Boxplot representing distribution of values for peak and falling stages of the event and for the entire 2003/2004 wet season.
7.2 Mid Daintree (At Ferry)

At mid Daintree, the event stage for each of the five sampling occasions is not known, i.e. whether the sampling was approximately taken in a rising, peak or falling stage of the hydrograph. As a result only very general comments about the spatial variation in each of the water quality parameters can be made for each sampling occasion. Comments about within or across event variation are not possible.

The automatic monitoring station samples used as a point of comparison for the mid Daintree samples is approximately 200m upstream of the ferry. To investigate representativeness of the mid Daintree automatic monitoring station, ideally samples would need to be taken much closer to the automatic monitoring station.

7.2.1. Turbidity

Figure 5A depicts turbidity on five separate sampling occasions at the Daintree River (ferry crossing), representing three separate rainfall events. For each sampling occasion there is very little variation in the turbidity across the river suggesting that during an event there is evidence of homogeneity in turbidity across the creek. It appears that turbidity values progressively increase as time progresses through the sampling occasions for the 1st event.

There is considerable difference between the automatic monitoring station turbidity values and the grab samples values during the 1st and 2nd events (there was no comparable automatic monitoring station turbidity readings to relate to the 3rd event) (Figure 5A). It is difficult to provide any definitive statement about this difference in turbidity as the higher automatic monitoring station values may be a result of the automatic monitoring station being upstream of the ferry crossing or that the auto-samples were not specifically triggered during the same period the ferry sampling occurred. Consequently, the representativeness of the automatic monitoring station can not be commented upon.

Figure 5B highlights that samples from the 3rd event were higher than those from the other 2 events, with values for the 3rd event getting towards the higher end of the turbidity values for the entire 2003/2004 wet season.

![Figure 5A: Laboratory Measured Turbidity in Collected Samples](image1)
![Figure 5B: Laboratory Turbidity From All Wet Season Samples](image2)

Figure 5 Turbidity (laboratory) values for representativeness study undertaken at Daintree River (ferry crossing) during 2003/2004 wet season. A) Depiction of three events including automatic monitoring station samples collected at approximately the same time during the events. B) Boxplot representing distribution of values for each event and for the entire 2003/2004 wet season.
7.2.2. Total Suspended Solids, Total Nitrogen, And Total Phosphorus

Figure 6, Figure 7 and Figure 8 depict very little variation in total suspended solids, total nitrogen and total phosphorus across the river during the 1st sampling occasion of event 1 and for events 2 and 3. However, there is considerable difference in the total suspended solids values for the 2nd sample collection in the 1st event. There is also considerable difference in the total nitrogen values for the 3rd sample collection during the first event. Total phosphorus exhibits considerable differences for the 2nd and 3rd sample collections for the 1st event. The reasons for these differences may be attributable to sampling methods employed during this sampling occasion or may show evidence of a lack of homogeneity in turbidity across the creek during this specific sampling occasion. It appears that total suspended solid, total nitrogen and total phosphorus values progressively increase as time progresses through the sampling occasions for the 1st event.

There is considerable difference between the automatic monitoring station derived total suspended solid values and the grab samples values during the 2nd event (there was no comparable automatic monitoring station turbidity readings to relate to the 3rd event) (Figure 6A). It is difficult to provide any definitive statement about these apparent differences and similarities in total suspended solids, total nitrogen and total phosphorus as the automatic monitoring station values may be a result of the automatic monitoring station being upstream of the ferry crossing or that the auto-samples were not specifically triggered during the same period the ferry sampling occurred. Consequently, the representativeness of the automatic monitoring station can not be commented upon.

<table>
<thead>
<tr>
<th>Sample Position</th>
<th>Event 1</th>
<th>Event 2</th>
<th>Event 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>0</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Centre</td>
<td>13:35</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>South</td>
<td>15:50</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

Figure 6 Total suspended solids values for representativeness study undertaken at Daintree River (ferry crossing) during 2003/2004 wet season. A) Depiction of three events including automatic monitoring station samples collected at approximately the same time during the events. B) Boxplot representing distribution of values for each event and for the entire 2003/2004 wet season.
Figure 7 Total nitrogen values for representativeness study undertaken at Daintree River (ferry crossing) during 2003/2004 wet season. A) Depiction of three events including automatic monitoring station samples collected at approximately the same time during the events. B) Boxplot representing distribution of values for each event and for the entire 2003/2004 wet season.

Figure 8 Total phosphorus values for representativeness study undertaken at Daintree River (ferry crossing) during 2003/2004 wet season. A) Depiction of three events including automatic monitoring station samples collected at approximately the same time during the events. B) Boxplot representing distribution of values for each event and for the entire 2003/2004 wet season.
8. Synthesis Of Findings

How Representative Were Sediment And Nutrient Concentrations In Relation To The Cross-Sectional Profile Of The Creek River During An Event?

With the cross-sectional transect taken at Saltwater Creek having 20-25 minute intervals between each sampling point, it is not possible to ascertain if the gradual decline in water quality parameters during the peak event stage can be attributed to spatial differences across the cross-section or time differences. 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.

For the cross-sectional transects taken at Daintree River (ferry) the main limiting factor for interpreting the results is having no information about the event stage when sampling was occurring (i.e. was it during a rising, peak or falling stage of the hydrograph). Nonetheless, the data shows evidence of homogeneity for turbidity across the river during each of the five sampling occasions. For the other parameters (total suspended solids, total nitrogen and total phosphorus) there is conflicting evidence suggesting at some stages homogeneity and other heterogeneity in measurements taken across the river. Without replicate measurements at each spatial position sampled, it is not possible to determine if heterogeneity is truly present or if the variability across the transect is due to sampling error measurements. The results outlined above have been summarised in Table 1.

How representative were event sediment and nutrient concentrations for samples taken by the automatic samplers compared to grab samples?

Very little data were collected for considering this question. While sample replication is required to consider this question in full, the results for the falling event stage at Saltwater Creek can be used to make comment about the context of representativeness being considered here as there was specific triggering undertaken to initiate an automatic sample when grab samples where taken. This was not the case for the peak event stage at Saltwater Creek or at all for the Daintree River (at ferry).

During the falling events stage at Saltwater Creek there was evidence suggesting similarity between automatically collected, grab and intake samples for each of the four water quality parameters considered. While there was also this same kind of evidence during the peak event stage for total suspended solids and total phosphorus at Saltwater Creek, the lack of support for turbidity and total nitrogen may be attributable to real differences or may be due to having had to match samples to the automatic record rather than having samples specifically triggered.

Likewise, the lack of evidence of similarity suggested by sampling undertaken at the Daintree River (ferry) may be a reflection of true differences, or may be due to the fact that grab sample timing had to be matched to the automatic record or because the automatic station was approximately 200m upstream of the ferry. Interestingly, evidence of similarity was found for total phosphorus at each Daintree River sampling occasion (except for event 3 where there was no relevant automatic station samples for matching). The results outlined above have been summarised in Table 2.
Table 1. Summary of results for cross-sectional event sampling taken at Saltwater Creek and Daintree River (at ferry) to ascertain the degree of homogeneity across the waterway. Two stages within a single event were sampled at Saltwater Creek (peak and falling) and five sampling occasions for three events sampled at Daintree River. ? – refers to insufficient evidence to comment on degree of homogeneity across the waterway; ✓ – refers to evidence suggesting homogeneity across the waterway; na - insufficient data (only one sample) to comment on degree of homogeneity across the waterway.

<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>Saltwater Creek</th>
<th>Daintree River (at ferry)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak</td>
<td>Falling</td>
</tr>
<tr>
<td>Turbidity</td>
<td>?</td>
<td>✓</td>
</tr>
<tr>
<td>TSS</td>
<td>?</td>
<td>✓</td>
</tr>
<tr>
<td>TN</td>
<td>?</td>
<td>✓</td>
</tr>
<tr>
<td>TP</td>
<td>?</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 2. Summary of results for comparing grab event samples to automatically collected event samples and samples taken next to auto-station intake at Saltwater Creek and Daintree River (at ferry) to ascertain the degree of similarity in the water quality parameters measured. Two stages within a single event were sampled at Saltwater Creek (peak and falling) and five sampling occasions for three events sampled at Daintree River. ? – refers to insufficient evidence to suggest similarity between automatically collected and grab samples; ✓ – refers to evidence suggesting similarity between automatically collected and grab samples; ☑ – refers to evidence suggesting similarity between automatically collected, grab and intake samples; na - insufficient data to comment on similarity between automatically collected and grab samples.

<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>Saltwater Creek</th>
<th>Daintree River (at ferry)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak2</td>
<td>Falling1</td>
</tr>
<tr>
<td>TP</td>
<td>✓</td>
<td>☑</td>
</tr>
</tbody>
</table>

1triggered sample taken by automatic monitoring station and near intake sample collected during grab sampling.
2lack of triggered sample taken by automatic monitoring station and lack of near intake sampled collected during grab sampling. From continuous automatic monitoring record samples matched to those taken nearest in time to grab sampling.

9. Recommendation

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.
Representativeness Study Instructions  
Prepared by Peter Fitch 12/3/2003

Introduction
The requirement for a representativeness study is detailed earlier in this Appendix. Briefly the two questions that need to be answered are:
- Is sampling on one point within the stream representative of the whole stream?
- Is the auto-sample the same as a grab sample taken from the same point? ie sampling with an auto-sampler does not modify the sample in any way

To answer these questions a one-off study is required.

Note: At no time does CSIRO expect any staff members to put themselves in an unsafe situation. Safety first always!

Study Requirements
Auto-Sample versus Grab Sample

For Saltwater Creek and the Lower Daintree (at the pontoon) 2 grab samples will be taken at the same point in the water (or as close as possible to) the autostation intake at the same time that the autostation takes 2 samples. This synchronization will be difficult and require good co-ordination. The sampling must be completed within 15-20 minutes to allow for statistical analysis.

<table>
<thead>
<tr>
<th>Site</th>
<th>Rising stream</th>
<th>Peak stream</th>
<th>Falling stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Daintree</td>
<td>2 samples</td>
<td>2 samples</td>
<td>2 samples</td>
</tr>
<tr>
<td>Saltwater Creek</td>
<td>2 samples</td>
<td>2 samples</td>
<td>2 samples</td>
</tr>
</tbody>
</table>

Representativeness Samples

For Saltwater and Lower Daintree (at the pontoon) 5 samples will be taken at even intervals across the stream or river. Below the centre 3 sampling points at a depth of 2m or 50% of stream depth another 3 samples will be taken. This is illustrated in the diagram below and the sampling positions are listed in Table 1. This sampling as above must be repeated at 3 hydrograph levels rising, peak and falling.
Figure 9 Illustration of sampling points within stream

- 5 Samples evenly across stream
- 3 Samples Underneath 3 center surface samples
  50% of Stream Depth (2m)

Autostation

Representativeness sample
Sampling Change Sample
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Distance from Left Bank looking Upstream (% of stream width)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>17 (half way between one third and the bank)</td>
</tr>
<tr>
<td>0</td>
<td>34 (one third)</td>
</tr>
<tr>
<td>0</td>
<td>50 (halfway)</td>
</tr>
<tr>
<td>0</td>
<td>67 (2 thirds)</td>
</tr>
<tr>
<td>0</td>
<td>84 (halfway between 2 thirds and the right bank)</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>64</td>
</tr>
</tbody>
</table>

Table 3 Sampling position in stream

**Method**

**Surface samples**
Surface samples will be taken as per current EPA developed sampling protocol that is used by Douglas Shire. This procedure must be documented to be included in the report.

**Sub-Surface samples**
A sub surface sample must be obtained using an appropriate sampling bottle that remains sealed until the appropriate depth samples and then can be sealed for the removal from the stream. As with the surface samples, this procedure must be documented to be included into report.

**Bottle Marking**
The bottles will be marked and the following must be recorded.
- Site (LD or SW)
- Study (R-representativeness, C-grab/auto comparison)
- Day Time
- Position in stream meters from left bank looking upstream (X), depth (Y) in meters.
- Distance (Z) up or down stream from autostation intake + upstream, - downstream

**Responsibilities (Organisation)**

**DSC (Peter Bradley)**
- Co-ordination of sampling staff during events.
- During 3 levels of hydrograph for Saltwater Creek, take the 8 stream samples as per Table 1.
- From Saltwater and Lower Daintree at 3 levels of hydrograph as per Table 1, take 2 samples at a point as close as possible to the auto-station sample intake.

**CSIRO**
- Provide information to DSC about the status of hydrographs (ie when is it rising, peak and falling). (peter Fitch)
- Trigger autostations to take comparative samples (Peter Fitch)
- Assist DSC in obtaining samples (Tony Webster and Mark Disher if required)

**NRM (Gary Drake)**
- Provide advice and equipment for taking subsurface samples
- Provide equipment and during 3 levels of hydrograph for the Lower Daintree at the pontoon, take the 8 stream samples as per Table 2.

**Processing of Samples**
Samples are to be processed as per normal DSC processing protocols, and would be handed over to Kim as per usual.

David McJannet¹ and Peter Fitch²

¹CSIRO Land and Water, Atherton
²CSIRO Land and Water, Townsville

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1. Introduction
The effect of land use on aquatic systems can be measured using a variety of techniques. The technique of choice is dependent on the question of interest. If the focus of the study is on the health of the freshwater system then it is often suitable to use ambient water quality measures. However, when the focus of the study is on the downstream impacts of land use on estuarine or coastal systems, knowledge of both the water quality and quantity is needed. In this situation water quality on its own will not give the true picture of the impact on the downstream system. The integration of water quality and quantity is often termed 'load'.

Sediment and nutrient loads are not measured directly; rather load estimates are inferred from measurements of sediment or nutrient concentration and water discharge (Letcher et al., 1999). In the DSWQP the initial focus was on obtaining accurate sediment and nutrient concentration data. Efforts to obtain estimates of water discharge were also initiated, however, it was acknowledged early in the project that obtaining estimates of water discharge (Q) in high flow events can be dangerous and expensive, and often require many years of data to produce reliable estimates from rating curves. Also, the location of a number of the sampling sites in the estuarine area meant that traditional techniques for calculating discharge are not appropriate and loads could only be estimated for the stations in non-tidal areas (Upper Daintree and Upper Mossman).

In this appendix, we outline the following:
(i) the range of methods and techniques available for estimating loads (Section 2);
(ii) we recommended the most appropriate load estimating technique and present loads for TSS, TN and TP for the Upper Mossman and Upper Daintree based on the available data collected in the 2003/04 wet season (Sections 3 and 4)
(iii) we test the suitability of the collected samples for estimating loads (Sections 3 and 4)
(iv) we outline the issues related to estimating loads for the community samples (Section 5)

The loads calculations in this appendix are based on the data presented in Appendix E.

2. Calculating Loads For Automatic Sampling Stations
It is important to note that all approaches assume that the error in estimating flows are small or are at least consistent at all sampling times and that the point of sample collection is representative of average conditions. With these assumptions in mind it is important for us to recognise the limited extent of our dataset and short time period over which data has been collected at the Douglas Shire automatic sampling stations. With additional years of data collection, the accuracy and precision of load estimation techniques will improve. With this in mind, readers are urged to exercise caution in the interpretation of the load estimates reported in the following sections of this report.

Loads for Upper Daintree, Upper Mossman and the two flumes were calculated using a software package called PlaNet. PlaNet has been developed by Greenbase Consulting Pty Ltd for the Water and Rivers Commission Western Australia (http://www.greenbase.com.au/). PlaNet is an integrated software system for developing sampling programs for loads and trends, taking targeted samples via automatic samplers, and analysing data collected from sampling programs to derive and quantify errors for loads and trends. In this project we used PlaNet to analyse data collected from our automatic sampling stations and to calculate loads using a variety of estimation techniques.

The PlaNet software package allows the user to analyse their collected discharge and concentration data and calculate loads using a range of estimation techniques. In this report we analyse our data using linear interpolation, Beale estimator, arithmetic mean, discrete integration, and limited arithmetic mean techniques. Full descriptions of the mathematical methodology behind these techniques is beyond the scope of this report, however, detailed descriptions are available in Letcher et al., (1999), Degens and Donohue (2002) and the PlaNet user guide.
Estimating loads is not a simple process of selecting a technique and running the calculation. Different techniques are best suited to certain situations and the choice of technique will be determined by the available flow and concentration dataset and catchment conditions. To illustrate the variation in load estimates calculated using different techniques, and to emphasise the need to choose techniques carefully, we have used PlaNet to calculate loads for the Upper Mossman (Table 1) and Upper Daintree (Table 2) using five different methods. From these tables it can be seen that estimates can vary enormously and well informed decisions need to be made regarding selection of estimation method. The loads calculated for Upper Mossman and Upper Daintree will be discussed further below while loads for the flumes will be discussed in Appendix H.

Table 1. Load estimation for Upper Mossman based on five different calculation techniques.

<table>
<thead>
<tr>
<th>Load Calculation Technique</th>
<th>Total Nitrogen (Tonnes)</th>
<th>Total Phosphorus (Tonnes)</th>
<th>Total Suspended Sediment (Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Linear interpolation</td>
<td>151</td>
<td>4.48</td>
<td>2902</td>
</tr>
<tr>
<td>2 Beale Estimator</td>
<td>213</td>
<td>11.89</td>
<td>9033</td>
</tr>
<tr>
<td>3 Arithmetic mean</td>
<td>318</td>
<td>13.51</td>
<td>8811</td>
</tr>
<tr>
<td>4 Discrete Integration</td>
<td>334</td>
<td>18.45</td>
<td>14,002</td>
</tr>
<tr>
<td>5 Limited arithmetic mean</td>
<td>203</td>
<td>8.71</td>
<td>5678</td>
</tr>
</tbody>
</table>

Table 2. Load estimation for Upper Daintree based on five different calculation techniques.

<table>
<thead>
<tr>
<th>Load Calculation Technique</th>
<th>Total Nitrogen (Tonnes)</th>
<th>Total Phosphorus (Tonnes)</th>
<th>Total Suspended Sediment (Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Linear interpolation</td>
<td>2,479</td>
<td>68</td>
<td>84,902</td>
</tr>
<tr>
<td>2 Beale Estimator</td>
<td>3,905</td>
<td>268</td>
<td>257,830</td>
</tr>
<tr>
<td>3 Arithmetic mean</td>
<td>4,272</td>
<td>248</td>
<td>229,982</td>
</tr>
<tr>
<td>4 Discrete Integration</td>
<td>4,978</td>
<td>341</td>
<td>321,522</td>
</tr>
<tr>
<td>5 Limited arithmetic mean</td>
<td>3,365</td>
<td>195</td>
<td>185,078</td>
</tr>
</tbody>
</table>

3. Upper Mossman Loads

Loads for the Upper Mossman station were calculated using the 174 samples analysed and the linear interpolation method (Equation 1). This technique was chosen for this site as it is known to perform well when data sets are extensive and have a temporal resolution representing changes in flow conditions (Degens and Donohue, 2002).

\[
\text{Load} = \sum_{j=1}^{n+1} \sum_{i} q_{t} \frac{C_{t_{i}}(t_{i+1} - t) + C_{t_{i+1}}(t - t_{i})}{t_{i+1} - t_{i}}
\]

Equation 1

Where, \( C_{t_{i}} \) is concentration measured at time \( t_{i} \), \( C_{t_{i+1}} \) is concentration measured at the next time, \( t_{i} \) and \( t_{i+1} \) are the times at the beginning and end of each interval when concentrations were measured (from times 0 to \( n \)) and \( t \) is the time at any time between \( i \) and \( i+1 \) when concentrations were sampled and flow data was recorded. \( q_{t} \) is the flow recorded at time \( t \) for intervals between times \( t_{i} \) and \( t_{i+1} \), when concentration measurements were taken. Using this technique estimates for mass loads and resulting delivery rates were calculated for Upper Mossman (Table 3). Delivery rates of 17.4, 0.52 and 334 kg/ha were estimated for total nitrogen, phosphorus and suspended sediment, respectively.
Table 3. Upstream contributing area, discharge, loads and delivery rates for Upper Mossman between 01/12/03 and 30/06/04 using linear interpolation.

<table>
<thead>
<tr>
<th>Upstream contributing area</th>
<th>8,677 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Discharge (01/12/03 – 30/06/04)</td>
<td>280,895 ML</td>
</tr>
<tr>
<td><strong>load (tonnes)</strong></td>
<td><strong>delivery rate (kg/ha)</strong></td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>151</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>4.48</td>
</tr>
<tr>
<td>Total suspended sediment</td>
<td>2902</td>
</tr>
</tbody>
</table>

3.1 **Assessment Of The Suitability Of The Collected Samples For Estimating Loads**

Due to the inherent problems associated in obtaining load estimates, it is prudent to perform some further analysis to seek additional confidence in the load estimates from the collected samples. The approach we have taken is to use a model, based on the relationship between collected flow and point concentration data, to reconstruct a continuous concentration series. In this case, the ‘model’ is then applied to the measured flow data to develop a continuous time series of concentration. The continuous series is then used to estimate load (referred to as ‘continuous load’). Using the continuous series, concentration values at the actual collection times used in the field, are extracted. These extracted samples and associated discharge are then used to estimate loads (referred to as ‘sample load’). The sample load is then compared to the continuous load. The closer the sample load is to the continuous load, the more confidence we have in our ability to accurately estimate actual stream loads from the collected samples. In our analysis we have used two models; the USGS 7 parameter model (Cohn et al., 1992) and a stratified 2nd order polynomial regression model.

A comparison of the continuous and sample load for the two different models is shown in Table 4. Technique 1a is the USGS 7 parameter model (Cohn et al. 1992) which uses seven parameters (related to concentration, discharge and time) to create a model of flow against concentration. This method was used to estimate a continuous data set of concentration data which was then converted to a load based on linear interpolation. Technique 2a is a stratified regression technique for modelling the relationship between concentration and flow based on a second order polynomial. As with the technique 1a, a continuous data set of concentration data was produced which was then used to calculate loads based on linear interpolation. Technique 1b and 2b use the same modelling techniques applied in 1a and 2a but this time only the modelled concentrations at the time that samples were taken by the automatic sampler were used to estimate loads using linear interpolation techniques. Techniques 1b and 2b provide us with a means by which to assess the suitability of our sampling strategy.

Table 4. Continuous and sample loads for total nitrogen, phosphorus and suspended sediment at Upper Mossman.

<table>
<thead>
<tr>
<th>Load Calculation Technique</th>
<th>Total Nitrogen (Tonnes)</th>
<th>Total Phosphorus (Tonnes)</th>
<th>Total Suspended Sediment (Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a USGS 7 parameter model (Continuous Load - Linear interpolation)</td>
<td>171</td>
<td>4.53</td>
<td>2512</td>
</tr>
<tr>
<td>1b USGS 7 parameter (Sample Load – Linear Interpolation)</td>
<td>129</td>
<td>4.42</td>
<td>4133</td>
</tr>
<tr>
<td>2a Stratified regression (2nd order polynomial) (Continuous Load - Linear interpolation)</td>
<td>113</td>
<td>5.05</td>
<td>3563</td>
</tr>
<tr>
<td>2b Stratified Regression</td>
<td>98</td>
<td>4.67</td>
<td>3704</td>
</tr>
</tbody>
</table>
In trying to recreate the continuous load of total nitrogen load from the USGS model our sample load produced a underestimate of 25%, while the continuous load from the stratified regression technique was underestimated by 12%. These results suggest that the nitrogen load calculated from the collected samples (Table 3) is likely to be an underestimate of the real load.

Using the USGS 7 parameter model our sample load of phosphorus was only a 2% less than the continuous load, while using the stratified regression technique our sample load underestimated continuous load by 8%. These results suggest that the phosphorus load calculated from the collected samples (Table 3) is likely to be a reasonable estimate of the real load.

The technique we have used to assess the suitability of our collected samples to calculate loads is limited by the strength of the relationships between concentration and flow. The USGS model of predicted total suspended sediment performed poorly resulting in a poor performance of our sampling strategy. Sample load for USGS was 64% greater than USGS continuous load. The stratified regression model sample load was 4% greater than the corresponding continuous load. The strength of our load estimate based on collected samples is uncertain for total suspended sediment because of the poor performance of the USGS model although the stratified regression model suggests we have a reasonable estimate.

4. Upper Daintree Loads

Loads for the Upper Daintree station were calculated from the 44 samples analysed and the Beale estimator technique (Beale 1962). Letcher et al., (1999) recommend using the Beale estimator when dealing with limited data sets. Loads calculations in this section are only preliminary estimates because of the limited data set available from the first years sampling and the unfortunate failure of the automatic sampler during the largest event.

The Beale Estimator applies a bias correction factor to a summed terms ratio estimator. The Beale ratio estimator is shown in Equation 2

\[
Load = Q_a \left( \frac{\bar{l}}{\bar{q}} \right) \left( 1 + \frac{1}{N} \frac{\text{cov}(l,q)}{\bar{q}} \right)
\]

Equation 2

Where:
- \(Q_a\) - is annual flow
- \(\bar{q}\) - is average load for times when samples were collected
- \(\bar{l}\) - is average flow for times when samples were collected
- \(N\) - is the number of samples collected during the year
- \(\text{cov}(l,q)\) - is the co-variance between sampled loads and flow at time of sampling
- \(\text{var}(q)\) - is the variance of the flows at the time of sampling

Using the Beale technique, estimates for mass loads and resulting delivery rates were calculated for Upper Daintree (Table 5). Delivery rates of 39.4, 2.65, and 2478 kg/ha were estimated for total nitrogen, phosphorus and suspended sediment, respectively. This table represents the first estimates of loads coming out of the naturally forested part of the Upper Daintree catchment. Delivery rates of nitrogen, phosphorus and sediment were much higher at Upper Daintree than at Upper Mossman and may in part be related to differences in vegetation cover and/or soil type. The Upper Mossman is completely covered by dense rainforest, a large proportion (~50%) of the Upper Daintree is open Eucalypt woodland.
Table 5. Upstream contributing area, discharge, loads and delivery rates for Upper Daintree between 01/12/03 and 30/06/04.

<table>
<thead>
<tr>
<th></th>
<th>Upper Daintree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream contributing area</td>
<td>90,865 ha</td>
</tr>
<tr>
<td>Total Discharge</td>
<td>1,530,000 ML</td>
</tr>
<tr>
<td></td>
<td>load (tonnes)</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>3,581</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>241</td>
</tr>
<tr>
<td>Total suspended sediment</td>
<td>225,200</td>
</tr>
</tbody>
</table>

4.1 Assessment Of The Suitability Of The Collected Samples For Estimating Loads

Load estimation errors related to sampling are explored using the USGS 7 parameter model and a stratified regression technique. These modelling methods were used to create a continuous data set of concentration data which was then converted to a load based on linear interpolation. Technique 1b and 2b use the same modelling techniques applied in 1a and 2a but this time only the modelled concentrations at the time that samples were taken by the automatic sampler were used to estimate loads using linear interpolation techniques.

Table 6 Continuous and sample loads for total nitrogen, phosphorus and suspended sediment at Upper Daintree.

<table>
<thead>
<tr>
<th>Load Calculation Technique</th>
<th>Total Nitrogen (Tonnes)</th>
<th>Total Phosphorus (Tonnes)</th>
<th>Total Suspended Sediment (Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a USGS 7 parameter model</td>
<td>2,140</td>
<td>310</td>
<td>423,600</td>
</tr>
<tr>
<td>1b USGS 7 parameter (Sample load – Beale)</td>
<td>3,452</td>
<td>214</td>
<td>207,900</td>
</tr>
<tr>
<td>2a Stratified regression (2nd order polynomial) (Continuous load - Linear interpolation)</td>
<td>993</td>
<td>166</td>
<td>688,940</td>
</tr>
<tr>
<td>2b Stratified Regression</td>
<td>3,581</td>
<td>241</td>
<td>225,200</td>
</tr>
</tbody>
</table>

The sample load for total nitrogen overestimated the continuous load calculated using the USGS model by 60%, while the continuous load from the stratified regression technique was overestimated by 260%. These results suggest that the nitrogen load calculated from the collected samples (Table 5) should be treated with caution. However, it should also be realised that the model strength for testing the Upper Daintree sample load estimates is limited because of the small number of samples available, particularly later in the season.

Using the USGS 7 parameter model our sample load of phosphorus was 30% less than the continuous load, while using the stratified regression technique our sample load overestimated continuous load by 45%. The sample load for sediment was 50% less than USGS continuous load. The stratified regression model sediment sample load was 67% less than the corresponding continuous load.

The small number of sample collected at Upper Daintree made model development difficult and relationships between certain parameters are weak. Analysis of load data and performance of the sampling strategy is particularly difficult because it is hard to determine whether the results are
reflecting sampling error or model development error. Further data collection in future years will help clarify these issues.

5. Loads And Community Sampling
Calculation of loads from the grab samples collected by the community is not achievable. The reasons for this stem from the lack of data regarding flow in the stream from which samples have been collected. In some cases the depth of the stream when samples were collected was recorded, but without any information on the velocity of the stream or the availability of a rating curve any estimates of discharge would have unacceptable levels of error, hence, comparison between streams would be meaningless. Point measurements of depth when samples are collected also reveal very little about the size or duration of an event. This is important to remember considering estimates of load require good estimates of discharge.

Application of the Manning’s n approach to calculate a discharge is not appropriate at the grab sample sites because of the lack of any data set by which to compare results too, therefore the accuracy of the estimate is unknown. This technique was applied to the Upper Mossman station, however, at this station we had the NRM Mossman station downstream to compare results against.

The application of the community grab samples comes in the comparison of nutrient concentration data in different parts of the catchment dominated by different land uses. Even the comparison of nutrient concentrations at different sites can be complicated by mismatch in sampling times which limits the comparability of results.

6. Future Work Needed To Obtain Loads In Each Catchment
In this report we have made some initial attempts at estimating loads but a lot more sample collection and analysis is required before any confidence in estimates can be achieved. There is a lot of planning taking place at the moment in catchments up and down the coast to set target loads for water quality improvement. Targets are generally being set for each catchment based on results from modelling exercises. With this in mind, accurate calculation of loads is important for two reasons: 1) we need to know that models are producing valid predictions, and 2) we need to demonstrate compliance with set targets. The sense in setting targets for catchments which exhibit large year to year variability may be questionable, but none the less, efforts to demonstrate compliance are a necessity.

If estimates of loads are to improve we need to have a strong methodology for determining flow from our catchments. In non-tidal areas rating curves need to be developed over a number of seasons. In tidal areas, where rating curve techniques do not work, a completely new set of techniques to determine flow is needed. These techniques could include use of Doppler based flow meters which ‘look’ at direction and rate of flow in cells across the river channel, or could include estuarine modelling techniques which separate tidal and river flows. Research in this area is very limited and requires a lot more work before confidence in flow estimates can be achieved. Bearing in mind that many rivers in Australia experience large tidal fluctuations (e.g. the entire wet tropics region) which push many kilometres inland, issues to do with tidal influences on load estimates are significant.

To determine reliable loads in Douglas shire in the future better directed sample collection will be required. Based on the samples available, there is a lot of uncertainty around load estimates. Many of the load estimation techniques will not perform properly if insufficient data are supplied and false and misleading results can result. Estimates of error associated with the load calculations for Upper Mossman and Upper Daintree have not been made directly. The linear interpolation technique used for Upper Mossman does not allow calculation of standard errors. The Beale technique used at Upper Daintree does permit calculation of standard error but with such a small data set with limited temporal spread calculations of error are very large and are somewhat meaningless. Despite this, we believe it is important to discuss the errors associated with load estimates for future years of the DSC water quality project so as not to hide the true picture of
confidence in load estimates. It is through being open about the potential error surrounding our estimates that we can demonstrate that calculating loads is not an exact science. There is a lot of room for improvement and we need to ensure that funding agencies, and governing bodies realise this. Once awareness is raised about the current uncertainties in load estimation, we can start to move forward and improve the situation.

7. Discussion

Initial estimates of loads delivered during 2003/4 at the Upper Daintree and Upper Mossman sites have been presented, however, it should be noted that these load estimates are subject to considerable errors given the gaps in the data (primarily at the Upper Daintree site), the short duration of the study, the approximate nature of discharge measurements and the sensitivity of the estimates to the algorithm used to calculate loads. Nutrient and sediment loads could not be calculated at the Saltwater Creek, Lower Daintree and Lower Mossman sites because these sites were tidal.

The delivery rates of nitrogen, phosphorus and sediment were much higher at the Upper Daintree than at Upper Mossman site. This may be related to differences in vegetation cover and/or soil types. The Upper Mossman is completely covered by dense rainforest, while about 50% of the Upper Daintree catchment is open Eucalypt woodland. Analysis of the data suggests that the TP load estimate at the Upper Mossman site is likely to be reasonable, but the TN load is likely to be an underestimate. The accuracy of the other loads could not be established from the data.

References


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

Rebecca Bartley¹, John Armour², Peter Fitch³, David McJannet¹, Bronwyn Harch⁴, Sarah Thomas⁴ and Tony Webster⁵

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1. Introduction

It is acknowledged that there is an excess of nutrients (nitrogen and phosphorus) being exported from many of the Great Barrier Reef catchments (McKergow et al., In Press). In the Wet Tropics region, a considerable amount of these nutrients are coming from fertilised agricultural land uses such as sugar cane. One mechanism for reducing the amount of nutrients being exported to marine waters, is to reduce the amount of fertiliser being used. However, it is uncertain what the effect of reducing fertiliser application rates will be on (a) the concentration of nutrients in surface waters, (b) the concentration of nutrients being leached below the root zone, and (c) the growth rate and quality of the plant material.

To determine the effect of reduced fertiliser application on (a), (b) and (c) above, a paired flume trial was set up on a sugar cane plot in the Saltwater Creek Catchment. The block for this trial is located on Sandy McDonald’s farm, which is approximately 8km north of Mossman on the Mossman-Daintree Road adjacent to the Saltwater Creek bridge (see Figure 1 of Final Report). Unlike the river monitoring stations, the flume study allows us to quantify the effect of fertiliser reduction independently of other potential nutrient sources such as bank and drain erosion. This information is very useful to evaluate proposed best management practices for sugar cane production, as well as for use in load prediction models such as SedNet and ANNEX (see Bartley et al., 2004).

This report will document the results of water quality and quantity aspect of the study. The effect of the trial on the quality and quantity of the sugar cane produced is documented in Webster et al., (In Prep). The sugar cane production aspect of this trial was part of an SRDC project and is not a contracted component of the DEH funded study.

In this trial there were two nitrogen (N) application rates: (1) the conventional rate the grower normally applies (~ 190 kg N/ha), and (2) a reduced rate (~98 kg/ha N) based on the Thorburn replacement theory (Thorburn et al 2003). This theory advocates applying 1.1kg of N per harvested tonne of cane from the previous crop harvested. The replacement rate of 1.1kg has been modelled as sustainable based on environmental losses of 10% of applied fertiliser N. This field trial will ground truth the theory. Should this reduced application rate have no adverse impact on soil or crop health over a number of years and locations, it will be endorsed as the BMP rate sugarcane growers should be applying. Additional to this trial are five complementary demonstration sites where the replacement theory application rate is being applied on different farms with differing soil types, form of N, varieties, block history and management.

1.1 Site Information

The soil of the entire block is consistent and is a well drained soil formed on alluvium described by Murtha (1989) as dark greyish brown silty clay loam A horizon; yellowish brown silty clay loam to light clay B horizon with moderate fine blocky structure. The soil is classified by Northcote (1979) as Uf6.34/p. The block for this trial is 3.25 hectares. It is currently growing the 3rd ratoon crop of Q174 which was harvested on 3/9/03. Table 1 presents the recent block history. The block was ploughed out and replanted during the 2000 season as the farmer does not practice fallowing. The block has been continuous cane for at least 30 years.

Table 1. Block history for trial location.

<table>
<thead>
<tr>
<th>Year</th>
<th>Variety</th>
<th>Class</th>
<th>Tonnes</th>
<th>Tonnes/ha</th>
<th>CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Q120</td>
<td>7th Ratoon</td>
<td>259.3</td>
<td>79.8</td>
<td>11.0</td>
</tr>
<tr>
<td>2001</td>
<td>Q174</td>
<td>Replant</td>
<td>208.0</td>
<td>64.0</td>
<td>13.6</td>
</tr>
<tr>
<td>2002</td>
<td>Q174</td>
<td>1st Ratoon</td>
<td>335.1</td>
<td>103.1</td>
<td>13.2</td>
</tr>
<tr>
<td>2003</td>
<td>Q174</td>
<td>2nd Ratoon</td>
<td>290.5</td>
<td>89.4</td>
<td>12.4</td>
</tr>
</tbody>
</table>
1.2 **Trial Setup**

The trial consists of six plots, three replicates of each treatment (Figure 1). Only plots 1 and 2 were monitored for water quality changes. The plots were large enough to produce 15 tonnes of cane (minimum rake size) so mill samples could be taken. The advantage of having a complete rake for each plot is the mill can provide data for total weight, CCS (brix and pol), fibre, and NIR data on ash and moisture. Samples of shredded cane were also taken to the mill for dry matter content and nitrogen analysis.

The grower has been applying 6 bags per acre of CK150 for many years to all ratoon crops. For ease of application this trial will use the conventional rate of 190 kg N/ha, but will apply it as urea, avoiding the need to supply P and K. Previous soil testing shows P and K are high and not needed. The replacement theory advocates applying 1.1 kg N / tonne of harvested cane. As the previously harvested crop yielded 89 tonnes/ha, this trial applied 98 kg N/ha.

![Figure 1. Plot treatment areas on the trial block.](image)

1.3 **Monitoring Stations And Lysimeters**

To measure the amount of water, sediment and nutrients transported off the different fertiliser treatments, two flumes were installed, one of each on Plots 1 and 2. The two 9 inch Parshall flumes, with a three row buffer, are equipped with a monitoring station which includes an ISCO automatic water sampler, stage recorder located in a stilling well, rain gauge and solar panel (e.g. Figure 2). The stage recorders are attached to Campbell CR10X data loggers. All equipment is linked to telemetry which downloads to a CSIRO Land and Water data centre website ([http://www.data-tv.csiro.au/data-tv/index.htm](http://www.data-tv.csiro.au/data-tv/index.htm)). The samplers were set to collect samples according to the overall water quality management strategy (Appendix C). The sites were also be surveyed usual total station surveying gear to determine the total contributing area and slope of each flume site (Table 2).

<table>
<thead>
<tr>
<th>Flume</th>
<th>Area (m²)</th>
<th>Slope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3300</td>
<td>0.65</td>
</tr>
<tr>
<td>2</td>
<td>2600</td>
<td>0.33</td>
</tr>
</tbody>
</table>

In addition to the surface hydrology measurements, staff from QDNR&M were involved in the project to assist in understanding the quantity of water and nutrients that are passing below the root zone. This aspect is of particular interest to the local cane farmers and will provide a much more rigorous understanding of the overall nitrogen and phosphorus budget. This part of the
project involved the installation of 10 barrel lysimeters (5 in each treatment, 3 under the plant cane and 2 in the inter row) in each of the fertiliser treatment plots (Figure 2). The lysimeters were connected to a vacuum line that was then emptied into a series of water traps (Figure 2). The lysimeters have collected water draining through the soil profile from a defined surface area at a depth of 1 m. This is assumed to be below >90% of the crop roots. Drainage and nutrient discharge can be calculated from the volume and nutrient content of the water. This set measured both the concentration and amount of water passing below the root zone.

Figure 2. Flume setup at Saltwater Creek (left) and lysimeter setup at the flume site (right)

Figure 3. Layout of flumes and lysimeters with respect to fertiliser trial
2. Methods For Analysing The Data

The flumes installed are 9 inch Parshall flumes that have a standard calibration for converting stage (mm) into discharge (litres/second) according to Equation 1.

\[
Q \text{ (L/s)} = 0.0132 \times \text{stage (mm)} \quad \text{Equation 1}
\]

To determine the runoff or discharge \(Q\) for each flume Equation 1 was applied to all of the stage data collected for the seven month period. Some corrections were made to the raw stage data due to slight ponding of water in the base of the flumes during small rainfall events. These corrections are believed to have improved the runoff calculations.

Table 3 shows the collection history for both flumes during the 2003/04 wet season. The number of samples triggered, collected and analysed for each station is detailed. As mentioned earlier, both flumes systems were plagued by problems resulting from faulty equipment and sample collection was far from optimum. Further compounding these problems is the lack samples analysed for both stations. Although a reasonable number of samples were collected for both stations the number analysed is far less than that needed to get reliable estimates of loads from these stations.

Table 3. Collection history for the flumes over the 2003/04 wet season

<table>
<thead>
<tr>
<th></th>
<th>Flume 1 (98 kg N/ha)</th>
<th>Flume 2 (190 kg N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples triggered</td>
<td>3044</td>
<td>1073</td>
</tr>
<tr>
<td>Samples collected</td>
<td>80</td>
<td>283</td>
</tr>
<tr>
<td>Samples analysed</td>
<td>20</td>
<td>33</td>
</tr>
</tbody>
</table>

Given the small number of samples collected for each flume, available techniques for estimating loads are limited and it is not possible to test the suitability of the sampling strategy. Because of the sparse data set, estimates of load were made using an un-stratified Beale technique (see Henderson and Harch 2005). Caution must be exercised in interpreting the results below and it must be stressed that further samples and flow data are needed in subsequent years to improve load estimates from different farming practices. Only 25% of the samples collected from Flume 1, and 12% of samples collected from Flume 2 have been analysed. It may be possible to improve some of the load estimates if more of these samples are analysed at the lab.

3. Results

3.1 Flume 1

Figure 4 shows the discharge and concentration of total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS) for Flume 1 for the study period (December 2003 to July 2004). The hydrographs of the flumes are much more ‘flashy’ than the river stations, with the flume hydrographs being characterised by distinct flow peaks followed by a drop to no flow. The data shows that there are much higher concentrations of sediment and nutrients at the start of the wet season indicating that the ‘first flush’ process appears to be occurring in the flumes. This ‘first flush’ process is expected in these tropical environments where high intensity storms fall after considerable periods of no rain.
Figure 4. Discharge and total nitrogen and total phosphorus (A) and discharge and total suspended sediment (B) for Flume 1.

3.2 Flume 2
Figure 5 shows the discharge and concentration of total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS) from Flume 2 samples. The hydrograph of Flume 2 shows similar patterns to Flume 1 with distinct flow peaks followed by a drop to no flow. The number of samples collected for this flume is more than for Flume 1, however, more samples need to be analysed to adequately represent the load changes through the wet season. As with all other stations, it is possible from the collected samples to see the drop in concentration of sediment and nutrients as the wet season progresses.
Figure 5. Discharge and total nitrogen and total phosphorus (A) and discharge and total suspended sediment (B) for Flume 2.

### 3.3 Flume Comparison

Despite the small number of water quality samples analysed, an attempt was made to calculate loads for the two flume plots. Estimated load delivery rates of TN, TP and TSS for Flumes 1 and 2 are shown in Table 4. Information in this table is also presented graphically in Figure 6.

Table 4. 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>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)
Figure 6. Comparison of the surface runoff (A), total nitrogen and phosphorus (B), and total suspended sediment (C) delivery rates for the 2003/2004 study period.

The calculated loads of TN, TP and TSS from the high and low fertiliser plots are shown in Error! Reference source not found.. They show that higher loads of sediments and nutrients were lost from the plot with the higher fertilization rate. Error! Reference source not found. 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.

The problems encountered in estimating loads from limited datasets is further illustrated by the data presented in Figure 7 which shows the range of concentrations measured from Flumes 1 and 2 for samples of TSS, TN and TP. The range of TSS concentration values between the two flumes is similar, however, the median values are very different. For Flume 1, there were 20 samples analysed with a median TSS concentration of 37.32 mg/l. Flume 2 had 33 samples analysed producing a median TSS concentration of 71 mg/l. There was also a large difference between the median TP values measured between the two flumes (0.25 mg/l for Flume 1 and 0.58 mg/l for Flume 2). The TP data shows a similar pattern to the sediment data, as expected, as the most of the phosphorus is adsorbed to the sediment particles. The TN data is slightly different to the TSS and TP data in that the median values are not as different (2.05 mg/l for Flume 1 and 2.6 mg/l for Flume 2), however, the range of estimates is very large.

Interpretation of loads results is complicated by the limited datasets of concentration for Flumes 1 and 2. Analysed samples were collected at different times during the study period and at different positions on hydrographs. As an example, median TSS of Flume 2 was double that of Flume 1 but this only reflects the fact that more samples were taken at higher concentrations. A more extensive data set spread across the season would strengthen load estimates dramatically.

Although predicted loads of TN follow the pattern expected from the two flumes given the different application rates of fertiliser, it is not possible to say with any confidence whether the cause of the
difference in loads between the two flumes is real (and accurate) or an artefact of errors introduced to loads calculations by sampling problems. In summary, caution is advised in interpreting results. Analysis of more of the collected samples would help to strengthen load estimates but budgetary constraints prevent this.

![Boxplot comparison of the sediment concentrations measured from Flume 1 (n = 20) and Flume 2 (n =33)](image)

**Figure 7.** Boxplot comparison of the sediment concentrations measured from Flume 1 (n = 20) and Flume 2 (n =33)

### 3.4 Lysimeter Results

**Drainage volumes**
The first drainage samples were collected on 15 December 2003 and then as needed during the wet season. Samples from 9 drainage events (15/12/03-19/1/04) from rainfall of 467 mm have been analysed for N and P. The mean drainage volumes (and standard errors) were 555 (23) mm for Flume 1 (98 kg N/ha) and 568 (46) mm for Flume 2 (190 kg N/ha). This is clearly in excess of the rainfall recorded for this period and is assumed to reflect preferential drainage pathways due to the soil disturbance during installation.

Drainage data from another 9 drainage events are available for the period 21/01/04 - 19/02/04. There was 644 mm of rain and drainage of 539 (29) mm and 526 (11) mm for Flume 1 and Flume 2, respectively. For this period, the drainage was an average of 82% of rainfall. This is still higher than expected but indicates that the hydraulic properties of the lysimeter system are ‘settling in’.

**N and P movement**
Mean NO₃ (nitrate + nitrite, with nitrite assumed to be very low for all occasions except shortly after N fertiliser application) concentrations for both N treatments reached a peak on 17-22/12/03 after 168 mm of rain in December. Apart from the first sampling, mean NO₃ concentrations were always higher in the high N treatment (Flume 2) than in the low N treatment (Flume 1). Individual NO₃ concentrations were as high as 7.5 mg N/L for the low N plot and 15.8 mg N/L for the high N plot.
Concentrations reduced over the sampling period to mean concentrations of 0.1 mg and 1.5 N/L on 19/1/04, for low N and high N, respectively.

![Graph showing nitrate concentration comparison between Flume 1 and 2 for early and mid wet season events.](image)

**Figure 8.** Comparison between nitrate concentrations for Flume 1 and 2 between early and mid wet season events.

Loads of N moving below 1 m were calculated from individual nitrate concentrations and volumes of water collected in the water traps. Adjustments were made to the volume calculations (reduced by 40%) to account for ‘over sampling’ the drainage. A detailed water balance is required to validate this adjustment. Over the 5 week period for which analytical data are available (15/12/03-19/1/04), leaching losses of N (and standard errors) were 5 (1.7) and 13 (5.1) kg/ha for the low and high N, respectively.

Concentrations of filtered reactive phosphate were very low in all samples (<0.08 mg/L) resulting in low P losses of <0.01 kg P/ha below 1 m in the soil profile. Tests are currently underway to establish the effect of P sorption by the ceramic cups used to collect the water samples on P concentrations in the sample.

**Summary**

The NO₃ loss by drainage below 1 m over a 5 week period following the first rains of the season were as high as 13 kg/ha from the 190 N treatment. This is approximately the same as that reported from surface water and sediment over the entire growing season. Subsurface movement of N is clearly an important loss mechanism in well-drained soils used for sugar production in the wet tropics. Funding is being sought to analyse samples for at least 9 more events up to 19 February 2004. These are currently in storage in Mossman and Brisbane.

### 3.5 Summary Of Surface And Sub-Surface Data

The main aim of this trial was to assess if there was a measurable difference in the amount of nitrogen lost to surface or sub-surface waters as a result of halving the fertiliser application rate. Due to the lack of samples analysed this wet season, it is difficult to make any robust conclusions regarding the difference in the amounts of nitrogen lost under each nitrogen trial. There are, however, some early trends suggesting that halving the fertiliser rate does have a measurable difference on the amount of nitrogen lost in surface and sub-surface water.
According to the data in Table 5, 83% and 81% of the total nitrogen movement below the root zone is in the form of NOₓ (nitrate + nitrite) for Flumes 1 and 2, respectively. NOₓ is a reactive form of N and excess NOₓ is ecosystems can to serious damage. An increase in the level of N in surface waters can lead to algal blooms, a reduction of species richness and diversity and even a change in species composition (Hatch et al., 2002).

It appears that the total loss of nitrogen is roughly proportional to the amount of fertiliser that was put on each flume. Flume 1 lost ~16% of the fertiliser to surface or sub-surface waters and Flume 2 lost ~15%. The main difference between the two flumes is that the sub-surface pathway dominates the TN losses for the higher fertiliser site (Flume 1, 58%), and surface water dominates the lower fertiliser application site (Flume 2, 61%) (Table 5).

Overall, there is ~44% more nitrogen being lost to water 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 too high and results in higher environmental losses of nitrogen.

Table 5. Description of the nitrogen losses to surface and sub-surface flows from the flumes

<table>
<thead>
<tr>
<th></th>
<th>Flume 1</th>
<th>Flume 2</th>
<th>% difference between two flumes assuming Flume 2 is current condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contributing area</td>
<td>0.33 ha</td>
<td>0.26 ha</td>
<td></td>
</tr>
<tr>
<td>Fertiliser application</td>
<td>98 kg N/ha</td>
<td>190 kg N/ha</td>
<td>48%</td>
</tr>
<tr>
<td>Total Rainfall</td>
<td>9.77 ML (2960 mm)</td>
<td>7.703 ML (2962 mm) &lt;0.1%</td>
<td></td>
</tr>
<tr>
<td>Total Surface Runoff</td>
<td>3.3 ML (1000 mm)</td>
<td>2.53 ML (973 mm) 3%</td>
<td></td>
</tr>
<tr>
<td>Total nitrogen (TN)</td>
<td>9.54 kg/ha</td>
<td>11.58 kg/ha</td>
<td>18%</td>
</tr>
<tr>
<td>NOₓ delivery to sub-surface water</td>
<td>5 kg/ha</td>
<td>13 kg/ha</td>
<td>61%</td>
</tr>
<tr>
<td>Total nitrogen (TN)</td>
<td>16 kg/ha</td>
<td>6 kg/ha</td>
<td>63%</td>
</tr>
<tr>
<td>Total loss of TN</td>
<td>15.54 kg/ha</td>
<td>27.58 kg/ha</td>
<td>44%</td>
</tr>
</tbody>
</table>

Figure 9. Graph of the difference in TN between surface and subsurface flows between Flume 1 and 2
4. Optimised Strategy For Flumes For Future Wet Season Sampling

4.1 Introduction
To optimise and provide a robust flume sampling strategy for future wet seasons, two main aspects were considered:

(i) to determine the number of samples required to detect a pre-specified statistical difference for a number of water quality parameters when two different fertiliser application rates are investigated.

(ii) to ensure that an adequate temporal sequence of data are collected and sent away for analysis;

There is a limited set of data available for considering these two aspects of optimising the flume sampling regime (for the “first flush period” during December 2003 and January 2004 Flume 1; n = 11 and Flume2; n=19 & for the “after first flush period” post January 2004 Flume 1; n = 9 and Flume2; n=13). The limited nature of the data limits the statistical treatment of the data and the temporal correlation amongst these effectively repeated measurements has not been explicitly taken into account in the calculations. Another confounding issue is that the individual samples collected from the two flumes were often collected at different points on the hydrograph. This means that, in many ways, we are not comparing two independent data sets. If considerably more samples were collected from both flumes, with samples spread across the full range of the hydrograph, the specific point at which the samples were collected on the hydrograph would not be an issue. However, with so few samples, the data from the two flumes are highly skewed due to the variable discharge collection points. Nonetheless, a statistical analysis of the data was undertaken, but these assumptions and limitations in the data need to be taken into consideration when evaluating the results.

4.2 Optimisation Of Sampling Effort For Detecting Fertiliser Treatment Differences

4.2.1 Statistical Analysis
For the planning of sampling effort for subsequent monitoring studies, sample size calculations were conducted to provide an indication of the relative number of samples that would be required to be able to detect specified differences in water quality parameter values across the two fertiliser application treatments. The sample size calculations conducted in this section assumed that the data available were not correlated, which is a rather strong assumption to make given the low number of samples available for analysis. Power and sample size calculations are predicated on Normally distributed data. The observed distributions for the sediment and nutrients, while positively skewed, were not as strongly skewed as might be expected. Sample size requirements were examined on the raw and the log-transformed scales. As little difference was found in the suggested sampling requirements, the raw variates are used for simplicity and ease of interpretation here.

Due to the assumptions and low number of samples used in this analysis, the results are considered to be preliminary only and can be revised when more data becomes available.

To investigate the required sample sizes, estimates were made of means and pooled variance across both sets of flume data. Note that the data used here have been split into those representing the first flush of the 2003/2004 wet season (December 2003 and January 2004) and those identified as “after the first flush” (post January 2004), as identified in Sections 3.1 (Figure 27). The overall mean and variance in these two time periods are so different that sample size determination using these data together would bias the sampling effort due to the large variance in this broader time period.
It is also assumed that these data sets provide realistic estimates of mean and variance for each time period for the two fertiliser application treatments. To determine the number of samples that need to be collected from each flume, six different scenarios were used. These scenarios included differences of 5, 10, 25, 50, 75 and 90% from the standard fertiliser application rate (190 kg N/ha) to the reduced fertiliser application rate (98 kg N/ha). This means that if you use a detectable difference value of 5% then you will be able to pick up a 5% difference in the mean values of the two trials. An ability to pick up differences at this level may be required if ecological systems (i.e. in-stream fish populations) are very sensitive to nitrate levels in the river. If however, it is only important to pick up large changes in water quality then it may be more appropriate to use a 50% or 75% detectable difference level. However, using this level means that there may be a statistical (and possible ecologically) significant difference in the trial, but you won't pick it up until there is >50% difference in the means from the two flumes. In summary, the lower the detectable difference size (i.e. 5%) the higher the number of samples that are required to measure a difference. Also the lower the detectable difference size, the more robust the analysis and therefore the conclusions that can be drawn from the study.

4.2.2 Sample Size Determination Results For “First Flush”
Figure 1 provides the results of the power and samples size determinations for each of the water quality parameters considered during the “first flush” time period. Note all recommendations given are the minimum set of samples to be taken from each flume.

**Total Suspended Solids**
Mean TSS from the standard fertiliser application rate was approximately 13% higher than the reduced rate treatment (Flume 1 average = 94.8; Flume 2 average = 84.0; pooled flume variance = 28.1). Comparing this result to the 10% detectable difference scenario depicted in Figure 10a, suggests that for this level of detectable difference between the treatments approximately 175 samples are required from each flume to be confident that this difference in TSS can be determined as a statistically defensible difference (with 80% power and α=0.05). The main reason for this relatively large number of samples is because the mean difference in TSS between the two sites – using the 2003/2004 data – is relatively small and the pooled variance relatively large. When a detectable difference is small and variance relatively large it follows that more samples are required to detect the difference.

If a different level of detectable difference is required for TSS, Figure 10a can be used in determining the appropriate number of samples for each of the flumes. For a detectable difference of 50% from the standard fertiliser, approximately 10 samples would be required from each flume (with power 80% and α=0.05).

**Total Nitrogen**
The mean TN concentration from the standard fertiliser application rate was approximately 27% lower than the reduced rate treatment (Flume 1 average = 3.1; Flume 2 average = 4.3; pooled flume variance = 2.2). Comparing this result to the 25% detectable difference scenario depicted in Figure 10b, suggests that for this level of detectable difference between the treatments approximately 70 samples are required from each flume to be confident that this difference in TN can be determined as a statistically defensible difference (with 80% power and α=0.05).

If a different level of detectable difference is required for TN, Figure 10b can be used in determining the appropriate number of samples for each of the flumes. For a detectable difference of 50% from the standard fertiliser, approximately 20 samples would be required from each flume (with power 80% and α=0.05).

**Total Phosphorus**
Mean TP concentration from the standard fertiliser application rate treatment was approximately 20% higher than the reduced rate treatment (Flume 1 average = 0.76; Flume 2 average = 0.63; pooled flume variance = 0.22). Comparing this result to the 25% detectable difference scenario depicted in Figure 10c, suggests that for this level of detectable difference between the treatments
approximately 35 samples are required from each flume to be confident that this difference in TP can be determined as a statistically defensible difference (with 80% power and $\alpha=0.05$).

If a different level of detectable difference is required for TP, Figure 10c can be used in determining the appropriate number of samples for each of the flumes. For a detectable difference of 50% from the standard fertiliser, approximately 10 samples would be required from each flume (with power 80% and $\alpha=0.05$).

![Graphs showing sample size versus power for TSS, Total Nitrogen, and Total Phosphorus.](image)

Figure 10. Sample size versus power for total suspended solids, total nitrogen and total phosphorus using six scenarios for minimum detectable differences including 5, 10, 25, 50, 75 and 90% from the standard fertiliser application rate (190 kg N/ha) to the reduced fertiliser application rate (98 kg N/ha). Determinations are based on the “first flush” time period in December 2003/January 2004. Note the sample size is the number of samples to be taken from a single flume, consequently actual samples need to be doubled for two flumes. A 10% difference reflects the approximate mean detectable difference for total suspended solids. A 25% difference reflects the approximate mean detectable difference for both total nitrogen and total phosphorus.

### 4.2.3 Sample Size Determination Results For After The “First Flush”

Figure 11 provides the results of the power and samples size determinations for each of the water quality parameters considered during the “after first flush” time period. Note all recommendations given are the minimum set of samples to be taken from each flume.

**Total Suspended Solids**

Mean TSS concentration from the standard fertiliser application rate treatment was approximately 64% lower than the reduced rate treatment (Flume 1 average = 16.9; Flume 2 average = 47.0; pooled flume variance = 24.4). Comparing this result to the 50% detectable difference scenario depicted in Figure 11a, suggests that for this level of detectable difference between the treatments approximately 20 samples are required from each flume to be confident that this difference in TSS can be determined as a statistically defensible difference (with 80% power and $\alpha=0.05$).

If a different level of detectable difference is required for TSS, Figure 11a can be used in determining the appropriate number of samples for each of the flumes. For a detectable difference
of 25% from the standard fertiliser, approximately 70 samples would be required from each flume (with power 80% and \( \alpha = 0.05 \)).

**Total Nitrogen**

Mean TN concentration from the standard fertiliser application rate treatment was approximately 4% lower than the reduced rate treatment (Flume 1 average = 1.16; Flume 2 average = 1.2; pooled flume variance = 0.59). Comparing this result to the 10% detectable difference scenario depicted in Figure 11b, suggests that for this level of detectable difference between the treatments approximately >300 samples are required from each flume to be confident that this difference in TN can be determined as a statistically defensible difference (with 80% power and \( \alpha = 0.05 \)).

If a different level of detectable difference is required for TN, Figure 11b can be used in determining the appropriate number of samples for each of the flumes. For a detectable difference of 50% from the standard fertiliser, approximately 20 samples would be required from each flume (with power 80% and \( \alpha = 0.05 \)).

**Total Phosphorus**

Mean TP from the standard fertiliser application rate treatment was approximately 15% lower than the reduced rate treatment (Flume 1 average = 0.19; Flume 2 average = 0.22; pooled flume variance = 0.059). Comparing this result to the 10% detectable difference scenario depicted in Figure 11c, suggests that for this level of detectable difference between the treatments approximately 195 samples are required from each flume to be confident that this difference in TP can be determined as a statistically defensible difference (with 80% power and \( \alpha = 0.05 \)).

If a different level of detectable difference is required for TP, Figure 11c can be used in determining the appropriate number of samples for each of the flumes. For a detectable difference of 50% from the standard fertiliser, approximately 10 samples would be required from each flume (with power 80% and \( \alpha = 0.05 \)).

![Graphs of TSS, Total Nitrogen, and Total Phosphorus](image)

Figure 11. Sample size versus power for total suspended solids, total nitrogen and total phosphorus using six scenarios for minimum detectable differences including 5, 10, 25, 50, 75 and 90% from the standard fertiliser application rate (190 kg N/ha) to the reduced fertiliser application rate (98 kg N/ha). Determinations are based on the “after first flush” time period in December 2003/January 2004. Note the sample size is the number of samples to be taken from a single flume, consequently actual samples need to be doubled for two flumes. A 50% difference reflects
the approximate mean detectable difference for total suspended solids. A 10% difference reflects the approximate mean detectable difference for both total nitrogen and total phosphorus.

### 4.3 Recommendations

The sample size determination results for the “first flush” and “after first flush” time periods have been summarised below for the specific detectable differences of 10, 25, 50, 75, 90 and 95% from the standard fertiliser treatment (190 N kg/ha). To be able to use these results, it is important to be able to determine the relevant detectable difference that the flume monitoring program is aiming for. If a high level of rigor is needed, such that all data sets from the flumes are statistically robust and defensible under all conditions, then a detectable difference of between 5-25% is advised. However, if this study is only trying to get a ‘rough’ idea of the effect of fertiliser treatment on water quality then a detectable difference of between 50-90% would be sufficient. We also need a better understanding of what level of nitrate in river water is harmful to aquatic species. This information will help focus the specific detectable difference to be used in the statistical power analysis.

As shown in this section, the ability to determine the difference in water quality coming off the two flumes (with different fertiliser application rates of 190 versus 98 kg N/ha), varies with the number of samples collected. If for example, a detectable difference of 50% was thought to be the relevant impact that needs to be detected by the monitoring program for TSS, TN and TP across the fertiliser application rates, then results in Table 1 suggest 20 samples should be collected.

Table 6. Sample size determination results for the “first flush” and “after first flush” time periods have been summarised here for the specific detectable differences of 10, 25, 50, 75, 90 and 95% from the standard fertiliser treatment (190 N kg/ha). Note 5 samples were taken as the minimum number per flume. All numbers in the table refer to numbers required for EACH flume. Bold figures indicate the percentage detectable differences found retrospectively using the 2003/2004 data.

| Detectable Differences from Standard Fertiliser Treatment (190 N kg/ha) | “First Flush” December 03/January 04 | “After First Flush” post January 04 |
|---|---|---|---|---|---|---|
| | TSS | TN | TP | TSS | TN | TP |
| 10% | 180 | > 300 | 195 | > 300 | > 300 | 195 |
| 25% | 30 | 70 | 35 | 70 | 85 | 35 |
| 50% | 10 | 20 | 10 | 20 | 20 | 10 |
| 75% | 5 | 5 | 5 | 10 | 10 | 5 |
| 90% | 5 | 5 | 5 | 10 | 10 | 5 |
| 95% | 5 | 5 | 5 | 5 | 5 | 5 |

### 5. Discussion And Conclusions

It is important to note that the results of the above analysis must be treated with caution. The small number of samples available violates the statistical assumptions necessary to make definitive conclusions. What we have achieved, however, is the design of techniques to undertake this analysis in the future. Given appropriate datasets, the developed technique will provide an excellent tool for designing future sampling strategies. We recommend that at least 70 samples (but probably more) need to be collected from both flumes to represent the main features of the hydrograph. Without this data the method outlined can not be applied with confidence.

This section of the report documented the effect of altering the amount of fertiliser applied to a sugar cane plot, and consequently the quality of water running off the plot as surface water and below the root zone. The study used two flume systems, one with the current fertiliser rate of 190 kg/ha of N (Flume 2) and one with half that rate, 98 kg/ha N (Flume 1). Unfortunately, due to the
low number of samples analysed from the two flumes over the 2003/04 wet season, it is difficult to

draw robust and statistically defensible conclusions from this study. There are, however, a number of

preliminary outcomes from this study including:

- For all of the water quality parameters (TSS, TP and TN), flume 2 (190 kg/ha N) had higher
  runoff concentrations and loads than Flume 1. However, it is uncertain as to whether these
  data reflect the actual difference in fertiliser application rates or simply reflect a lack of
  samples;
- The nitrate concentrations and loads measured in the sub-surface (lysimeter) samples from
  Flume 2 are much higher than Flume 1;
- Overall, it appears that there is a 44\% more nitrogen (surface and sub-surface) being lost
  from Flume 2 than Flume 1;
- The 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.
- The optimised strategy for the flumes provides a range of potential sample sizes that all
  depend on the quality, rigor and question being asked of the data;
- Recommended sample sizes were put forward for TSS, TP and TN, however, they vary
  considerably between variables;
- Seeing that nitrate is the main variable of interest in the flume study, the statistical analysis
  suggests that between 70 and 100 samples are required from both flumes in the upcoming
  wet season so that a statistical difference in the level of nitrate removed in runoff between
  the two flumes can be measured.

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1. Introduction

This appendix presents the results of the community monitoring program. The community monitoring program has seen a total of 135 baseflow condition samples collected between September 2003 to June 2004. The program has also seen 109 event samples collected during the 2003 & 2004 wet season (Table 1); 60% of the event samples collected were analysed and 88% of the baseflow samples collected were analysed. Monitoring results for all the analysed water samples available as at September 2004 have been used in the statistical analyses conducted. Only those samples with a full parameter set are used. Results for turbidity, total suspended solids, total nitrogen and total phosphorus are provided below. Dobbie and Harch (2004) provides statistical analysis of historic water quality data from the shire.

Table 1. Summary of the number of event and baseflow samples both collected and subsequently analysed for the four catchments representing the river and creek system in Douglas Shire from September 2003 to June 2004.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Number of event samples analysed / collected</th>
<th>Number of baseflow samples analysed / collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mowbray</td>
<td>9 / 13</td>
<td>9 / 11</td>
</tr>
<tr>
<td>Mossman</td>
<td>20 / 38</td>
<td>35 / 45</td>
</tr>
<tr>
<td>Saltwater</td>
<td>28 / 47</td>
<td>28 / 35</td>
</tr>
<tr>
<td>Daintree</td>
<td>6 / 11</td>
<td>33 / 44</td>
</tr>
<tr>
<td>TOTAL</td>
<td>63 / 109</td>
<td>105 / 135</td>
</tr>
</tbody>
</table>

2. Methodology

Results for each monitoring site are presented within the context of its river catchment. General background information about each of the community monitoring sites is provided, along with the number of samples collected and analysed. The temporal record of total nitrogen, total phosphorus, total suspended solids and laboratory turbidity for all the sites within a catchment are given on the same plot for comparative purposes. The QEPA (2001) draft water quality guidelines, relevant to Douglas Shire upper catchment, lower catchment and mid estuarine waters, are also depicted as a point of reference. Note that there was no guideline value for total suspended solids.

3. Findings From Mowbray River Catchment

Background to Mowbray River at Fishing Bridge (Lower Catchment)

As there is no automatic monitoring station on the Mowbray River, community monitoring was important for assessing water quality issues. There were some limitations in community involvement due to lack of expressions of interest coming from residents of the Mowbray area, with Douglas Shire Council staff enlisted to travel from Port Douglas out to the Mowbray River Bridge site.

Table 2 shows that 69% of the event samples collected were analysed and 82% of the baseflow samples were analysed. With a total of only 18 samples to consider for both ambient and event conditions, only general observations can be made. Measurements taken in ambient condition in the Mowbray River catchment suggest the sites were within QEPA water quality guidelines (which supports the recommendation in the main report) for Douglas Shire to consider reducing the number of non-event samples sent away for laboratory analysis (Figure 1). During event conditions there was a considerable degree of variability amongst the parameters.

With no automatic sampling station in the Mowbray River catchment and only one community monitoring site, Douglas Shire should consider including additional sites into the sampling program to
ensure the catchment’s water quality is adequately represented. A minimum of two sites (upper and lower) should be considered for both ambient and event conditions.

Table 2. Summary of the number of event and baseflow samples both collected and subsequently analysed for two community grab sampling sites representing the Mowbray River catchment. Analysed data includes those samples processed up until September 2004 and included in the Douglas Shire web based data repository at the end of September 2004.

<table>
<thead>
<tr>
<th>Location</th>
<th>Event Samples Collected</th>
<th>Event Samples Analysed</th>
<th>Baseflow Samples Collected</th>
<th>Baseflow Samples Analysed</th>
<th>Total Collected</th>
<th>Total Analysed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mowbray River At Fishing Bridge</td>
<td>13¹</td>
<td>9</td>
<td>11</td>
<td>9</td>
<td>24</td>
<td>18</td>
</tr>
</tbody>
</table>

¹Note: due to extreme weather conditions one event sample was taken upstream at Digger’s Bridge (200m downstream of the Old NRM gauging station).

Figure 1. Time series plots of event and baseflow condition data at two sites within the Mowbray River catchment for A) total nitrogen, B) total phosphorus, C) total suspended solids and D) laboratory turbidity. All data was collected as part of the community grab sampling program co-ordinated by Douglas Shire Council. In order from lowest in catchment to highest: Mowbray At Bridge (LC), Mowbray At NRM (UC).
4. Findings From The Mossman River Catchment

Results for the Mossman main river channel sites will be presented together (Figure 2) and then results for the South Mossman sites will be outlined.

Background to Lower Mossman
The Lower Mossman site reflects the land use impacts on two major rivers and one major creek as well as their tributaries which then all merge into the Mossman River, i.e., Cassowary Creek, South Mossman River and Mossman River. Increased influences from the change of land use becomes more relevant with industry (Mossman Mill/Industrial Estate), urban, cane farming, roads, sewage treatment plant, extractive industry, horticulture and transport all adding to the possible impacts and influences which contribute to water quality.

Background to Mossman at Foxton Bridge NRM Gauging Station (Lower Catchment)
This site enhances the data already available from the NR&M gauging station located at the same site. Accessibility is available during both event and ambient flow conditions. This is the main site that also allows the general public a chance to see the Water Quality Improvement Program in action with many pedestrians and passing motorists taking an interest in the sampling taking place. This site reflects the land uses and impacts of cane farming, urban, roads and tourism.

Background to Upper Mossman Grab and Rex Creek (Upper Catchment)
These sites have been chosen to represent a true rainforest site that is accessible by the community volunteers. The site is located at the intake for the Mossman/Port Douglas water supply. The Rex Creek is a tributary to the Mossman River. Table 3 shows that 53% of the event samples collected were analysed and 78% of the baseflow samples were analysed.

Table 3 Summary of the number of event and baseflow samples both collected and subsequently analysed for seven community grab sampling sites representing the Mossman River catchment. Analysed data includes those samples processed up until September 2004 and included in the Douglas Shire web based data repository at the end of September 2004.

<table>
<thead>
<tr>
<th>Location</th>
<th>Event Samples Collected</th>
<th>Event Samples Analysed</th>
<th>Baseflow Samples Collected</th>
<th>Baseflow Samples Analysed</th>
<th>Total Collected</th>
<th>Total Analysed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Mossman Grab</td>
<td>4</td>
<td>3</td>
<td>9</td>
<td>8</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Mossman At Foxton</td>
<td>15</td>
<td>7</td>
<td>14</td>
<td>12</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td>Upper Mossman Grab</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rex Creek</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>6</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>South Mossman At Old NRM Station</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Parkers Creek</td>
<td>14</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Cassowary Creek</td>
<td>4</td>
<td>3</td>
<td>10</td>
<td>7</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>TOTAL</td>
<td>38</td>
<td>20</td>
<td>45</td>
<td>35</td>
<td>83</td>
<td>55</td>
</tr>
</tbody>
</table>

For all parameters, measurements taken in ambient condition suggest sites in the main channel of the Mossman River were within, or close to, QEPA water quality guidelines (Figure 2). There was evidence of little variability in measurements during this period (which supports the recommendation in the main report for Douglas Shire to consider reducing the number of ambient samples sent away for laboratory analysis). It is interesting to note that there is very little difference in ambient conditions at
any of the three sites on the main channel of the Mossman River. During event conditions there was a considerable degree of variability amongst the parameters and across the sites. This suggests potential to decrease the number of sites from four to two sites (representing upper and lower catchments influences), and use the extra resources elsewhere in the monitoring program.

![Graphs of data](image)

Figure 2. Time series plots of event and baseflow condition data at four sites within the main channel of the Mossman River for A) total nitrogen, B) total phosphorus, C) total suspended solids and D) laboratory turbidity. All data was collected as part of the community grab sampling program co-ordinated by Douglas Shire Council. In order from lowest to highest in the catchment: Lower Mossman Grab (LC), Mossman At Foxton (LC), Upper Mossman Grab (UC), Rex Creek (UC).

**Background to South Mossman at QNRM Gauging Site (Lower Catchment)**

**Background to Parker’s Creek (Lower Catchment)**
Parker’s Creek runs behind the South Mossman suburban area (including the cemetery) past the township of Mossman (including the Mossman Mill) and into the South Mossman River. Limitations of Parker’s Creek is that it is a seasonal flowing creek. The community involvement was through students of the Mossman State High School. Sample collection for students was restricted to school hours and the frequency at which the creek flows. From a public relations point of view, this site is extremely important in bringing the wider community into the project, regardless of it’s limitations.
Background to Cassowary Creek (Upper Catchment)
This site contributes to the existing historical ambient monitoring data collected by the QEPA. Land uses that impact upon this creek range from extractive industry and road haulage depot to sugar cane farming and rural residential. South Mossman River laboratory turbidity measurements were within, or close to, QEPA water quality guidelines (Figure 3). The total nitrogen and total phosphorus concentrations were, however, higher than the QEPA guidelines at this site. There was evidence of little variability in total suspended solids measurements during this period. During event conditions there was a considerable degree of variability amongst the parameters and across the sites.

![Graphs showing data for total nitrogen, total phosphorus, total suspended solids, and laboratory turbidity.](image)

Figure 3. Time series plots of event and baseflow condition data at two sites within the South Mossman River catchment for A) total nitrogen, B) total phosphorus, C) total suspended solids and D) laboratory turbidity. All data was collected as part of the community grab sampling program coordinated by Douglas Shire Council. In order from lowest to highest in the catchment: South Mossman At NR&M (LC), Parkers Creek (LC), Cassowary Creek (UC).

5. Findings For Saltwater Creek Catchment

Background to Miallo Bridge (Lower Catchment)
This site is accessible during event and ambient flow conditions by a community volunteer who lives within close proximity to the site. This site is the lowest of the community monitoring sites for the Saltwater catchment but is located above the automatic station. Therefore, this site and those upstream provide important ambient flow data and have the potential to complement the samples collected and analysed from the automatic station.
**Background to Polleti Bridge (Lower Catchment)**

The Polleti Bridge site gives the community volunteer/s easy access to the Saltwater Creek, with safety only an issue during major events. The variety of land uses increases at this point in the catchment with sugar cane farming being the major form of primary production, and horticulture and irrigation used in a small area. The large rainforest area captured in the catchment, farm houses and a small subdivision (approximately 10 houses) are also factors considered in selecting this sampling site.

**Background to Upper Saltwater NRM Gauging Station (Upper Catchment)**

The Upper Saltwater Site is complemented by the NRM gauging station, which provides flow ratings curves that enhance data collected for this site. The site is inaccessible during major events. The land uses above this site are largely rainforest plus a small farming area. Table 4 shows that of the 60% of the event samples collected were analysed and 80% of the baseflow samples were analysed.

Each of the three sites representing the Saltwater Creek catchment show very similar baseflow condition for each of the water quality parameters considered (total nitrogen, total phosphorus, total suspended solids and laboratory turbidity), with all sites within the guidelines for baseflow condition (Figure 4). Each site varies with respect to the concentrations reported during event condition, with the Polleti Bridge site having, in general, less variability in event concentrations. These differences may be due to the position of sites within the catchment relative to different land uses. This suggests potential to decrease the number of samples during the dry season, thereby, freeing up resources for elsewhere in the monitoring program.

Table 4. Summary of the number of event and baseflow samples both collected and subsequently analysed for three community grab sampling sites representing the Saltwater Creek catchment. Sites are listed in order from most upstream to most downstream site in the catchment. Analysed data includes those samples processed up until September 2004 and included in the Douglas Shire web based data repository at the end of September 2004.

<table>
<thead>
<tr>
<th>Location</th>
<th>Event Samples Collected</th>
<th>Event Samples Analysed</th>
<th>Baseflow Samples Collected</th>
<th>Baseflow Samples Analysed</th>
<th>Total Collected</th>
<th>Total Analysed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Saltwater Ck</td>
<td>16</td>
<td>14</td>
<td>12</td>
<td>9</td>
<td>28</td>
<td>23</td>
</tr>
<tr>
<td>Saltwater At Polleti Bridge</td>
<td>19</td>
<td>9</td>
<td>11</td>
<td>8</td>
<td>30</td>
<td>17</td>
</tr>
<tr>
<td>Saltwater At Miallo Bridge</td>
<td>12</td>
<td>5</td>
<td>12</td>
<td>11</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>TOTAL</td>
<td>47</td>
<td>28</td>
<td>35</td>
<td>28</td>
<td>82</td>
<td>56</td>
</tr>
</tbody>
</table>
Figure 4. Time series plots of event and baseflow condition data at three sites within the Saltwater Creek catchment for A) total nitrogen, B) total phosphorus, C) total suspended solids and D) laboratory turbidity. All data was collected as part of the community grab sampling program coordinated by Douglas Shire Council. In order from lowest in catchment to highest: Saltwater At Miallo (LC), Saltwater At Polleti (LC), Upper Saltwater (UC).

6. Findings For Daintree River Catchment

Background to Pontoon (Mid Estuarine)
This site is located midstream in the vicinity the public pontoon area approximately 500 m upstream from the Daintree Ferry. This site complements the automatic station with some limited event sampling and ambient sampling. This is a tidal site with the community volunteer taking samples from his tour boat. This not only raises awareness of the project among the general public and tourists, but also allows mid stream sampling due to the fact that there is no bridge crossing near this site. The land uses above this site are forests in the upper catchments of the Daintree River and its tributaries, Daintree township, sugar cane production, commercial tourist boating tours, cattle grazing, and roads.

Background to Lower Stewart Creek (Lower Catchment)
Stewart Creek Bridge, which is located downstream from the Upper Stewart Creek site, was selected to increase the representation of cattle grazing as the major land use for this sub-catchment. It provides data representing a large cattle grazing area.

Background to Stewart Creek Bridge (Lower Catchment)
Access to the Stewart Creek Bridge and mid stream sampling during events needed to be carefully considered with safety being the major concern.

Background to Upper Stewart Creek (Upper Catchment)
This site is a unique site. Its remoteness represents some logistical problems due to accessibility during and after large events. As a sub-catchment of the Daintree River, the Upper Stewart Creek site provides information in relation to waters exiting protected forests that enters grazing properties. A constraint to this site is that the creek rises rapidly and can remain impassable for many days, thus
delaying the pick-up of samples. This has been addressed through the generosity of the volunteer’s spare fridge/freezer which has been now set aside for the water samples. This fridge/freezer meets the requirements set by EPA on the storage of water samples.

**Background to Upper Daintree River (Upper Catchment)**

Located on private property approximately 300m downstream from the automatic station, this site is an ambient site only due to safety issues associated with sample collection during event conditions. There is no bridge to take samples from during events, large crocodiles frequent the area and it is inaccessible during high rainfall periods. This site gives the project valuable ambient data which complements the automatic stations that are not designed to sample during low water levels. Land uses consist of a small proportion of grazing, with rainforest making up the large proportion. Table 14 shows that of the 54% of the event samples collected were analysed and 75% of the baseflow samples were analysed.

Each of the five sites representing the Daintree River catchment show very similar baseflow condition for each of the water quality parameters considered (except total nitrogen), with most sites falling within the guideline range for baseflow condition (Figure 5). There was evidence of little variability in total suspended solids measurements during this period. During event conditions there was a considerable degree of variability amongst the parameters and across the sites. This suggests potential to decrease in the number of sites (representing upper and lower catchments influences) during baseflow conditions, and use the extra resources elsewhere in the monitoring program.

Table 5. Summary of the number of event and baseflow samples both collected and subsequently analysed for five community grab sampling sites representing the Daintree River catchment. Analysed data includes those samples processed up until September 2004 and included in the Douglas Shire web based data repository at the end of September 2004.

<table>
<thead>
<tr>
<th>Location</th>
<th>Event Samples Collected</th>
<th>Event Samples Analysed</th>
<th>Baseflow Samples Collected</th>
<th>Baseflow Samples Analysed</th>
<th>Total Collected</th>
<th>Total Analysed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Stewart Creek</td>
<td>5</td>
<td>3</td>
<td>12</td>
<td>9</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Stewart Creek Bridge</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Lower Stewart Creek</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Daintree Pontoon (Mid-Stream)</td>
<td>1</td>
<td>0</td>
<td>12</td>
<td>9</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Upper Daintree Grab</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>8</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>11</strong></td>
<td><strong>6</strong></td>
<td><strong>44</strong></td>
<td><strong>33</strong></td>
<td><strong>53</strong></td>
<td><strong>39</strong></td>
</tr>
</tbody>
</table>
7. **Overall Recommendations**

Providing recommendations about the optimal spatial locations for the community ambient monitoring must consider the objectives of the program; a) to provide a mechanism for community ownership of information generated in the shire, and b) to provide an understanding of knowledge based on information collected from water monitoring.

Keeping the objectives and the analysis results in mind, Douglas Shire Council should consider continuing the sampling program undertaken by the community volunteers with a focus on monitoring at least one site in the upper and lower reaches of the river system and where possible a number of sites positioned throughout the catchment, where the sites are matched to the various land uses in the catchment. Also, where there are major tributaries for a river, monitoring should be also undertaken from at least one site to represent the characterisation of the tributary or where possible at a number of sites along the traverse of the tributary.
Douglas Shire Council should also consider the implementation of a water sample selection strategy that only sends away either 10 samples (‘one in winter’ scenario) or 8 samples (‘one in May-Sept’ scenario) to the laboratory for analysis (see Harch and Thomas, 2004). The choice of whether to send 10 or 8 samples per location per year must be guided by the analysis budget set for the ambient monitoring program. It is of particular comfort to know that the full set of monthly ambient samples would be collected and stored in case circumstances or the initial sample analysis results suggest that the additional samples should be analysed retrospectively.

It must be recognised that the value of community samples in terms of looking at the effect of different land uses on water quality is very limited. The samples from different sites are collected at different times, and the magnitude of events is unknown because no depth measurements were made. These factors make it very hard to evaluate the inputs of nutrients and sediments from different land uses and reflect the problem that the collection methods did not meet the requirements of the objectives. Load calculations are currently impossible from these community collected samples. That being said, there is much value in raising the awareness of community collectors to water quality issues and the illustrating to them that changes to on-farm practices can improve water quality.

8. Discussion

The community monitoring shows that, under baseflow conditions, the concentrations of TN and TP in the Mowbray River are within the EPA guidelines for the lower catchment but above the guideline set for the upper catchment. Under peak flows, both parameters are well above the guidelines. In the main channel of the Upper Mossman River, both TN and TP were within, or close to, the water quality guidelines during baseflows. However, both TN and TP are well above the guidelines standards in Cassowary Creek during baseflows. All parameters were within the guidelines for baseflow condition at all community monitored sites in Saltwater Creek. At all five community monitoring sites in the Daintree River and its tributaries, phosphorus and turbidity concentrations were within the guideline range for baseflow conditions. However, the total nitrogen concentrations were sometimes above the guidelines.

The community monitoring program has been able to show the extent to which baseflow conditions meet water quality standards, although it is not suited to measure loads or to sample peak flow conditions.

References


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

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1. Introduction
The aim of this appendix is to describe the development of a future load-based water quality monitoring strategy for the Douglas Shire catchments. This involves reviewing both the data collected and the lessons learnt from the interim monitoring strategy for the 2003/04 wet season, and the relevant load estimation literature from elsewhere, and synthesizing this information into a general strategy for a loads-based monitoring program for catchments in the wet tropics. The information contained in this appendix are covered in much more detail in Henderson and Harch (2005).

The fundamental questions the load-based monitoring strategy must address are:
• How to choose the samples to be taken?
• How often too sample or how many samples are required?
• How to estimate the sediment and nutrients loads?

In making decisions on these questions it is important that the resulting load monitoring program be practical and widely usable. Richards (1999) describes some key attributes of an ideal program, suggesting that it should:
• Deliver estimates of load with high accuracy and precision.
• Use methods that are robust to small departures from the assumptions
• Be easy to use.
• Be broadly applicable to rivers with different flow and climate characteristics, and to different various water constituents.
• Be objective.

2. Summary Of Messages From The Interim Douglas Shire Study
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 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 fact that the majority of loads are moved during the middle of the wet season when rivers flows are greater, progressively larger events are required to generate similar loads as the 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. Other features that are specific to individual catchments may also need to be recognized for an optimal program.

3. Designing A Loads-Based Monitoring Strategy
Extensive reviews of the requirements of sediment and nutrient load estimation may be found in Degens & Donohue (2002), Letcher et al. (1999), Littlewood (1992) and Richards (1999). This section describes the choices that must be made and outlines some of the alternatives.

The sediment or nutrient load is defined as the mass of the constituent that passes through a cross-section of the river in a specified period of time. It may be expressed as

$$L = K \int c(t)q(t)dt$$

where $L$ is the load, $K$ is a unit conversion constant, $c(t)$ is the concentration, $q(t)$ is the flow and $t$ denotes time. The product $c(t)q(t)$ is known as the instantaneous load or flux and corresponds to the rate at which the load is passing through the cross-section of river in an instant of time. The load is usually given in tonnes or kilograms.
The discharge is the volume of water passing through a cross-section of the river in a specified period of time. The instantaneous discharge is known as the flow or the discharge rate and is typically expressed as m$^3$/s. The integral of the flow over time is the discharge. Techniques for calculating discharge are described in Appendix D.

Resource and other constraints limit the number of samples that can be collected for subsequent laboratory analysis. It is important that those samples that are selected facilitate the most reliable estimation of sediment and nutrient loads possible. The decision on which samples to choose is governed by the sampling strategy. 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 availability of historical records
- The method and equipment available for collection
- The characteristics of the load delivery process in that catchment, e.g. is load delivery event driven
- Other hydrological characteristics, e.g. catchment size, response time of streams to rainfall.
- The technique that will be used to estimate sediment and nutrients loads.
- The water constituent of interest. The sampling requirements for different nutrients and other water quality parameters may be different because they respond differently over the hydrograph.

There are a variety of sampling strategies used in practice. These are briefly described in Henderson and Harch (2005). A good review may be found in Degens & Donohue (2002). See also Richards (1999), Littlewood (1992), Thomas (1985) and Thomas & Lewis (1993, 1995).

4. Future Sampling Strategy For 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 and ultimately onto the Greater Barrier Reef. An interim monitoring strategy was implemented for the 2003/04 wet season. Five sites were used: two upper catchment sites on the Mossman and Daintree rivers and three lower catchment sites on the Mossman and Daintree rivers and at Saltwater Creek. Automatic samplers were placed at each of these sites to enable the potential continuous measurement of hydrological conditions during the wet season, and coupled with laboratory analyses of water samples collected and accurate measures of discharge, facilitate the estimation of these loads.

The main body of this report and associated appendices describe the interim monitoring strategy implemented, review the data that was collected and summarize the knowledge gathered. This report 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 (Degens & Donohue 2002; Littlewood 1992; Rekolainen et al. 1991; Richards & Holloway 1987). A monitoring program that performs well for TSS will invariably cope with constituents that are not as variable.

4.1. Upper Catchment Case Study: Upper Mossman

Upper Mossman is the most complete of the two upper catchment sites in the Douglas Shire sites for the 2003/04 wet season. There is good coverage of all events, with the exception of a large event in mid March when there were some equipment-related problems and no samples were taken. In all 653 samples were triggered and 173 samples sent to the laboratory for analysis. Figure 1 presents the hydrograph and measurements of the total suspended sediment concentrations and instantaneous loads observed.
4.1.1. Calculation Of Loads

The naïve calculations of sediment and nutrient loads from the data collected during the interim monitoring program can lead to some unreliable estimates (see Appendix G). For instance, an interpolative method with the large portions of the inter-event times missing and the lack of records for one of the largest and longest lasting events in March will result in a biased estimate of load. For reliable load estimation it is critical that we account for the distribution of the samples available in relation to the features identified during the exploratory data analysis, namely the majority of the loads being transported during high-flows and the exhaustion over the course of the wet season.

The total sediment load was estimated using the Beale ratio estimate\(^1\). This was considered the best estimator given concentrations were not available consistently throughout the 2003/04 wet season. Note in particular the lack of sampling for the major event in March 2004 and any sampling after the start of May.

Other load estimation methods were examined for the 2003/04 wet season. Interpolation methods were affected by some large amounts of non-sampling and the insufficient sampling during inter-event conditions. The regression approach to load estimation was trialled, and while useful, the relationship between concentration and predictors like discharge and time from the samples observed was not found to be strong ($R^2 \approx 2/3$). Average methods were harder to justify given the purposive sampling and were not found to be as precise as the Beale estimator.

The Beale ratio estimator is well supported in the literature. Richards (1999) in reviewing the findings of a large number of studies suggested that in general that the ratio methods outperformed both regression and averaging approaches, showing low to no bias, relatively high precision and fairly robust to unusual observations when used with bias correction and in stratified mode. Preston et al. (1989) and Letcher et al. (1999) concurred with this view but noted that the ratio estimator sometimes exhibited less precision.

An added feature of a ratio estimator is that some measure of uncertainty is available through an approximate mean square error (MSE). This derives from traditional sampling theory (see for example Cochran 1977) under the assumption that the flow and concentration pairs are independently selected. Baum (1982) describes the MSE in more detail. As the bias is expected to be small for even moderate sample sizes the MSE is typically taken as a variance estimate.

For Upper Mossman we reduce the observed data set to hourly measurements of discharge and concentration. A total of 147 samples are available. The application of the Beale estimate to this data yields a sediment load of 6412 tonnes for the 213 day period of interest. This however fails to recognise the stratification in place, where more sampling effort is put into high-flow conditions and leads to a biased estimate.

Application of the Beale estimator to this data in stratified mode involves applying the Beale estimator to each stratum separately and summing the stratum load estimates to give the total load. Ideally these strata should be chosen a priori and reflect the increased sampling effort during the high-flow conditions where loads are expected to be more variable. An a posteriori stratification applied after the data is collected may also be used but care must be demonstrated as it can actually reduce the precision. Richards (1999) recommends that if a posteriori stratification is imposed that load calculations be made with and without it to assess whether there is merit in the stratification.

\(^1\) The Beale Ratio estimate tries to improve on the information contained in the observed discharge and concentration pairs by using all the 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. It follows from this that the total load may be estimated by

$$L = \frac{\bar{T}}{\bar{q}} Q$$

where $Q$ is the total discharge over the period and $\bar{T}$ and $\bar{q}$ are the average load and discharge from the sample data respectively. A biased-corrected version of this is typically used and seeks to adjust the estimate for the correlation between discharge and load. See Henderson & Harch (2005).
The stratification advocated in Figure 1 is in depth and time, with two strata used for each. The season is divided into 'early wet' and 'late wet' with a cut-off of February 1st 2004. Depth is used to divide the flow conditions into 'low' and 'high' flow, though the depth threshold is allowed to change with the time stratum in order to account for the change in inter-event flow exhibited over the 2004 wet season. For the early wet the threshold is set at 0.5 metres, while for the late wet it increases to 0.7 metres. In this instance both the depth and time-based partitioning are necessary to reflect the actual stratification into event and inter-event conditions identified by the rate of rise algorithm. If for example we relied solely on a stratification based on depth any changes over time (e.g. in flow or due to exhaustion) may not be accounted for adequately.

![Graph showing depth over time with strata](image)

Figure 1. Upper Mossman hydrograph and stratification (blue lines). Analysed observation are given by the red crosses.

This stratification is arbitrary and one of a number of stratifications that could be used. There is no reason why more than two strata could not be used, though the paucity of observed concentration data over some parts of the hydrograph precludes some of the more obvious alternatives. See for instance the lack of samples taken during low-flow or inter-event conditions for the 2003/04 season.

The data from these strata are summarized in Table 1. Note in particular the much higher average and standard deviation for the flux during high flow conditions.

The stratified Beale estimator is applied to the strata suggested in Figure 1. The total sediment load is estimated to be 4991 tonnes with an approximate standard error of 640 tonnes. Standard error was calculated using the technique described by Richards (1999). Table 2 breaks the contributions down by the 4 strata used. The greatest contribution clearly comes during the late wet season high-flow conditions. The ratio used in the Beale estimator (adjusted for the correlation between load and discharge) is larger for the high-flow periods, which is consistent with the notion that the majority of the load is carried in a small proportion of large events.
Table 1. Strata summary statistics for the instantaneous load (flux). Total number of units ($N$), observed number of samples ($n$), sample mean ($m$) and standard deviation ($s$). Note the depth thresholds for the ‘early wet’ and the ‘late wet’ are 0.5 and 0.7 metres respectively.

<table>
<thead>
<tr>
<th></th>
<th>Early $&lt; 1/2/2004$</th>
<th>Late $1/2/2004&lt;$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>$N$ 1378</td>
<td>$n$ 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$m$ 6.4</td>
<td>$s$ 6.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2353</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.7</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>$N$ 111</td>
<td>$n$ 23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$m$ 33.4</td>
<td>$s$ 42.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1271</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15.7</td>
<td>24.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1489</td>
<td>3624</td>
<td>5113</td>
</tr>
</tbody>
</table>

Figure 2 plots the sediment flux and discharge data used for each strata and enables us to examine the appropriateness of the Beale load estimate procedure. For both low flow sub plots there are some large fluxes recorded for the higher discharge. In particular we are looking for an instantaneous load (flux) with a mean and variance that is proportional to the discharge. Overall the assumptions appear to be supported, though that would need to be confirmed over future years.

Note that the estimated TSS load here differs from the load reported by the Beale estimate in Appendix G because the stratification used is different. In Appendix G strata were assigned according to whether measurements are taken on the rising or falling stages of the hydrograph and whether the event was a ‘first flush’ or not. In the stratification advocated here, the strata are assigned according to time and depth. These are found to represent the pattern of variation in the TSS flux more effectively and deliver a better load estimate with the Beale estimator. This highlights the importance of choosing the strata carefully.

Table 2. Estimated discharge and sediment load by strata. The ratio refers to the multiplier of the total stratum discharge used by the Beale estimate.

<table>
<thead>
<tr>
<th></th>
<th>Early low</th>
<th>Early high</th>
<th>Late low</th>
<th>Late high</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge (ML)</td>
<td>15778</td>
<td>6201</td>
<td>86551</td>
<td>172247</td>
<td>280777</td>
</tr>
<tr>
<td>Ratio</td>
<td>0.0063</td>
<td>0.0398</td>
<td>0.0078</td>
<td>0.0232</td>
<td></td>
</tr>
<tr>
<td>Load (tonnes)</td>
<td>99</td>
<td>243</td>
<td>674</td>
<td>3975</td>
<td>4991</td>
</tr>
<tr>
<td>Approx s.e. (tonnes)</td>
<td></td>
<td></td>
<td></td>
<td>640</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Total suspended sediment instantaneous load (flux) vs discharge by strata. The slope of the red line in each plot relates to the ratio used in the stratified Beale estimator.

Figure 3 and Figure 4 repeat the procedure for total nitrogen and total phosphorus and plot the instantaneous load against the discharge for the 4 strata. The load estimated using the Beale estimator is given in Table 3.

Figure 3. Total nitrogen instantaneous load (flux) vs discharge by strata. The slope of the red line in each plot relates to the ratio used in the stratified Beale estimator.
Figure 4. Total phosphorus instantaneous load (flux) vs discharge by strata. The slope of the red line in each plot relates to the ratio used in the stratified Beale estimator.

Table 3. Estimated discharge and nitrogen and phosphorus load by strata.

<table>
<thead>
<tr>
<th></th>
<th>Early low</th>
<th>Early high</th>
<th>Late low</th>
<th>Late high</th>
<th>Total</th>
<th>std error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge (ML)</td>
<td>15778</td>
<td>6201</td>
<td>86551</td>
<td>172247</td>
<td>280777</td>
<td></td>
</tr>
<tr>
<td>Total nitrogen load (tonnes)</td>
<td>25.7</td>
<td>9.1</td>
<td>51.3</td>
<td>95.9</td>
<td>182</td>
<td>102</td>
</tr>
<tr>
<td>Total phosphorus load (tonnes)</td>
<td>0.2</td>
<td>0.4</td>
<td>1.4</td>
<td>5.1</td>
<td>7.1</td>
<td>21.9</td>
</tr>
</tbody>
</table>

**4.1.2. Examining The Required Sampling Frequency**

One of the most natural ways of determining the number of samples required to estimate sediment and nutrient loads with a prescribed precision is to use a regression model derived from the observed TSS and discharge data to estimate the TSS concentrations for all points in time. From there, the discharge and estimated TSS concentration may be taken as the complete data and exposed to different sampling regimes and intensities in order to draw an indication of the sampling frequency required.

This regression relationship is typically developed on the logarithmic scale (i.e. log concentration and log discharge) as regression terms, in particular discharge, have been found to be additive on the log-scale and because this better satisfies the assumptions of a linear regression model.

The regression model will however predict log concentration. Unfortunately the naïve back-transformation (i.e. exponentiation) leads to biased estimates of the predicted concentration. There has been a large contribution to the literature on providing corrections for this bias. See for instance Cohn et al. (1989, 1992), Ferguson (1986) and Koch & Smillie (1986). The approach
taken here is to assume the residuals are Normally distributed and back transform the sum of the prediction on the log scale and half the estimated residual variance from the regression model.

Figure 5. Instantaneous total suspended sediment concentration and discharge from Upper Mossman.

All observed TSS and discharge pairs were used to derive the regression model. The data available is presented in Figure 5, and while higher concentrations tend to occur at greater discharges there is also a large increase in variability. This is a phenomenon that makes consideration of the relationship on the log scale a necessity.

Linear and quadratic terms in time are included so as capture the exhaustion. This simple model used may then be represented as follows

$$\log(\text{concentration}) = \beta_0 + \beta_1 \log(\text{discharge}) + \beta_2 \text{time} + \beta_3 \text{time}^2 + \epsilon$$

where $\beta_0$, $\beta_1$, $\beta_2$ and $\beta_3$ are the regression coefficients and $\epsilon$ the random error.

More complicated regression models may be used. In particular more flexible functions of discharge and time may be sought. Additional covariates may also be included, for example a term indicating whether the sample was taken on the rising or falling stage might be introduced in order to address any perceived hysteresis. Autoregressive errors might be introduced to account for any serial correlation in the data.

The described regression model fits the observed data reasonably well, though it only explains about 2/3 of the variation of the log concentration. The polynomial terms in time are found to be important predictors.

This regression model is then used to predict the TSS concentration at all times. The estimated sediment load for the complete data set is 3996 tonnes, more than 1000 tonnes less than the estimate for the actual data. This follows because the predicted TSS from the regression model has reduced some of the variation in the concentrations.

In order to assess the sample size that we may require we need to investigate the variability in the Beale estimate of load estimates under alternative and equi-likely sample sets. The intention being to identify the sample size required to yield a reliable estimate of load regardless of the actual samples times selected.
The observed discharge and the predicted concentration from the regression model are thus taken as complete data and sample sets of a given sample size are then created by randomly sampling within the 4 strata in Figure 1. The precise allocation of the sampling effort to the strata is predetermined and recognizes that the more variable strata should demand more sampling effort in relative terms so that they are well characterized and the total load is estimated as efficiently as possible. Statistically this is known as the ‘Neyman allocation’. It uses the size (in total number of units available for sampling) and the variance of the strata (Table 1) to determine the optimal allocation. These proportions are usually taken as indicative with the actual effort allocated to nearby round numbers or increased for small strata so that the sampling effort is large enough to avoid them being unduly affected by unusual values.

Table 4. Relative sampling proportions using the observed TSS and TSS as estimated by the regression model. The allocated sampling proportions are given in the bottom row and increase the proportions in the less sampled strata as a contingency.

<table>
<thead>
<tr>
<th>Strata</th>
<th>Early low</th>
<th>Early high</th>
<th>Late low</th>
<th>Late high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed TSS</td>
<td>0.01</td>
<td>0.05</td>
<td>0.03</td>
<td>0.91</td>
</tr>
<tr>
<td>Estimated TSS</td>
<td>0.01</td>
<td>0.07</td>
<td>0.10</td>
<td>0.81</td>
</tr>
<tr>
<td>Allocated</td>
<td>0.025</td>
<td>0.075</td>
<td>0.10</td>
<td>0.80</td>
</tr>
<tr>
<td>sampling</td>
<td>proportions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4 presents the suggested allocations for the strata in Figure 1 and the sample sizes and standard deviations given in Table 1. The allocation is also given for the standard deviations derived from the regression-estimated TSS. The final allocation used is the last line of the table and subjectively combines this information and notably increases the allocation in the early low strata as a precaution. The great majority of the sampling effort is dedicated to the late season – high flow strata. This should come as no surprise given it is a stratum with a large number of sampling units and high variability.

Table 5 presents the simulation results of the TSS load estimate using the Beale estimator for a range of sample sizes. 1000 alternative samples sets are drawn for each sample size. The average of those 1000 simulations of each sample size is fairly close to the 3996 tonnes obtained using the predicted TSS concentrations for all hourly time points. As the sample size increases however the variability of those estimates falls and the estimated load become more closely clustered around the true value. This is particularly evident in Figure 6 which presents all the simulation results graphically. It follows from Table 4 and Figure 6 that to estimate the sediment load with an accuracy of 1000 tonnes (±25%) we would need in the vicinity of 100-125 samples. To increase the precision to 500 tonnes (±12.5%) the sample size needs to increase to approximately 400 samples. That these sample sizes are so large for what are still fairly wide intervals reflects the variability in loads at the Upper Mossman location.

Table 5. Summary of average TSS load estimate and the empirical 90% simulation interval half-width for 1000 sample sets from a range of possible sample sizes.

<table>
<thead>
<tr>
<th>Sample size</th>
<th>75</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average estimate</td>
<td>3880</td>
<td>3918</td>
<td>3892</td>
<td>3900</td>
<td>3969</td>
<td>3933</td>
<td>3953</td>
<td>3967</td>
<td>3988</td>
</tr>
<tr>
<td>90% simulation interval half-width</td>
<td>1283</td>
<td>1050</td>
<td>908</td>
<td>874</td>
<td>757</td>
<td>650</td>
<td>583</td>
<td>490</td>
<td>432</td>
</tr>
</tbody>
</table>
Figure 6. Estimates of total load under simulated sampling regimes of various sizes. The red lines correspond to the 90% set bounds. The blue line the target load.

Different allocations of effort to 4 strata are found to affect the range of the load estimates. For instance, allocating the sampling effort to the strata according to the size of the strata leads to even wider intervals. This is found to also occur if an averaging load estimation method based on the 4 strata is used.

The conclusions reached from these simulations must be seen as an indication only. The precise number required may depend a lot on the characteristics of the season. Moreover, the regression estimated TSS will be expected to show less variability than the true TSS (by virtue of explaining only 2/3 of the variation) and this may carry through to load estimates that also show less variability than we might otherwise expect. On the other hand, in practice we may be placing our observations more systematically along the hydrograph, rather than randomly sampling, and accrue greater efficiency that way.

Another way of obtaining an indication of how many samples may be required is to consider how well the observed hydrograph is represented by various sample sizes. While the changes in the flux are distinct from those of the hydrograph, they are strongly related and it seems very reasonable to assume that a sampling regime that characterizes the hydrograph well will also capture changes in the sediment and nutrient flux, and thus provide reliable estimate of the load.
This is investigated for the Upper Mossman hydrograph. A stratified systematic sampling regime is employed to choose the sample points for simplicity. The hydrograph is divided fairly roughly into event and inter-event conditions with the different systematic sampling intensities used for the event and inter-event times (Figure 7). In order to focus our sampling effort during event conditions the time increment between samples is assumed to be 5 times as large for the inter-event conditions as for the event conditions. Other multiples were trialled but 5 was found to place approximately 75-80% of the total sampling effort during event conditions.

Each sample data set selected is then interpolated to give an approximate hydrograph. The closer this hydrograph is to the true hydrograph the more effective the sampling regime has been at representing changes in the system. The effectiveness of a sample size is assessed by computing the integrated squared difference between the approximate and true hydrograph. For continuous functions \( f \) and \( g \) this is defined as \[ \int (f(t) - g(t))^2 dt. \] In this instance we use a discrete approximation to this functional form by interpolating \( f \) and \( g \) to hourly increments and summing all the squared differences.

Figure 8 plots the integrated square difference as function of sample size. While the integrated squared difference clearly decreases as the sample sizes increases, it appears that beyond a sample size of around 100-125 the additional sampling effort results in much more modest decreases in the integrated square difference.

Somewhere in the vicinity of 100-125 samples, with the great majority dedicated to event conditions, might then be expected to characterize the hydrograph reasonably well. Provided the patterns for sediment and nutrient flux are strongly related to changes in depth this conclusion might also be extended to representing flux.

![Graph showing event and inter-event stratification](image-url)

Figure 7. Event and inter-event stratification used to assess sample sized required for representation of the Upper Mossman hydrograph.
4.1.3. Future Sampling Regime For Upper Mossman

- Use the rate of rise algorithm to direct the sampling effort to the event and inter-event strata.
- 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.
- While inter-event conditions make a small contribution to the load it is important that the sampling effort be increased during those times (over the effort in the interim monitoring program) for reliable load estimation.
- Reduce unnecessary over-sampling caused by depth fluctuations around sample trigger points.
- Take at least 100 samples.
- It is important to take samples during the dry/winter. As this is expected to make a very modest contribution to load and sampling may not be possible with the auto-sampler due to the low depth it is proposed that a (community) grab sample be taken once per month throughout the year.
- If too many samples are triggered, or if a strategy of over-sampling is adopted, and the sample number must be thinned 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. Examine the patterns of variations in the flux and use that to help determine the ideal stratification.
- Use the Beale ratio estimator, with bias correction, to estimate load. It is however important to assess whether the underlying assumptions for the Beale estimator are met. It is strongly encouraged that other load estimation also be investigated. If different methods are giving fairly consistent load estimates that gives us greater confidence that we are close to the mark.
4.1.4. Future Sampling Regime For Upper Daintree

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

4.2. Lower Catchment Case Study: Saltwater Creek.

Saltwater Creek has the most complete data record for the lower monitoring sites. A total of 400 samples are triggered and 105 samples analysed from the 2003/2004 wet season. The samples analysed are concentrated on some of the larger stream events, though no samples are analysed during the largest event in early March. There is an equipment-related breakdown in sampling in April. Saltwater creek is tidally influenced.

4.2.1. Calculation Of Sediment Loads

Load can not currently be estimated from the sampling undertaken at any of the lower catchment sites because there is no measure of discharge available. Methods that are used at the upper catchment sites (rating curves or Manning’s equation) assume the flow is uni-directional. These are not appropriate when there are significant tidal incursions and the freshwater gets pushed back. Doppler velocity meters may enable discharge to be calculated when there are changes in direction of the flow, though are expensive. They are described in more detail in Appendix D.

The calculation of load in tidally influenced sites is a significant challenge. Not only because of the difficulty in determining sediment and nutrient delivery when discharge is hard to measure, but because the interaction between the tidal and freshwater incursions may affect the entire biogeochemistry and influence what is eventually carried onto the GBR. Webster et al (in press) use a modelling approach to investigate the interaction between river sediment and nutrient delivery and the tidal processes.

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 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 to arrive at an improved sampling strategy for the site.

4.2.2. Sampling For Concentration Data

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 strategy outlined in this section should be followed.

The strong tidal influence at the lower sites makes it critical to use an EC-triggered sampling regime in order to avoid sampling when conditions are dominated by tidal incursions. The challenge is to improve the use of depth information in the regime so that obvious freshwater
events are sampled more heavily than during the baseflow phase. The proposed way of doing this is to use the average depth, calculated over the previous 24 hour period. In taking the depth over 24 hours the hope is to at least partially filter out the changes in depth due to the tides and to represent any changes due to the stream discharge more reliably.

The rate of rise regime is preserved but the time triggered sampling is forced to increase in frequency when the average 24 hour depth is high and likely to be influenced by a freshwater event. An average depth threshold needs to be set to make the distinction between the two time-based sampling intensities. For example, during base flow mode we might take a sample if the time since the last sample was greater than 48 hours. If however the 24 hour average depth is high, and we are likely to be in an event, we may choose to take a sample if the time since the last sample was greater than 6 hours say. The increase in sampling intensity thus reflects the desire to capture freshwater incursion events better.

Figure 9 plots the average 24 hourly depth on top of the Saltwater Creek hydrograph. While it is clearly still variable, the averaging has removed a great deal of the cyclical variation in depth caused by the tides and enables us to link changes in average depth to freshwater incursion events.

An example of the samples that might be collected for the 2003/04 wet season using this methodology is given in Figure 10 and Figure 11. In this example total 225 samples are collected, 82% of those taken during event times. The average depth threshold for determining event mode is set at 1.25 metres. When the average depth exceeds this threshold the site is deemed to be in event mode and samples are triggered every 6 hours, as compared to the less frequent sampling every 48 hours during inter-event mode. Samples are only taken when EC is less than 100 (µS/cm).

Figure 9. Saltwater Creek hydrograph with average 24 hourly depth superimposed in dark blue. The line at an average depth of 1.25 metres is a possible threshold for determining whether conditions are in event mode.
Figure 10. Depth and samples triggered at Saltwater Creek from December 2003 to July 2004 for an example sampling strategy. The blue segments indicate where the average 24 hour depth places the site in event mode.

Figure 11. EC and samples triggered at Saltwater Creek from December 2003 to July 2004 for an example sampling strategy. The blue segments indicate where the average 24 hourly depth places the site in event mode.
The proposed upper and lower sampling strategies still require specific parameters to be selected to govern the sampling frequency and responsiveness to changes in the depth or EC.

4.2.3. Examining The Required Sampling Frequency

Characterizing constituent concentrations at Saltwater creek is a more general aim than the estimation of mass loads. As such it is more difficult to determine how many samples should be taken. It is proposed to make this decision on the basis of statistical power. In doing so we seek to identify the number of samples required to detect a specified change in the mean wet season concentration for total suspended sediment, total nitrogen and total phosphorus. Unfortunately this is not possible for Lower Daintree and Lower Mossman because fewer samples are taken and those that are tend to focused in a short window of time, rather than across the season. The sediment and nutrient data collected for Saltwater creek is overlayed on the hydrograph in Figure 12.

Figure 12. TSS, TP and TN concentrations at Saltwater Creek over the 2003/2004 wet season.

The TSS concentration data collected at Saltwater Creek during the 2003/04 wet season is summarized in Table 6, where the number of observations collected, the mean and the standard deviation for TSS are stratified according to the time in the wet season and the average 24 hourly depth. The wet season is partitioned into 3; December – February, March and April-June. The average 24 hourly depth is divided into two categories, a low inter-event category and a high event category according to the depth being less than or greater than 1.25 metres (the mean and median average 24 hourly depth are 1.29 and 1.18 metres respectively and governed this choice). This is an arbitrary post-stratification and is heavily influenced by the pattern of the observed data. The
proportion of time the Saltwater Creek conditions are in each of the 6 strata for the 2003/04 wet season are also given in Table 5. Low inter-event conditions in March are clearly fairly rare.

The stratified mean and standard deviation for TSS are 32.69 and 35.69 (mg/L) respectively and indicate the high variability in the concentration data. They are considered more representative than the unstratified equivalents because they account of the distribution of the observed concentrations across the conditions. The unstratified mean and standard deviation in this instance fail to recognize the strong emphasis on the sampling during event conditions.

While only a small number of samples are available with which to calculate the stratum means and the standard deviations, particularly for the low inter-event conditions, the summary data largely fit the pattern expected. The mean and standard deviation for the TSS concentrations are both notably higher during event conditions. Moreover, the mean and standard deviation decrease as the wet season progresses which is consistent with the exhaustion processes discussed earlier in this report.

Table 6. Saltwater Creek - summary of total suspended sediment by time in the wet season and the 24 hourly average depth.

<table>
<thead>
<tr>
<th>Average 24 hourly depth</th>
<th>Time</th>
<th>December to February</th>
<th>March</th>
<th>April to June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (≤ 1.25m)</td>
<td>Stratum proportion</td>
<td>0.31</td>
<td>0.02</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td># of samples</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>33.8</td>
<td>19.5</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>standard deviation</td>
<td>42.3</td>
<td>9.2</td>
<td>4.4</td>
</tr>
<tr>
<td>High (&gt; 1.25m)</td>
<td>Stratum proportion</td>
<td>0.12</td>
<td>0.13</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td># of samples</td>
<td>29</td>
<td>51</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>74.4</td>
<td>53.3</td>
<td>26.0</td>
</tr>
<tr>
<td></td>
<td>standard deviation</td>
<td>59.6</td>
<td>35.8</td>
<td>23.7</td>
</tr>
</tbody>
</table>

In order to determine the sample size required to characterize TSS concentrations at Saltwater Creek we use the notion of statistical power. More specifically, we are interested in determining the sample size required to detect a change in the mean TSS concentration of a pre-determined proportion ($\lambda$) with probability (power) equal to $\rho$. These numbers are given by

$$n \approx \left[ s \left( z_\alpha + z_\rho \right) / \bar{c} \lambda \right]^2$$

where $s$ is the standard deviation, $\bar{c}$ is the mean concentration, $z_\alpha$ is the appropriate quantile from the standard Normal distribution for a probability of a type 1 error of $\alpha$, and $z_\rho$ corresponds to the quantile from the standard Normal distribution for power (probability) equal to $\rho$.

The sample sized required to detect percentages in the mean concentration ranging from 0.10 to 0.50 for $\alpha=0.05$ and power $\rho$ of 0.80 are presented in Figure 13. Over 100 samples are required to detect a change in the mean concentration of 25%. Larger changes will be detected with smaller sample sizes. For instance, around 45 samples will detect a change of 40% from the baseline level. These percentage changes may occur over a number of seasons/years.
Figure 13. Sample sized required to detect an effect size as a percentages of the mean TSS concentration ranging with 80% power.

The required sample numbers in Figure 13 are based on detecting a change from a known baseline TSS mean concentration. When we are interested in detecting a difference of the same proportion between samples taken for two seasons the numbers will need to be doubled.

These sample size calculations are very approximate and are based on the assumptions of Normally distributed data and random sampling, neither of which are strongly justified for the 2003/04 wet season data.

There is some argument that the sample size calculations should be conducted on the log transformed variate. While the TSS concentration data collected at Saltwater Creek is positively skewed, the log transformation is found to be too strong for inducing the Normally distributed data upon which the sample size / power calculations are predicated. The untransformed data is thus used here for simplicity. If it is subsequently found that TSS is indeed log-Normally distributed, the suggested required sample sizes are likely to enable us to detect smaller percentage changes in the log-transformed variate. There is therefore more power to detect a difference with the sample sizes quoted.

The allocation of the sampling effort (sample size) to strata like those in Table 6 can be determined by the strata standard deviations and the proportion of time conditions for the 2003/04 wet season fall in each stratum. This is known as the ‘Neyman allocation’ (Cochran, 1977). Assuming the effort is placed evenly throughout the year and changes only with the average 24 hourly depth stratification, we would allocate 56% of the effort to sampling during event conditions.

4.2.4. Future Sampling For Concentration Characterisation At Saltwater Creek

- 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 EC trigger to avoid taking samples when conditions are most affected by tidal incursions.
- Use the average 24 hourly depth, 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 amidst event conditions and less frequently during inter-event conditions.
- Seek to take around 60 samples initially.
- Place approximately 60% of the sampling effort into event conditions.
4.2.5. Future Sampling For Concentration Characterisation At Lower Mossman And Lower Daintree

The concentration data collected at the Lower Mossman and Lower Daintree sites is significantly poorer than Saltwater Creek and does not allow a similar analysis. Conditions are however very similar with strong tidal incursions playing an important role in the conditions at all the monitoring sites. It is recommended that an identical strategy be employed at all lower catchment sites. The threshold for the average 24 hourly depth and the EC triggering values must be selected for each site individually to account for the different depth and salinity characteristics.

5. Conclusion

Ideally 5 -10 years of data is required to develop robust methods for estimating load. This ensures we encounter events and sequences of events of a varied nature and have a program that may cope with the strong year to year variation in discharge and load. The conclusions reached here are based on one season of data and should be treated with some caution for this reason.

It is important to direct more sampling effort to those times that have larger and more variable flux patterns. The rate of rise algorithm is advocated for this because it makes the stratification between event and inter-event conditions without relying on any pre-conceived notion of a threshold depth. This is particularly useful in the Douglas Shire catchments because the inter-event depth increases substantially from the early wet season to the middle of the wet season. It is recommended that at least 100 samples be taken at the Upper Mossman and Upper Daintree sites with 75-80% of the sampling taking place during event conditions.

As data is collected over more years and the hydrograph and sediment/nutrient delivery process are better understood a probabilistic approach (e.g. a flow-stratified regime) may be an attractive option because it naturally provides unbiased estimates of load and the precision.

Additional resources need to be placed into estimating discharge at the upper catchment sites. The rating curves used need to be further developed so that depth records may be reliably turned into discharge measurements and that source of uncertainty in load estimation be reduced.

Community sampling may be necessary at the upper catchment sites, particularly during the season when the depth falls below a level at which the automatic sampler can draw samples. It is recommended that a community grab sample be undertaken once per month during inter-event conditions throughout the entire year. Community sampling at sites other than those with automatic samplers may help satisfy other water quality objectives but is of limited value for the estimation of sediment and nutrient loads.

The largest impact from anthropogenic activity in the Douglas Shire will occur at the lower catchment sites. Sediment and nutrient loads can however not be estimated at these sites because no reliable measure of discharge is currently available for the tidally affected locations. In order to progress this it is critical to investigate a range of possible solutions to determining discharge when there are tidal incursions and the flow is not uni-directional. At the moment, the sampling strategy for the lower catchment sites is very much about characterizing concentrations at those locations. No conclusions can be reached about load.

In order to sample for concentration effectively we must take account of the electrical conductivity and sample only when it is low so as to avoid taking tidally affected samples. It is also recommended that a continuous 24 hourly average depth be used to filter out the effect of the tides and identify larger stream events that should be sampled more intensively. Seek to place approximately 60% of the effort into event conditions and take around 60 samples initially.

The Beale ratio estimator is advocated as the preferred load estimation method. It is well supported in the literature, less dependent on the timing of the actual samples taken, naturally copes with stratified sampling, is relatively robust to missing or unusual values and does not make large sampling demands. Alternative methods for load estimation should also be trialled. Obtaining consistent estimates of load using different approaches adds support to the load estimate. It is
however important to thoroughly investigate whether the data collected support the assumptions underlying the load estimation method. Loads should not be estimated blindly.

A greater consideration of the uncertainty in load estimation is warranted. The provision of accurate standard errors or measures of precision will lead to more informed decision making.

The ability to detect trends and compliance with target loads is intimately tied to the precision of the load estimates. More precisely measured sediment and nutrient loads will invariably enable trends to be detected more quickly or smaller trends to be discovered. It is important that consistent load estimation procedures be used to facilitate fair comparisons. Any changes to the sampling strategy should also be carefully noted in order to avoid potential confounding issues.

The load-based monitoring program for the Douglas Shire is still in a characterization phase. The sampling regimes should be reviewed each year as more data is collected and knowledge about the systems and the appropriate choices of parameter settings improves. An optimal sampling strategy for load estimation will only be achieved by seeking to continually improve.

References


