NATURAL RESOUCES OF THE BARRON RIVER CATCHMENT 2

Water Quality, Land Use & Land Management Interactions

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Natural Heritage Trust

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Natural Resources of the Barron River Catchment 2.

Water quality, land use and land management interactions

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ACRONYMS

ANZECC	Australian and New Zealand Environment and Conservation Council
BRICMA	Barron River Integrated Catchment Management Association
CMSS	Catchment Management Support System
DNR	Department of Natural Resources
DSS	Decision Support System
FNQ2010	Far North Queensland 2010
ICM	Integrated Catchment Management
MDIA	Mareeba Dimbulah Irrigation Area
NHT	National Heritage Trust
NSW	New South Wales
QDPI	Queensland Department of Primary Industries
QLD	Queensland
STP	Sewage Treatment Plant
WAMP	Water Allocation and Management Plan

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EXECUTIVE SUMMARY

The Barron River in north Queensland is one of the most heavily utilised and impacted of all wet tropics streams. The river, and its tributaries, originate on the Atherton Tablelands and pass forests, agricultural lands, water impoundments and the townships of Atherton and Mareeba before entering the Great Barrier Reef lagoon at the city of Cairns. The Barron River Integrated Catchment Management Association (BRICMA) was formed as part of the integrated catchment management initiative and required quality baseline information to assist in formulating and implementing its strategies. A project titled "Techniques for optimal environmental management of tropical catchments" was funded by the National Heritage Trust (NHT) program and undertaken by a joint Department of Natural Resources (DNR) and Department of Primary Industries (QDPI) team to address this requirement.

Key findings presented in this report (number 2 in the Natural Resources of the Baron River catchment series) include:

- the whole catchment has over two thirds of its area as forest, but specific sub-catchments have large proportions of agricultural or urban land use and some have poor riparian cover;
- the work shows that large quantities of sediment and nutrient are mobilised during major storm events in the catchment. This material will eventually be transported to the Great Barrier Reef lagoon, although large quantities are retained in Lake Tinaroo;
- water quality over most of the catchment is within acceptable limits although there are some specific 'hot spots' that need to be addressed, including the sewage treatment plants (STP) within the catchment; and
- a decision support tool for developing co-operative nutrient management strategies has been developed and is available for use.

There are a number of actions that can be taken by the community at large and organisations, such as BRICMA, to ensure that the Barron River catchment retains its valuable contribution to the north Queensland environment. These include

- sponsoring a "whole of catchment" approach to sediment and nutrient management, which attaches importance to all land and all waterways in the Barron River catchment;
- managing point sources of sediments and nutrients in the catchment. These include STP's and intensive livestock enterprises. Best practice guidelines already exist for several intensive livestock industries, which should be followed. Technology for reduced emissions from STP's exist and an increased effort to installation throughout the catchment should occur;
- improving the management of diffuse sources of sediment by an increased commitment to soil conservation practices throughout the catchment including on farm (conservation cropping and soil conservation works) and on roadways, particularly gravel roadways. Dynamic best practice guidelines should be developed with industry and agencies to achieve optimum results;
- implementation of urban sediment and nutrient management practices to reduce loads flowing into watercourses. These include the use of gross pollutant traps and urban wetlands for filtering runoff waters. Planning

guidelines should be developed to limit sediment flows during annual wet seasons;

- the cataloguing of all water quality data, and other data, for the catchment should continue under the existing BRICMA Meta-data project;
- continued community monitoring of water in the catchment to provide important insights to the health of the catchment. The community monitoring effort should develop new ways to incorporate a broad cross section of catchment landholders; and
- using decision support systems (eg WinCMSS) and information with catchment stakeholders to develop mutually agreed management plans. This report and project provides the tools to develop such plans for nutrient management on a catchment basis.

INTRODUCTION

The Barron River system is one of the most heavily utilised and impacted of all the wet tropics streams in Queensland. The river is sourced as small, forested, freshwater tributaries in the Atherton Tablelands and discharges into the Coral Sea as a major perennial watercourse (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). Land use in the catchment includes intensive and extensive agriculture, recreational activities, rural residential and urban areas. The importance of the catchment is recognised in Integrated Catchment Management (ICM) initiatives, NHT strategies and the FNQ2010 planning process. Public concern for the well being of the river system is evident in local publications and the willingness of the broader community to participate in planning processes.

The Queensland Government initiated the ICM process to involve the community in developing coordinated and participatory plans for catchments throughout the State. The process in the Barron River commenced with the Barron River Overview Study (Anderson 1993) which was conducted between 1992 and 1993, and subsequently led to the formation of the Barron River Integrated Catchment Coordinating Committee, later renamed as the Barron River Integrated Catchment Management Association Inc. (BRICMA). This catchment group and its zone fora are now well established and recently completed the Barron River Catchment Management Strategy (BRICMA 1998). During the development of the strategy, BRICMA identified a need for information on the environmental status of the waterway and factors affecting water quality.

Funding was successfully sought from the NHT to undertake a project to meet needs identified by BRICMA. A team of biologists and soil scientists from the Departments of Natural Resources and Primary Industries was assembled for project activities. It was recognised that the project would also provide a basic pro forma for projects in other catchments where assessment of the river system requires a holistic approach encompassing biological, physico-chemical and socio-economic aspects, linked to ICM strategic documents.

The specific objectives of the project were:

- to undertake a comprehensive environmental audit of the Barron River system encompassing its stream ecology, water quality and wetlands;
- to monitor the impacts of catchment land use and their management practices in the catchment on the environment and water quality;
- to facilitate community access to these data through publications, demonstrations and user friendly computer software; and
- to provide information and guidelines through community consultation for the optimal management of the Barron River.

Volume two of the Natural Resources of the Barron River Catchment provides baseline information on biophysical parameters, including nutrient levels in the Barron River and its tributaries, and identifies potential problem areas. It also provides information on the nutrient production capacities of various land use and management, and provides a basis for the development of management plans using a simple decision support tool.

Plate 1. Gauging station at Kauri Creek.

Plate 2. Event flow at Hemmings Road.

Plate 3. Barron River below Lake Placid.

BACKGROUND / LITERATURE REVIEW

A number of recent literature reviews on the Barron River exist and each covered important aspects of resource management and environment in the catchment. The reviews include:

- Werren (1997) who considered the rehabilitation needs of the Barron River catchment with a vegetation perspective;
- Cogle *et al.* (1998) who dealt with water quality and stream health in the Lake Tinaroo catchment;
- Brizga *et al.* (1999) who presented environmental considerations for the Barron WAMP, with particular reference to environmental flows; and
- AGE Consultants (1999) who reviewed literature on the Barron River catchment identifying new information on flood and riverine management.

Lake Tinaroo and Catchment Water Quality
In the upper Barron River, Mitchell *et al.* (1991) showed that a relationship existed between phosphate concentration and rainfall events, over one month at the start of the wet season. However they did not find a similar relationship for nitrate. Littlemore *et al.* (1991) reported nutrient levels in Lake Tinaroo and identified inflows from agricultural (Barron River, Peterson Creek, Mazlin Creek) and urban catchments (Mazlin Creek) as the major source of nutrients to the dam. These authors also concluded that the phosphorus fixing property of the basaltic clays in the catchment helped reduce dissolved phosphorus concentrations. Hlaing (1991) was similarly concerned with the high concentrations of nitrate and phosphate originating from the Barron River and Mazlin Creek, but neither report considered nutrient loading from dam inflows.

Hlaing (1991) also discussed major land use changes that occurred in the catchment including the conversion of crop land to pasture and the causes of high sedimentation rates at the mouth of Mazlin Creek. In some parts of the catchment, rainforest has recently been cleared to make way for agricultural use, in addition to that cleared in past decades. Indeed, Collins (1994) reported that between 1978 and 1988, a further 8.9% of the 1978 rainforest area was cleared on the Atherton Tableland, some of which is in the Lake Tinaroo catchment.

Land management changes have resulted in an increase in fertiliser application to agricultural lands (Hlaing, 1991). However, while Littlemore *et al.* (1991) expressed concern at the quantities applied, little work has been done to estimate fertiliser efficiency or crop nutrient removal and its effect on nutrient runoff.

Data on water temperature, dissolved oxygen and stratification, collected by the Queensland Department of Primary Industries - Fisheries, over two years (MacKinnon and Herbert, 1996) showed that Lake Tinaroo exhibits thermal stratification throughout most of the year. During the study, breakdown in stratification occurred in late May to June and persisted until September. From October to May, multiple thermoclines developed however localised disruption of stratification by oxygenated, cool denser inflows occurred during flood events. Russell (1987) showed similar responses during 1973 and 1974.

A preliminary study of water quality in Lake Tinaroo was undertaken by Cullen (1988) for Queensland Department of Primary Industries (QDPI)- Water Resources. Several recommendations were made, and in response to the rising public concern for water quality in Lake Tinaroo, DPI-Water Resources initiated several water studies (Poplawski, 1994). The objectives of these studies were:

- to monitor inflow and dam nutrient levels (Water Resource Commission, 1993); and
- to provide an outline of water quality policy for the Tinaroo Falls Dam (Water Resource Commission 1992a).

Comprehensive reports (Lee Young, 1995a,b) recommended that water quality monitoring continue for a further three years from 1995, as inconsistencies in methodology and some unusual results precluded use of data from previous studies. The report also found that:

- high levels of total nitrogen (Total N) and total phosphorus (Total P) persisted in Mazlin Creek;
- Total P levels in Lake Tinaroo were within the acceptable range, but Total N levels sometimes exceeded acceptable levels; and
- phytoplankton growth was likely to be limited by phosphorus.

Monitoring of algal populations in the lake is currently being undertaken by DNR-State Water Projects and it has been found that blue green algae populations' fluctuate with seasonal impacts (D. Grace, State Water Projects, pers. comm.).

Sewage effluent release into Mazlin Creek from the Atherton STP does not consistently meet licence requirements (Atherton Shire Council, 1996), however a strategy was developed to implement improved management over the next five years. The strategy included the construction of a balancing storage so that effluent can be used for irrigation of local farms and forested areas. Recently an upgrade to the existing STP has been announced.

Important information on the nutrient flows and biological properties of waterways in the Lake Tinaroo catchment and Lake Tinaroo was published in a recently completed NLP funded project (Cogle *et al.*, 1996; Gourley *et al.*, 1996; Herbert *et al.*, 1996; Wright *et al.*, 1996; Cogle *et al.*, 1998). This project emphasised the deleterious impact of poor water quality in Mazlin Creek on nitrogen and phosphorus loads entering the lake and discussed the value of biological indicators for identifying water quality in the catchment.

Barron River Water Quality (below Lake Tinaroo)

Water quality in the Barron River was assessed intermittently during the 1974/75 wet season by Whelan (1977 a and b). He concluded that a large quantity of nutrients was being transported down the river, but that nutrient concentrations were not overly high. In a preliminary desktop assessment, Moss *et al.* (1992) estimated annual nitrogen loads (647 000 kg), phosphorus loads (90 000 kg) and sediment loads (137 000 000 kg) for the Barron River and concluded they were in the low end of the range for Queensland coastal rivers. However, they also found that the generation rate (kg ha^{-1}) of these contaminants was in the middle of the range for Queensland catchments.

A baseline environmental survey conducted for the Cairns International Airport included an analysis of water quality in the lower reaches of the Barron River (Australian Centre for Tropical Freshwater Research, 1995). This study found that levels of the nutrients (nitrogen and phosphorus) at times exceeded Australian New Zealand Environmental Conservation Council (ANZECC) guidelines. The large impact of the sewage outfall, near the mouth, was also emphasised. Devine and Taylor (1999) provides further information on water quality in the Barron River estuary and, in particular, concentrations of water quality parameters during Cyclone Sadie (29 January 1994). The Department of Environment and Heritage (1993) compiled water quality data from across Queensland including the Barron River.

The Barron River Catchment Overview Study (Anderson *et al.*, 1993) identified water quality, water supply and land use conflict as major issues in the Barron River catchment. The study included public consultation involving 450 people of whom seventy three percent rated water pollution as a key issue. A community Waterwatch program is underway within the Barron River catchment (Wright *et al.*, 1996).

General Water Quality References

The Australian Journal of Soil and Water Conservation (1991) and the conference on "Downstream Effects of Land Use" (Hunter *et al*., 1996a) compiled current knowledge on water quality in Australia. These reviews emphasised that water quality as an Australia-wide issue was increasing and that change in land use and land management was needed to address many of the causes. Cullen (1991) noted that both non-point sources such as agricultural and urban runoff, along with point sources such as STP's were contributors of contaminants and emphasised the importance of storm flows to the total contaminant export in waterways.

Meybeck (1982) compiled available international information on carbon, nitrogen and phosphorus transport in world rivers. This broad ranging review provided nitrogen and phosphorus data for both tropical and temperate streams and also data on carbon levels. The author concluded that man's impact resulted in an increase in nitrogen and phosphorus levels in surface waters. Furnas (1991) reviewed the dynamics of nutrients in tropical aquatic ecosystems. While this review was biased to marine waters, it provides further data on nutrient levels in tropical freshwaters and discussed nutrient transformation processes, including loss mechanisms. The exchange of nutrients between the water column and sediments was also considered.

A nutrient generation databook (Marston *et al.*, 1993) was compiled as part of the Catchment Management Support System (CMSS) framework (Farley and Davis 1993). These data and a subsequent computer based database, NEXSYS, provided a valuable summary of results from the literature for nutrient generation from different land uses and management. Due to the location of previous research, however, much of the information was from southern Australian or overseas locations.

A conference on the impact of land based activities on the Great Barrier Reef Lagoon was held in 1991 and an edited proceedings of papers are available (Yellowlees, 1991). Baldwin (1992) reported on the impact of elevated levels of nutrients in the Great Barrier Reef lagoon levels being higher in areas adjacent to greater human use. Brady *et al.* (1991) assessed water quality in the Barron River / Trinity Inlet area and compared it to waters at Green Island over a 20 month period. Elevated levels of nitrogen and phosphorus at some sites were related both to the season and the proximity to the Barron River mouth. They also found elevated chlorophyll-a levels were associated with a sewage treatment plant on Green Island.

The Trinity Inlet Management Program (1996) released an updated brochure detailing outputs from a pollutant export model for Trinity Inlet at Cairns. The brochure identified the major contribution from urban lands of nitrogen and phosphorus loads into the catchment.

Caitcheon *et al.* (1995) working in the Chaffey Reservoir catchment, New South Wales (NSW), noted that sulphate, derived from fertiliser, may exchange for phosphate attached to bottom sediment in the anoxic layers of the reservoir. These authors also identified natural basalt derived phosphorus as the major source of water borne phosphate and recommended reservoir management as more appropriate in these circumstances to prevent blue-green algae problems, rather than improved catchment management.

Soil erosion on the Atherton Tablelands is currently being monitored as part of a project funded by the Australian Centre for International Agricultural Research (ACIAR) (L. Cogle, DNR, pers. comm.). This work has shown the importance of reducing cultivation and increasing crop residue cover on reducing soil erosion and runoff. In the adjacent Johnstone River catchment, on-site soil erosion in conventionally cultivated cane lands ranged between 47 and 505 t ha^{-1}, compared to <15 t ha^{-1} for no tillage cultivation (Prove *et al.*, 1995). Further studies of the impact of this on catchment water quality are underway (Prove *et al.*, 1994; Moody *et al.*, 1996; Hunter, 1993a,b; Hunter, 1994; Hunter *et al.*, 1996b).

Russell and Hales (1993) and Russell *et al.* (1996) reported on the stream habitat and fish resources of the Johnstone and Russell/Mulgrave Rivers (respectively) in north Queensland. Both reports identify human activities, both urban and agricultural, as damaging stream habitat and urge the development and implementation of strategies through the ICM process.

Urban Water Quality

The contribution of urban activities on water quality can be large and may result from both non-point and point sources (Connell, 1984). Changes in the levels of dissolved oxygen, petroleum hydrocarbons and polychlorinated biphenyls were associated with urban environments, as was eutrophication and siltation of waterways.

Sharpin (1994) reviewed the issues associated with urban stormwater and identified that:

- the impacts of urbanisation of catchments affected both hydrology and contaminant transport;
- hydrologic effects included higher peak flows and runoff volumes, which are dependent more on extent of impervious ground surface rather than the antecedent moisture; and
- that contaminants vary both in type and proportional importance and include sediment, nutrients, metals and toxicants, oxygen demanding substances, bacteria and hydrocarbons. Mathematical modelling tools are available to assess the potential severity of problems and possible management structures (McAlister, 1991).

Sharpin (1994) noted that there were several management practices including retarding basins for peak flow management, infiltration basins to reduce runoff volumes and erosion control, stormwater treatment, wetlands, detention basins for control of contaminants. Lehmann and Handyside (1995) were concerned that there was limited data available on the performance of many urban pollution control structures. These authors reviewed the usefulness of a range of structures including trash racks, gross pollutant traps, pollution control ponds and discuss the circumstances under which these structures will meet objectives for water quality levels.

Weeks (1980) studied urban pollution from a number of catchments in Melbourne. He showed an association between contaminant exports (kg) and runoff volumes. Pollutant exports from industrial catchments were approximately double that from residential catchments, with little difference between old and new residential catchments.

The Co operative Research Centre (CRC) for Catchment Hydrology is currently studying the impacts of urban land uses on the export of various contaminants and have estimated the annual generation rates of various activities (Wong, 1999).

Water Quality Guidelines

Guidelines for water quality available for a range of purposes have been written by a number of organisations and are constantly under review. Nationally, ANZECC (1992) compiled indicative guidelines for all uses. These guidelines have recently been reviewed and have been released in draft mode (ANZECC, 1999). Specific guidelines include those for drinking water (NHMRC, 1987), recreational uses (NHMRC, 1990; Australian Water Resources Council, 1987), and agriculture (Gill, 1986).

Movement of Nutrients off Land and Down Waterways - Enrichment Ratios and Delivery Ratios

Delivery Ratios: Sediments and nutrients move through the catchment across land surfaces and into waterways (nutrients in waterways may also be sourced from groundwater spring flow, but this will not be covered by this report). In the 1950's, it was realised that sediment deposition in reservoirs was different to the catchment erosion potential (Novotny and Chesters, 1989). The difference between the two became known as the "delivery ratio" and represents the factor that must be applied to point scale estimates of soil or nutrient movement to achieve catchment estimates. In other words, there is assimilation of sediment and nutrient between the source and the waterway outlet. However, as Novotny and Chesters (1989) and Sebrie (1991) points out that, over the long term a natural stream must transport essentially all the sediment delivered to it. The timebase for transport varies depending on the catchment, two extremes would be a steep mountain stream; and a large flat wetland.

Enrichment Ratios: Eroded soil contains valuable nutrients and is made up of different size fractions. Since the fine fraction is often preferentially eroded, information on the enrichment of eroded soil is useful in evaluating the impact of soil erosion on productivity and offsite pollution. Enrichment ratios are the common description of such a process and are defined as the ratio of nutrient or particle size concentration in eroded sediment to that in the original soil (Pallis *et al.,* 1990).

Quantification of nutrient movement within catchments and deposition within channels and water storage's requires an understanding of how these two processes combine (Novotny and Chesters, 1989), particularly if these ratios are being used in the development of management plans. Indeed, Finlayson and Silburn (1996) note that, except for certain landscapes, money spent on farm for sediment control is unlikely to improve downstream sediment yield in any reasonable timeframe. However, benefits to nutrient and pesticide movement may occur in the short term, since these solutes tend to move in solution or with fine sediment.

Effect of Riparian Zone and Grazing

The issue of cattle grazing along the riparian zone of rivers and creeks and lakeshores is a community issue. It is clear, that in many regions, further work needs to be undertaken (Bunn, 1993; Kumar *et al.*, 1996) and a major national project funded by the Land and Water Resources Research and Development Corporation is currently underway. The National project has a site in the Johnstone River (Prosser, 1996) and this will provide some information of relevance to the Barron River catchment, having some similar soils and land uses. Riparian management in the wet tropics was the subject of a forum in 1996, which brought together all stakeholders in the catchment (Johnstone River Catchment Management Association, 1996). Forums of this nature are crucial for integration of the needs of all stakeholders using the catchment.

Waterways with grazed riparian zones, have higher sediment and phosphorus concentrations than non grazed riparian zones (Owens *et al.*, 1996; Phillips and Moller, 1995; Williamson *et al.*, 1996). Williamson *et al.* (1996) also found that while dissolved nitrogen concentrations increased, this response was offset by a decrease in organic nitrogen.

Marlow *et al.* (1987) found a positive correlation between streambank moisture content and channel bank changes. The implication being that management should reduce cattle access to streambanks during periods of high moisture ie. when banks can be deformed easily. A recent report from the Kondinin Group (1996) provided information for managing stock watering from natural sources.

Methods for Water Quality Assessment

The first prerequisite for water quality assessment is to determine the primary aim of the water sampling program. Water quality issues range from human health, agricultural use, recreational use and ecosystem protection. An excellent coverage of this is provided by ANZECC (1992), while locally, the Barron River Overview Study covers issues of local interest (Anderson *et al.*, 1993). Following identification of the aims, valid and cost effective techniques need to be determined (Maher *et al.*, 1997). An important aspect is to provide information back to stakeholders, both on the type of sampling program and the data collected in the water quality monitoring programs (Hart, 1993).

Norris and Georges (1986) provided a broad review of water quality assessment techniques including physical, chemical, biological and statistical methods. Rayment and Poplowski (1992) edited workshop proceedings on water quality sampling and monitoring and covered all issues important for sampling programs.

In Queensland, a water quality monitoring network, based on streamflow gauging stations and some other sites, has been set up by the DNR (1996a,b and c). This network is part of a national monitoring program and considers stream health, biological, chemical and physical parameters.

An awareness and education program, Waterwatch, is also underway in Queensland with a local program in the Lake Tinaroo catchment (Wright *et al.*, 1996). This program involves catchment members in water quality monitoring, with analyses dependent on the resources and interests available. Wright *et al.* (1996), Foster and Sylow (1994) and Pfueller (1995) discussed the usefulness and value of these approaches.

Recently a spatially intensive approach to water quality monitoring was proposed (Grayson *et al.,* 1997; Eyre and Pepperall, 1999). This approach utilised an intensive collection of samples from a large number of sites in a short time period. It provided detailed information for one time period and hence reflected land use, geology and land management unaffected by climate variability. It thus can provide a valuable basis for management solutions, however it may not be as useful in environments with strongly defined wet and dry seasons, when major quantities of solutes are mobilised during high streamflows.

Lamb and O'Donnell (1996) have reported on the potential for airborne video assessment of water quality, however their study only reported the results with suspended sediment and was conducted along a large river (Murray River). CASI airborne spectrometer scanning has been used to identify blue green algae outbreaks in the Hawkesbury River (Jupp *et al.,* 1994). The potential for this technique is immense but further calibration and research is required to allow it to be a useful management tool. Its potential may be limited in areas with small streams and overhanging riparian vegetation.

Caitcheon *et al.* (1995) used a range of methods including stable and unstable isotopes, magnetic minerals and geochemistry to discriminate between sources of phosphate in the Chaffey Reservoir. This involved samples from catchment soils, streambanks and reservoir sediments. Maher *et al.* (1995) note also the usefulness of iron impregnated strips suspended in water bodies as being a better indicator of available phosphorus than soil science based approaches. Grayson *et al.* (1996) proposed that turbidity could be easily measured as a surrogate for sediment load and Total P loads and presented supporting data from a 5 000 km^2 catchment.

The use of sterols (including coprostanol) as markers for identifying the source of pollutants is gaining acceptance (Writer *et al.,* 1995; Quemeneur and Marty, 1994; Sadler, 1986) and recent reports have shown it to be useful in central NSW (R Leeming, CSIRO, Hobart, pers. comm.). Leeming and Nichols (1995) undertook new and innovative research to distinguish between different sources of faecal pollution in waters using sterols. While the techniques are still being calibrated, their work was able to identify birds (seagulls etc.) as major sources of faecal contamination in parts of the Tuggerah Lakes. In other parts, herbivores (cows, sheep and kangaroos) were the largest contributors. Domestic animals (dogs and cats) were found to be intermediate contributors whereas humans were minor contributors of faecal matter. A recent study (Lemming, 1999) was also conducted in the Lake Tinaroo catchment. These techniques are important tools in identifying the distribution and fate of organic matter and, linked with techniques for identifying sources of nutrients, hydrocarbons and pesticides, will provide a basis for water pollution management plans.

The methods listed above relate to the water body. Since the source of nutrient input to waterways is usually located within the catchment, surveys of catchment land users have often been used to identify major potential nutrient sources. This can also be used for other contaminants as well. Locally, Valentine 1988, the Johnstone River Catchment Management Association (1996), Pulsford (1991) and Arakel *et al.* (1993) have used such techniques. However, it is important to realise that increased fertiliser applications in a catchment may not necessarily mean increased nutrients in waterways and that increased crop production may require and utilise greater quantities of fertiliser nutrients (Rayment *et al.*, 1996).

Management Plans and Guidelines
Management plans developed in consultation with stakeholders have become a central decision making forum in many regions for managing land and water issues. In the context of this report, the Barron River Integrated Catchment Management Association strategy, the Barron River WAMP (Water Allocation Management Plan) and the Danbulla Recreational Plan in the Upper Barron River have already been alluded to. The Department of Natural Resources also plans to facilitate a stakeholder based nutrient management plan for the Lake Tinaroo catchment. Regionally, the Trinity Inlet Management Plan is another example of a spatial or catchment plan to minimise adverse anthropogenic impacts.

Shafron (1995) discussed the role and value of the “Algal Management Strategy for the Murray Darling Basin” (Murray Darling Ministerial Council, 1994). Background information to the strategy is also available (Murray Darling Commission 1993). Bek and Robinson (1991) supply further information for a range of NSW rivers including the Murray Darling system. The development of a strategy for such a large water resource and catchment provides confidence that plan development is possible for smaller catchments. Another example is the “Nutrient Management Strategy for Victorian Inland Waters” (State of Victoria, 1995).

In addition to management plans, which generally take a broader perspective, guidelines are often produced for targeted issues. Examples of relevance to this report are:

- guidelines for effluent disposal produced by the Queensland Dairyfarmers Organisation (1993). These illustrate the pro-active approach shown by industry groups to answer community water quality concerns; and
- guidelines for the monitoring and sampling of blue green algae in freshwater bodies produced by Water Resources (1992b) exist for Queensland.

Decision Support Systems and Modelling
Decision Support Systems: Decision support systems (DSS) basically refers to a range of methods or systems, which aid decision making. It has been used to include fact / information sheets, photographic handbooks, action learning exercises where participants take part in knowledge gathering and make decisions based on the acquired knowledge, and more commonly to computer based systems. Davis *et al.* (1996) reviewed computer based DSS and their use in catchment management and noted that these tools are increasingly being used in environmental and natural resource management decision making to assist decisions but not to make the decision itself. These authors discussed the requirements of managers for DSS as having: a) predictions of the future; b) an ability to explore as many possible solutions as possible; and c) an intuitive user interface. Several simple and complex DSS's were assessed, including LANDASSESS, CMSS, AEAM, HYDRA and MODSS. CMSS requires inputs of nutrient generation rates. This information has been provided by the authors in the form of a substantial literature review and a computer based expert system called NEXSYS (CSIRO, 1995). The toolkit approach to DSS (the development of simple procedures that combined make a DSS, but which can be used individually) is a further innovation.

Modelling: Modelling of the environment using computer simulation is becoming an increasingly important part of DSS. It has been an important subject on its own for many years. Modelling of runoff and solute movement may be undertaken at different scales (Grayson, 1992). Point scale modelling considers a site to have uniform site characteristics and predicts the outputs for particular management systems eg. PERFECT (Littleboy *et al.,* 1989), EPIC (Williams, 1983). Larger scale modelling at paddock, sub-catchment or catchment scales may use averaged parameters to represent a heterogeneous land area (lumping) and/or may use grids of like soil properties within the modelled area (distributed parameter), each linked hydrologically. Gallant and Moore (1992 and 1993) reviewed these models, amongst others. These authors evaluated a range of models for determining the fate of chemicals in the environment. In particular AGNPS, CREAMS and GLEAMS, ANSWERS, HSPF and SWAM were considered for surface runoff models. Foerster and Milne-Home (1995) evaluated the use of the AGNPS model (Young *et al.,* 1989) in mini catchments in northern NSW.

METHODOLOGY

Characteristics of the Barron River Catchment

The catchment encompasses an area of approximately 218 000 ha in far north Queensland between latitudes 17°30’ and 16°45’, and longitudes 145°15’ and 145°45’.

Vegetation in the catchment includes tropical rainforest, closed and open sclerophyll forest and plantation pine forest. There is a significant agricultural industry, which includes dairy, grazing, horticultural crops, field crops and sugar. The agricultural industry is primarily found in the area around Atherton and Mareeba and in the Barron River delta (see Land use section).

The main population centres are Atherton, Mareeba, Kuranda and Cairns (northern suburbs), while there are a number of smaller centres at Tolga, Kairi, Yungaburra, Tinaroo Township, Walkamin, Biboorah and Koah.

Climate
A number of publications are available on characteristics of the Barron River catchment. Huda *et al.* (1991) undertook an agroclimatic analysis of several locations in north Queensland including sites within the catchment. The climate is tropical monsoonal and rainfall is seasonal with approximately 70% falling during the months December – May. There is also a major effect due to orography. The orographic effects are exhibited by the marked reduction in rainfall from south east of the catchment to northwest, due to the high mountain ranges along the southeastern and eastern catchment boundary.

Altitude, average annual rainfall and evaporation for five centres in the catchment (Upper Barron, Atherton, Kairi Research Station, Mareeba and Cairns) are shown below in Table 1 (Jackie Balston, Queensland Department of Primary Industries, pers. comm.).

Table 1. Climate and topographic information for the Barron River Catchment

Site	Altitude (m)	Average Annual Rainfall (mm)	Average Annual Evaporation (mm)
Upper Barron	800	2103	N/A
Atherton	770	1395	N/A
Kairi Research Station	715	1233	1132
Mareeba	406	910	1643
Cairns	3	2129	1570

Hydrology
The Barron River is a perennial watercourse with several tributaries entering the main channel along its length. The major tributaries include Leslie Creek, Scrubby Creek, Rocky Creek, Tinaroo Creek, Emerald Creek, Granite Creek, Clohesy Creek, Flaggy Creek and Freshwater Creek.

Tinaroo Falls Dam (436 500 ML) on the Barron River and Copperlode Dam (44 500 ML) on Freshwater Creek are major water impoundments in the catchment. Water from Tinaroo Falls Dam is channelled out of the Barron River catchment to the upper Mitchell River, as part of the Mareeba Dimbulah Irrigation Area (MDIA). Water is also redirected within the Barron River catchment (to Emerald and Davies Creeks), as part of the MDIA.

Geology and soils

The Barron River catchment exhibits a range of parent materials. In the upper catchment, metamorphic and granite dominate the higher elevations. These same geological features also dominate the middle of the catchment between Mareeba and Kuranda. Basalt flows cover a large proportion of the area between the Crater (Mount Hyipamee National Park) and Mareeba, particularly around the Atherton area. Alluvium underlies the area on the coastal plain. A comparison of the geomorphology of the Barron River with southern Australian streams was undertaken by Douglas (1966a and b).

A number of soil surveys have been conducted in the upper catchment and in the MDIA. These have identified the fertile krasnozem (ferrosol) soils farmed productively in the area around Atherton and the red earth (kandosol) and alluvial soils farmed in the MDIA. Agricultural land use is limited in the area between Mareeba and Kuranda due to poor soils. Kent and Tanzer (1983) and Warrell *et al.* (1984) reported on the agricultural potential and soils of areas of the Atherton Tableland. More recently, Laffan (1988) undertook a soil and land use study of the Atherton Tableland at a scale of 1:100 000 and a more detailed soil and land use study (1:50 000) (Malcolm *et al.*, 1997) is now available. A study of the suitability for effluent absorption (Gutteridge, Haskins and Davey, 1991) was undertaken to identify soils, landforms and factors which limit effluent absorption in the gazetted Lake Tinaroo catchment area. Soil assessment of the catchment east of Mareeba is limited to a reconnaissance survey of potentially arable land in the Kuranda/Myola and Clohesy/Koah areas (Nagel *et al.*, 1996) and some unpublished mapping on the coastal plain.

Land Use

Land use was determined by aerial photo interpretation followed by ground truthing. Three sets of colour aerial photographs were used, these were: a) 1:25000 flown in 1994 (DNR); b) 1:12000 flown in 1996 (Environmental Protection Authority); and 1:25000 flown in 1997. Ground truthing was undertaken up to January 1999.

Land use was classified into 15 broad groups. These groups were purposely broad, since land use in some parts of the catchment varies annually eg peanuts and maize were identified under *Other Crop* because these crops are often rotated annually. However, BRICMA requested that some agricultural land be identified specifically hence, *Sugar* and *Dairy* farming were identified and mapped separately.

The following provides a summary of characteristics of each land use:

- Aquaculture - redclaw and fish ponds (smaller ponds not identified);
- Cleared land - recently cleared land, rifle ranges, scrapes;
- Dairy - dairy farming;
- Forest - pine forest, open forest, rainforest;
- Grazing - grazed land (not dairy);
- Industrial - abattoir, waste transfer stations, STP’s, industrial estates;

- Other Crop - for example, peanuts, maize;
- Other - airports, nursery, intensive livestock (pigs, poultry), cemeteries, and golf courses;
- Quarry - stone and gravel quarries;
- Rural Residential - low density residential areas;
- Sugar - sugar cane cropping;
- Tree Crops - mangoes, avocadoes, lychees etc;
- Tourist - camping grounds, caravan parks;
- Urban - high density residential areas; and
- Water - large areas of open water.

Sub-catchments

The Barron River catchment has been sub-divided into a number of sub-catchments for water licensing purposes (Ray Walsh, DNR Mareeba, pers. comm). Our report utilised this grouping of sub-catchments, as its base *sub-catchment* map. These sub-catchments reflect the current state of development and land use in the Barron River catchment, but some areas were too detailed for our requirements. In these areas, we merged sub-catchments. An exception occurred around Lake Tinaroo, where the project identified several small sub-catchments (Kulara, Danbulla, Severin, Platypus, McLean and Maroobi), that were needed to adequately discuss nutrient generation from different land uses. Our report has divided up the total catchment into 22 sub-catchments (Map1).

Sampling Locations

Sites in the Barron River and its tributaries were chosen for water (temporal and event) (this report), fish, riparian vegetation / habitat, and macro-invertebrate sampling (Russell *et al.,* 2000).

Temporal water sampling
There were 41 water sampling sites (Table 2 and Map 1), which were selected on the basis of potential influence from upstream catchment activities. These sites included seven DNR Gauging Station sites, which measure streamflow, and one site at the hydroelectric station at Kuranda, which also had limited streamflow information. Sites had diverse histories. Several were continuing sites from previous projects studying water quality in the Lake Tinaroo catchment (Cogle *et al.,* 1998), others had been started as Waterwatch sites (N. Wright, Waterwatch, pers. comm.), while other sites were totally new. The new sites were all in the Barron River catchment below Lake Tinaroo.

Thirty-two sites were sampled monthly, whilst the remaining nine sites had a biannual sampling schedule. The biannual sites were considered to provide valuable upper tributary information and were sampled to gain a dataset/impression of water quality during the wet and dry seasons.

Table 2. Water quality sampling sites in the Barron River catchment.

ID	Creek Name	Site Name	Northing	Easting	Comments	Frequency
1	Maude Ck.	Morganbury Rd	8104236	331748	New WQ site	monthly
2	Mazlin Ck.	North of Golf Course (below Marnane's)	8090853	336326	Tinaroo Nutrient site	monthly
3	Piebald Ck.	Platypus Park	8088980	337494	Water Watch site	monthly
4	Scrubby Ck.	Bridge on Kennedy Highway.	8082385	340498	New WQ site	monthly
5	Goonara Ck. (Barron River)	Barron River at Gauging Station site.	8082137	341968	Water Watch site	monthly
6	Barron R.	Hemmings Road Crossing	8079186	340571	Tinaroo Nutrient site	monthly
7	Gwynne Ck.	Tropical Peat Road	8076853	343837	New WQ site	bi-annual
8	Leslie Ck.	Curtain Fig Road	8086576	347086	Water Watch site	monthly
9	Petersen Ck.	Gauging Station	8090710	348583	Gauging station/Tinaroo Nutrient site	monthly
10	Barron R.	Picnic Crossing Gauging Station	8090834	344444	Gauging station/Tinaroo Nutrient site	monthly
11	Mazlin Ck.	Gauging Station	8094493	345457	Gauging station/Tinaroo Nutrient site	monthly
12	Barron R.	Bridge Below Tinaroo Falls Dam	8101557	344786	Water Watch site	monthly
13	Kauri Ck.	Gauging Station	8104982	350765	Gauging station/Tinaroo Nutrient site	monthly
14	Mazlin Ck.	Beantree Bridge	8093537	340985	Gauging station/Tinaroo Nutrient site	monthly
15	Rocky Creek	Bones Knob Road	8095068	334175	New WQ site	bi-annual
16	Rocky Ck.	Past Rangeview	8098264	333532	New WQ site	bi-annual
17	Barron R.	Bridge on Henry Hannam Drive	8109390	336043	New WQ site	monthly
18	Barron R.	Kenneally Road, downstream of junction with Tinaroo Ck.	8118688	334296	New WQ site	monthly
19	Barron R.	Plowman's Crossing	8122340	331971	New WQ site	monthly
20	Granite Ck.	Mareeba Bridge	8122289	332298	New WQ site	monthly
22	Barron R.	Off Bilwon Road	8135783	332766	New WQ site	monthly
23	Shanty Ck.	Hodsic Road	8138423	334992	New WQ site	bi-annual
24	Emerald Ck.	Emerald Creek Falls	8116149	343994	New WQ site	bi-annual
25	Davies Ck.	below falls & park	8121185	347045	New WQ site	bi-annual
26	Davies Ck.	On road north of highway.	8130522	345478	New WQ site	monthly
27	Clohesy R.	Upper Clohesy River Road	8126921	352610	New WQ site	bi-annual
28	Clohesy R.		8138104	342377	Water Watch site	bi-annual
29	Barron R.	Koah (crossing)	8139318	341243	Water Watch site	monthly
30	Clohesy R.	At Koah (bridge)	8139095	341545	Mouth of Clohesy	monthly
31	Flaggy Ck.	At gauging Station	8142333	343606	New WQ site	monthly
32	Barron R.	Myola Bridge	8141811	351891	Gauging station	monthly
33	Flaggy Ck.	past Forestry camp	8147397	351146	New WQ site	bi-annual

ID	Creek Name	Site Name	Northing	Easting	Comments	Frequency
34	Granite Ck.	Granite Gorge	8114806	324099	New WQ site	monthly
35	Freshwater Creek	Last causeway to Crystal Cascades	8124100	359238	New WQ site	monthly
36	Barron R.	Emerald End Caravan park	8125694	332545	Water Watch site	monthly
37	Emerald Ck.	At back of Caravan park	8125738	332575	New WQ site	monthly
38	Barron R.	Old bridge crossing below Lake Placid	8135092	357586	New WQ site	monthly
39	Thomatis Ck.	Mouth	8137915	364436	New WQ site	monthly
40	Barron R.	Mouth	8134907	368195	New WQ site	monthly
42	Barron R.	Above Kuranda Weir	8139725	355120	New WQ site	monthly
43	Freshwater Ck.	Lower Freshwater Road	8133672	361699	New WQ site	monthly

NB: There were no sites numbered 21 or 41.

There were no sites sampled in the Lake Tinaroo storage by the current project; sampling in the Lake was undertaken by the State Water Projects group of DNR and is reported separately by this group.

Event water sampling

Event sampling was undertaken on the Barron River during the wet seasons in 1997/98 and 1998/99. Problems with equipment design resulted in only manually collected samples being collected in 1997/98, while automatic samples were collected during the 1998/99 wet season. Previous event sampling had been undertaken in the Lake Tinaroo catchment in 1995 (Cogle *et al.*, 1998).

Events were sampled for the wet season from November 1998 to March 1999 at two sites, Bilwon Gauging Station (site 22) and Kuranda Weir (site 42).

At both sites, a Sigma 910 automatic pump sampler was triggered by a float switch following a rise in water level). These units were configured to sample up to 24, 1-litre samples. The unit at Bilwon was gas refrigerated, as the site became isolated after heavy rain. This unit stored the samples at 1 degree Celsius until they could be retrieved. The unit at Kuranda was accessible during events and was packed daily with ice, and samples were collected within 6 to 12 hours.

Bilwon was located on a straight section of the river with a sandy substrate. Initially the trigger level was set just above the dry season base flow to sample the early wet season storms. After these had been sampled it was raised above the wet season base flow to sample the larger flows. For the early storms the sampling rate was 15 minute intervals early in the event to one hour later in the event to sample the rapid increase in discharge. Later after the wet season base flow had been established, the sampling rate was hourly early in the event and then lengthened to three or four hourly intervals to capture the long recessions.

The Kuranda weir site was located immediately upstream of the Barron Falls. The weir stores water for the Barron River power station and only overflows after a significant rainfall event. The height of the weir is six metres. At one side of the weir the inlets for the power station turbines are located. Water flows through these inlets daily. A float switch was positioned to start the sampler immediately the weir overflowed. Events were only sampled after the wet season base flow had been established. The first event was sampled at hourly intervals. Cyclone Rona (February 1999) was sampled at four hourly intervals for two days then 12 hourly for 10 days. An event in March was sampled initially at four hourly intervals for the first day, then 12 hourly for the second day and then 24 hourly for six days

Fish and stream habitat sites
Please refer to Russell *et al.* (2000).

Macroinvertebrate sites
Please refer to Russell *et al.* (2000).

Water Quantity Data.

Hydrographers at Mareeba DNR maintained the Barron River gauging stations (Table 3) and provided water quantity data to project staff. Collection of stream discharge data involved the use of automatic data loggers to record stream height. Mechanical recorders, in most instances also backed up the electronic loggers. The stream flows used for event sampling at Bilwon were linearly interpolated from hourly or 15 minute data. Average daily streamflows were also calculated from the streamflow data, for the temporal data calculations.

Table 3. Selected gauging stations in the Barron River catchment.

Location	Station ID
Goonara (Barron River)	GS110021A
Picnic Crossing (Barron River)	GS110003A
Kauri Ck (Main Rd)	GS110017A
Peterson Ck (Yungaburra Railway Bridge)	GS110019B
Mazlin Ck (Railway Bridge)	GS110018A
Barron River (Tinaroo Falls Dam Outlet)	GS110006C
Barron River (Mareeba)	GS110002A
Barron River (Bilwon)	GS110020A
Barron River (Myola)	GS110001D
Flaggy Ck	GS110011B

In addition to the DNR gauging stations, Stanwell Corporation (operator of the Barron Gorge Hydroelectric station at Kuranda) maintains streamflow data at the weir at the top of the Barron Falls. This data was accessed for streamflows during event flows greater than six metres at the Kuranda weir. Streamflow was interpolated from 15 minute streamflows from an electronic height recorder or directly from charts recorded on a Stevenson chart recorder.

Sampling Parameters and Techniques

Water analysis
Water was analysed *in situ* for dissolved oxygen, temperature, pH and conductivity using a multi-functional water quality meter and datalogger. There were two meters used, a Horiba Model U10 and a TPS FL90. Water samples were taken in one litre plastic bottles, supplied by the Mareeba DNR Analytical Chemistry laboratory, from the centre of flow and below the water surface and stored on ice during the half day sample run. A randomised method of taking duplicate samples was implemented to

assess sample variability. On return to the laboratory, water samples were analysed immediately for suspended solids and turbidity, and then frozen until analysis for ammonium-N, nitrate-N, Kjeldahl N, phosphate-P and Kjeldahl P in the DNR Mareeba Analytical Chemistry laboratory.

Analytical Techniques

The following techniques were used at the Mareeba Analytical Chemistry Laboratory.

Sediment load.
A measured volume of unfiltered water was filtered through a pre-washed and weighed glass fibre filter paper (0.7 mm). The weight of sediment on the filter paper was measured. From both the volume of water and the sediment weight, the concentration of sediment in the water was calculated (Eaton *et al.,* 1995).

Total kjeldahl nitrogen and phosphorus (TKN and TKP) digestion procedure
An aliquot (10 ml) of well mixed unfiltered water was digested in sulphuric acid and potassium sulphate with mercuric oxide added as catalyst. The digest was then diluted and analysed using automated continuous flow colourimetric techniques (Bran and Luebbe, 1990). During digestion nitrogenous (except nitrate-N) compounds are converted to ammonium ions while phosphorus compounds are converted to orthophosphate ions.

Determination
Nitrogen concentration in the digest was determined using the indophenol reaction method in which ammonia, sodium salicylate, sodium prusside and sodium dichloroisocyanurate react to produce an emerald green colour which was proportional to the amount of nitrogen present (Searle, 1984).

Phosphorus concentration in the digest was determined using the phosphomolybdic blue complex which was formed when phosphate-P reacted in an acid medium with ammonium molybdate (Murphy and Riley, 1962).

Nitrate-N, ammonium-N and ortho-phosphate
Analytical methods for these analytes broadly follow the automated, continuous flow methods described in Eaton *et al.* (1995). Filtered samples of water were used.

Nitrate-N concentration was determined using a procedure based on the Griess-Ilosvay reaction. Nitrate-N was first converted to nitrite-N with copper sulphate and hydrazine. The nitrite-N was coupled with N-(1-napthyl)ethylenediamine dihydrochloride to form a reddish-purple dye which was proportional to the amount of nitrite-N (Best, 1976).

Ammonium-N was determined using the indophenol reaction in which ammonia, sodium salicylate, sodium prusside and sodium dichloroisocyanurate react to produce an emerald green colour proportional to the amount of nitrogen present (Searle, 1984).
Phosphate-P was determined using the phosphomolybdic blue complex which is formed when phosphate-P is reacted in an acid medium with ammonium molybdate (Murphy and Riley, 1962).

Limits of detection and data description

Limits of detection for the data received from the laboratory *before 1998* were 0.002 mg L^{-1} for phosphate-P, 0.01 mg L^{-1} for ammonium-N and nitrate-N, 0.05 mg L^{-1} for total kjeldhal phosphate (TKP) and 0.17 mg L^{-1} for total kjeldhal nitrogen (TKN). *After 1998,* new lower detection limits were achieved. The new detection levels were 0.001 mg L^{-1} for phosphate-P, 0.001 mg L^{-1} for ammonium-N and nitrate-N, 0.002 mg L^{-1} for TKP and 0.17 mg L^{-1} for TKN.

Some results were below the detection limit. For the purposes of statistical analysis, data less than the detection limit was given a value. Several options exist for providing a value for data less than the detection limit. They include: a) eliminating the data; b) assigning the detection limit value; c) assigning half the detection limit value; and d) replacing the data with zero. In this report, samples with values below the detection limit were assigned values of half the detection limit.

For each individual sample, a Total N concentration was calculated by adding the nitrate-N concentration to the TKN concentration. Nitrogen attached to sediment and organic nitrogen can be calculated by subtracting the ammonium-N from the TKN concentration. Phosphorus attached to sediment can be calculated from the difference between Total P and phosphate-P. This does not account for simple organic nitrogen and phosphorus compounds, which may be measured in the ammonium-N or phosphate-P analyses, but gives some indication of the quantities associated with sediment.

Data Management

Water quality data collected as part this project was stored and analysed in Excel® spreadsheets.

Temporal solute loads were calculated for the sites with gauging information. The load was calculated by multiplying the concentration, at the sampling time, by the daily streamflow. This had a potential error of assuming that the concentration and streamflow had been constant throughout the day. This potential error is only of concern during major storm events and subsequent rising or declining streamflows.

Event loads for the 1998/1999 events were calculated by the *Brolga* program, which was developed by DNR. This program integrated the area below the Time vs Load (sediment or nutrient) curve to calculate the total load for the event. The time step was appropriate to the length of the event. Hydrologic discharges were interpolated linearly and sediment and nutrient concentration was interpolated by a quadratic estimation.

The data is available for interrogation at Mareeba using the *Christie* package developed by Richard Walton (DNR, Brisbane), and will be stored within the natural resource datasets at the Mareeba Geographic Information Service facility.

Decision Support Systems (DSS)

Catchment management support system

Setup for the Barron River

The Catchment Management Support System program (Farley and Davis, 1993) uses the concept of nutrient generation rates to estimate nutrient movement. It is a simplistic catchment scale DSS, but its value lies in its abilities as a presentation device and ease of use. Nutrient generation rates are estimated from available data, local knowledge and literature review. The values can be corrected at any time. Options for determining the effects of differing land management and land policies exist. A new version, WinCMSS, operates in a *Windows* environment as shown in Figure 1 (S. Cuddy, CSIRO, pers. comm.)

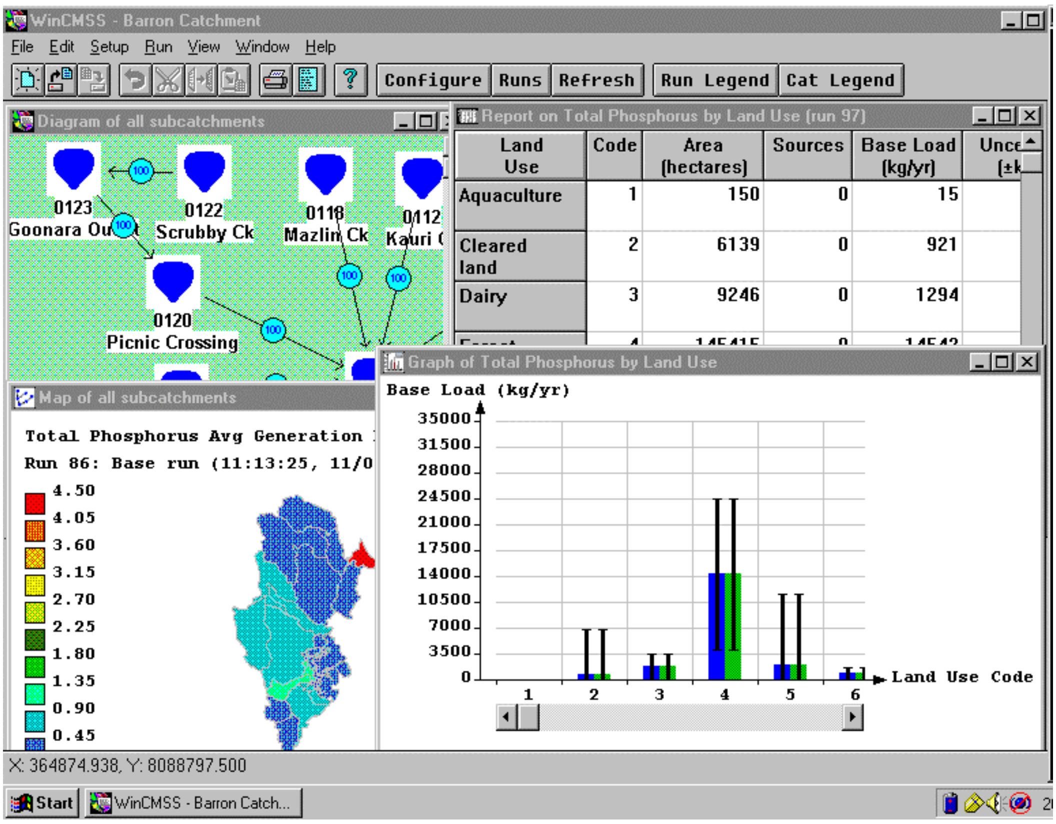


Figure 1. CMSS screen dump showing several presentations outputs for the program.

The program generates numerical values, graphs and maps of nutrient loads throughout the catchment. This is done by multiplying the relevant nutrient generation rate with the area of each land use and summing the nutrient loads from each land use. The initial calculation for nutrient loads is called the *base calculation*. The program is also capable of accounting for assimilation of nutrients as they move through the catchment.

Win-CMSS was set up for the Barron River catchment using 22 sub-catchments and 16 land-uses (including STP's). The sub-catchments are shown in Map1 and were identified as outlined in the previous sections. Land use areas for each sub-catchment are shown in Table 7 and Table 8. Generation rates for nutrient loads for each land use category (and sewerage treatment plants) are displayed in Table 4.

Use for nutrient management

WinCMSS can be used to develop nutrient management plans with community participation. One strength of the program is its ability to work in group situations. It is possible for participants to make land use and land management changes to see the effect of new land use and management on nutrient movement, albeit dependent on the assumptions of the program for nutrient movement. Comparisons of the changes to the *base calculation* are done using the "policy" facility. This facility allows the definition of land use and land management policies that superimpose over the existing *base calculation*.

For the purposes of this report several land use land management policies are demonstrated (Table 5).

Table 4. Nutrient generation rates (kg ha^{-1} yr^{-1}) used for the base runs in the Barron River catchment.
(Figures in brackets are the uncertainty factors) (STP – Sewage Treatment Plant).

Land Use	**Generation Rate (kg ha^{-1} yr^{-1})**	
	Nitrogen	**Phosphorus**
Aquaculture	1.0 (0.5)	0.1 (.02)
Cleared Land	1.5 (2.0)	0.15 (1.0)
Dairy	3.0 (2.4)	0.2 (0.19)
Forest	1.3 (0.4)	0.1 (0.4)
Grazing	1.5 (2.0)	0.15 (0.7)
Industrial	2.0 (1.3)	1.3 (1.0)
Other Crop	3.0 (2.6)	2.0 (0.7)
Other	1.0 (0.5)	0.3 (0.1)
Quarry	1.0 (0.5)	0.5 (0.3)
Rural residential	2.0 (1.2)	0.7 (1.2)
Sugar	3.0 (2.6)	2.0 (0.7)
Tree Crop	3.0 (1.5)	2.0 (1.2)
Tourist	2.0 (1.3)	1.3 (1.0)
Urban	0.5 (0.25)	0.1 (0.02)
Water	0.43	0.017
Mazlin STP	8585 (1700)	2318 (4600)
Aeroglen STP	39210 (14508)	15612 (4840)
Kuranda STP	39 (6)	14 (4)

Table 5. Example land use and land management policies used in Win CMSS runs for the Barron River catchment.

Policy No.	Land Use (LU) or Land Management (LM)	Sub-catchments affected	Policy details
1 Myola Urban Expansion	LU	Kamerunga	Convert all Rural Residential and all Grazing to Urban.
2 Koah Urban Expansion	LU	Davies/Clohesy	Convert all Rural Residential to Urban
3 Mareeba Urban Expansion	LU	Mareeba Outlet	Convert 500 ha of Rural Residential to Urban.
4 Atherton Urban Expansion	LU	Mazlin	Convert all Rural Residential to Urban Convert 400ha of Other Crop to Urban.
5 Development for Rural Residential at Lake Tinaroo	LU	Maroobi	Convert 400 ha of Grazing to Rural Residential
6 Forest Management	LM	All	Manage Forests to reduce generation
7 Reduced Tillage on Cropping Lands	LM	Kulara, Picnic, Mazlin, Peterson, Scrubby, Goonara	Reduced tillage on cropping soils
8 Gross Pollutant Traps in some Urban areas	LM	Kamerunga, Bilwon Outlet, Mareeba Outlet, Mazlin	Gross Pollutant Traps in urban area
9 Mazlin STP Upgrade	LM	Mazlin	Reduced discharge from Mazlin STP.
10 Improved nutrient management on Dairy Farms	LM	All	30 % reduction in N and P released from Dairy Farms.

RESULTS AND DISCUSSION

Land Use

The Barron River catchment has a range of land uses (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**) and is dominated on an areal basis (67.1%) by forested land, which includes Wet Tropical rainforests, open Eucalypt forests and plantation forests (Map 2). Each other land use constitutes less than 6.4% each of the total catchment as displayed in Table 6.

Table 6. Land Use in the Barron Catchment as a percentage of total land area.

Land Use	% of Barron Catchment
Aquaculture	0.1
Cleared Land	2.8
Dairy Cows	4.3
Forest	67.1
Grazing	6.4
Industrial	0.1
Other Crop	5.8
Other	0.6
Quarry	0.2
Rural Residential	3.7
Sugar	3.5
Tree Crop	1.7
Tourist	<0.1
Urban	1.6
Water	2.1

Individual sub-catchments (Table 7 and Table 8) however, have a different percentage land use makeup:

- dairy production is important in several sub-catchments in the Lake Tinaroo catchment. Specifically, Kulara, Goonara, Picnic Crossing and Peterson sub-catchments each have greater than 35% of their land area under dairy production;
- grazing is an important land use (greater than 19.1%) in the Maroobi, McLean, Severin, Mazlin and Peterson sub-catchments;
- cropping (Other Crop) is important, as a percentage of land area, in McLean, Kulara, and Picnic Crossing. On an areal basis, Mareeba Outlet and Granite each have the largest area in the Barron River catchment under this land use;
- rural residential accounts for 15.5% of the McLean sub-catchment, while on an areal basis Mareeba Outlet, Granite, Bilwon Outlet and Davies/Clohesy have greater than 1 000 ha of this land use;
- sugar was a large percentage land use (33.4%) in only the Barron Mouth sub-catchment (1 483 ha), however there was 1 996 ha in Mareeba Outlet and over 600 ha of sugar in Freshwater, Emerald, Bilwon Outlet, Granite and Picnic Crossing subcatchments; and

- forestry is the dominant land use in many sub-catchments, particularly downstream of Tinaroo Falls Dam.

A range of management practices is applied to each of the identified land uses. Further delineation of each land use on the basis of management practice could provide valuable information to improve the sediment and nutrient control for specific sub-catchments. It is recommended that this be undertaken as a collaborative effort with land managers, industry bodies and agencies to achieve best results. For example the use and development of “dynamic” best practice plans with land managers.

Roadways have not been explicitly identified in the report. A road coverage is available on Geographical Information System for the catchment and while the total area of roads is not large, specific sections, eg gravel or dirt roads, can have a relatively large offsite impact.

Plate 4. Land in the upper catchment is used for dairy and cattle grazing

Plate 5. A variety of field crops are grown in the middle catchment

Plate 6. Plantation forests are grown in parts of the catchment, including Lake Tinaroo.

Table 7. Land use areas (ha) for each sub-catchment in the Barron River catchment (above Tinaroo Falls Dam).

(% of sub-catchment area is shown in brackets for shaded boxes)

Land Use	Maroobi	McLean	Platypus	Severin	Kulara	Danbulla	Goonara	Scrubby	Picnic Crossing	Kauri	Mazlin	Peterson
Aquaculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.3	0.0	0.0	0.0	0.0
Cleared Land	436.2	188.8	0.0	36.3	129.0	20.4	0.0	0.0	101.2	0.0	82.6	0.0
Dairy Cows	469.6	19.1	0.0	0.0	375.5 (35.0)	0.0	2582.0 (36.8)	269.6	4690.7 (45.6)	0.0	77.0	757.8 (37.3)
Forest	1939.9 (36.1)	106.1	1233.7 (99.7)	1114.8 (59.6)	78.6	6529.2 (98.2)	3516.8 (50.1)	3538.2 (63.7)	958.2	1652 (100.0)	1566.1 (29.4)	427.3 (21.0)
Grazing	1910.8 (35.5)	270.5 (19.1)	0.0	720.9 (38.5)	85.8	74.3	703.8	700.7	975.4	0.0	1386.8 (26.0)	414.5 (20.4)
Industrial	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	0.0	0.0	9.6
Other Crop	22.1	518.5 (36.6)	0.0	0.0	241.0 (22.4)	0.0	53.8	96.1	2011.8 (19.6)	0.0	916.1	275.9
Other	38.6	20.3	0.0	0.0	0.0	0.0	12.5	18.5	162.8	0.0	48.0	1.2
Quarry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	83.7	11.9	0.0	0.0	0.0
Rural Residential	431.4	212.8 (15.0)	0.0	0.0	41.4	0.0	60.3	439.4	522.3	0.0	123.3	85.3
Sugar	0.0	0.0	0.0	0.0	114.6	0.0	80.8	271.7	679.8	0.0	343.2	0.0
Tree Crop	52.9	71.6	0.0	0.0	7.9	10.6	8.5	85.1	143.5	0.0	196.6	0.0
Tourist	14.4	0.0	4.0	0.0	0.0	15.5	0.0	0.0	0.0	0.0	2.4	0.0
Urban	56.2	7.5	0.0	0.0	0.0	0.0	0.0	4.8	7.0	0.0	583.4	54.3
Water	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.5	0.0	8.6	5.4
TOTAL	**5375.4**	**1415.0**	**1237.8**	**1871.9**	**1073.8**	**6649.9**	**7018.5**	**5554.1**	**10287.2**	**1652.0**	**5334.1**	**2031.6**

Table 8. Land use areas (ha) for each sub-catchment in the Barron River catchment (below Tinaroo Falls Dam).

(% of sub-catchment area is shown in brackets for shaded boxes)

Land Use	Mareeba Outlet	Emerald	Granite	Bilwon Outlet	Davies/ Clohesy	Myola Outlet	Flaggy	Kamerunga	Freshwater	Barron Mouth
Aquaculture	8.3	0.0	26.6	0.0	34.6	0.0	0.0	9.5	0.0	24.4
Cleared Land	1024.7	527.8	2224.9	953.7	235.9	95.4	0.0	23.6	12.0	45.5
Dairy Cows	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	18688.9 (61.9)	5186.2 (64.8)	8983.9 (47.9)	7702.0 (57.6)	25902.7 (90.2)	24681.9 (91.7)	14789.3 (97.5)	6584 (87.3)	8811.4 (82.3)	1424.3 (32.1)
Grazing	1642.2	195.5	1177.3	1144.7	537.9	1104.7	386.1	193.4	21.3	139.4
Industrial	38.7	0.0	54.4	36.7	0.0	0.0	0.0	0.0	6.7	72.0
Other Crop	3884.7	607.9	2675.4	644.5	413.3	119.0	0.0	0.0	0.0	0.0
Other	59.8	51.4	167.3	101.2	53.6	3.6	0.0	0.0	59.3	423.9
Quarry	28.9	0.0	175.2	0.0	0.0	0.0	0.0	0.0	73.5	44.9
Rural Residential	1733.2	242.2	1198.3	1113.9	1182.1	549.1	0.0	85.7	28.6	37.1
Sugar	1995.8	634.1	698.6	697.5	0.0	0.0	0.0	0.0	660.3	1483.8 (33.4)
Tree Crop	560.1	550.7	922.1	707.8	321.2	12.5	0.0	8.3	5.2	3.2
Tourist	0	0.6	18.2	4.0	0.0	0.0	0.0	0.0	4.3	0.0
Urban	513.1	0.0	375.8	163.6	0.0	50.5	0.0	467.8	707.3	535.5
Water	16.6	4.6	58.9	90.4	45.7	290.9	0.0	168.0	317.3	209.6
TOTAL	**30190.4**	**8001.0**	**18756.8**	**13360.0**	**28727.0**	**26907.6**	**15175.4**	**7540.3**	**10707.2**	**4443.6**

Physico-chemical Factors

The new ANZECC draft Guidelines (1999) for water quality utilise the concept of trigger levels. Draft interim trigger levels for assessing possible risk of adverse effects in different ecosystem types (ANZECC, 1999), are shown below in Table 9. These trigger levels are calculated from an acceptable range about the median of the available data and specifically the 20th and 80th percentile. For this reason, the data is presented in this report as median, 20th percentile, 80th percentile and the minimum and maximum figure.

The median can be defined as the central value in a set of observations ordered by magnitude, dividing the ordered set into two equal parts.

The 20th and 80th percentiles represent the figure that, after all values are ordered by magnitude, 20 percent or 80 percent of values, respectively, are lower than the defined percentile value.

Table 9. Draft interim trigger levels for assessing possible risk of adverse effects in different ecosystem types (ANZECC, 1999)

	Temperature (^{0}C)	**pH**	**Conductivity (DS m$^{-1)}$**	**DO (%)**	**Turbidity (NTU)**	**SPM * mg L^{-1}**	**Total P mg L^{-1}**	**Total N mg L^{-1}**
Lowland River	Outside 20-80th percentile range	6.6-8.0	0.050	90	10	6	0.037	1.600
Upland River	Outside 20-80th percentile range	6.5-7.5	0.011	92	5	2	0.035	0.340
Estuaries	Outside 20-80th percentile range	7.5-8.5	na	90	na	na	0.045	0.080

Note: na = not available.
* - suspended particulate matter

The following discussion will use the box and whisker diagram as a form of explaining the distribution of water quality sample results. The data has been combined from all sites within each sub-catchment into a box and whisker diagram (Figure 2) with median, minimum, maximum and 20th and 80th percentile defined. This division is based on the draft ANZECC guidelines, as explained above.

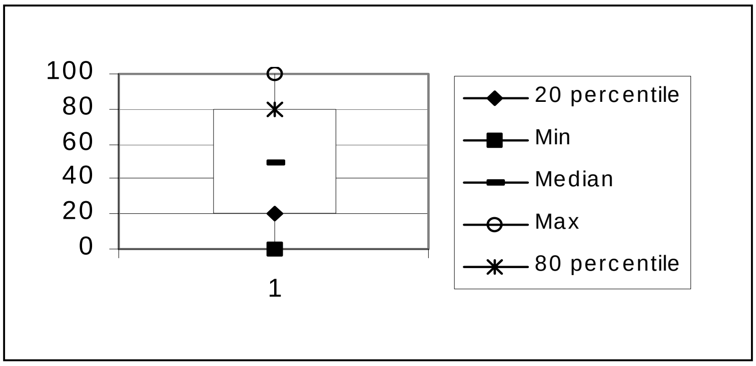


Figure 2. Box and whisker explanation

Water temperature:
Water temperatures recorded in the Barron River and its tributaries ranged between 12 ^{o}C and 32 ^{o}C, while median temperatures for sub-catchments ranged between 19 C and 27 ^{o}C (Figure 3). Median temperature in the main Barron River increased with

distance from the source. The trend in sub-catchments being Goonara < Scrubby < Picnic Crossing < Mareeba Outlet < Bilwon Outlet </= Myola Outlet < Kamerunga < Barron Mouth. Temperatures from tributary streams were lower than temperatures in the main Barron River channel. Temperatures generally reflected the length of watercourse from its respective source.

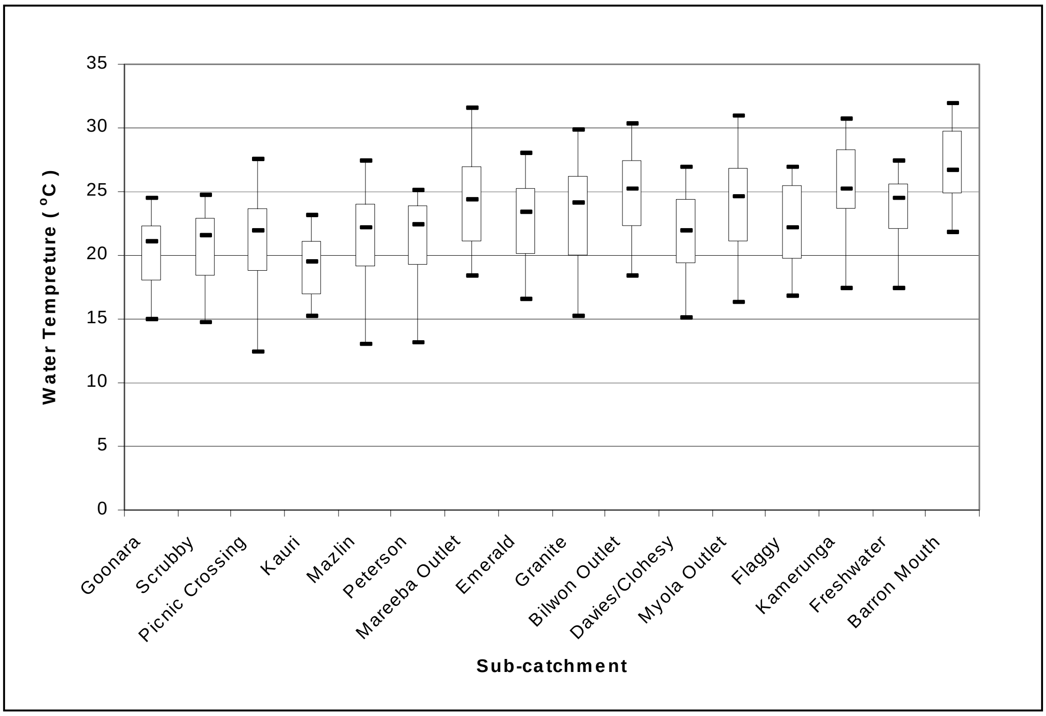


Figure 3. Temperature (°C) for sampled sites in the Barron River catchment. Sub-catchment name is given on the x axis.

pH:
The pH recorded in the Barron River ranged between 4.9 and 8.5, while median pH values ranged between 6.8 and 7.5 (Figure 4). A general trend of lower pH values with shorter watercourses existed and appeared unrelated to soils, although other factors may have caused this response. The low pH's in the Barron Mouth sub-catchment may be a cause for concern and should be investigated given the potential for acid sulphate soils in the region.

Conductivity:
Median conductivity was highest in the estuarine Barron Mouth sub-catchment (17.4 DS m^{-1}), (Figure 5). High outliers also existed in the Kamerunga and Freshwater (site 43) sub-catchments, due to estuarine influences. Median conductivities, across all other sub-catchments, were below 0.121 DS m^{-1} except in the Granite sub-catchment (0.207 DS m^{-1}). High conductivities were recorded at site 1 in Maude Creek, which is a tributary of Granite Creek, downstream of a piggery. Granite Creek is also adjacent to the Cattle Creek sub-catchment in the Mitchell River catchment, and Cattle Creek is known to have potential saline problems. It is possible that the geological similarities between the sub-catchments (Granite Creek and Cattle Creek) are reflected in higher conductivities in Granite Creek compared to other Barron River sub-catchments.

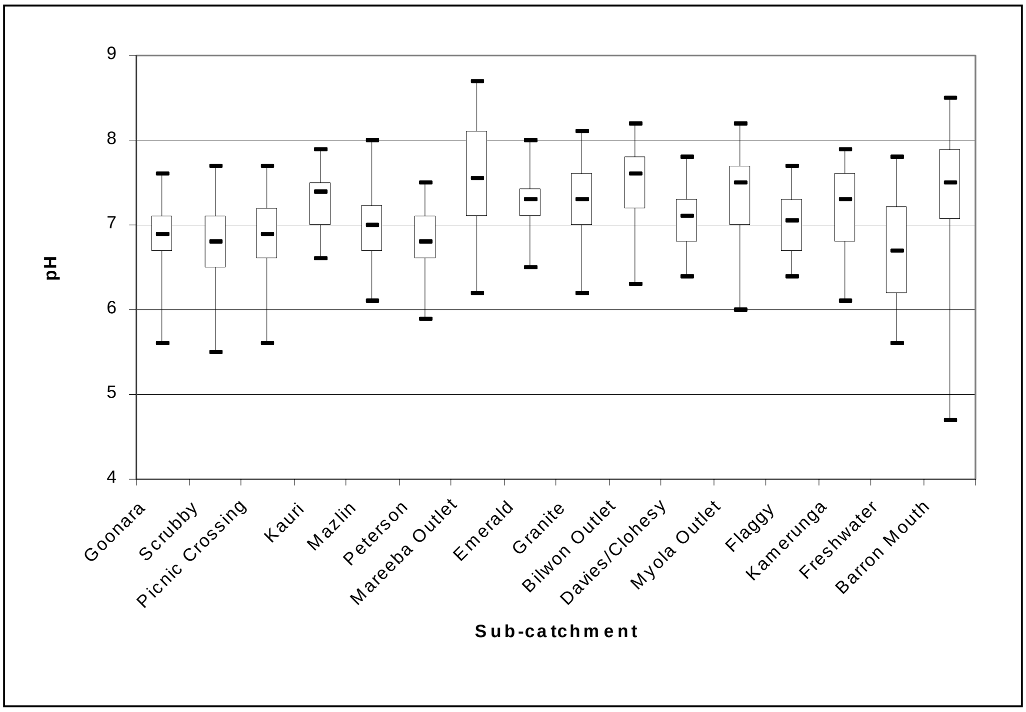


Figure 4. pH for sampled sites in the Barron River catchment. Sub-catchment name is given on the x axis.

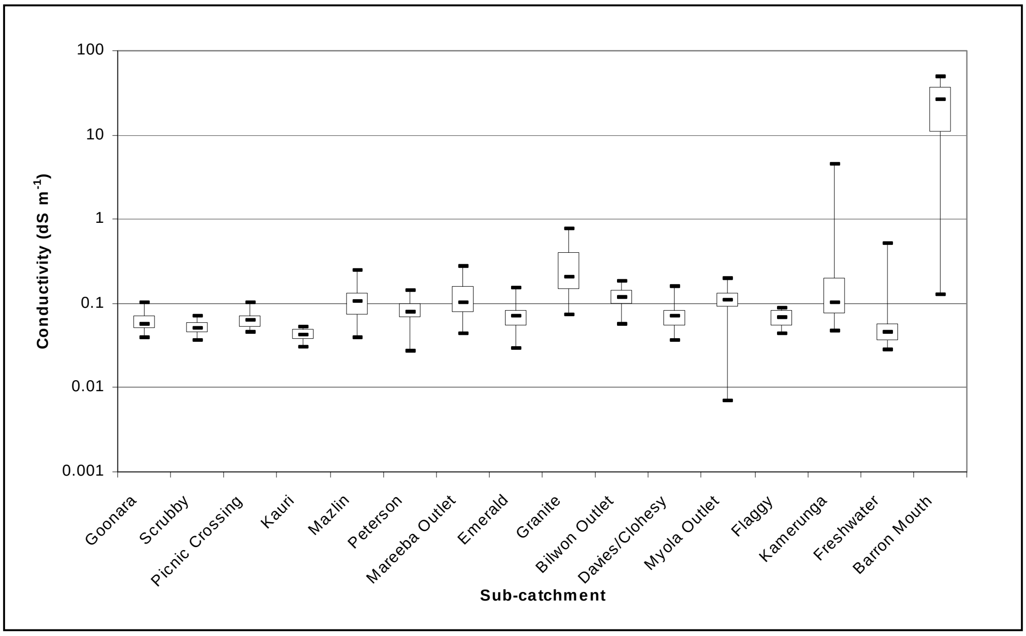


Figure 5. Conductivity (dS m^{-1}) for sampled sites in the Barron River catchment. Sub-catchment name is given on x axis. The y axis is a logarithmic scale.

Dissolved oxygen:

Dissolved oxygen medians ranged between 66% (Scrubby) and 101% (Mareeba Outlet) (

Figure ***6***). Low values were recorded in several sub-catchments (Scrubby, Picnic Crossing, Mazlin, Mareeba Outlet, Granite, Myola Outlet, Flaggy) indicating that adverse effects on aquatic organisms or on sediment – water interactions in these waterways may occur. These low values were associated with point sources discharge from STP's and intensive livestock industries. The high values are of equal concern and may be due to a proliferation of aquatic plant biota in the waterway, particularly in Mazlin and Mareeba Outlet. [It should be noted that if water is rapidly agitated for 5 to 10 minutes it will become saturated with oxygen (100% or 8.26 mg/L at 25^{o}C and 101.3 kP$_a$.) (WPCF, 1988). Alternatively water can become super-saturated (>100%) in the presence of bacterial activity and photosynthesis].

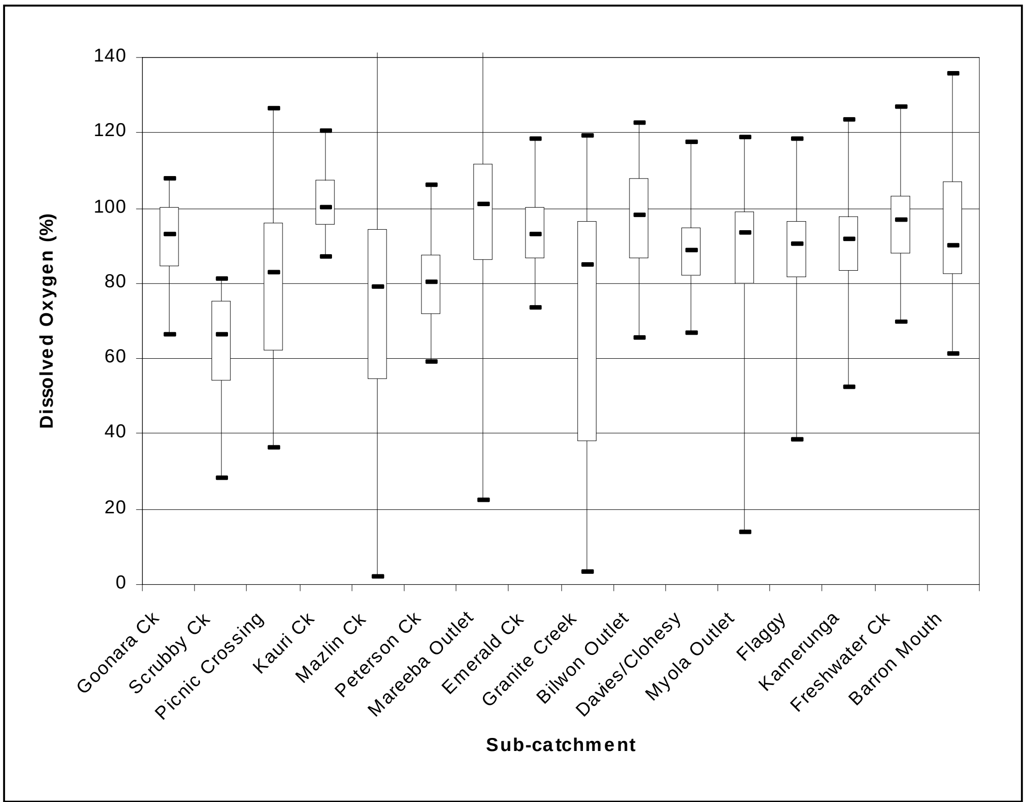


Figure 6. Dissolved oxygen (%) for sampled sites in the Barron River catchment. Sub-catchment name is given on x axis.

Turbidity:
Median turbidity ranged between 1 and 23 NTU (
Figure ***7***). Data generally reflected results found for suspended solids. The new draft ANZECC trigger level (ANZECC 1999) is 5 NTU for Upland Rivers and 10 NTU for Lowland rivers; levels for the Barron River catchment often exceed these values.

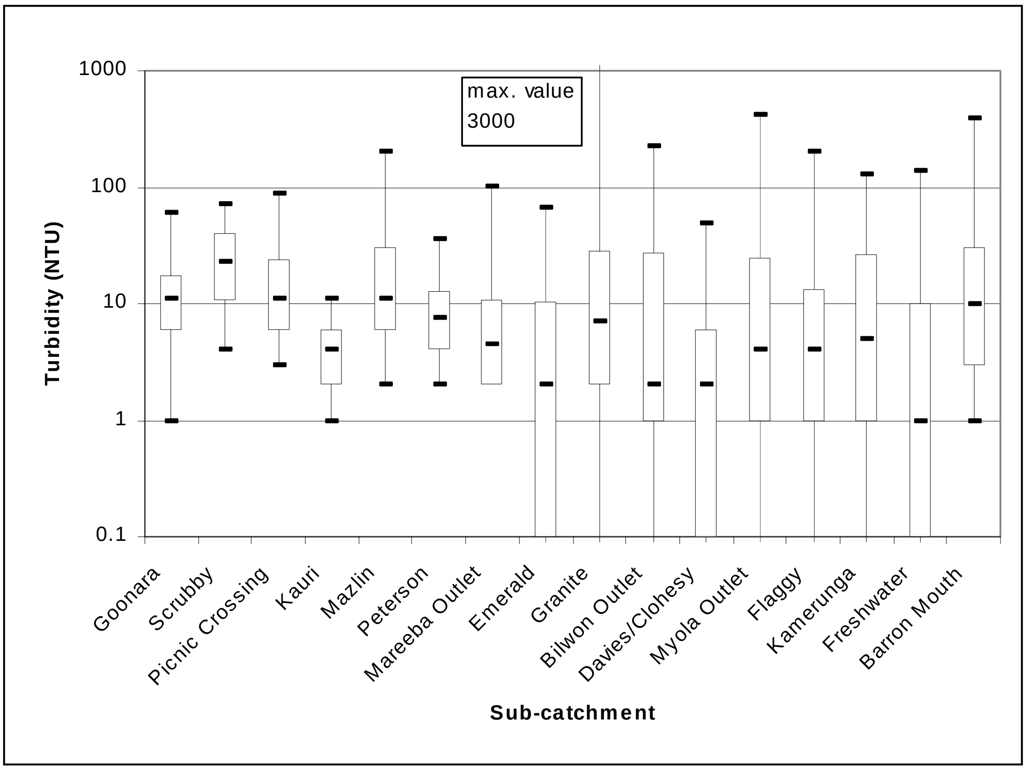


Figure 7. Turbidity (NTU) for sampled sites in the Barron River catchment. Sub-catchment name is given on x axis. The y axis is a logarithmic scale.

Temporal Nutrient Flows – Concentrations

Suspended solids:
Median suspended solids concentrations did not exceed 20 mg L^{-1} except in Barron Mouth (
Figure ***8***), which has estuarine influences. All sub-catchments except the Barron Mouth recorded 80th Percentile data below 30 mg L^{-1}. High outliers occurred at many sites due to sampling at times of high flow or after storms. The tropical monsoonal environment of the region results in periodic large streamflows and high suspended solid loads, particularly if exposed land surfaces eg agricultural tillage or urban development occur at the time of high rainfall.

Ammonium-N:
The ammonium medians for all sub-catchments were above 0.005 mg L^{-1} (
Figure ***9***).

In the Lake Tinaroo catchment, Goonara, Mazlin and Peterson had medians above 0.020 mg L^{-1} and except for Mazlin (0.088 mg L^{-1}), had 80th percentiles below 0.050 mg L^{-1}.

Below Lake Tinaroo, the Barron Mouth sub-catchment was the only one to have high median (0.038 mg L^{-1}) and 80th percentile (0.337 mg L^{-1}) figures. This occurred at both Thomatis Creek and the Barron Mouth sites and hence may not only be due to the effluent from the Northern STP discharging into the Barron River arm.

High outliers (> 1mg L^{-1}) occurred in the Mazlin and Granite sub-catchments, which reflect sites close to the Atherton Sewage Treatment Plant and a piggery on Maude Creek respectively.

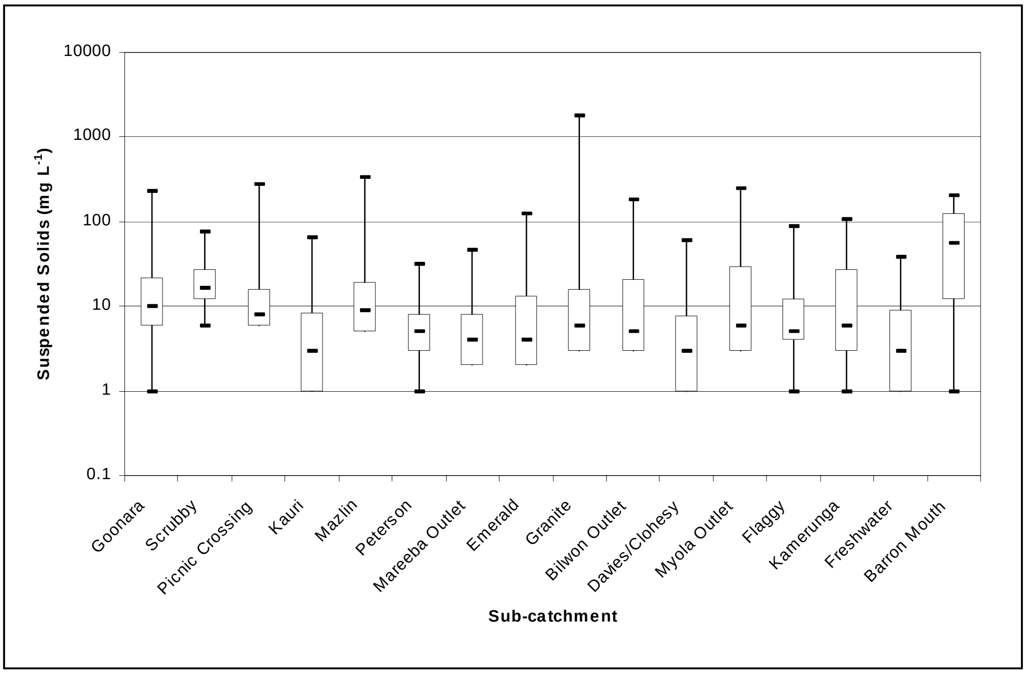


Figure 8. Suspended solids (mg L^{-1}) for sampled sites in the Barron River catchment.
Sub-catchment name is given on x axis. The y axis is a logarithmic scale.

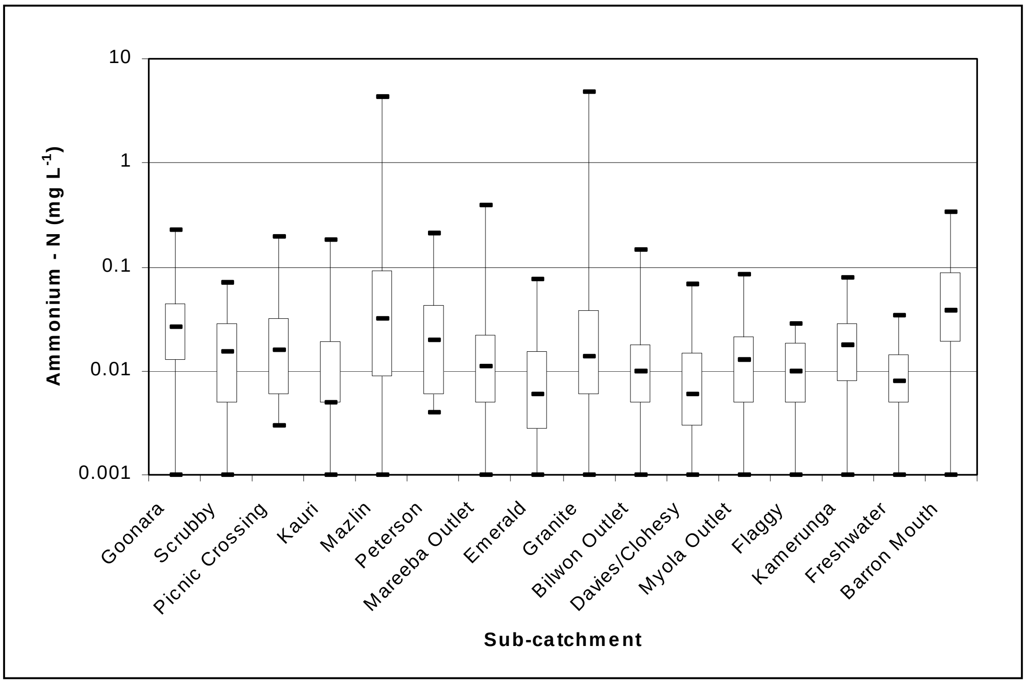


Figure 9. Ammonium – N (mg L^{-1}) for sampled sites in the Barron River catchment. Sub-catchment name is given on x axis. The y axis is a logarithmic scale.

Nitrate –N:
The Nitrate-N medians for all sub-catchments, except Mazlin (0.532 mg L^{-1}), were below 0.155 mg L^{-1} (Figure 10).

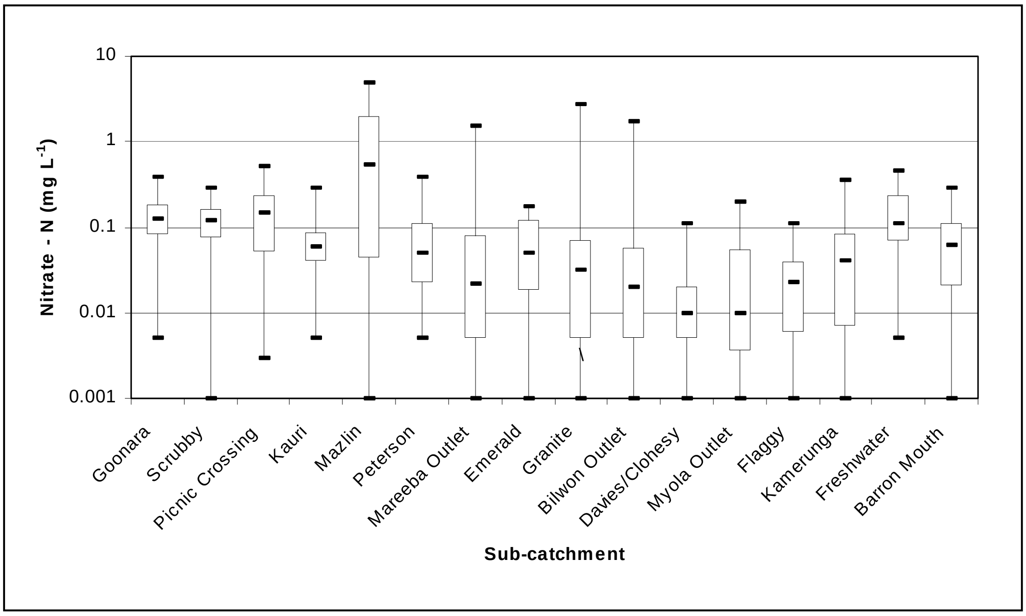


Figure 10. Nitrate – N (mg L^{-1}) for sampled sites in the Barron River catchment. Sub-catchment name is given on x axis. The y axis is a logarithmic scale.

In the Lake Tinaroo sub-catchment, Goonara, Scrubby, Picnic Crossing, and Mazlin sub-catchments had medians above 0.100 mg L^{-1} and all sub-catchments, except Kauri, had 80th percentile figures at or above 0.100 mg L^{-1}. Mazlin was particularly high with an 80th percentile of 1.96 mg L^{-1}.

Below Lake Tinaroo, median and 80th percentile figures were below 0.100 mg L^{-1}, except in the Freshwater sub-catchment, where the median was 0.113 mg L^{-1} and the 80th percentile was 0.232 mg L^{-1} and Emerald sub-catchment where the 80th percentile was 0.118 mg L^{-1}. The Freshwater result was surprising and may be due to a number of factors from urban expansion to the rural activities in the sub-catchment.

Outliers occurred in Mazlin (4.95 mg L^{-1}) and Granite (2.72 mg L^{-1}) sub-catchments, probably reflecting the previously mentioned sewage treatment plant and piggery, and also occurred in the Mareeba Outlet (1.55 mg L^{-1}) and Bilwon Outlet (1.76 mgL^{-1}) sub-catchments, which are below areas of major urban and rural development.

Phosphate-P
The phosphate-P medians for all sub-catchments, except Mazlin (0.074 mg L^{-1}) and the Barron Mouth (0.018 mg L^{-1}) sub-catchments, were below or equal to 0.015 mg L^{-1} (Figure 11).

In the Lake Tinaroo catchment, all sub-catchments, except Mazlin had 80th percentile figures below 0.016 mg L^{-1}. The figure for the Mazlin sub-catchment (0.354 mg L^{-1}) reflects the impact of two sites (sites 11 and 14) downstream of the Atherton STP.

Below Lake Tinaroo, the 80th percentile data was below 0.015 mg L^{-1} except for Mareeba Outlet (0.029 mg L^{-1}), Granite (0.029 mg L^{-1}), Bilwon Outlet

(0.023 mg L^{-1}) and Barron Mouth (0.056 mg L^{-1}).

Outliers were below 0.46 mg L^{-1}, except in the Mazlin subcatchment, with a maximum of 1.019 mg L^{-1}.

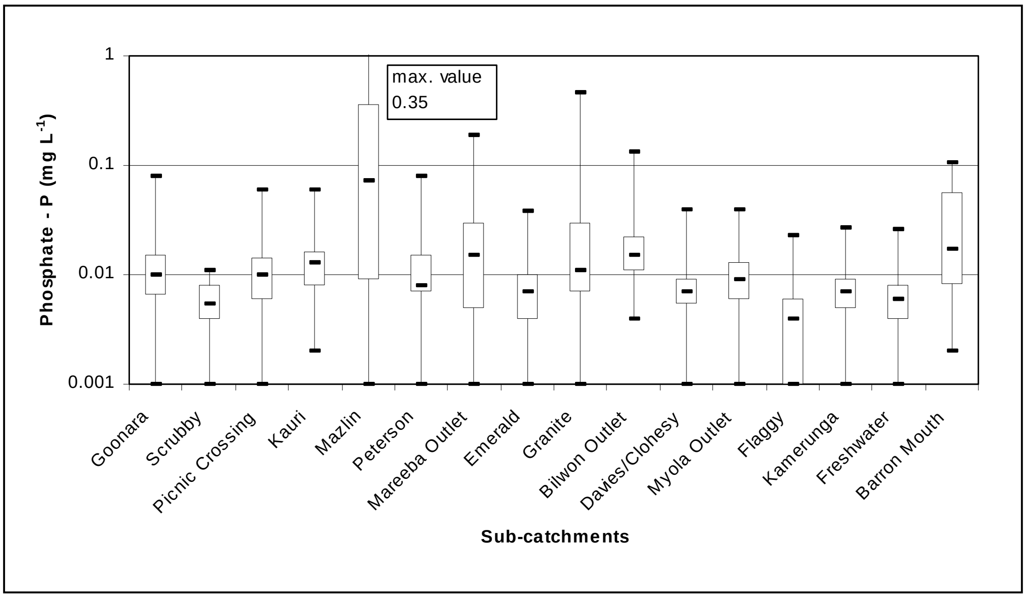


Figure 11. Phosphate – P (mg L^{-1}) for sampled sites in the Barron River catchment. Sub-catchment name is given on x axis. The y axis is a logarithmic scale.

Total –N:
The Total N medians for all sub-catchments above Lake Tinaroo, except Kauri (0.163 mg L^{-1}) and Peterson (0.310 mg L^{-1}), were above the draft ANZECC trigger level of 0.340 mg L^{-1} (Figure 12). Mazlin was particularly high at 1.213 mg L^{-1}. Below Lake Tinaroo all medians were below 0.340 mg L^{-1}.

In the Lake Tinaroo catchment, all sub-catchments, had 80th percentile data above 0.340 mg L^{-1}.

Below Lake Tinaroo, all 80th percentile data were above 0.340 mg L^{-1}, except in the Emerald (0.282 mg L^{-1}), Davies Clohesy (0.193 mg L^{-1}) and Flaggy (0.285 mg L^{-1}) sub-catchments.

Outliers occurred in Mazlin (10.11 mg L^{-1}) and Granite (12.71 mg L^{-1}).

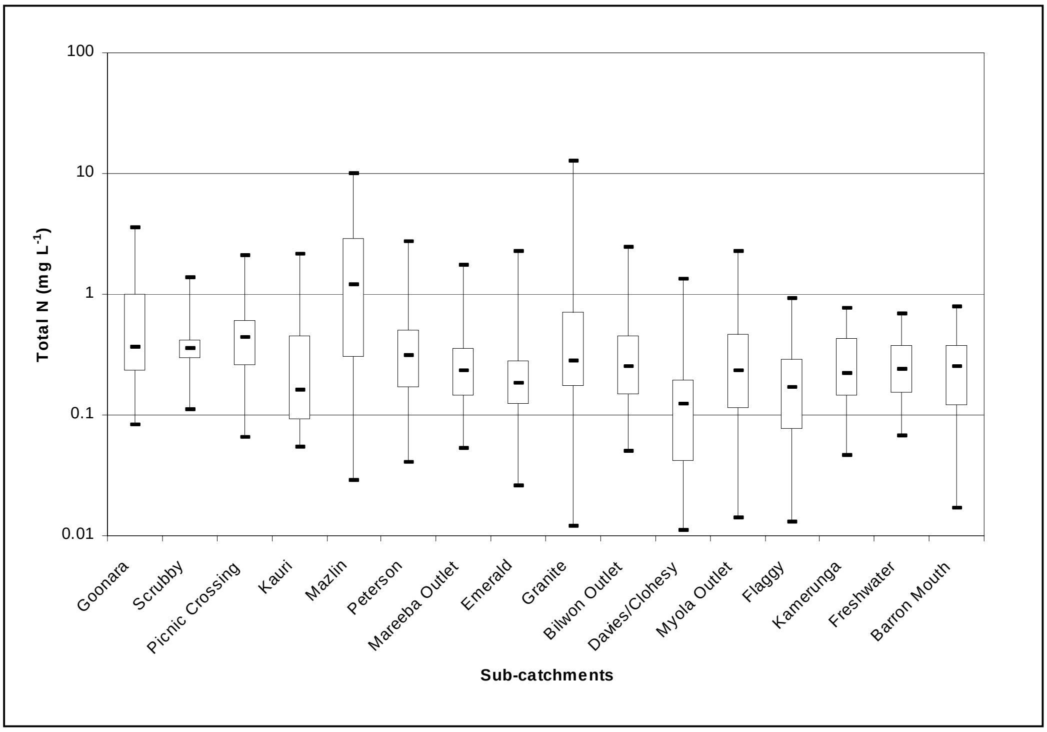


Figure 12. Total nitrogen (mg L^{-1}) for sampled sites in the Barron River catchment. Sub-catchment name is given on x axis. The y axis is a logarithmic scale.

Total P

The Total P medians for all sub-catchments, except Mazlin (0.137mg L^{-1}), were below the draft ANZECC trigger level of 0.035mg L^{-1} (
Figure ***13***).

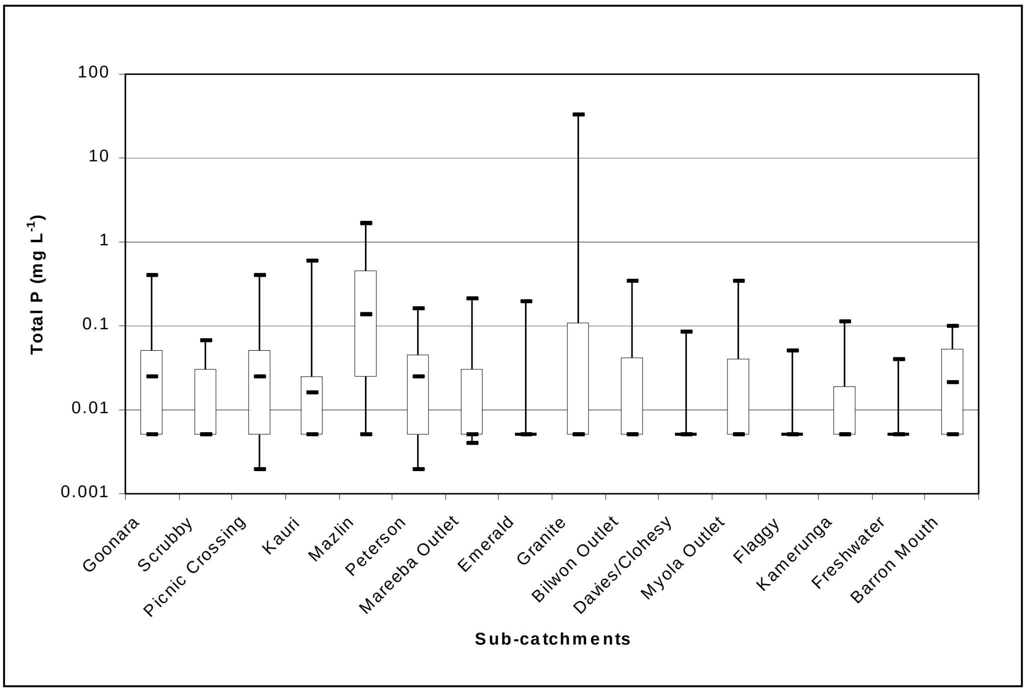


Figure 13. Total-P (mg L^{-1}) for sampled sites in the Barron River catchment. Sub-catchment name is given on x axis. The y axis is a logarithmic scale.

In the Lake Tinaroo catchment, all sub-catchments, except the Scrubby (0.030mg L^{-1}) and Kairi (0.025 mg L^{-1}) sub-catchments had 80th percentile figures above 0.035 mg L^{-1}.

Below Lake Tinaroo, the 80th percentile data for sub-catchments was below 0.035 mg L^{-1} except for Mareeba Outlet (0.0308 mg L^{-1}), Granite (0.107 mg L^{-1}), Bilwon Outlet (0.041mg L^{-1}), Myola Outlet (0.0394 mg L^{-1}) and Barron Mouth (0.047 mg L^{-1}).

Substantial outliers of 33.45 mg L^{-1} in Granite and 1.65 mg L^{-1} in Mazlin were identified. The value in Granite was recorded early 1997, when high concentrations were found in Maude Ck. These have since decreased due to management changes, but are still often above 2.00 mg L^{-1}.

Correlations Between Measured Parameters:

Linear correlations between selected water quality parameters measured are presented in Table 10. Relationships identified are listed below:

- ***Turbidity and suspended solids*** were generally well correlated and only in the Peterson, Freshwater and Barron Mouth sub-catchments were poor correlations found. It is possible that tannins may have influenced this result in Peterson, although this effect would also have occurred in other smaller sub-catchments such as Kauri, Davies/Clohesy and Flaggy, where fringing vegetation is high. Another factor may be cattle dung. Estuarine influences are likely causes of the poor correlations in Barron Mouth and Freshwater sub-catchments;

- ***Total P and Suspended Solids*** were correlated in many sub-catchments indicating that the 2 solutes often are transported together. This occurred across a range of land use, soil types and geologies. In sub-catchments with basaltic geology, this relationship may be due to the sorption of phosphorus to sediments;

- ***Total N and Suspended Solids*** were correlated in some sub-catchments, particularly those draining from the ranges in the centre of the Barron River catchment;

- ***Nitrate-N and Phosphate-P*** were correlated in both the Granite and Mazlin sub-catchments and this appeared to be particularly related to sites adjacent to urban areas and point source rural discharge;

- ***Phosphate-P and Total P*** were correlated in the Mazlin sub-catchment where there is a major impact by the Atherton STP; and

- ***Nitrate-N and Total N*** were correlated at a number of sites and overall in the Freshwater, Mazlin and Flaggy sub-catchments. The response seemed to be related both to forested and urban areas, although in both Freshwater and Mazlin the correlation was highest at sites below an urban or rural residential influence.

Table 10. Linear correlations between sample parameters for selected sub-catchments.

Sub-catchment	Turbidity/ Suspended Solids	Total P/ Suspended Solids	Total N/ Suspended Solids	NO3-N/ PO4-P	PO4-P/ Tot P	NO3-N/ Tot N
Scrubby	0.48	0.47	0.51	-0.32	0.42	0.08
Goonara	0.51	0.88	0.45	0.04	0.31	0.00
Picnic Crossing	0.62	0.90	0.44	0.10	0.15	0.02
Mazlin	0.81	0.26	0.14	0.80	0.74	0.85
Peterson Creek	0.09	0.12	0.27	0.24	0.50	0.13
Kauri	0.49	0.36	0.72	-0.05	0.35	-0.07
Granite	0.95	0.99	0.84	0.86	0.00	0.12
Mareeba Outlet	0.85	0.49	0.25	0.68	0.67	0.52
Bilwon Outlet	0.94	0.88	0.55	0.04	0.50	0.39
Emerald	0.89	0.96	0.93	0.37	0.49	0.34
Davies / Clohesy	0.59	0.60	0.69	0.15	0.00	0.48
Flaggy	0.88	0.64	0.91	0.12	-0.20	0.86
Myola Outlet	0.95	0.85	0.81	0.62	0.41	0.37
Kamerunga	0.75	0.50	0.76	0.30	0.44	0.43
Freshwater	0.29	0.58	0.31	0.03	0.05	0.84
Barron Mouth	0.19	0.36	0.18	0.54	0.52	0.58

Trends over time:

Total Phosphorus
A representative selection of catchment data is discussed in this section to cover the trends found across all catchments.

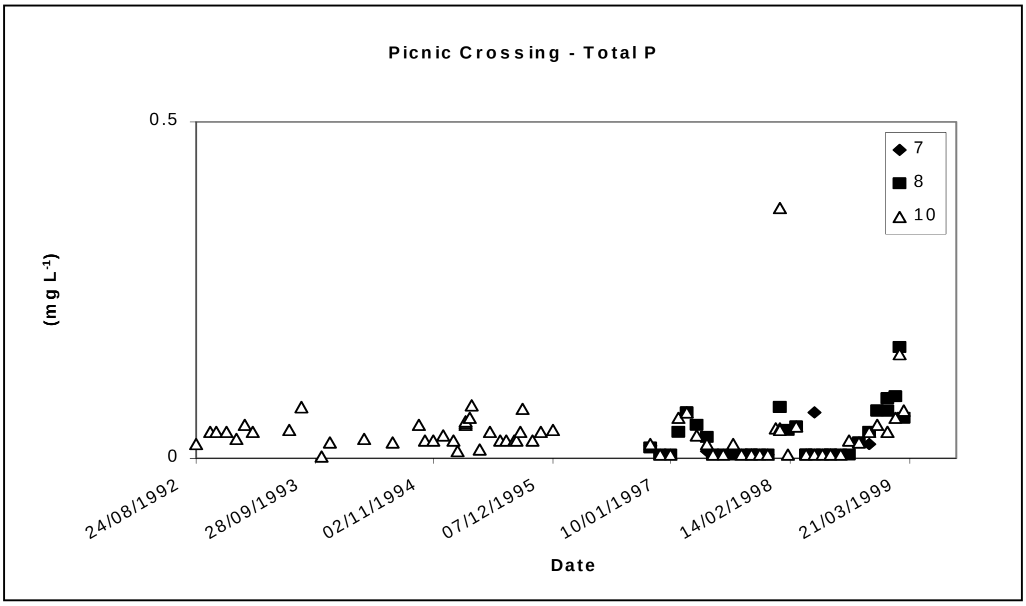
During the last six years there has been little change in the Total P concentrations measured in the Picnic Crossing or the Mazlin sub-catchments (

Figure *14*). These figures suggest that either management has not changed in these catchments or that any changes that have occurred are not apparent given the intensity of sampling conducted by the project. The high concentrations in Mazlin illustrate the continuing influence of the Atherton STP, even though lower emissions over time have been reported (Atherton Shire Council, pers comm.). It is also likely that sediment and nutrients, which have been deposited in the waterway overtime, will also continue to mobilise during subsequent years.

Total phosphorus concentrations in the Granite sub-catchment were generally high in Maude Creek (site 1), downstream of a piggery. These levels were not dissimilar to those in the Mazlin sub-catchment. Concentrations at other sites were generally low for the three years of sampling.

The Davies/Clohesy sub-catchment had low concentrations of Total P over most of the last three years, except for a small number of relatively high values probably related to wet season mobilisation of phosphorus. This was also found in the forested Kauri sub-catchment.

The Barron Mouth sub-catchment had a range of Total P values, which were not dissimilar to those for the Picnic Crossing sub-catchment. It is noticeable that the sampling at the mouth of the Barron River (site 40) was higher than the values at the mouth of Thomatis Creek (site 39). This is probably related to releases from the Northern STP at Aeroglen in Cairns.



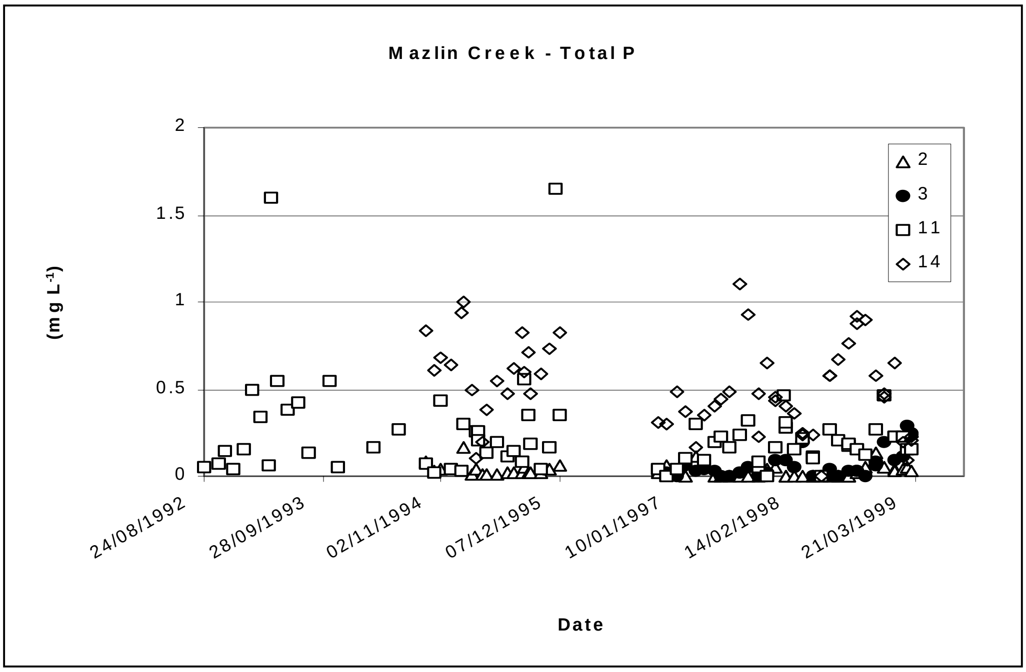


Figure 14. Total phosphorus trend comparison between sites.
(grid lines are spaced at 0.5 mg L^{-1})

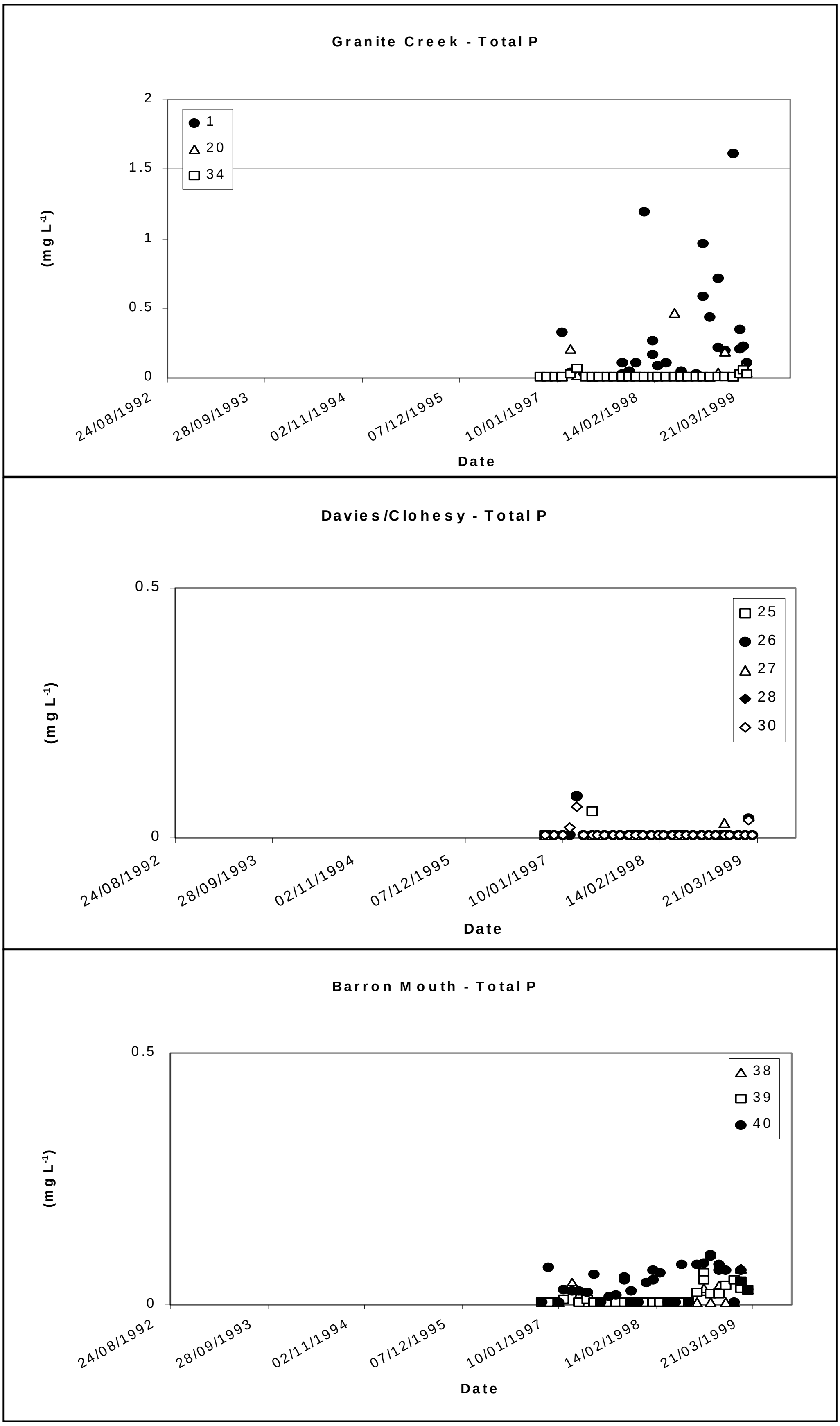


Figure 14. Total phosphorus trend comparison between sites (continued).

Total N:
During the last six years there has been little change in the total nitrogen concentrations measured in the Picnic Crossing or the Mazlin sub-catchments (*Figure 15*). These figures suggest that either management has not changed in these catchments or that any changes that have occurred are not apparent with the current intensity of sampling. The high concentrations in Mazlin illustrate the continuing influence of the Atherton STP. It is also likely that sediment and nutrients, which have been deposited in the waterway overtime, will also continue to mobilise during subsequent years.

Total nitrogen concentrations in the Granite sub-catchment were generally high in Maude Creek (site 1), downstream of a piggery. Concentrations at other sites were generally low for the three years of sampling.

The Davies/Clohesy sub-catchment had low Total N concentrations over most of the last three years, except for a small number of high values during the wet season of 1996/1997.

Total nitrogen values in Freshwater were not dissimilar to those in other multi-land use sub-catchments. However, a particular feature was the close relationship between nitrate-N and Total N at the lower Freshwater Creek site. This relationship was also found in several other sites, notably those influenced by urban and rural land use and it appears some forested land use.

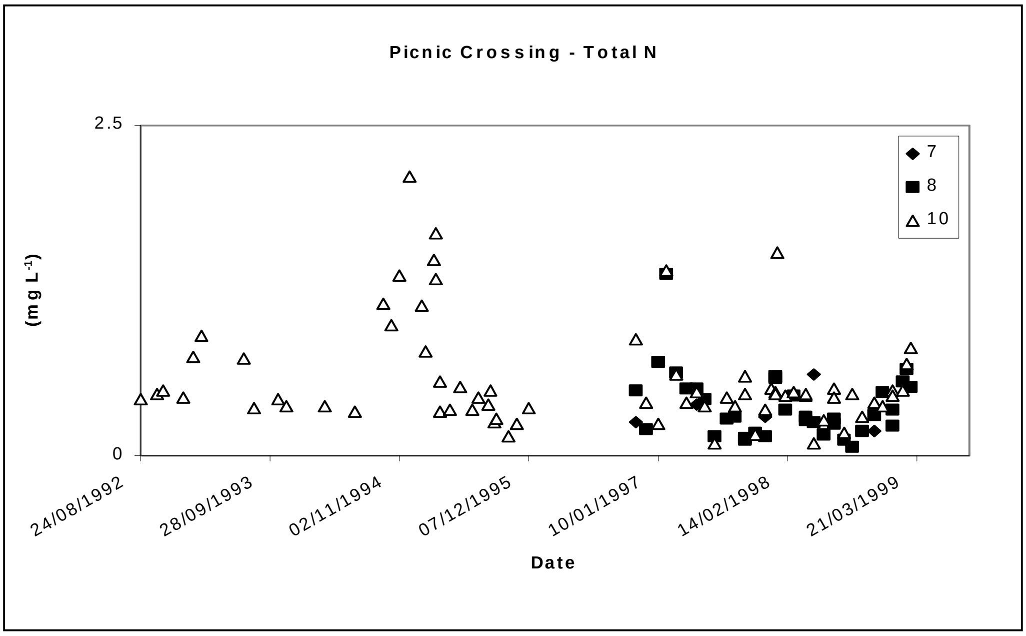


Figure 15. Total nitrogen trend comparisons between sites.
(grid lines are spaced at 2.5 mg L^{-1})

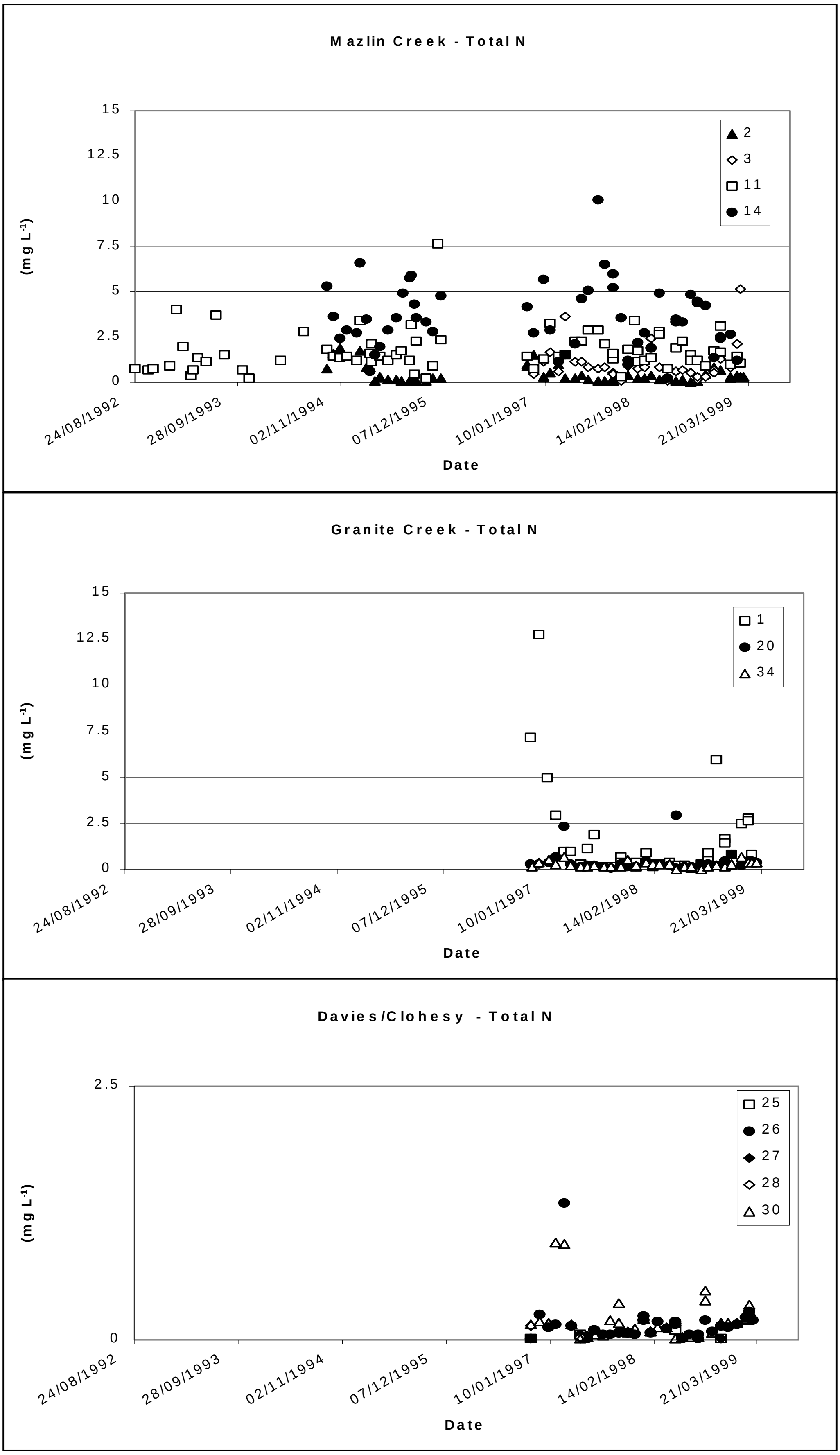


Figure 15. Total nitrogen comparisons between sites (continued).

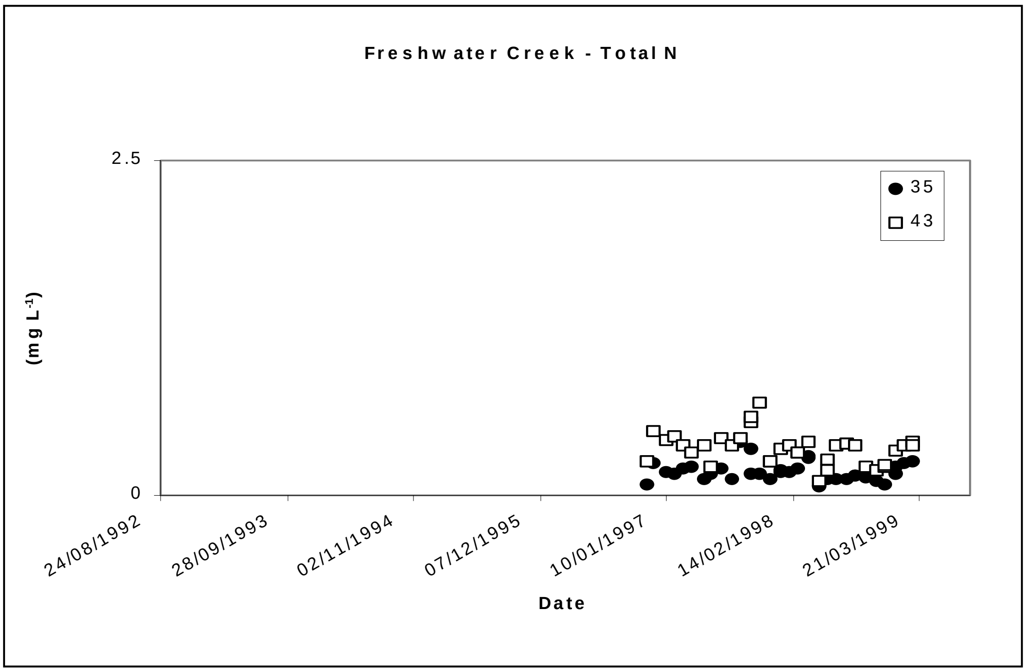


Figure 15. Total nitrogen comparisons between sites (continued).

Temporal Nutrient Flows – Loads and Discharge

Flow data from gauging stations along the Barron River was used to calculate the movement of nutrients and sediment for our temporal sampling. The value of this data is that it provides an estimate of the sediment and nutrient loads flowing through the Barron River system under non-event flow regimes at particular sites. (Note: This data is not for the sub-catchments, but for a single site in selected sub-catchments). Information for the loads during events is shown in the later section on event flows.

Discharge:
Site 32 in the Myola Outlet sub-catchment had the highest median streamflow (566 ML day^{-1}) (Figure 16) during our sampling times. This is the furthest downstream site on the Barron River main channel (Figure 16), that we report here, and hence it is understandable that this site would have the highest median discharge. Other main channel sites (site 5 in Goonara sub-catchment, site 10 in Picnic Crossing sub-catchment, and site 22 in Bilwon sub-catchment) also have relatively large median streamflows. It is notable that site 12, immediately downstream of Tinaroo Falls Dam has a median streamflow during the sampling period, of 19 ML day^{-1}. The low median streamflow at site 12 represents flow regulation practices for the adjacent irrigation area, as does the large variation in discharge. A consequence is that environmental flows in the Barron River are often very low below Tinaroo Falls Dam. Water quality at site 12 is also influenced by the flow regulation.

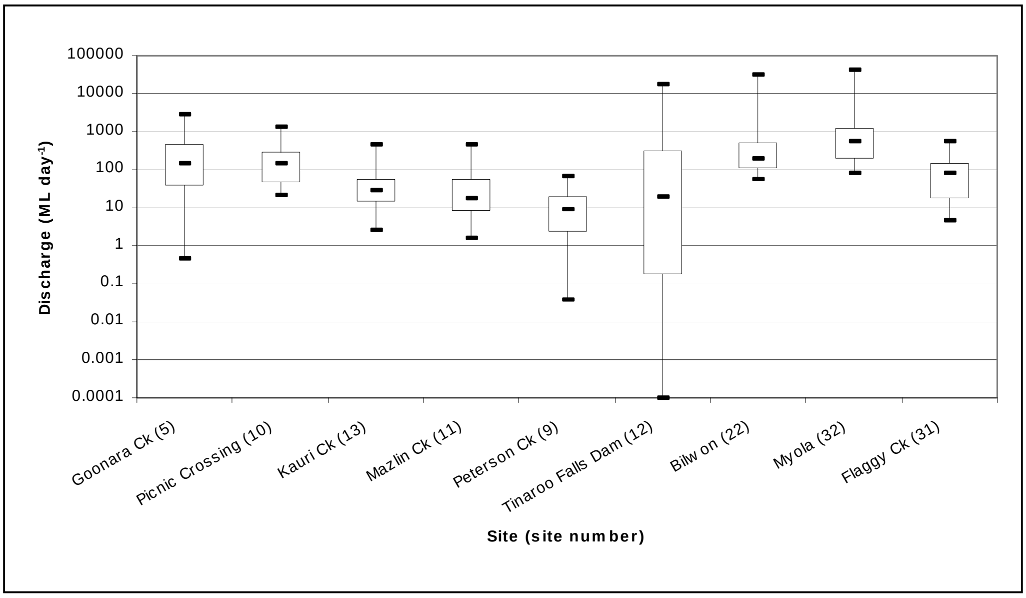


Figure 16. The discharge (ML day^{-1}) for sampled sites in the Barron River catchment. Sub-catchment name and site number (in brackets) is given on the x axis. The y axis is a logarithmic scale.

Suspended solids:
Site 32 in the Myola Outlet sub-catchment showed the highest median (2 628 kg day^{-1}) and 80th percentile for suspended solids (
Figure ***17***). This was more than double the value at site 22 in the Bilwon Outlet sub-catchment and suggests that inputs from tributaries between these sites (Clohesy Davies and Flaggy sub-catchments) contribute substantial sediment to the Barron River main channel. This contention is supported by the relatively high median (338 kg day^{-1}) at site 31 in the Flaggy sub-catchment.

The Barron River main channel at site 5 (Goonara Ck) and site 10 (Picnic Crossing) also have notable median amounts of suspended solids, that is, for the sampling times used in this project over one tonne of sediment per day was travelling along the waterway.

Evidence that Tinaroo Falls Dam is acting as a sink for the sediment flowing along the Barron River main channel is shown by interpreting the median suspended solids load at site 12 (below Tinaroo Falls Dam) and site 10 (Picnic Crossing). On the days that sampling was undertaken, at least 1 167 kg day^{-1} is retained in Lake Tinaroo during non-event flows. This figure is obtained by subtracting 10.7 kg day^{-1} (site 12 median) from 1 177 kg day^{-1} (site 10 median). This calculation is even more significant as it does not include contributions from other tributaries of Lake Tinaroo.

Ammonium-N:
Median loads of ammonium-N were highest at site 32 (Myola Outlet) and at site 10 (Picnic Crossing) and site 5 (Goonara Creek) (

Figure 18). It is interesting that loads at the later two sites were so high given the smaller catchment area. These loads could be attributed to the disturbance of riparian cover and to differences in sub-catchment land uses (Russell *et al.,* 2000).

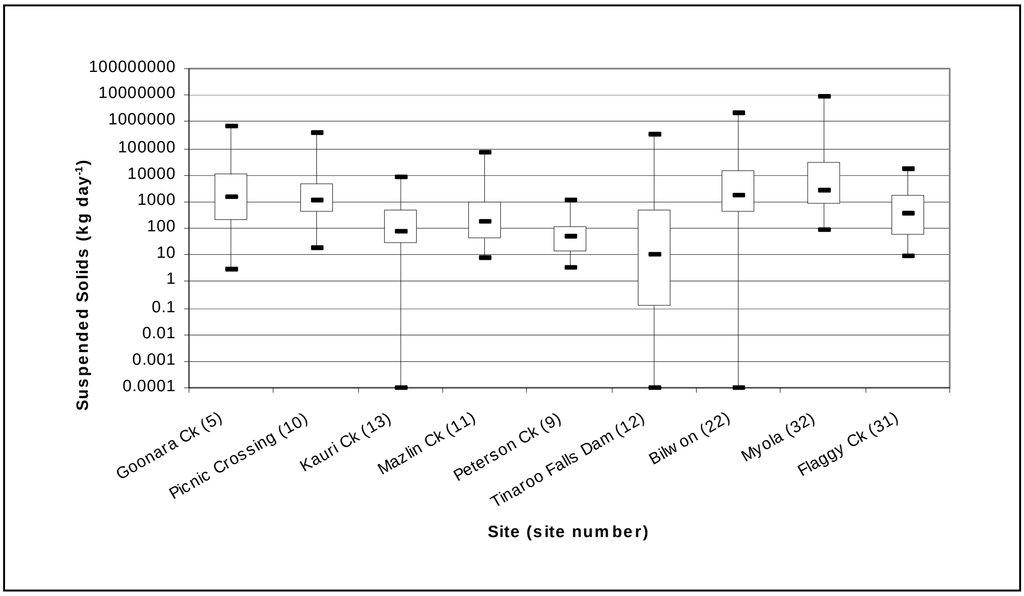


Figure 17. The suspended solid load (kg day^{-1}) for sampled sites in the Barron River catchment.
Sub-catchment name and site number (in brackets) is given on the x axis. The y axis is a logarithmic scale.

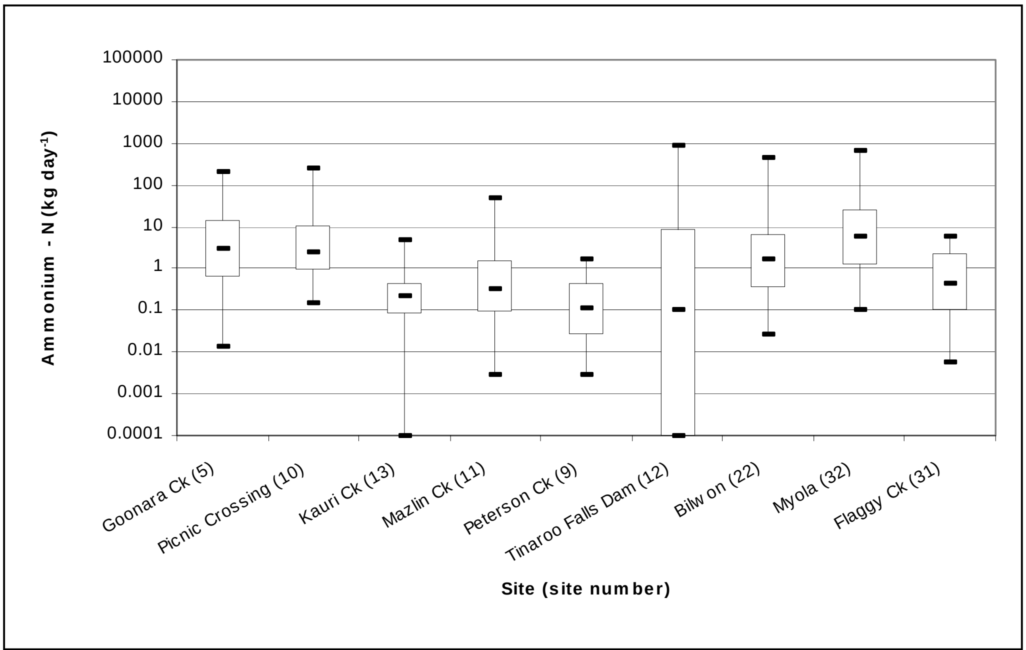


Figure 18. The ammonium-N load (kg day^{-1}) for sampled sites in the Barron River catchment.
Sub-catchment name and site number (in brackets) is given on the x axis. The y axis is a logarithmic scale.

Nitrate –N:
Median nitrate-N loads were highest at site 11 (Mazlin sub-catchment), site 10 (Picnic Crossing sub-catchment) and site 5 (Goonara sub-catchment) (

Figure ***19***). The high values probably reflect land uses in this catchment, although the three sub-catchments drain from a mix of rural and urban land uses, including the STP in Mazlin Creek. Loads from sites below Lake Tinaroo are substantially lower. While there may be some relationship to geology and soil type in the Lake Tinaroo catchment, these figures are somewhat concerning, as nitrate-N is a readily available form of nitrogen.

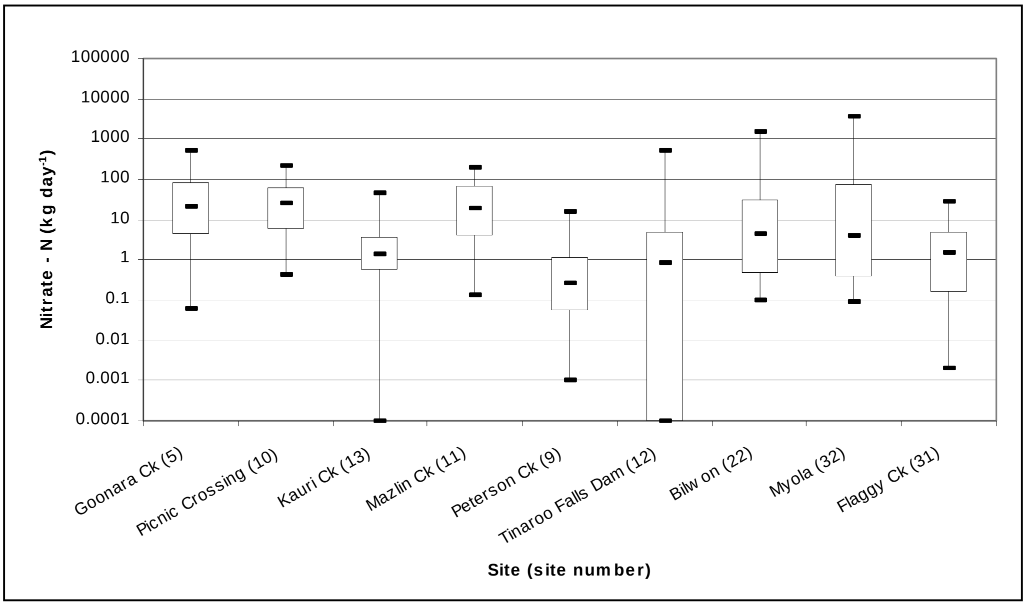


Figure 19. The nitrate-N load (kg day^{-1}) for sampled sites in the Barron River catchment.
Sub-catchment name and site number (in brackets) is given on the x axis. The y axis is a logarithmic scale.

Total –N:
Median loads of Total N were highest at site 32 (Myola Outlet sub-catchment; 91 kg day^{-1}) (Figure 20). Other high median Total N loads were at site 5 (Goonara sub-catchment; 51 kg day^{-1}), site 10 (Picnic Crossing sub-catchment 63 kg day^{-1}) and site 22 (Bilwon Outlet sub-catchment; 69 kg day^{-1}). This supports the contention that the Lake Tinaroo catchment contributes large quantities of Total N to the Barron River system, however, a large part of this is retained in Lake Tinaroo. It is also important to note that a larger proportion of the Total N load in the upper Barron River catchment is nitrate-N compared to that in other parts of the catchment.

Phosphate-P
Median loads of phosphate-P were highest site 32 (Myola Outlet sub-catchment; 3.29 kg day^{-1}) and site 22 (Bilwon Outlet sub-catchment; 2.87 kg day^{-1}) (
Figure ***21***). Loads at site 11 (Mazlin sub-catchment) were also high at 2.1 kg day^{-1} and probably represent the effect of the Atherton STP. As the Atherton STP is a point source, management to reduce the phosphorus loads in the Lake Tinaroo catchment would perhaps be easiest to undertake in the Mazlin sub-catchment. Loads at site 5 and 10 in the Goonara and Picnic Crossing sub-catchments were between 1.3 and 1.6 kg day ^{1}.

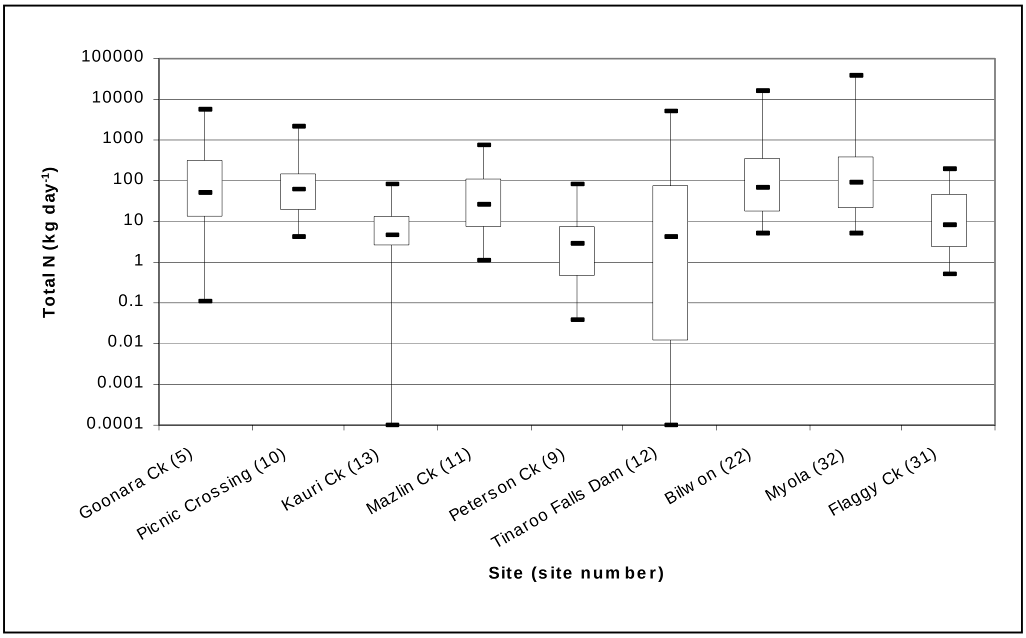


Figure 20. The Total N load (kg day^{-1}) for sampled sites in the Barron River catchment.
Sub-catchment name and site number (in brackets) is given on the x axis The y axis is a logarithmic scale.

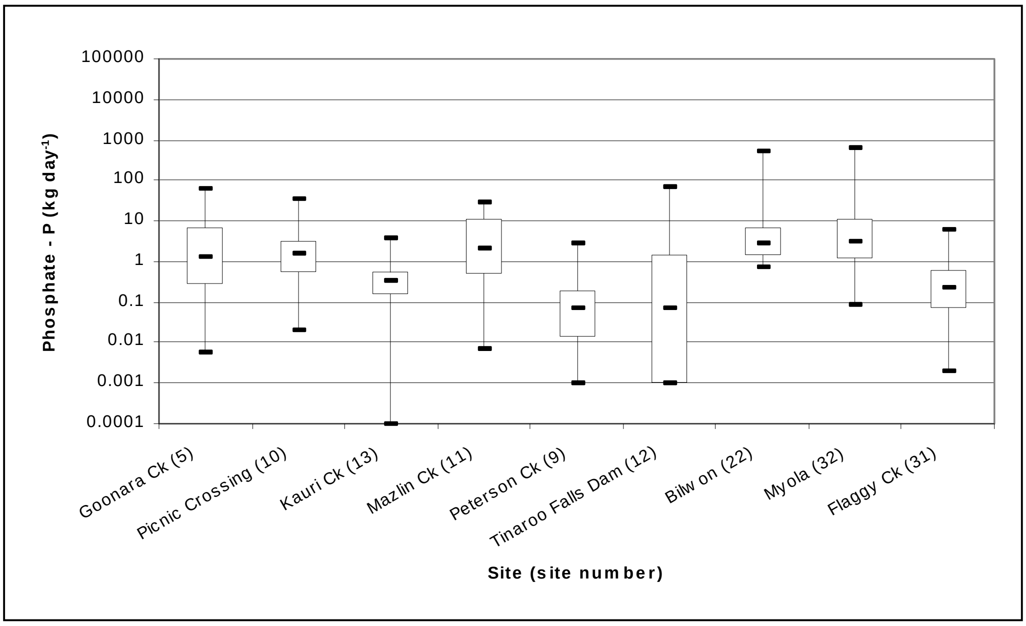


Figure 21. The phosphate-P load (kg day^{-1}) for sampled sites in the Barron River catchment.
Sub-catchment name and site number (in brackets) is given on the x axis The y axis is a logarithmic scale.

Total P
Median loads of Total P were highest at site 11 (Mazlin sub-catchment) and site 32 (Myola Outlet sub-catchment) (

Figure ***22***). The large difference between these sites in terms of discharge and catchment area emphasise the dramatically high quantities of phosphorus, which originate in Mazlin Creek. Loads at site 5 and 10 in the Goonara and Picnic Crossing sub-catchments were between 2.3 and 2.9 kg day^{-1}.
Some caution is warranted in interpreting the results from different sub-catchments due to different underlying soil and geology. The basaltic soils of the Upper Barron catchment contain higher levels of phosphorus and hence if sediment movement is high, phosphorus movement will occur. The comparison of generation rates in catchments with similar characteristics (see later section) is necessary, to identify where new management options may be relatively more beneficial.

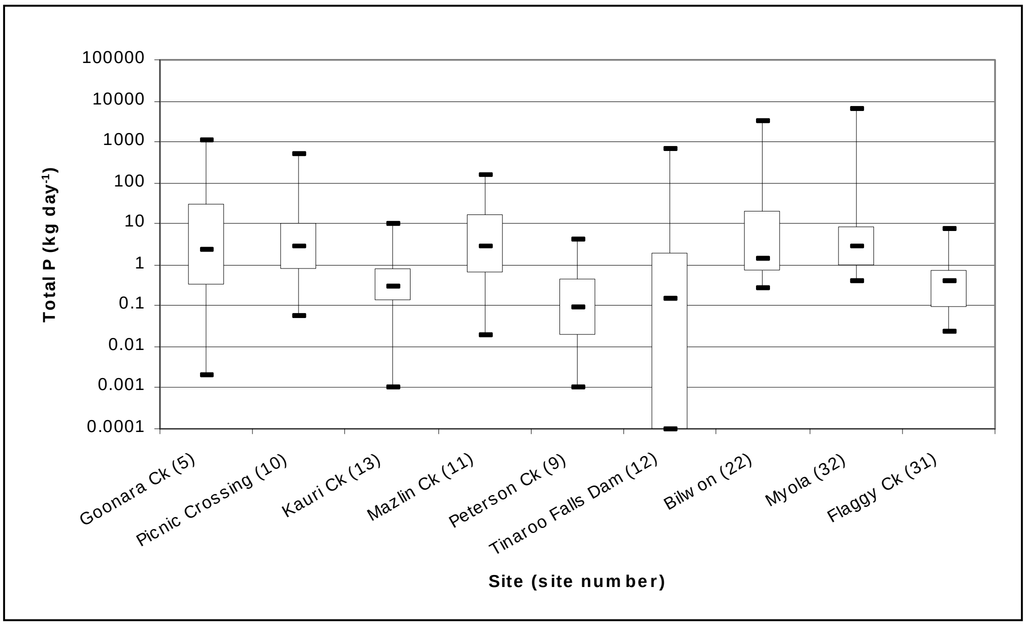


Figure 22. The Total P load (kg day^{-1}) for sampled sites in the Barron River catchment.
Sub-catchment name and site number (in brackets) is given on the x axis. The y axis is a logarithmic scale

Temporal Nutrient Flows – Nutrient Generation Rates

Nutrient generation rates were calculated to assist with comparisons between sub-catchments (Table 11). The rates were calculated by dividing the median nutrient load at each site, (which had discharge data), by the sub-catchment area and multiplying by 365 (days). The unit is kg ha^{-1} year^{-1}. The rates need to be treated with some caution, as the nutrients are sourced from several land uses and, in the case of Picnic Crossing, Bilwon and Myola Outlets from upstream river sources. As the rates represent only temporal data and do not incorporate event flow data, they will also underestimate the annual load.

Discharge:
Kauri and Goonara had the highest median discharge rates for the temporal sampling times. The data from the long term records shows that temporal sampling times occurred at lower discharge rates, and hence our temporal sampling clearly represents stream properties during non-event flows. Event flows are discussed in the later section.

Table 11. Nutrient generation rates per year, for selected sub-catchments.
Figures are divided by the total catchment area for that sampling site, including upstream of the sub-catchment boundary).

	Goonara	**Picnic Crossing**	**Kauri**	**Mazlin**	**Peterson**	**Bilwon Outlet**	**Myola Outlet**	**Flaggy**
	ML ha^{-1} $year^{-1}$							
Temporal Discharge rate	7.44	2.25	6.26	1.19	1.71	0.58	1.08	1.98
Long Term Discharge Rate **(collected daily and including events)**	n/a	5.74	7.15	2.40	2.85	1.45	3.55	6.22
	kg ha^{-1} $year^{-1}$							
Suspended Solids	81.01	18.79	17.50	11.71	9.36	4.99	5.00	8.14
Ammonium-N	0.16	0.04	0.05	0.02	0.02	0.01	0.01	0.01
Nitrate-N	1.14	0.39	0.30	1.27	0.05	0.01	0.01	0.04
Total-N	2.67	1.01	1.06	1.87	0.49	0.21	0.17)	0.21
Phosphate-P	0.07	0.03	0.08	0.14	0.01	0.01	0.01	0.01
Total-P	0.12	0.05	0.07	0.21	0.02	0.004	0.01	0.01

Suspended Solids:
The generation of suspended solids was highest in the Lake Tinaroo catchment with the Goonara, Picnic and Kauri sites substantially higher than other sites.

These data suggests that even during non event flow conditions, the Barron River upstream from Lake Tinaroo has a problem with suspended solid generation, either through soil erosion or in stream sediment mobilisation. Kauri Creek also needs particular consideration given that its suspended solid generation originates from a forested catchment. While relatively high levels of suspended solids are expected during periods of rainfall in forested areas, there appears to be some evidence that additional stream sources may have resulted from road runoff in the Kauri Creek sub-catchment. This may be relatively easy to control. Flaggy Creek is a broadly similar sub-catchment. It is apparent that while suspended solid generation rates were not as high as in Kauri Creek, the comparative discharge for the sampling period (1.98 ML ha^{-1} $year^{-1}$) was much lower and also lower than the long term discharge rate (6.22 ML ha^{-1} $year^{-1}$).

Ammonium-N:
Ammonium-N generation rate was highest in the Goonara Creek sub-catchment. This sub-catchment has a large proportion of both dairy and forest, whereas the broadly similar Picnic Crossing sub-catchment (area and ammonium-N load) has a smaller area of forest. Perhaps organic matter decomposition from the forest land use contributes to higher ammonium loads. However intensive sampling within the sub-catchment is necessary to confirm this suggestion.

Nitrate –N:
Nitrate-N generation rates were highest in Mazlin Creek and Goonara Creek and Picnic Crossing sub-catchments. These catchments have a variety of land uses, but are dominated by the dairy industry.

Total –N:
Total-N generation rates were highest for Picnic Crossing, Goonara Creek, Mazlin Creek and Kauri Creek.

Phosphate-P
Mazlin Creek had the highest phosphate-P generation rate, while Goonara Creek and Kauri Creek had mid range generation rates. Phosphate-P levels below Lake Tinaroo were low and were comparable to Peterson creek.

Total P
Mazlin Creek had the highest Total P generation rate, which was due to the contribution of the Atherton STP.

Event data – Nitrogen, Phosphorus, Sediment Solids

Event sampling was conducted at several sites in the Barron River catchment. Pumping samplers were installed at the Mazlin Creek, Picnic Crossing, Peterson Creek and Kauri Creek gauging stations during the 1994-95 season; these data were reported by Cogle *et al.* (1998). During the 1998-99 wet season pumping samplers were installed at the Bilwon Gauging station and the Kuranda Weir at the Barron Gorge Hydroelectric Station.

Barron River at Bilwon Gauging Station (site 22)

Seven events were sampled at Bilwon. The first event was a small storm on the 3 November 1998. There were 6 samples taken over three hours, which covered the rising limb of the hydrograph but did not cover the recession. The event had a peak discharge of 740 ML day^{-1} (data not shown).

The second event was between 11 and 13 January 1999. The sampling covered the entire event including the recession. The event had two peaks and a peak discharge of 1 421 ML day^{-1}. There was a good distribution of samples across the whole event (Figure 23).

The third event on the 14 and 15 January 1999 and was of similar size to the second event with a peak discharge of 1 140 ML day^{-1}. This event was adequately sampled across the entire event (Figure 23).

The fourth event occurred between the 16 and 17 January 1999 with a peak discharge of 1 017 ML day^{-1}. There was a good distribution of samples across the entire event (Figure 23).

The fifth event was between the 18 and 21 January. This was a larger event with a peak discharge of 2 414 ML day^{-1}. The event peaked early with a long recession. There was a good distribution of samples across the event (Figure 23).
The sixth event was larger again and occurred between the 28 and 30 January. The peak discharge was 3 997 ML day^{-1} and had two peaks. The initial peak had a good sampling density but the second peak only had three samples taken during its duration. The recession was sampled adequately (Figure 23).

The seventh event was Cyclone Rona. The event occurred between the 11 and 13 February 1999. The peak discharge was 156 108 ML day^{-1} (Figure 24). This was the largest event sampled in the 3 years of the study. The rising limb had a good sampling density and the middle of the event had a sufficient sampling density but the recession was not fully sampled due to the site becoming inaccessible.

Suspended Solids

Suspended solid concentrations at Bilwon Gauging Station for the events sampled were much higher than the median for the temporal monthly sampling (Figure 23). Generally, the suspended solid concentrations were high early in the event then decreased to follow the trend for streamflow. Data from the event on 14 and 15 January 1999 (Figure 25) illustrate this trend. The highest concentrations of suspended solids were measured at the start of the Cyclone Rona event (Figure 24). The third event, had an unusually high suspended solid concentration relative to both the streamflow and the previous or later measured events.

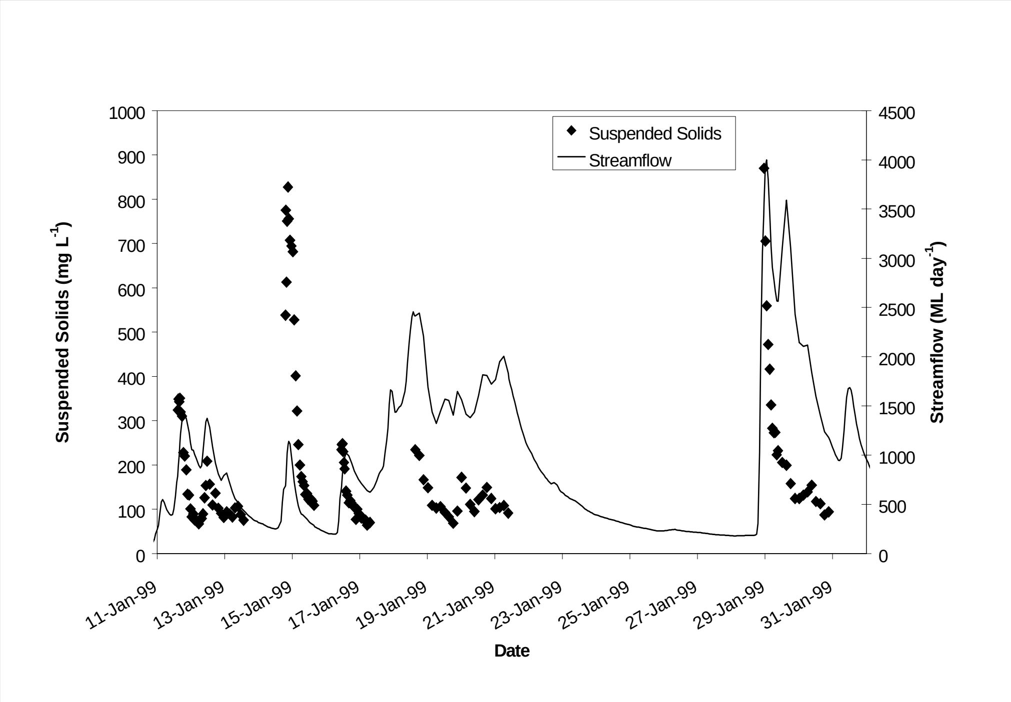


Figure 23. Suspended solids (mg L^{-1}) and streamflow (ML day^{-1}) for event sampling at Site 22 (Bilwon) between 11 and 31 January 1999.

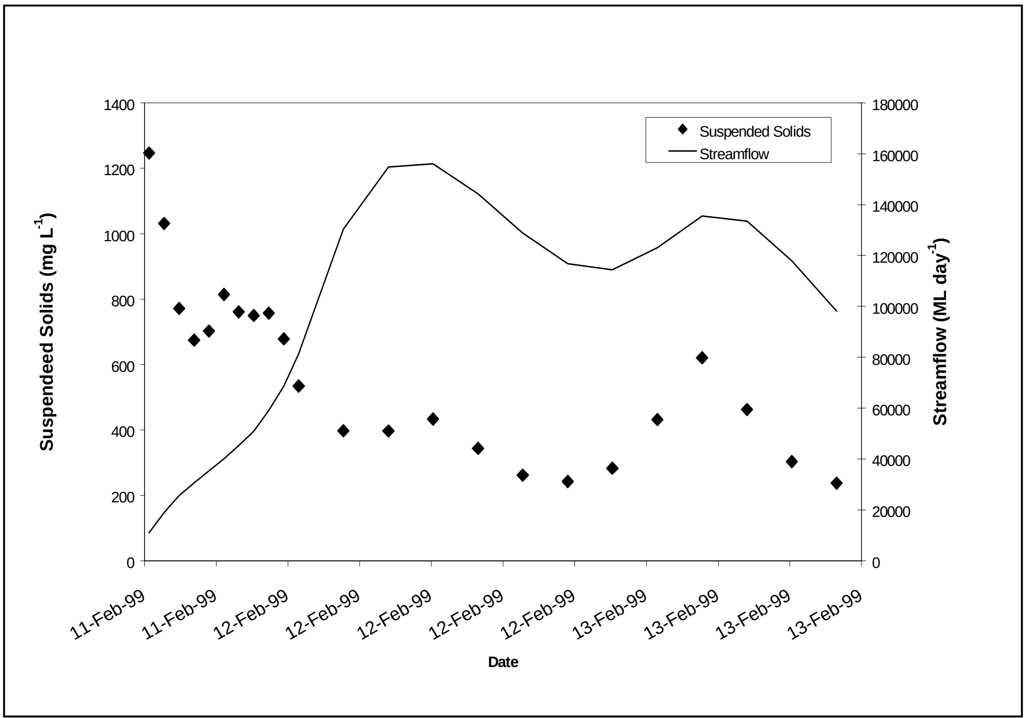


Figure 24. Suspended solids (mg L^{-1}) for event sampling at Site 22 (Bilwon) between 11 and 13 February 1999 (Cyclone Rona).

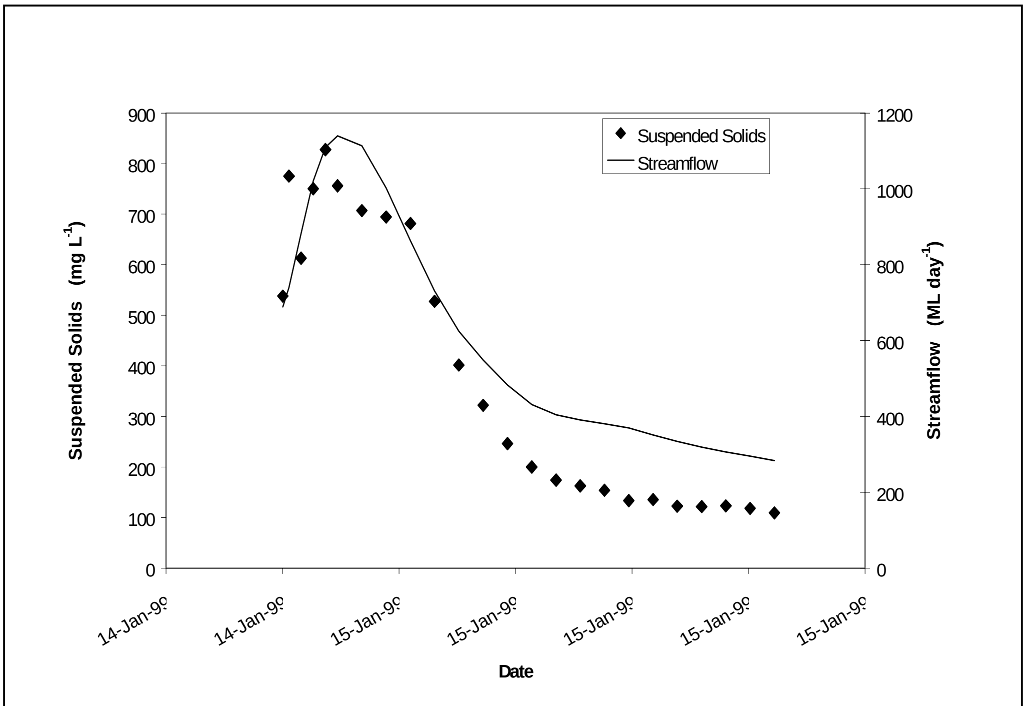


Figure 25. Suspended solids (mg L^{-1}) and streamflow (ML day^{-1}) for event sampling at Site 22 (Bilwon) between 14 and 15 January 1999.

Ammonium-N

Ammonium-N concentrations did not follow any obvious trend (
Figure ***26***). Most values were below the median value for monthly sampling.

The ammonium-N concentrations were highest during an event in January, which corresponded to an event when the suspended solids were high. Invertebrate biodiversity at Bilwon was also low at this time (Russell *et al.* 2000) inferring that perhaps freshly rotting organic matter may have affected water quality over a longer timeframe.

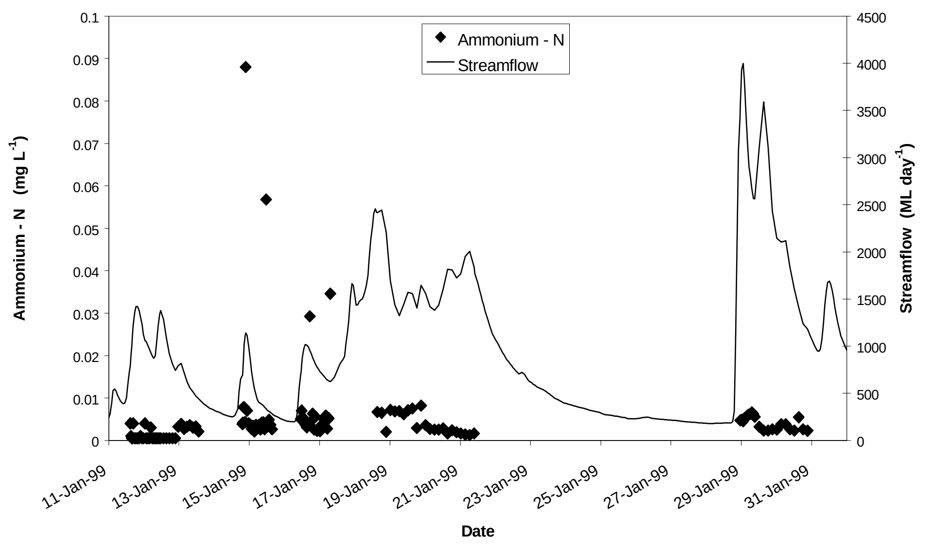


Figure 26. Ammonium-N (mg L^{-1}) for event sampling at Site 22 (Bilwon) between 11 and 31 January 1999.

Nitrate-N

Nitrate-N concentrations were highest early in the wet season and generally decreased across the wet season for the same streamflow (

Figure ***27***). The concentrations measured early in the wet season were marginally higher than the monthly temporal concentrations. Nitrate-N concentrations were relatively very low during the sixth sampled event in late January despite a medium streamflow and did not dramatically increase during Cyclone Rona, even though streamflows were much higher.

Table 12. Correlations between water quality parameters for events at Bilwon Gauging Station.

	Streamflow	Suspended solids	NH4-N	NO3- N	PO4-P	Total N	Total P
Streamflow	1						
SusSoilid	0.298	1					
NH4-N	0.083	0.220	1				
NO3- N	-0.122	-0.204	0.146	1			
PO4-P	0.212	-0.223	0.024	0.105	1		
Total N	0.303	0.716	0.262	0.105	0.098	1	
Total P	0.547	0.728	0.215	-0.074	0.182	0.903	1

Total N

The Total N concentrations were generally higher when the suspended solid concentrations were high (
Figure *28*). There was a strong correlation between suspended solids and Total N (Table 12). This also generally corresponded to periods when streamflow was high.

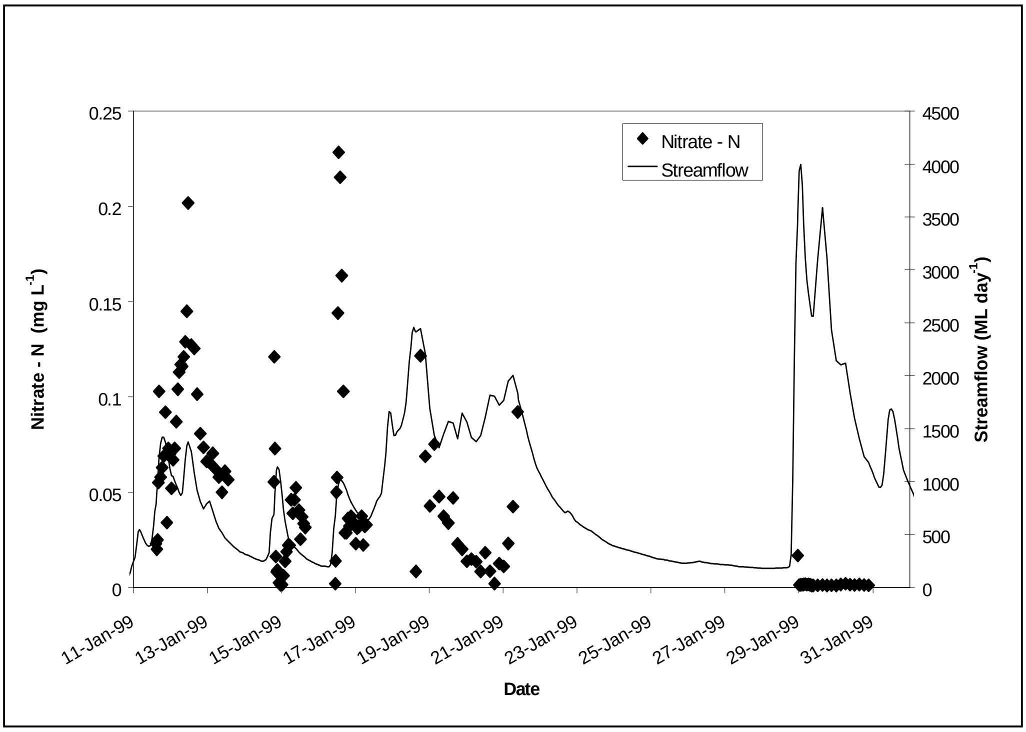


Figure 27. Nitrate-N (mg L^{-1}) for event sampling at Site 22 (Bilwon) between 10 and 30 January 1999.

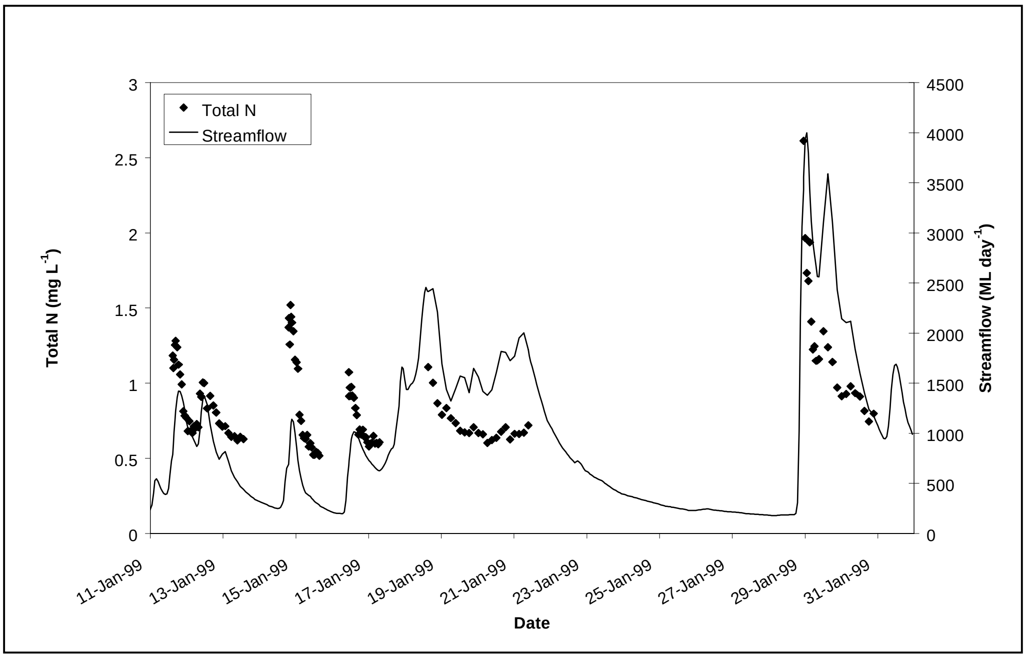


Figure 28. Total N (mg L^{-1}) for event sampling at Site 22 (Bilwon) between 11 and 31 January 1999.

Phosphate-P

Phosphate-P concentrations were highest for the event in late January (Figure 29). The first sampled event in late November also had high phosphate-P concentrations (data not shown). The majority of the concentrations for the events were below the median for the monthly temporal data.

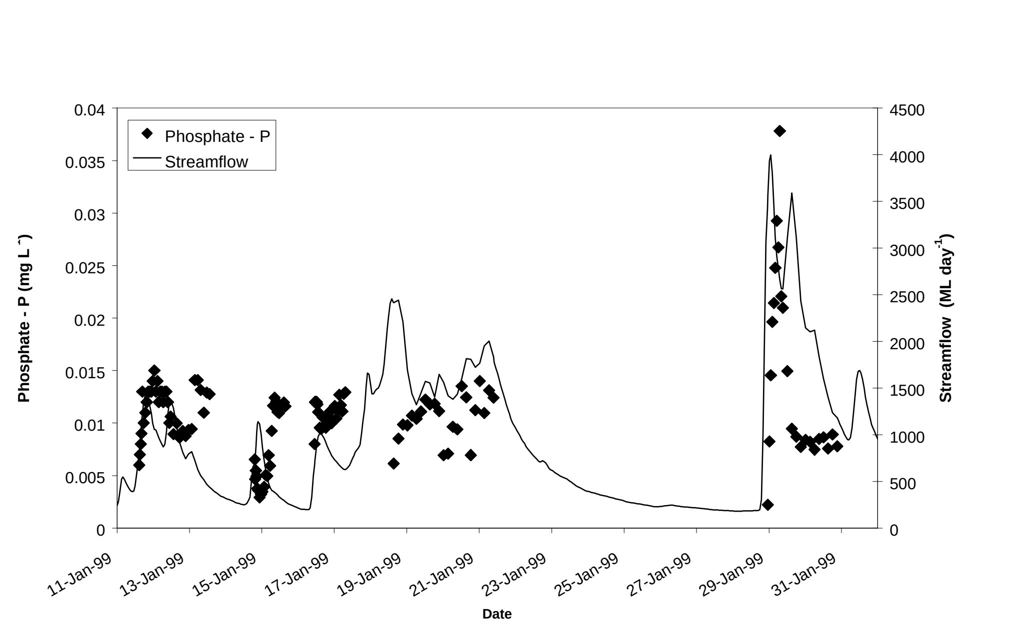


Figure 29. Phosphate-P (mg L^{-1}) for event sampling at Site 22 (Bilwon) between 11 and 31 January 1999.

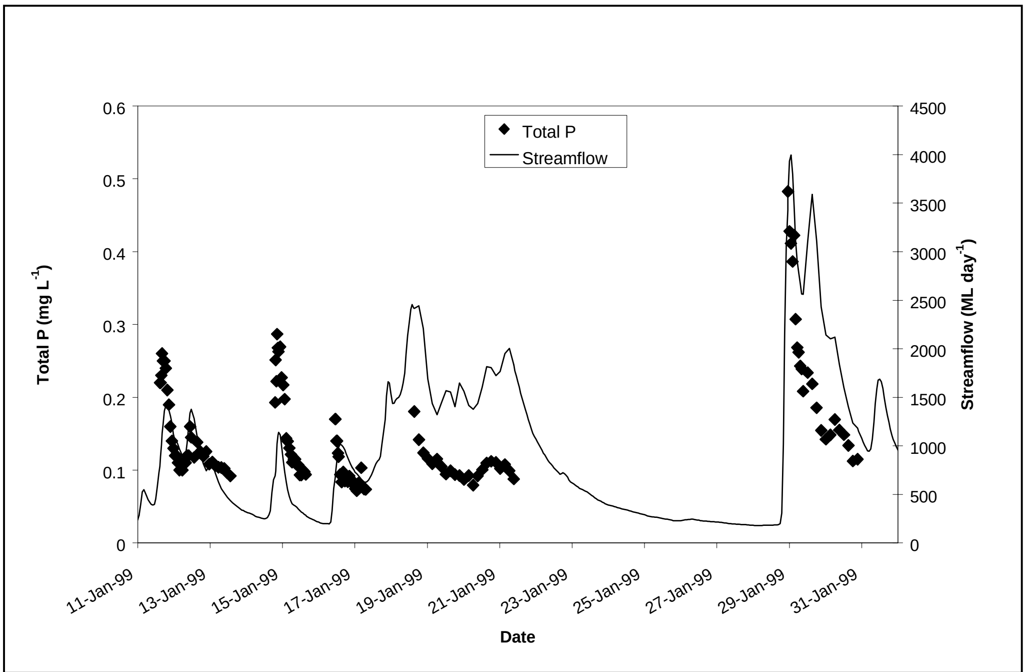


Figure 30. Total P (mg L^{-1}) for event sampling at Site 22 (Bilwon) between 11 and 31 January 1999.

Total P

Total phosphorus concentrations for all flood events were al well above the monthly temporal medians Figure 30) and ANZECC guidelines. There was high correlation between suspended solids and Total P. Generally, Total P concentrations were high early in the event and subsequently decreased to follow the trend for streamflow, similar to Total N and suspended solids.

Event Loads

Over 94% of the suspended solid, nitrogen and phosphorus loads for the events sampled were transported in the two days of Cyclone Rona. It is probable that this figure would be higher if the recession for this event had been sampled for a longer period.

Table 13. Sediment and Nutrient Loads for Bilwon Gauging Station for events sampled between November 1998 and March 1999.

Start	Finish	Suspended Solids	NH4-N	NO3-N	PO4-P	Total N	Total P	Total Discharge
		t	kg	kg	kg	kg	kg	ML
3/11/99 2:09	**3/11/99 4:09**	16.5	1.6	15.4	0.9	100.7	17.4	60
11/1/99 14:43	**13/1/99 13:28**	257	2.5	164.6	20.9	1545.9	256.5	1832
14/1/99 19:13	**15/1/99 15:28**	232	6.6	11.7	3.1	485.9	91.3	493
16/1/99 11:00	**17/1/99 7:15**	80	4.1	47.2	7.4	487.6	63.2	684
18/1/99 15:25	**21/1/99 9:24**	598	18.8	170.3	48.9	3,399	499.0	4665
28/1/99 23:12	**30/1/99 21:12**	1,092	17.5	7.0	60.2	5,577	1,034	4668
11/2/99 14:43	**13/2/99 12:43**	86,426	1,700	7,092	3,081	268,810	72,015	210604
TOTAL	**All events**	88,700	1,751	7,508	3,222	280,406	73,976	223,004

Barron River at Kuranda Weir (Site 42)

Three events were sampled at Kuranda. The first event was on the 18 and 19 January. Samples were taken at hourly intervals for 8 hours. This provided an adequate spread of samples over the rising limb of the hydrograph but there were no samples during the recession due to a broken sampler hose. This was a minor event (data not shown).

The second event was Cyclone Rona (11 to 13 February 1999). Samples were initially taken at four hourly intervals for the first three days and then at twelve hourly intervals for the next eight days. Despite the apparently long intervals both the rising and falling limbs of hydrograph had a good distribution of samples. The long intervals allowed the long recession to be adequately sampled (Figure 31).

The third event was between the 13 and 23 March 1999. Initially the sampling interval was two hourly for four hours, then 12 hourly for the next three days and then 24 hours for the remaining five days. This was a long sustained flow and there was a significant flow over the spillway of Tinaroo Falls Dam. The sampling intervals were adjusted to sample representatively over this long event (Figure 31).

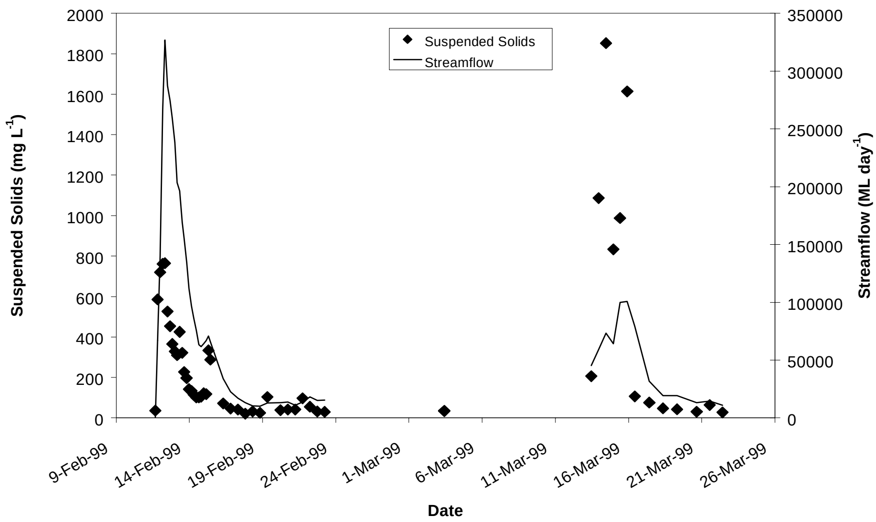


Figure 31. Suspended solids(mg L^{-1}) for event sampling at Site 42 (Kuranda) between 9 February and 26 March 1999 (includes Cyclone Rona).

Suspended Solids

Suspended solid concentrations at Kuranda Weir for the events sampled were much higher than the median for the temporal monthly sampling (Figure 31). Generally, the suspended solid concentrations were high early in the event then decreased to follow the trend for streamflow. The highest concentrations were measured at the start of the third sampled event (13 to 23 March1999) an event in mid March.

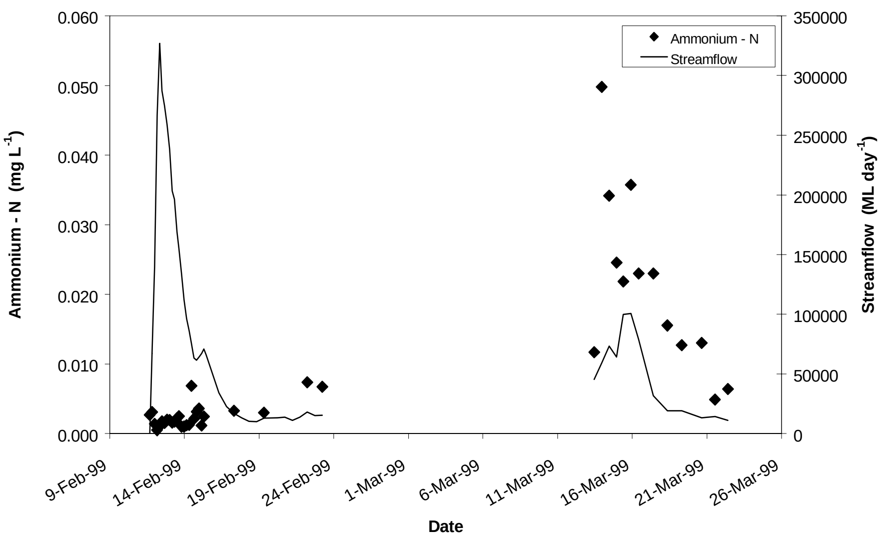


Figure 32. Ammonium-N (mg L^{-1}) for event sampling at Site 42 (Kuranda) between 9 February and 26 March 1999 (includes Cyclone Rona).

Ammonium-N

Ammonium-N concentrations did not follow any obvious trend (Figure 32). Most values were below the median value for monthly sampling, except for the event monitored between 13 and 23 March 1999.

Nitrate-N

Nitrate-N concentrations did not follow any obvious trend) and were generally slightly higher than the monthly temporal concentrations (Figure 33).

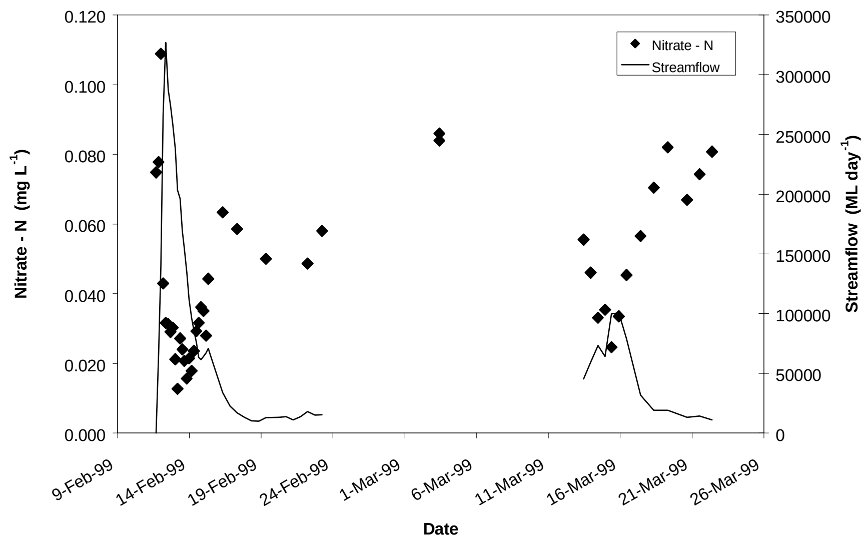


Figure 33. Nitrate-N (mg L^{-1}) for event sampling at Site 42 (Kuranda) between 9 February and 26 March 1999 (includes Cyclone Rona).

Total N

The Total N concentrations were higher when streamflow and the suspended solid concentrations were high (
Figure ***34***). There was a strong correlation between suspended solids and Total N (Table 14). The highest total N concentration was measured during the third sampled event between 16 and 23 March 1999.

Table 14. Correlations between water quality parameters for events at Kuranda Weir.

	Streamflow	Suspended Solids	NH4-N	NO3- N	PO4-P	Total N	Total P
Streamflow	1						
Suspended Solids	0.438	1					
NH4-N	-0.229	0.584	1				
NO3- N	-0.583	-0.280	0.064	1			
PO4-P	-0.621	-0.254	0.212	0.414	1		
Total N	0.471	0.973	0.468	-0.271	-0.268	1	
Total P	0.484	0.919	0.423	-0.370	-0.171	0.940	1

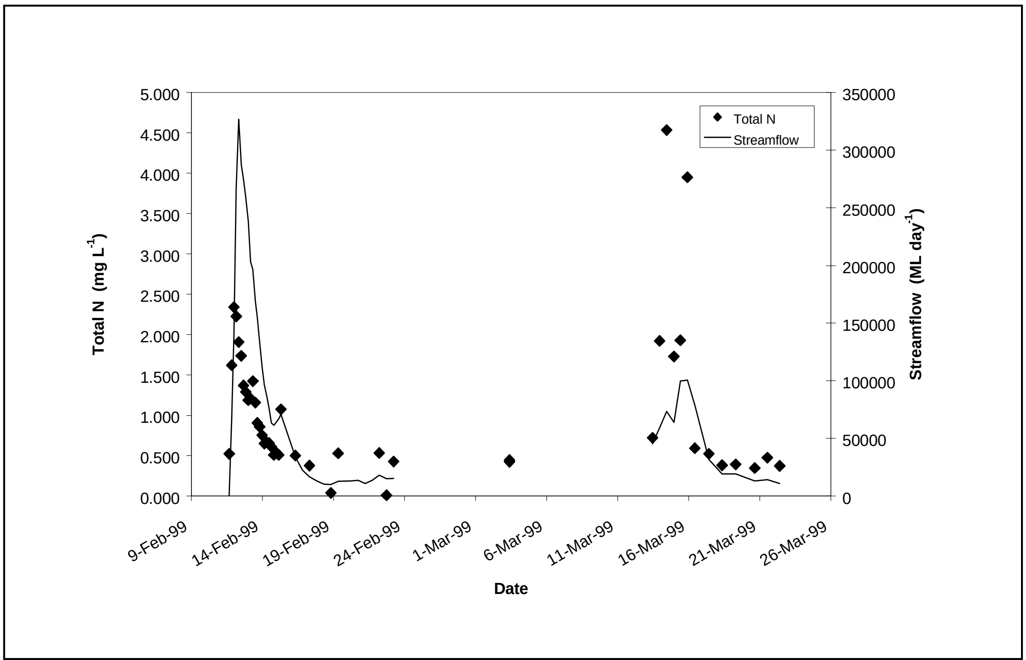


Figure 34. Total N (mg L^{-1}) for event sampling at Site 42 (Kuranda) between 9 February and 26 March 1999 (includes Cyclone Rona).

Phosphate-P

Phosphate-P concentrations did not follow any obvious trend (Figure 35) and were generally slightly higher or similar to the monthly temporal concentrations.

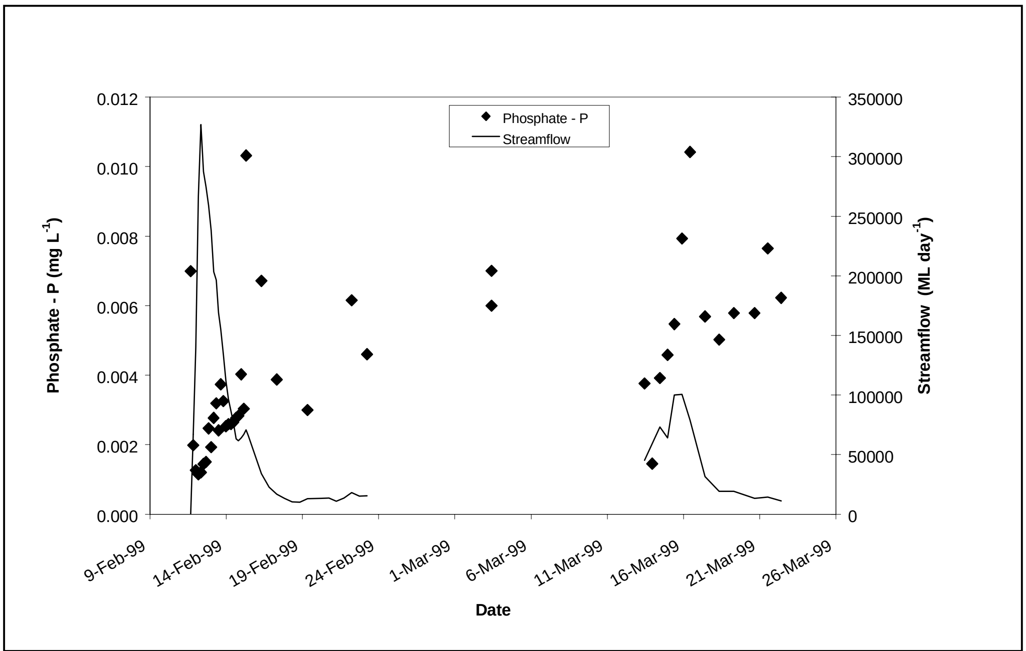


Figure 35. Phosphate-P (mg L^{-1}) for event sampling at Site 42 (Kuranda) between 9 February and 26 March 1999 (includes Cyclone Rona).

Total P

Total phosphorus concentrations were all well above the median value for the monthly sampling (Figure 36). There was a high correlation between suspended solids and Total P (Table 14). Generally, total P concentrations were high early in the event and subsequently decreased to follow the trend for streamflow.

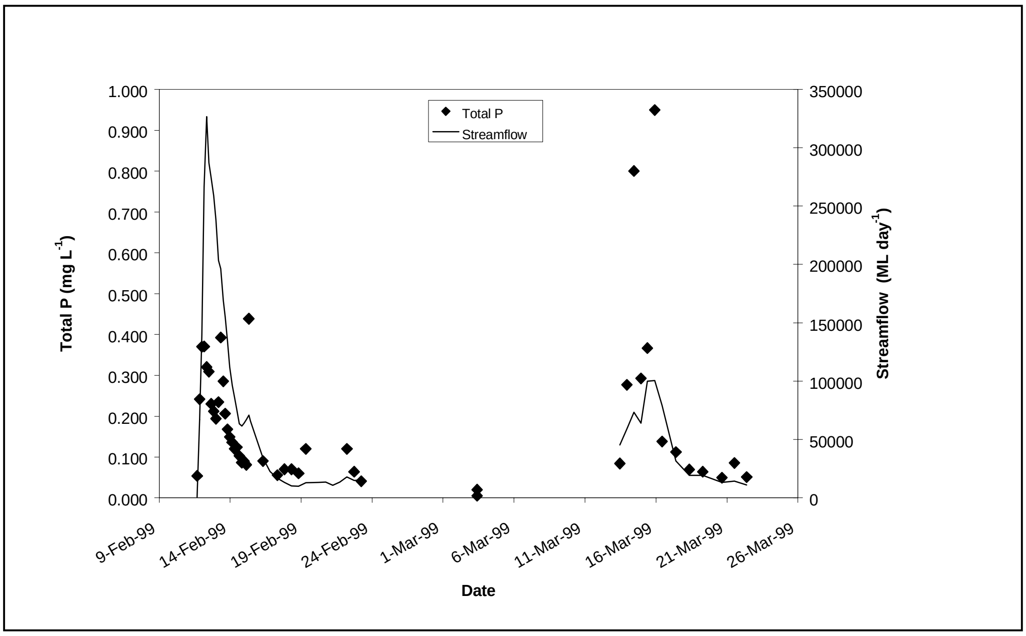


Figure 36. Total P for event sampling at Site 42 (Kuranda) between 9 February and 26 March 1999 (includes Cyclone Rona).

Event Loads

Calculated sediment and nutrient loads for Kuranda weir are displayed in Table 15 and shows that a large mass of suspended solids passed the weir for both major events. The suspended solids concentrations were highest early during the event in March and stayed high for entire event. This resulted in a higher load of suspended solids passing the weir for the March event despite having a lower total flow than Cyclone Rona.

Table 15. Calculated Sediment and Nutrient Loads for Kuranda Weir.

Start	Finish	Suspended Solids	NH_4-N	NO_3-N	PO_4-P	Total N	Total P	Total Discharge
		t	kg	Kg	kg	kg	kg	ML
18/1/99 23:28	**19/1/99 7:28**	28	1.5	14.6	1.6	145.4	15.9	241
11/2/99 16:08	**15/2/99 7:27**	229 285	977	17 926	1 258	752 722	138 122	558 415
13/3/99 10:47	**23/3/99 9:35**	256 730	9 473	17 230	2 253	624 204	121 639	370 377
TOTAL	**All events**	486 043	10 452	35 170	3 512	1 377 072	259 777	786 989

Comparison of Water Quality Data collected in the Barron River Catchment

Several water sampling programs have been undertaken in the Barron River. Many of these programs were identified in the report on water quality in the Lake Tinaroo catchment (Cogle *et al.* 1998).

Collation of data from the Environmental Protection Agency (EPA) and Waterwatch sites into the sub-catchments used by our project, allowed some comparative analysis. For the purposes of this report we show the comparisons for the Picnic Crossing and the Freshwater Creek sub-catchments (Figure 37 and Figure 38). The NHT (our project) and Waterwatch sampling programs were conducted over generally similar time periods (1994 to date), however the EPA sampling program, which was conducted from 0 to 28 km from the Barron River mouth, has been underway for a much longer period (it commenced in 1982).

Median data in the Picnic Crossing sub-catchment were generally similar for NHT and Waterwatch data, except for phosphate-P. A similar response is found for Freshwater Creek sub-catchment for all data sources, but again phosphate-P results for Waterwatch are very high. These phosphate-P results are a matter for some concern and consideration should be given to changing the methodology, particularly if data is to be used in any way, apart from awareness exercises

These results do however show the value of community based water sampling in providing a broad overview of water quality in waterways and comparative information across catchments. Provided that adequate quality control and data management programs are in place, community groups and government agencies can gain substantial information for both planning and implementation of catchment management from such community water sampling programs.

Comparisons between the 3 sampling programs for the Freshwater sub-catchment shows the broader range for conductivity in the EPA results. This is probably due to the larger timeframe (1982-1999) of their sampling and the contribution of sites closer to estuarine influences in this sub-catchment.

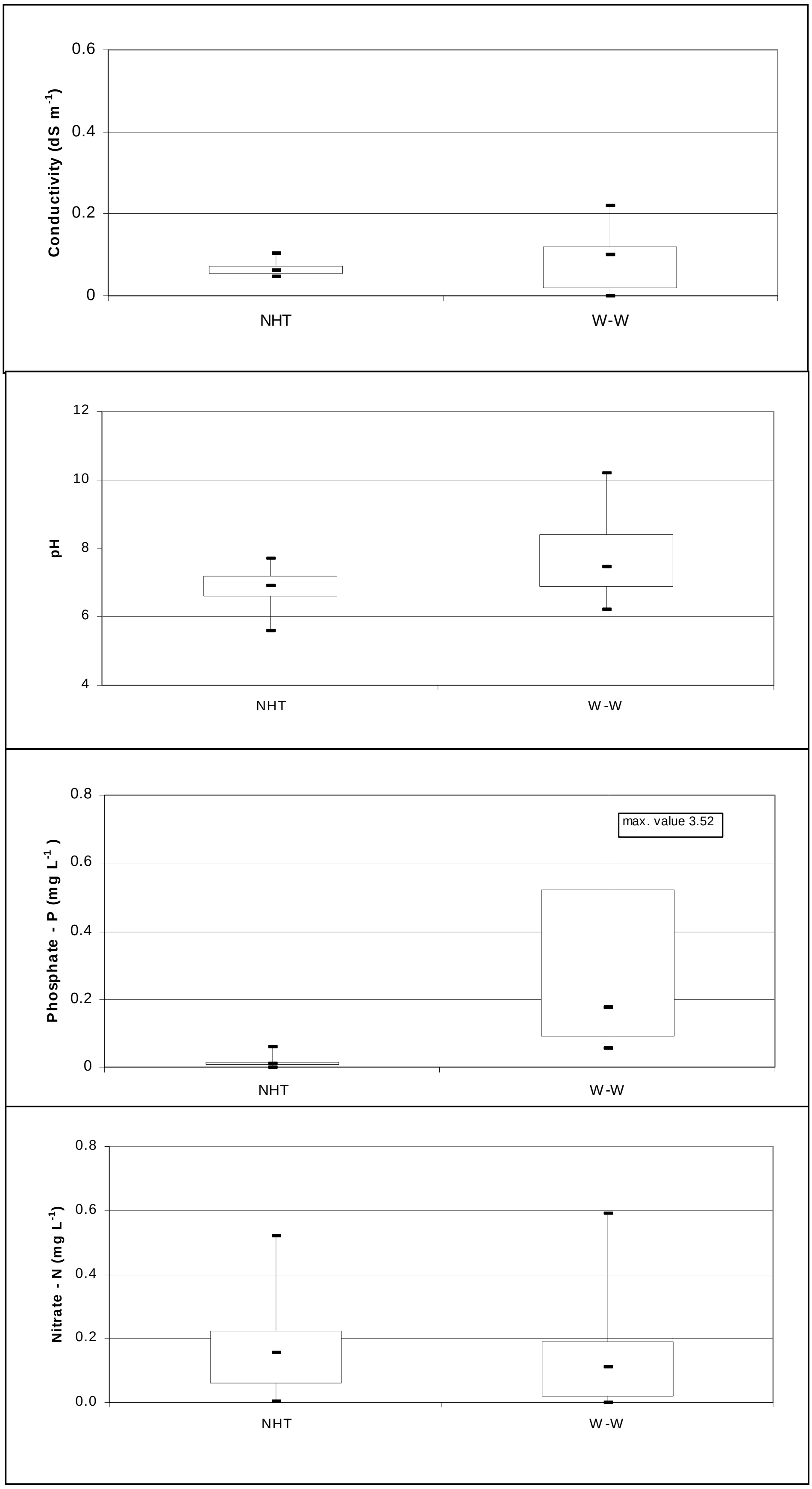


Figure 37. Picnic Crossing water quality comparison.

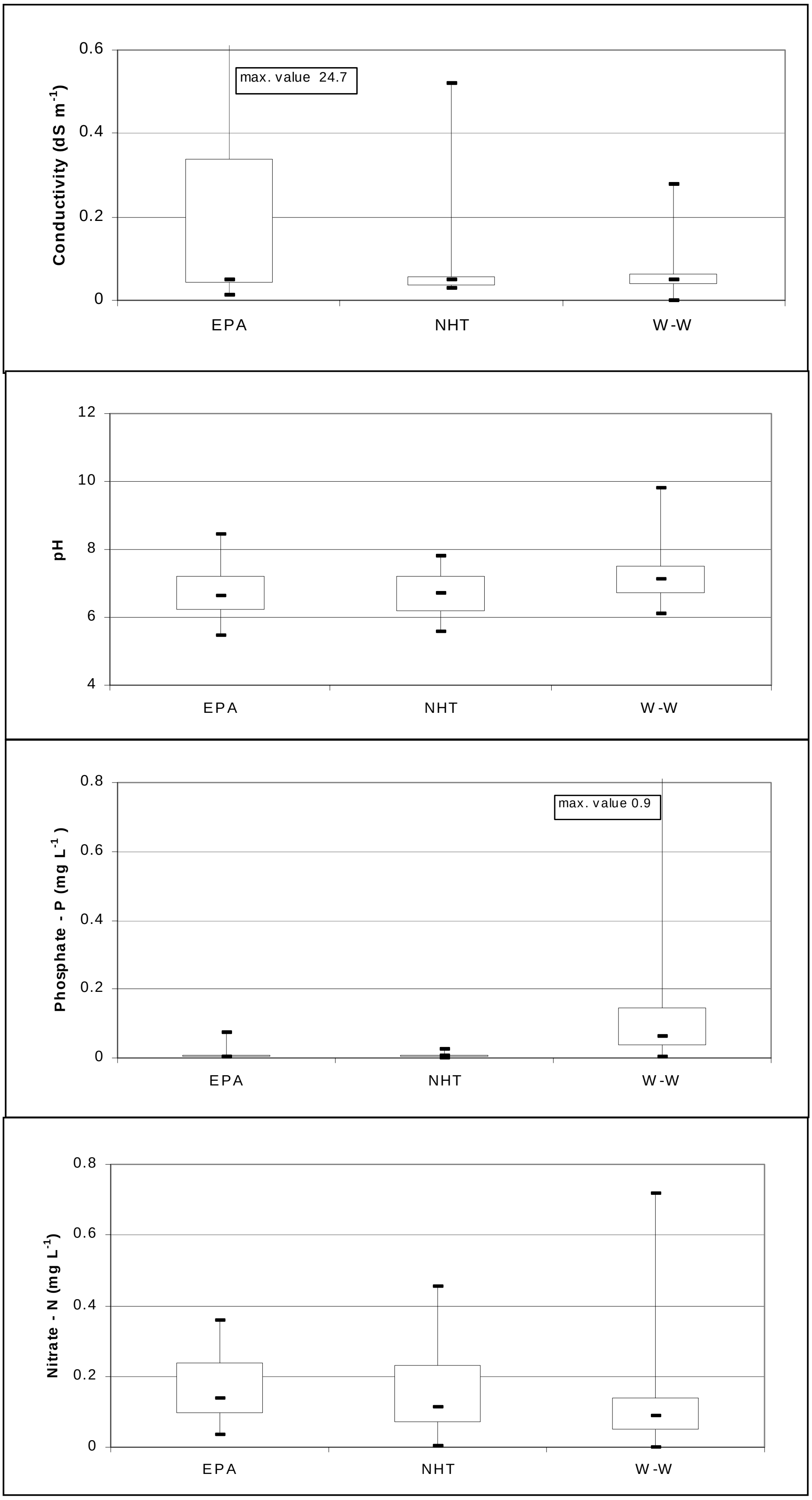


Figure 38. Freshwater Creek water quality comparison.

Decision Support Systems (CMSS)

The decision support tool CMSS has been run for the Barron River catchment using data obtained in the project and from other sources, as discussed previously. In addition to base runs (Table 16), which provide an estimate of nutrient flows (nitrogen and phosphorus) under current conditions, several policy runs (scenarios representing new management options) were conducted (Table 17). However, it must be emphasised that the value of CMSS is its ability to be used interactively with stakeholders. Hence, the results presented here are an example of possible scenarios for the catchment to demonstrate the potential impact of new nutrient management strategies.

Table 16. Base nitrogen and phosphorus outputs from each sub-catchment.
These figures are unrouted (ie. outputs are for the individual sub-catchment and are not cumulated).

Catchment	Nitrogen			Phosphorus		
	Kg	% of Total	Uncertainty	Kg	% of Total	Uncertainty
Goonara	13939	4	6514	1308	1	741
Scrubby	8857	2	2291	1785	2	622
Picnic	26691	7	12715	7304	7	1886
Peterson	4581	1	2135	952	1	384
Mazlin	18890	5	4265	6481	7	4795
Kulara	2727	1	1182	872	1	246
Danbulla	8670	2	2616	691	1	461
Severin	2585	1	1511	225	<1	512
Maroobi	8699	2	4185	1179	1	1429
McLean	3120	1	1529	1431	1	467
Platypus	1606	<1	494	124	<1	86
Kauri	2148	1	661	165	<1	116
Granite	33330	8	9704	11543	12	3372
Mareeba Outlet	52287	13	14327	17110	18	3824
Emerald	13238	3	3114	4059	4	1202
Davies/Clohesy	39510	10	10589	5022	5	1985
Flaggy	19805	5	5966	1537	2	1070
Myola Outlet	35612	9	10145	3369	3	1911
Kamerunga	10138	3	2733	1393	1	672
Freshwater	15256	4	4027	3225	3	1046
Barron Mouth	47673	12	15044	19728	20	4982
TOTAL	392922	100	80653	95819	100	20580

Base Run
The base run (Table 16, and Figure 41) estimates that the Barron Mouth, Mareeba Outlet and Granite Creek sub-catchments individually yield between 12 and 20 % of the total phosphorus in the catchment, before routing, and that other sub-catchments yield less than 7%. The base runs also estimate that Mareeba Outlet, Barron Mouth, and Davies Clohesy Outlets yield between 10 and 13% of the total nitrogen, however Myola Outlet and Granite Ck sub-catchments also each contributed 9%. Nutrient generation rates are calculated on a sub-catchment basis (Figure 40 and Figure 42) to show which sub-catchments have the greatest rate of nitrogen and phosphorus production. The outputs for the base run show that the Barron Mouth sub-catchment has the highest nitrogen and phosphorus generation rates, followed by the Mazlin sub-catchment.

Nutrients are subject to a number of processes (absorption, biological uptake or release), which change their concentration and quantity in the water column. Those nutrients removed by deposition in sediment and/or biological uptake are held for a range of time periods depending on river flows and morphology and biological turnover times. The nutrient loads presented in Table 16 are for nutrients from land surfaces in the sub-catchment and do not include those nutrients already in the waterway. The estimations are also not routed or assimilated, and no account of possible nutrient removal is provided.

Potential sources of error in the estimates of total nutrient production from the Barron River catchment presented in (Table 16*)* are:

- an inaccurate estimation of nutrient generation rate. However, comparison to the rates calculated from our data suggests that the rates used in Win-CMSS are within reasonable limits of uncertainty; and
- not accounting for routing of nutrients in the water column either by: Inadequate reduction of nutrient load due to deposition; and/or Inadequate increase of nutrient load due to re-entrainment of nutrients into the water column.

Tinaroo Falls Dam is a major barrier to the movement of nutrients downstream. A comparison of temporal loads at the Dam site (12) and Picnic Crossing (10) show that only around 10% of nutrients move downstream of the dam (see Temporal Nutrient Flows – Loads and Discharge). Hence, Lake Tinaroo is a major sink for nutrients, but just as noteworthy is that it prevents a large proportion of nutrients moving from the Lake Tinaroo catchment to the Great Barrier Reef lagoon. CMSS has been set-up to limit the transfer of nitrogen and phosphorus below Lake Tinaroo to 10%. Figure 43 shows how nutrients are routed in the current setup of CMSS and Figure 44 illustrates the effect on nitrogen flows through the catchment.

Uncertainty

Nutrient generation rates used in CMSS have a “uncertainty” term associated with them. This represents the confidence with the designated generation rate used in the calculations. The results presented in (Table 16) show uncertainty values. These represent the level of confidence in the predicted loads.

Policies

The policy runs (Table 5) utilise a major feature of CMSS whereby the impact of selected management options on nutrient loads in the catchment and its sub-catchments can be estimated. The assumption being that the impact on nutrient generation of the management option is known. However, even if it isn’t, the estimated changes to nutrient flows in the catchment can still provide valuable understanding for catchment stakeholders.

The policy runs show the impact of a change in land use or management and the results of selected policies are shown in Table 17 and Table 18. The cells in these tables show the difference in nitrogen or phosphorus loads following the policy intervention on a sub-catchment basis or the total Barron River catchment. For example policy 5 reduces the nitrogen load by 200 Kg Nitrogen yr^{-1} or 2% in the Maroobi sub-catchment and reduces the load by the same amount for the total catchment, assuming no routing, but as a percentage the change is very minor (Table 17).

A noticeable impact of these example runs is that while the impact of an option may be large in an individual sub-catchment, its impact over the whole catchment is low except for policy 6 on nitrogen. Policy 6 was the only option that showed an effect on all sub-catchments and hence it is perhaps understandable that it would impact on the total catchment nutrient production.

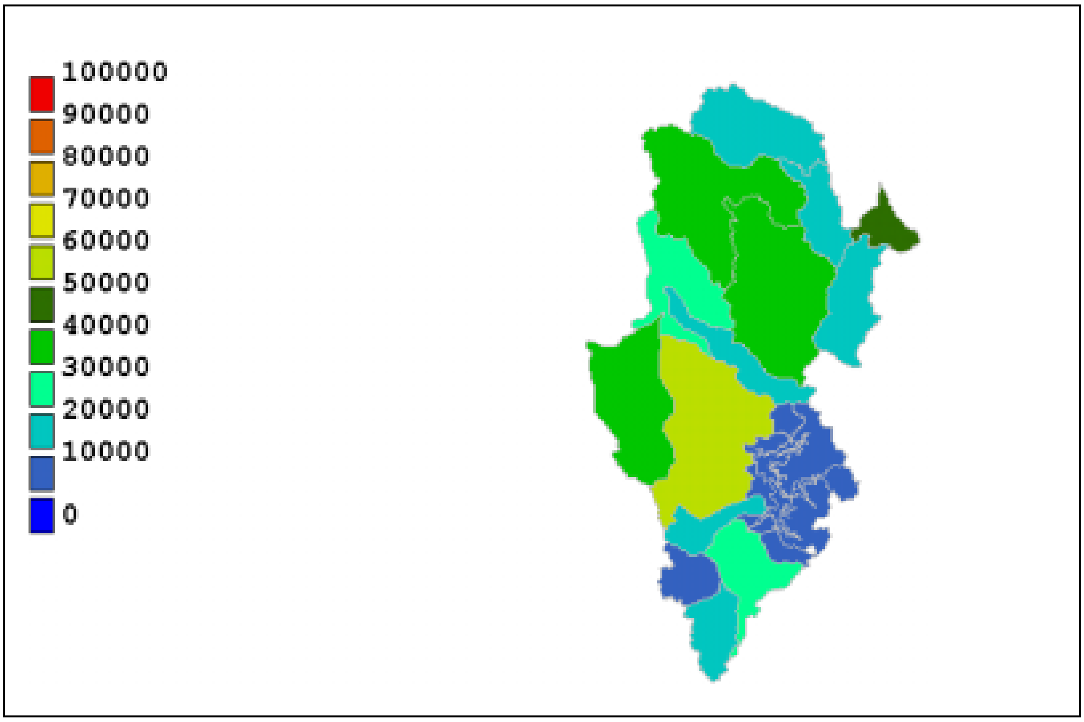


Figure 39. WinCMSS estimated Total Nitrogen Loads (kg/yr) – Unrouted.

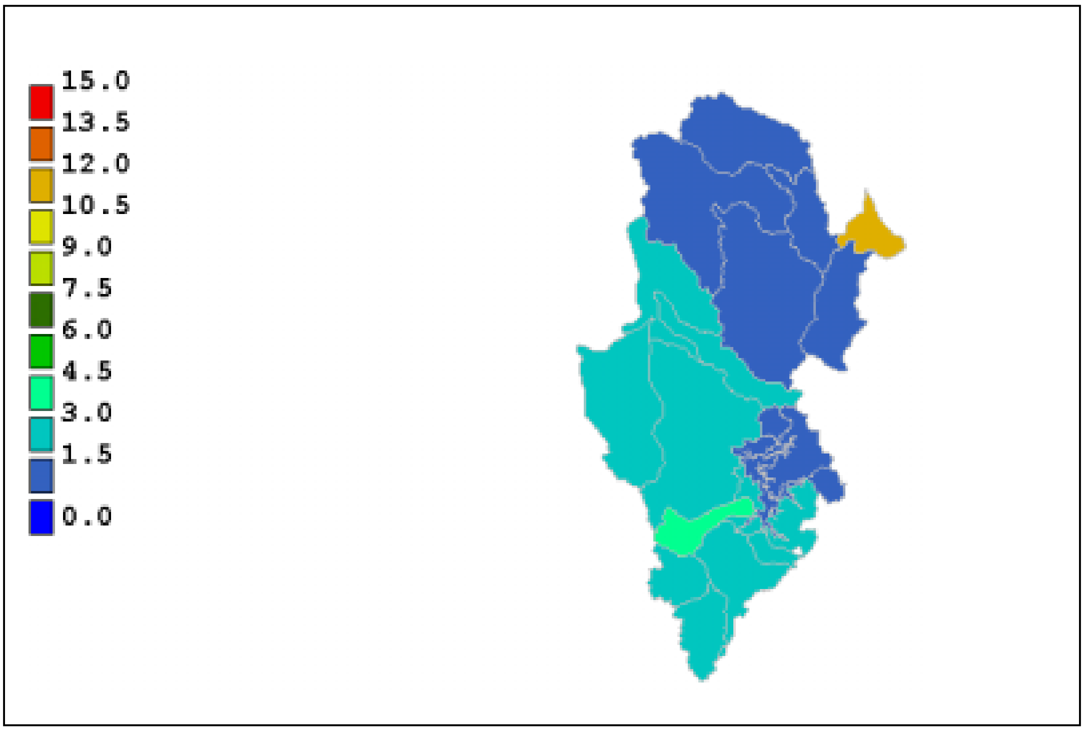


Figure 40. WinCMSS estimated Average Total Nitrogen Generation Rates (kg/yr/hectare) –Unrouted.

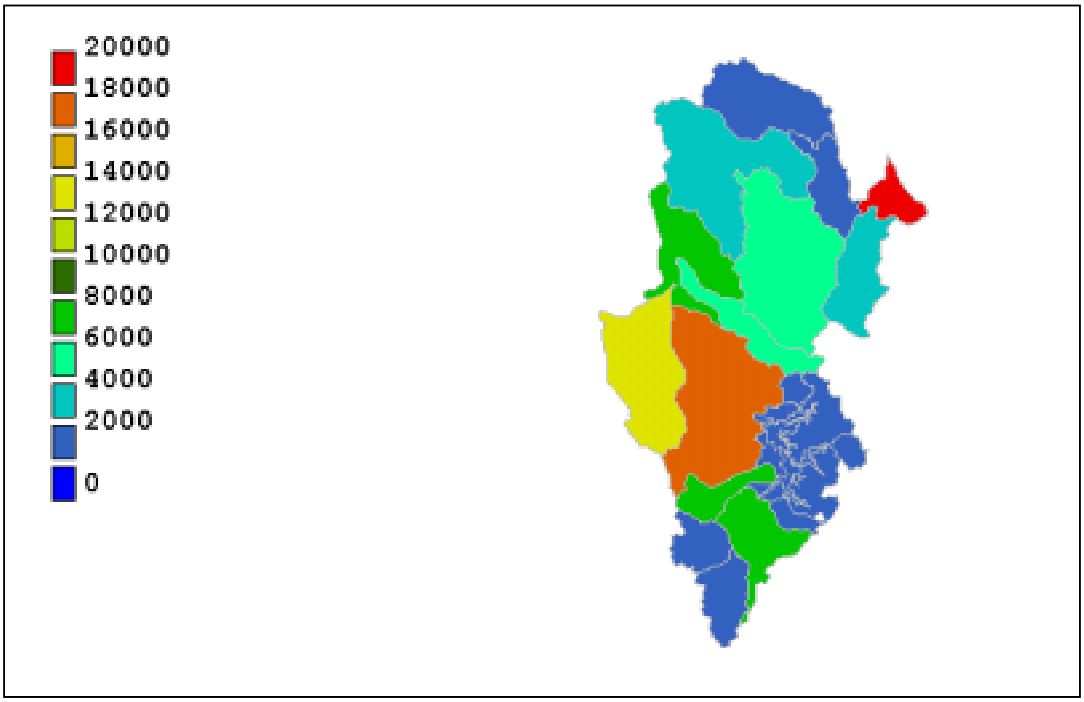


Figure 41. WinCMSS estimated Total Phosphorus Loads (kg/yr) – Unrouted.

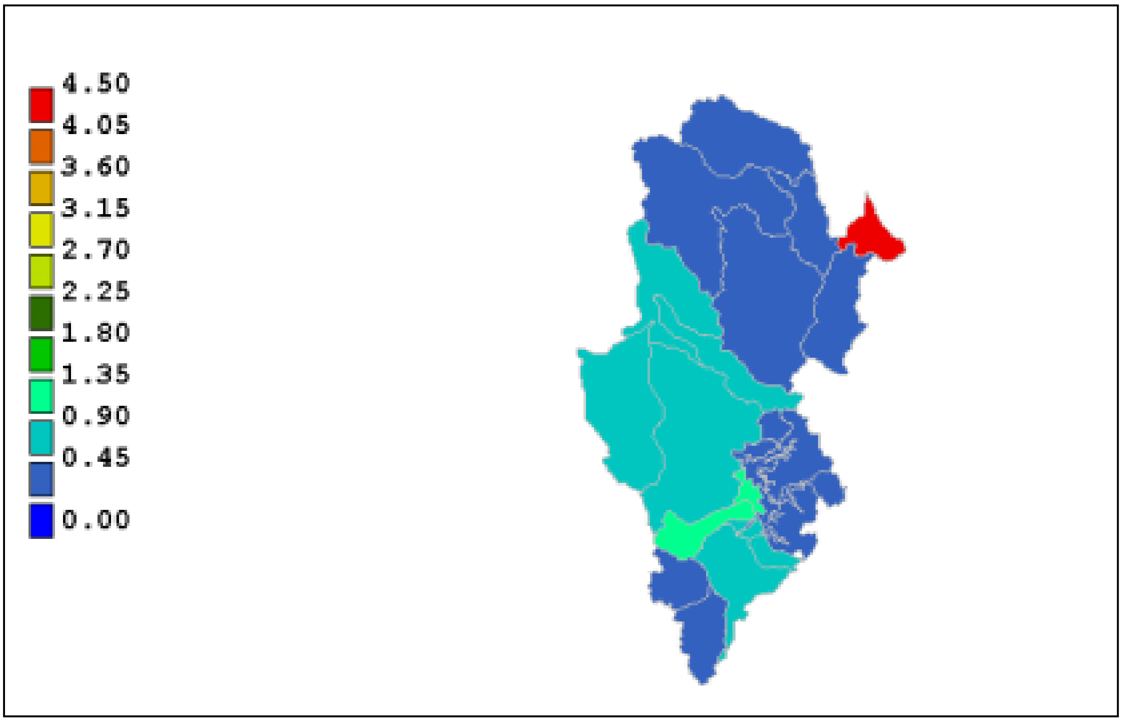


Figure 42. WinCMSS estimated Average Total Phosphorus Generation Rates (kg/yr/hectare) – Unrouted.

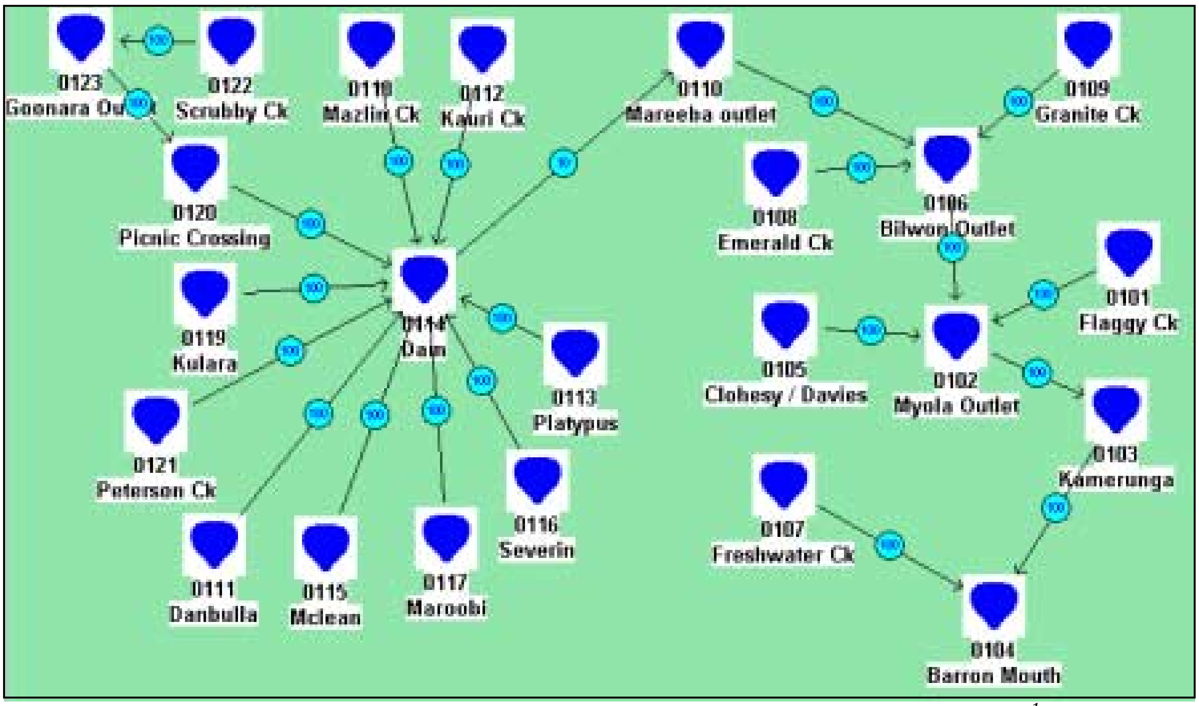


Figure 43. Diagrammatic representation of the routing of Total Nitrogen Loads (kg yr^{-1}) through the catchment.
(Note that this shows 100% between all catchments, except between Dam and Mareeba Outlet, which is 10%).

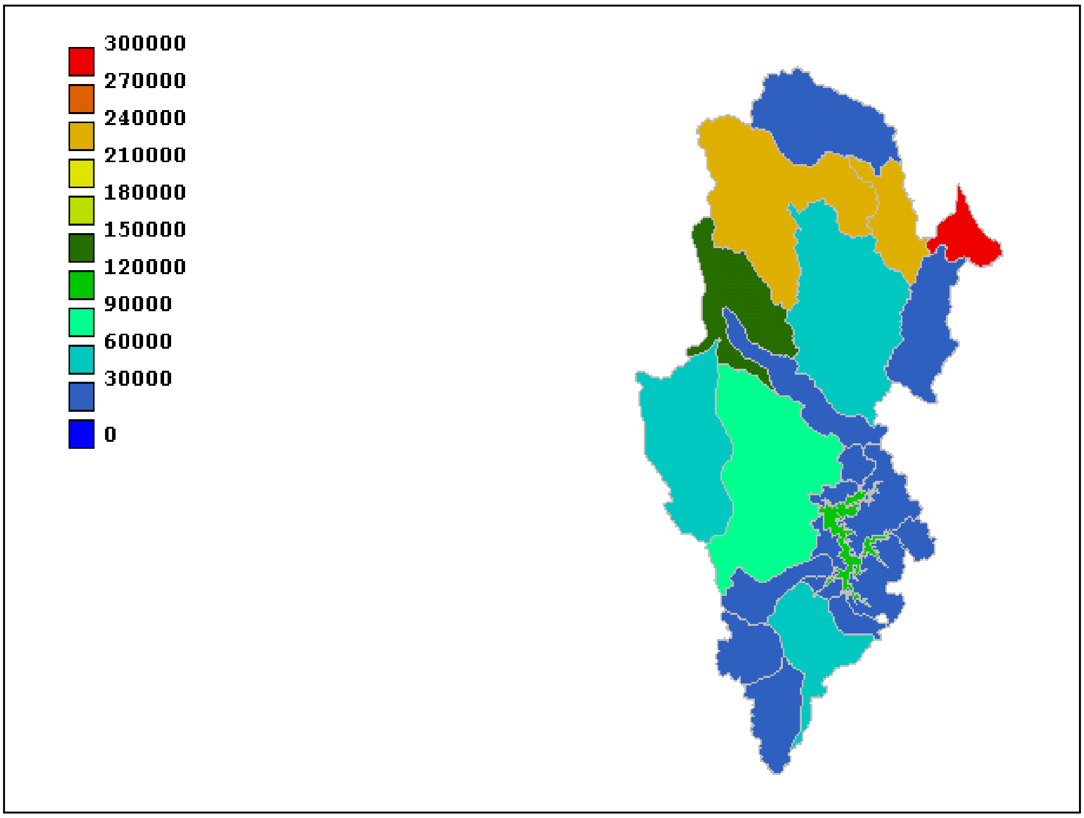


Figure 44. Win CMSS estimated total Nitrogen Loads (kg yr^{-1}) – Routed through the catchment.

Table 17. Change and % change in nitrogen flows from the catchment and its sub-catchments after policy intervention.

	Policy Number									
Catchment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Kg Nitrogen yr^{-1} (% relative change)									
Goonara						1372 (11)	97 (1)			2324 (20)
Scrubby						1380 (18)	173 (2)			243 (3)
Picnic						374 (1)	3622 (16)			4222 (19)
Peterson						167 (4)	497 (12)	205 (0)		682 (17)
Mazlin				400 (2)		611 (3)	1649 (10)		6095 (48)	69 (0)
Kulara						31 (1)	434 (19)			338 (14)
Danbulla						2546 (42)				
Severin						435 (20)				
Maroobi					-200 (-2)	757 (10)				423 (5)
McLean						41 (1)				17 (1)
Platypus						481 (43)				
Kauri						644 (43)				
Granite						3504(12)				
Mareeba Outlet						7289 (16)				3 (0)
Bilwon Outlet						3004 (16)		66 (0)		
Emerald						2023 (18)				
Davies/Clohesy						10102 (34)				
Flaggy						5768 (41)				
Myola Outlet						9626 (37)				
Kamerunga	-96 (-1)					2568 (34)		187 (2)		
Freshwater						3436 (29)				
Barron Mouth						555 (1)				
TOTAL	-96			400	-200	56714 (17)	6472 (2)	691 (0)	6095 (2)	8321 (2)

Table 18. Change and % change in phosphorus flows from the catchment and its sub-catchments after policy intervention.

	Policy Number									
Catchment	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Kg Phosphorus yr^{-1} (% relative change)									
Goonara						88 (7)	54 (4)			155 (13)
Scrubby						88 (5)	96 (6)			16 (1)
Picnic						24 (0)	2012 (38)			281 (4)
Peterson						11 (1)	276 (41)			45 (5)
Mazlin				206 (3)		39 (1)	916 (16)		1530 (31)	5 (0)
Kulara						2 (0)	241 (38)			23 (3)
Danbulla						163 (31)				
Severin						28 (14)				
Maroobi					-220 (-16)	49 (4)				28 (2)
McLean						3 (0)				1 (0)
Platypus						31 (33)				
Kauri						41 (33)				
Granite						225 (2)				
Mareeba Outlet			-300 (-2)			467 (3)		133 (1)		
Bilwon Outlet						193 (3)		43 (1)		
Emerald						130 (3)				
Davies/Clohesy		-710 (-12)				648 (15)				
Flaggy						370 (32)				
Myola Outlet						617 (22)				
Kamerunga	-274 (-16)					165 (13)		122 (10)		
Freshwater						220 (7)				
Barron Mouth						36 (0)				
TOTAL	-274	-710 (-1)	-300	206	-220	3638 (4)	3595 (4)	450 (0)	1530 (2)	554 (1)

GENERAL DISCUSSION

Concentrations of Event and Temporal Flows

The highest concentrations of suspended solids, total N and total P were sampled during large streamflow events at the pumping sampler sites. These concentrations were often substantially higher than those measured by the temporal sampling program (Table 19) and indeed the new draft ANZECC guidelines. An important feature of these high streamflow concentrations was also the large amount of measured variability. Generally, higher concentrations occurred as streamflow increased and declined as streamflow decreased. In contrast to the concentrations of suspended solids, total N and total P, concentrations of nitrate-N, ammonium-N and phosphate-P were not substantially different to median temporally sampled results. This emphasised the large impact of suspended material as the source of nutrients during large streamflows.

The possible sources for the increased suspended solid concentrations during large streamflow events include:

- mobilisation from previously dry streambanks and streambank collapse;
- increased scour of the streambed mobilising previously deposited material; and
- increased runoff from catchment land uses during storms eg cropping and grazing land, new urban developments.

The temporal sampling indicated that a large variation in physico-chemical concentrations occurs across the catchment water sampling sites. The variation appeared related to point sources such as sewage treatment plants, and rural effluent from piggeries and dairy farms; and to runoff from urban areas and roads. However, our results did not discount that differences in catchment properties such as soil type may have a impact on nutrient concentrations in waterways of the Barron River catchment.

Loads of Event and Temporal Flows

The combination of high flows and high sediment and nutrient concentrations resulted in higher loads moving through the Barron River catchment during large rainfall events than during base flow conditions, and agrees with the findings of others in the Barron River (Devine and Taylor, 1999, Cogle *et al.*, 1998). The results emphasise that if an accurate indication of the load of sediment, nutrients or other parameters moving through a river system is required, then event sampling is an absolute necessity and infrastructure needs to be set-up to obtain this information. It is also important to note that bedload quantities were not considered in our work and can be significant contributions to the export of sediment from river systems.

A major concern of many people is the quantity of sediment and nutrients leaving coastal waterways to the Great Barrier Reef Lagoon. Using our data for temporal water sampling and the limited event sampling at Kuranda and Bilwon we estimated quantities moving through the system annually for 1999. The estimated load was calculated by multiplying the median temporal daily load by 365 days and adding the total event loads. There are many assumptions in this calculation as not all events were measured, and it is very likely that higher quantities of sediment, nitrogen and phosphorus moved through the Barron River system during this period.

Table 19. Estimated annual quantities (tonnes) of suspended solids, total nitrogen and total phosphorus based on the 1999 events and 1996-1999 median temporal loads.

	Bilwon (Site 22)			**Myola (Site 32) / Kuranda (Site 42)**		
	Temporal	**Events**	**Total**	**Temporal**	**Events**	**Total**
	tonnes					
Suspended solids	603	88700	89303	959	486043	487002
Total Nitrogen	25	280	305	33	1377	1410
Total Phosphorus	1	74	75	1	259	260

It is proposed that the Kuranda (/Myola) data be assumed as an estimate of sediment and nutrient exported from the Barron River during 1999. These data are also in general agreement with that presented by Moss *et al.* (1992) of 114 000 tonnes sediment, 647 tonnes nitrogen and 90 tonnes of phosphorus exported from the Barron River (Model 2).

Another feature of the calculated information (Table 19) is that a substantial contribution of sediment, nitrogen and phosphorus, appears to originate from the catchment or the waterways downstream of Bilwon. This is proposed since event monitoring for the Kuranda site was for a shorter timeframe than that at Bilwon and the quantities of suspended solids, total nitrogen and total phosphorus at Kuranda were substantially higher.

Nutrient and sediment management

Management to control sediment and nutrient movement needs to address the whole catchment including the tributaries of the Barron River. Since it is apparent that water quality is impacted by both high and baseflow conditions, these management options may include:

- improved sewage treatment at Mazlin (already underway) and Barron Mouth (Aeroglen STP). However, high concentrations during high flows may persist due to sediments and nutrient collected in the waterway over time;
- improved land management practices in rural land uses including riparian planting (Russell *et al*., 2000), off stream watering points for cattle, and soil conservation practices;
- the use of pollutant traps in urban areas and controls on sediment from roadways; and
- wetland filtering of runoff.

The interaction between riparian disturbance and land use with water quality

Stream habitat and riparian corridor were categorised as most disturbed in the Lake Tinaroo catchment (Russell *et al*., 2000). This corresponds to the Goonara, Scrubby, Picnic Crossing and Mazlin sub-catchments of this report, where the highest median sediment and nutrient concentrations occurred for the temporal sampling. The correlation between results of the biological and physico-chemical sampling add further weight to recommendations to rehabilitate riparian areas in this section of the Barron River catchment. One caveat however is that the Lake Tinaroo catchment had the more fertile soils of the Barron River catchment and these soils may result in a larger contribution of nutrient runoff to waterways.

Land use in the various sub-catchments varied both in percentage and absolute amounts. The percentage of non-forested land use in the Lake Tinaroo catchment is also much lower than other sub-catchments except for the Barron Mouth. This provides a basis for the correlation between higher sediment, nitrogen and phosphorus loads in the Lake Tinaroo catchment with non-forest land-use and poor riparian cover.

However, in calculations of the contribution of various land-uses to sediment and nutrient loads in waterways, it is normally the total land area that is used. In addition to large areas of forest, there are large areas of *other crop* in the Mareeba Outlet, Granite, Picnic and Mazlin sub-catchments, areas of *sugar* in the Barron Mouth, Mareeba Outlet and Granite sub-catchments and large areas of *dairy* in Goonara, Picnic Crossing and Peterson sub-catchments. Improved land management practices for these land uses will potentially deliver large reductions in sediment and nutrients moving into the Barron River system. A component of improved catchment management could also be adequate riparian strips to filter solutes from runoff waters prior to entry to the river or its tributaries. Russell et al. (2000) identified areas for such revegetation.

The large area of forests has already been mentioned. These make a large contribution to the Barron River catchment ranging from timber production, recreational pursuits, wilderness and the general ecological health the region. While forests are generally viewed favourably, it should not be discounted that sediment and nutrient production does occur from these areas and management, (eg. road and track management, forest harvest practices, picnic area maintenance) is still required to reduce sediment and nutrient movement from these areas.

Impoundments in the Barron River catchment

There are 2 major impoundments in the catchment viz, Copperlode Dam and Tinaroo Falls Dam. Copperlode Dam contains a catchment that is forested and contrasts with that at Tinaroo Falls Dam, which has the largest relative area of agriculturally altered land in the catchment. Concentrations of sediment and nutrients below both dams (Sites 12 and 35) indicated only small quantities moved past these sites during normal flows. Measurements above Tinaroo Falls Dam indicated that large quantities of sediment and nutrient flowed into Lake Tinaroo, but that a significant proportion may retained in the impoundment and not released into the Great Barrier Reef lagoon. Hence the consequences of the sediment and nutrient movement from catchment land surfaces may be felt in each of the impoundments. Indeed there have already been concerns about blue green algae in Lake Tinaroo. Land management practices need to be instigated to reduce sediment and nutrient movement to the lakes. Equally however in Lake Tinaroo there has already been a substantial movement of material into Lake Tinaroo and awareness that management of potential problems caused by this is required.

Decision Support Systems

The decision support system, CMSS, has been shown to provide information in broad agreement with measured nutrient load data. This provides general confidence in the basic CMSS methodology. The value of the tool is its ability for use in community groups (eg BRICMA) to compare and prioritise management options subject to accepted uncertainty levels. It is also possible to incorporate financial costings into the analysis.

RECOMMENDATIONS

The Barron River catchment has been subject to many anthropogenic influences, including land clearing for cropping and the establishment of urban areas. While water quality is generally acceptable, this report has identified areas within the catchment where resource health is damaged and has provided a basis for the evaluation of new management, in the form of clear baseline water chemistry and land use parameters. There are a number of actions that can be taken by the community at large and organisations, such as BRICMA, to ensure that the catchment retains its valuable contribution to the north Queensland environment. These include:

- sponsoring a Whole of Catchment approach to sediment and nutrient management, which emphasises importance to all land and all waterways in the Barron River catchment;
- managing point sources of sediments and nutrients in the catchment. These include sewage treatment plants and intensive livestock enterprises. Best practice guidelines already exist for several intensive livestock industries, which should be followed. Technology for reduced emissions from STP's exist and an increased effort to installation throughout the catchment should occur;
- improving the management of diffuse sources of sediment by an increased commitment to soil conservation practices throughout the catchment including on farm (conservation cropping and soil conservation works) and on roadways, particularly gravel roadways. Dynamic best practice guidelines should be developed with industry and agencies to achieve optimum results;
- implementation of urban sediment and nutrient management practices to reduce loads flowing into watercourses. These include the use of gross pollutant traps and urban wetlands for filtering runoff waters. Planning guidelines should be developed to limit sediment flows during annual wet seasons;
- the cataloguing of all water quality data, and other data, for the catchment should continue under the existing BRICMA Meta-data project;
- community monitoring of water in the catchment to provide important insights to the health of the catchment. The community monitoring effort should develop new ways to incorporate a broad cross section of catchment landholders; and
- using decision support systems (eg WinCMSS) and information with catchment stakeholders to develop mutually agreed management plans. This report and project provides the tools to develop such plans for nutrient management on a catchment basis.

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