CRC REEF RESEARCH CENTRE TECHNICAL REPORT NO. 62

Sediments and nutrients in north Queensland tropical streams: changes with agricultural development and pristine condition status

Jon Brodie[1, 2], Alan Mitchell[1]

[1] Australian Centre for Tropical Freshwater Research, James Cook University, Townsville Qld 4811
[2] CRC Reef Research Centre, PO Box 772, Townsville Qld 4810

CRC Reef Research Centre is a knowledge-based partnership of coral reef ecosystem managers, researchers and industry. Its mission is to provide research solutions to protect, conserve and restore the world's coral reefs. It is a joint venture between the Association of Marine Park Tourism Operators, Australian Institute of Marine Science, Great Barrier Reef Marine Park Authority, Great Barrier Reef Research Foundation, James Cook University, Queensland Department of Primary Industries & Fisheries, Queensland Seafood Industry Association and Sunfish Queensland Inc. The University of Queensland is an associate member.

A report funded by CRC Reef Research Centre.

Established and supported under the Australian Government's Cooperative Research Centres Program.

CRC Reef Research Centre
PO Box 772 Townsville Qld 4810
Telephone: 07 4729 8400
Fax: 07 4729 8499
Email: info@crcreef.com
Website: http://www.reef.crc.org.au/

National Library of Australia Cataloguing-Publication entry

Brodie, Jon.
Sediments and nutrients in North Queensland tropical streams : changes with agricultural development and pristine condition status.

Bibliography.
ISBN 1 876054 96 4.

1. River sediments - Queensland, Northern. 2. Rivers - Environmental aspects - Queensland, Northern. I. Mitchell, Alan W. (Alan William), 1946- . II. CRC Reef Research Centre. III. Title. (Series : CRC Reef Research Centre technical report ; 62).

551.354099436

Online document

This publication should be cited as: Brodie J, Mitchell A. 2006;.Sediments and nutrients in north Queensland tropical streams: changes with agricultural development and pristine condition status. CRC Reef Research Centre Technical Report No. 62, CRC Reef Research Centre, Townsville, Australia.

Published by CRC Reef Research Centre, PO Box 772, Townsville 4810
Australia

Table of Contents

Executive Summary

In the present report data from water quality studies in north and central Queensland draining pristine or semi-pristine systems is reviewed. Data published only in 'grey' literature, such as government department reports, research organizations (universities, ACTFR, CSIRO, Land and Water Australia) technical reports, state of the environment reports and other similar material have been collated. Collectively, these data sets represent a large number of samples taken from pristine sites that have not previously been compared. For each study, the locations of all sites within the catchments are mapped, the categories of land use upstream of the sites listed and the water quality data from these sites summarised and graphically compared. Six broad land use categories have been assessed against water quality for the north Queensland region, 'natural', 'forestry', 'grazing', 'intensive', 'urban' and 'water habitats'. Percentage land uses of the upper catchment for each site are listed, along with statistical comparisons of the data sets, as box plots and as tabulated measures. General comments on the nature of water draining from other land uses are also included.

In tropical Queensland intensive studies of river suspended sediment (SS) and nutrient dynamics have been restricted to streams on the north-east coast between the Fitzroy and Normanby Rivers. Historical conditions in these rivers were probably characterized by low/moderate SS concentrations and low concentrations of dissolved inorganic nitrogen and phosphorus in flow events. In summary, waters draining pristine rainforest and woodlands in northern Australia have been found to have moderate concentrations of dissolved organic nitrogen (DON) and phosphorus (DOP) (DON average 0.155; median 0.092 mg/L N and DOP average 0.011; median 0.007 mg/L P), low to moderate concentrations of particulate nitrogen (PN) and phosphorus (PP) (PN average 0.077; median 0.038 mg/L N and PP average 0.014; median 0.004 mg/L P) and low concentrations of dissolved inorganic nitrogen (DIN) and phosphorus (DIP) (DIN average 0.037; median 0.019 mg/L N and DIP average 0.005; median 0.003 mg/L P) (Table 21). Nitrogen speciation in waters draining pristine land is dominated by DON with significant spikes of PN in first-flush rainfall events. High PN at these times is probably associated with increased erosion when vegetation cover is lowest, immediately following the dry season, as well as land slips during heavy rainfall, with both processes contributing suspended sediment. Occasional spikes of DIN, mainly nitrate, in some pristine areas may be associated with groundwater discharge to the stream, often after the main peak flow. In savannah woodlands and grasslands with low grazing intensity, nitrogen speciation is also dominated by DON and phosphorus by DOP and PP. Concentrations of DIN and DIP are generally low except where groundwater inputs are involved.

The concentrations of nitrogen species lost from pristine tropical Australian systems are not dissimilar to those seen elsewhere in the tropics. Nitrate losses seem in general a little lower with mean concentrations of the order of 0.037 mg/L N compared to estimates of 0.075 mg/L N globally or 0.120 mg/L N in the Americas. Mean DON in northern Australian pristine systems (0.155 mg/L N) is also slightly lower than Lewis *et al.*'s values in the Americas (0.162 mg/L N), while mean PN in tropical Australia (0.077 mg/L N) is considerably lower (0.115 mg/L N in the Americas). However, all comparisons of means of this type are fraught with problems associated with the skewed nature of the data sets. Nevertheless, a comparison of 'pristine' mesic (moderate-high rainfall and runoff) and xeric (low rainfall and runoff) catchments in Queensland supports findings from other parts of the world that xeric catchments lose less nutrients overall than mesic catchments.

Introduction of agriculture has transformed SS and nutrient dynamics. Grazing has led to soil erosion and increased SS and particulate nutrient concentrations and fluxes in event flows. Fertilised cropping has resulted in increased nutrient inputs to catchments, where this land use forms a substantial proportion of the catchment area. Consequently, both particulate and dissolved inorganic nutrient concentrations and fluxes have increased from the introduction of these land uses. In general, north Queensland tropical rivers have episodic flows with most material transport occurring during large flow events. The restricted period of these highly energetic events implies that little trapping of materials in waterways occurs. Loads are transported efficiently downstream and processes such as denitrification and in-channel sedimentation may be of limited importance. Due to excessive nutrient inputs associated with agriculture, a number of northern freshwater, estuarine and coastal ecosystems are now eutrophic. Continued development, especially fertilised cropping, without adequate management of nutrient losses is likely to exacerbate these problems.

1. Introduction

Concern over the threat to northern Australian waterways and coastal ecosystems, and in particular those of the Great Barrier Reef World Heritage Area (GBRWHA), from terrestrial runoff of pollutants has strongly emerged over the last 25 years (Bennell, 1979; Baldwin, 1990; Brodie, 1995; Bell and Elmetri, 1995; Arthington *et al*., 1997; Brodie *et al*., 2001a; Brodie, 2002a; Haynes *et al*., 2001; Haynes and Michalek-Wagner, 2000, Furnas, 2003). Pollution of these waterways is dominated by runoff from upstream catchment lands. The principal land-uses in northern Australia contributing to this pollution are rangeland beef grazing and cropping, with lesser contributions from industrial, mining and urban development. Runoff of sediment, nutrients and pesticides is increasing and for most pollutants the load is estimated to be many times the natural amount discharged 150 years ago.

Northern Australian catchments were or are covered by seasonally dry forest, savanna woodland or monsoon forests while rainforest and closed forests dominate in wetter parts of the catchments. Most catchments are now used for agricultural or pastoral purposes. Rangeland beef grazing in native or improved pastures is the major land use by area with cropping (sugar, horticulture, grains, cotton) and urban/residential land uses occurring in smaller areas (eg in the Great Barrier Reef catchment, Gilbert and Brodie, 2001; Furnas, 2003). Sugarcane, the most important cultivated crop in northern Australia, is now harvested from over 400,000 ha primarily on the coastal plain south of the Daintree in Queensland and from smaller areas on the Atherton Tableland in Queensland and in the Ord River irrigation area of Western Australia.

As part of the process of European catchment development, forest and woodland vegetation has been cleared or thinned from a significant proportion of the catchments (Barson *et al.*, 2000; Accad *et al.*, 2001). Clearing for sugarcane farming, horticulture and urban development has resulted in the removal of lowland rainforest, native grasslands and freshwater wetlands bordering the coast, with significant clearing of coastal sclerophyll forests to support recent expansion of cropping. In Queensland, south of Cooktown, most freshwater wetlands on the lower floodplains of east-coast rivers have been converted to agricultural and urban use (Finlayson and Lukacs, 2003). These losses include 70% on the Herbert floodplain (Johnson *et al*., 1999), 40 to 60% on the floodplains of the Russell-Mulgrave, Tully-Murray and Johnstone Rivers (Russell and Hales, 1994; Russell *et al*., 1996a; 1996b) and more than 50% on the Burdekin-Haughton floodplain (Cappo *et al*., 1998; Finlayson and Lukacs, 2003). In the Mackay area considerable loss of mangroves has occurred since 1953 (estimated 9% loss) with a 43% loss of saltmarsh/saltpan in the same period (Winter and Wild, 1995). The reduction of both riparian vegetation and wetland area has led to a decline in the efficiency of these systems to perform their normal ecological functions.

Changed land use on catchments worldwide, particularly clearing of forest and woodland and its conversion to grazing, cropping and urban uses, has led to eutrophication in both fresh and coastal marine waters. The relationship of land use and nutrient export has been studied for some time (eg review of Beaulac and Reckhow (1982)). The idea of using the catchment (watershed) as the explanatory geographic unit also has a long history (eg Likens, 2001). Nitrogen (N) and phosphorus (P), along with carbon, iron and silicon, are essential elements in shaping the biotic status of waterways from mountain streams to the ocean. Throughout the world the problems of leakage of nitrogen and phosphorus from agricultural, industrial and urban systems to waterbodies (fresh, estuarine and marine) and resulting eutrophication are widespread.

The use of artificially fixed atmospheric nitrogen in fertiliser has surged in the last 50 years (Vitousek *et al*., 1997; Kaiser, 2001) and is now greater, on an annual basis, than the natural fixation of nitrogen. Widespread eutrophication of freshwater systems, particularly lakes, was recognised some decades ago and generally attributed to phosphorus pollution (Vollenweider, 1975; Correll, 1998). Eutrophication of estuarine and coastal systems is a more recent phenomenon and is associated with both nitrogen and phosphorus enrichment and also the stoichiometric balance of nitrogen, phosphorus and silicon (eg Cloern, 2001). Eutrophication of the Black Sea (Zaitzev, 1991), Baltic Sea (eg Sanden and Rahm, 1993), Chesapeake Bay (eg Boesch *et al.*, 2001), the northern Adriatic Sea (Justic, 1987), the North Sea (eg Riegman *et al.*, 1992), the Inland (Seto) Sea of Japan (Tatara, 1991) and the Gulf of Mexico (Rabalais *et al.*, 1996) are prominent examples. In southern Australia, eutrophication of coastal lagoons, lakes, estuaries and embayments is the rule from Morton Bay on the east coast to the Swan estuary in the west (Brodie, 1995).

It is recognised that the principal source of these problems are agriculture and additionally, in industrialised countries, fossil fuel combustion (Novotny and Chesters, 1989; Carpenter *et al.*, 1998; Howarth, 1998). At a global scale the signs of massively increased loadings of nutrients, particularly nitrogen, to waterbodies have been analysed by correlating nitrate concentrations in rivers with catchment development indicators such as human populations or fertiliser use. Clear relationships have been developed showing linear increases in nitrate concentrations (and loads) with catchment inputs (Peierls *et al.*, 1991; Caraco and Cole, 1999; 2001). The proportions of C:N:P (and Si) in watershed exports are also important. The agricultural development of catchments changes these ratios and hence may influence the type of algae growing in downstream environments by altering nutrient limitation parameters (Perakis, 2002). Changes are often towards 'less desirable' algal species (sometimes cyanobacteria) and disruption of trophic relationships may occur.

2. Catchment biogeochemistry

2.1 Northern Australian catchments

Northern Australian catchments are different to most around the world (Harris, 1995) with unusual biota and biogeography (Harris, 2001); low rates of atmospheric N deposition (Holland *et al.*, 1997); low human population densities; relatively low rates of river regulation; regular high turbidity; long-term, year-to-year climate variability and highly variable flow regimes (Finlayson and McMahon, 1988; Puckridge *et al.*, 1998). Many rivers regularly flush fresh to the sea (Eyre, 1998); and do not display 'normal' estuarine behaviour. Discharge of terrestrial material to the coast occurs predominantly during the major river floods generally associated with cyclonic rainfall events between November and May. The output from individual rivers varies from those such as the Tully which have multiple major flows each year, to those such as the Herbert and Pioneer which generally have one major annual flow, and those such as the Burdekin and both Queensland and Western Australian Fitzroy Rivers in which major flows are separated by periods of 4 to 10 years. Individual rivers also vary greatly in catchment area and mean annual discharge. A clear distinction divides the large 'dry' catchment rivers such as the Burdekin (catchment area, 133,000 km^2; annual mean discharge, 11 million ML) from the wet tropics rivers such as the Tully (catchment area, 2,850 km^2; annual mean discharge, 5.3 million ML).

In waterbodies in northern Australia it is important to distinguish water quality in flow event conditions from ambient (baseflow) conditions. Concentrations of water quality parameters such as suspended sediments and nutrients measured in flow events can be used to quantify contaminant loads from catchments to receiving waters (eg coastal waters) and may also give an indication of whole-of-catchment conditions. On the other hand, concentrations of water quality parameters measured in ambient (baseflow, low-flow, no-flow and pools in the river bed) conditions indicate the ambient water quality status, which probably persists for much of the year and influences the in-stream health of ecosystems.

The purpose of examining water quality data from a variety of sources in this review is to make a broadly-representative assessment of the effects of agriculture on sediment and nutrient status of northern Australian waterways. However 'water quality' can be interpreted in many ways depending on the question asked and the purpose for which the data was originally collected. In the monsoon conditions of northern Australia, at least two very different questions can be addressed and these in turn determine the methodolgy that should be employed in data collection. The first relates to loads, with sampling in high-flow conditions to determine loads discharged to downstream environments. The second relates to in-stream ecosystem health and no-flow, low-flow and baseflow conditions within catchment waterbodies. In the Australian wet and dry tropics, these two flow conditions (high-flow/event-flow and low-flow/no-flow/base-flow) are relatively well separated in time with just a short period each year (or even less than one per year in the dry tropics) dominated by high flows lasting from a few days to a few weeks. The rest of the year (usually 48 – 50 weeks) is dominated by low flow (or no flow) conditions.

During event flows in tropical systems, rivers may simply act as conduits, through which the bulk of materials such as suspended sediments, nutrients and pesticide residues pass without significant uptake or sequestration (Furnas and Mitchell, 2001). Hence, if it is required to measure loads (fluxes) of these materials (eg suspended solids, total nitrogen, total phosphorus) to downstream environments such as coastal waters, only sampling in event flows is needed. However, due to rapid changes in concentrations of such materials during the event cycle (Pearson et al., 2003), an intensive frequency of measurements, hourly or less during these events, is required for good estimates of loads. Intensive water flow data is also required for load calculation. In contrast, to assess the status of a waterbody consisting of pools in the river with no-flow or low-flow conditions most of the year, water quality parameters such as dissolved oxygen (DO), pH, chlorophyll *a,* conductivity, nitrate and turbidity will be more important than gauged flow, suspended solids, total nitrogen or total phosphorus. Some parameters such as DO and pH need to be measured at short intervals as they often fluctuate through the day/night cycle, while measurement of other parameters at monthly intervals may be adequate.

Water quality properties in event flow conditions are primarily determined by the geology, soil types, topography, land condition, land uses, vegetation types and status (i.e. large scale factors) in the catchment area above (i.e. draining to) the sampling site (Dillon and Molot, 1997). Local factors immediately adjacent to the sampling site may have little influence. In contrast, ambient water quality in a river reach or lagoon in low flow conditions is more likely to be determined by local conditions eg status of riparian vegetation, streambank erosion, cattle access, bed aggradation (e.g. sand slugs), shade, benthic sediment type, in-stream vegetation and weeds at the sampling site itself. Thus, to interpret water quality data in both conditions, a different set of explanatory data (variables) is also needed. In addition, the antecedent rainfall record is also important in determining solute concentrations in flow events. Following droughts, solute concentrations including nitrate may increase several fold compared to after non-drought conditions (Morecroft *et al.*, 2000) in 'wet' UK streams but in drier US streams the normal high concentrations of nitrate in the first flush were attenuated after drought (Dahm *et al.*, 2003).

2.2 Pristine forest and savannah systems

Studies in temperate forests that were considered to have little or no anthropogenic inputs in the northern hemisphere have been found to have high losses of N, often as nitrate. This finding was considered strange until it was realised that most of these losses were due to atmospheric deposition of N from fossil fuel burning, fertiliser use/volatilisation and subsequent precipitation into forests as acid rain (Jaworski *et al*., 1997; Paerl, 1997; Carpenter *et al.*, 1998). In the north-east USA forests (Fenn *et al*., 1998), nitrogen is found to be exported in inorganic form (80% nitrate, 10% DON). However, while much of the N draining forested catchments with high atmospheric inputs is in the form of DIN, the bulk of N exported from forests with low atmospheric inputs is in the form of DON.

For example, studies in South American temperate forests (mainly in Chile) with little or no atmospheric N deposition showed low losses of N, with that lost dominated by dissolved organic nitrogen (DON) (Perakis and Hedin, 2001; 2002). DON typically accounts for 70% of the load, with smaller proportions of DIN (13% ammonia and 4% nitrate) (van Breeman, 2002; Perakis and Hedin, 2002). Minimally disturbed North American watersheds with low atmospheric deposition also show patterns consistent with the South American examples (Lewis, 2002), as do temperate Australian streams, also with little anthropogenic atmospheric loading (Harris, 1999; 2001). In flow events, pristine forests in South America are known to export considerable concentrations and loads of dissolved organic nitrogen and phosphorus (Perakis and Hedlin, 2002) but very low concentrations and loads of dissolved inorganic and particulate N and P (Lewis *et al*., 1999).

It is now known from a range of studies, in both temperate and tropical forests (and grasslands and woodlands) not impacted by atmospheric deposition, that runoff and subsurface drainage from pristine systems generally has low concentrations of N (in range 0.05 – 0.4 mg/L) dominated by DON with low concentrations of particulate nitrogen (PN) and dissolved inorganic nitrogen (DIN). Much of the DON is presumed to be largely unavailable for algal growth in the short term (Smith and Hollibaugh, 1997; Aitkenhead and McDowell, 2000; but see Seitzinger and Sanders, 1997).

The underlying geology, and its effect on soil type and composition, may have significant effects on the nutrient status of waters draining the landscape. Volcanic rocks (eg basalts) are richer in phosphorus than granitic rocks and this factor is evident in the concentrations of P in water running off areas dominated by one of these rock types (Timperley, 1983; Eyre and Pepperell, 1999). Dillon and Kirchner (1975) observed that forested watersheds with sandy soils overlying granitic formations had one half the TP outputs of forested watersheds with loam soils overlaying sedimentary formations. Elevated nitrate concentrations may also be a function of catchment geology (Holloway *et al.*, 1998) where bedrock containing fixed nitrogen may contribute appreciable concentrations to surface waters.

2.3 Nutrient runoff changes with catchment development

Conversion of land from forest to other land uses increases overland flow of storm runoff and suspended sediment and nutrient exports (Hopkinson and Vallino, 1995; Williams and Melack, 1997). As land is cleared and landuse changes towards more agricultural and urban uses, the total amounts of N and P exported rise rapidly (Table 1; Young *et al*., 1996). Particulate matter exports increase relative to dissolved loads. N concentrations in receiving waters increase and the form of N changes from DON to nitrate, ammonia and PN that are more bioavailable than DON (Harris, 2001). Fluxes from the land via rivers to the coast range from 50 kg N /km^2/year in pristine forested catchments to nearly 1500 kg N/km^2/year from catchments draining into the North Sea from Europe (Howarth, 1998). Rates of atmospheric deposition of N range from 1 to nearly 1000 kg N/km^2/year (Holland *et al*., 1997). Atmospheric deposition is highest in the industrial areas of the Northern Hemisphere (200 – 400 kg N/km^2/year), where urban, industrial and transport sources dominate. Atmospheric deposition is elevated, through anthropogenic inputs, over all continents except Australia, but deposition is generally lower over the Southern Hemisphere continents (50 – 150 kg N/km^2/year). Modern cropping and fertiliser use, particularly since about 1950 in the developed world and since the 1970s in the third world (the 'green revolution') saw N and P dynamics of cropping systems dominated by artificial fertilisers (Vitousek *et al*., 1997; Matson *et al*., 1997).

In rivers affected by anthropogenic nitrogen loading, a rise in DIN as a proportion of TN as the TN increases is found throughout the world (Howarth *et al*., 1996; Downing *et al*., 1999). Similar trends have been shown in some Australian rivers (Harris, 2001). Harris (2001) showed that TN:TP was close to the Redfield ratio for 24 Sydney catchments. Forested catchments exported mostly DON with urban catchments exporting proportionally more DIN. As catchments were increasingly affected by deforestation and urbanization, the stoichiometry of the more available forms of N and P rose above Redfield. In the Murray River and other Victorian rivers, reaches of rivers rising in forested catchments have large proportions of their total N in the form of DON and PN (Harris, 2001).

Nitrate is a good indicator of catchment disturbance and development, with the correlation between nitrate in river water and human population in the river catchment well established (Peierls *et al*., 1991). Landuse change and reduction of forest cover also affects P exports (Harris, 2001). Most P is associated with suspended particulate matter. A considerable proportion of P exported downstream may not be bioavailable and the proportion of bioavailable to non-bioavailable P varies widely in waterways depending on geology, soil type, hydrology and P sources (Dillon and Kirchner, 1975; Oliver *et al*., 1993). P fertiliser use leads to both increased TP in streams as well as a higher proportion of bioavailable P.

Young *et al* (1996) summarised information on nutrient exports and land use in South-East Australian catchments showing the increase in exports with higher fertiliser use and more intensive landuses (Table 1). McKee *et al.* (2000; 2001) in their studies on nutrient exports from the Richmond catchment (northern NSW) summarise factor increases in nitrogen and phosphorus exports from different landuses using global data (Table 2). The increase in exports, compared to forest, with intensity of landuse is obvious.

Table 1. South-east Australia average annual nutrient export data (from Young *et al.,* 1996). (Note: "Range" and "Typical" categories described in paper).

Landuse	Total P (kg/ha/y)		Total N (kg/ha/y)	
	Range	Typical	Range	Typical
Forests	0.03 – 0.1	0.06	0.9 – 1.5	1.1
Improved pasture	0.1 – 0.7	0.30	0.6 – 4.6	3.3
Unimproved pasture	0.07	0.07	2.2	2.2
Cropping	-	-	-	-
Market gardens	2.7 – 14.3	7.1	20 – 34.5	26
Urban	0.4 – 3.6	1.0	3.2 – 22.4	6.6

Table 2. Comparison of exports of nutrients from different land uses as a factor increase compared to forest land (from McKee *et al.,* 2000).

Land use	Nitrogen (factor increase)		Phosphorus (factor increase)	
	World median	Tropical Australia	World median	Tropical Australia
Crop land	13.7	13.7	21.1	23.8
Horticulture	20.8	28.9	50.7	88.8
Improved pasture	4.6	5.6	7.9	13.8
Pasture	2.8	3.3	5.6	1.3
Urban	6.7	7.3	8.5	12.5
Forest	1.0	1.0	1.0	1.0

3. Suspended sediments and nutrients in waters draining pristine lands in northern and central Queensland

3.1 Objectives

In the present report, all available data from water quality studies in north and central Queensland draining pristine or semi-pristine (defined below) systems, much of which has only been published in the 'grey' literature is summarised. For each study, the locations of all sites within the catchments are mapped, the categories of land use upstream of the sites listed and the water quality data from these sites summarised and graphically compared. General comments on the water-quality characteristics draining from land uses other than pristine are also included.

3.2 Methods

In the present review, we summarise and analyse data from both high and ambient-flow conditions. While measurements during high-flow conditions provide the clearest information on the effects of catchment land use on water quality, these are often uncommon data from many historical data sets, in which samples had been collected at regular intervals rather than on a rainfall-mediated basis. However, we have tried to include high-flow data where we could. In many data sets reviewed it was difficult to determine the flow conditions, so the ranges of SS and nutrient concentrations given represent a mixture of both low flow and high flow results. Much of the data used in this review has been published only in 'grey' literature, particularly government department reports, research organization (universities, CSIRO, Land and Water Australia) technical reports, State of the Environment reports and similar material. In compiling this review the data has been assessed for validity as far as possible and the reports cited with as much detail as possible.

All nutrient concentrations are expressed as mg/L of the element (N or P), no matter what the species. Suspended sediment (SS) concentrations are also given in mg/L. In this review frequent mention will be made of concentrations of dissolved inorganic phosphorus (DIP). This quantity is measured in waters on a sample filtered through a 0.45 µm filter and thus represents an operational definition of 'dissolved' i.e. any inorganic phosphorus which passes the filter. This measure is often referred to as 'filterable reactive phosphorus' (FRP) and is normally made up primarily of orthophosphate (PO_4). However the measure may also incorporate various particulate fractions of size less than 0.45 µm (Oliver *et al.*, 1993) and various dissolved polyphosphates. For simplicity in this review it will be considered that the terms DIP, FRP and PO_4 are equivalent. The fraction termed dissolved organic phosphorus (DOP) is calculated by subtracting DIP from the total dissolved phosphorus (TDP) fraction. The DOP/TDP fraction is usually determined directly by Kjeldahl digestion or UV oxidation (only Set 14 – 3.13.14). Particulate phosphorus (PP) is sometimes determined directly (e.g. Set 14 – 3.13.14 as particulate material retained on GF/F filters) but also estimated indirectly by subtracting TDP from total phosphorus (TP). TP may be calculated as the sum of the dissolved and particulate fractions.

For N fractions, nitrate (NO_3) and nitrite (NO_2), usually a very small fraction, are determined separately or together. In this review, they are expressed as the combined (NO_X) fraction. The ammonia/ammonium fraction is expressed here as ammonia or NH_3 rather than ammonium or NH_4. The fraction termed dissolved inorganic nitrogen (DIN) is calculated as the sum of NO_X and NH_3 and is occasionally used in this analysis. DIN and DIP are useful measures as they represent the immediately bio-available fractions of N and P. The dissolved organic nitrogen (DON) fraction is calculated by subtracting NH3 from total dissolved nitrogen (TDN) if this is determined by Kjeldahl digestion or by subtracting DIN from TDN if it is determined by UV oxidation. Likewise with P, particulate nitrogen (PN) may be determined directly (Set 14) or estimated indirectly by subtracting TDN (or DIN +DON) from total nitrogen (TN). As above, TN may also be calculated as the sum of DIN, DON and PN.

3.2.1 Land use, GIS-based determinations

Percentage area land use was determined with the QLUMP GIS program (Queensland Land Use Mapping at Catchment Scale), a product of the National Land and Water Resources Audit (NLWRA, 2003). The land use interpretations in QLUMP derived from this audit, were based on the analysis of satellite images, aerial photographs and other observations. The initial release of QLUMP was dated at 1999 for most coastal areas of Queensland, and 1997 for the Fitzroy basin. However, QLUMP has been regularly updated. For the purpose of future reference, the version assigned to ACTFR in December 2004 and used here had the land use classification dates (luc_dates) as listed in Table 3 below:

Table 3: Dates of land use classifications as area proportions in the QLUMP version used here. Note: "luc_date" is land-use classification date in QLUMP.

Date (luc_date)	Percentage Area
27 Nov 2001	67.83%
01 Feb 2002	4.83%
28 Feb 2002	23.44%
27 Nov 2002	1.11%
27 Oct 2003	2.79%

It is not known when the actual observations were on which these classification dates were based. A discussion of the time-line mismatch between the QLUMP GIS classification and sample dates is given below (3.3.0).

The Australian Land Use and Management (ALUM) Classification, version (v5) was adopted for this compilation as a nationally consistent land use measurement scale. For the purpose of the present study, narrow land use categories were combined into a broader, condensed list (Table 4). Using detailed drainage maps (Courtesy, DNR&M), polygon areas were constructed to describe the sub-catchments for each sampling site upstream to their origin. Intersection of these polygons with the QLUMP digital data set produced lists of land use, defined by the 'area' above each site, from which broad land use summaries were constructed, as in Table 4.

Maps 1-12 depict the distributions of these six land-use categories defined in Table 4, as 'natural', 'forestry', 'grazing', 'intensive', 'urban' or 'water' (freshwater and estuarine/tidal areas) for the north Queensland area. Sample site locations of analysed data sets, shown as pristine (filled circle) or non-pristine ('bulls eye') are also shown. For convenience in identifying 'pristine' areas, Maps 13-24 depict just the 'natural' areas, overlaid with the sample sites, combined with identifying Site_codes (see 3.3). In the QLUMP GIS analysis to date, only near-coastal catchments have been compiled - note that the western boundary of these land use maps simply represents the cut-off limit of interpretation at that point in time. Because of this cut-off, a number of the more western sampling sites were excluded from consideration here.

In general, the land use obtained from the QLUMP GIS appeared to accurately match the local knowledge available for land use in specific areas. However a few anomalies were noticed. In a number of cases, former historically logged areas protected since 1988 as World Heritage Areas were identified as production forestry from native forests (QLUMP code 2.2). A clear example is cited in the upper Daintree River (Site 04-01, equivalent to 35-06 – see Tables 8 and 18). Conversely, the GIS did not identify pine forest plantations (QLUMP code 3.1) known to lie above Site 34-02 (Table 17) in the Whitfield Creek area (confirmed by John Faithful, personal communication). In this case, the land use was determined based on local knowledge. In the upper Daintree River (Site 04-01, equivalent to 35-06), native-species forestry appeared to have been overestimated by the GIS and this site was determined to be 'near-pristine'. In other, apparently pristine sites (specifically in Birthday Creek; set 31 and set 33) that lay outside of the 1999 QLUMP compilation area, the land use could not be estimated and these sites were not included in this analysis.

3.2.2 Pristine areas – an objective definition used in this study

It was considered that a 'wholly pristine' definition (100% ALUM Classification = 1, Conservation and natural environments) would be rare and so few sites and data would be available with accurate nutrient characterisation. Hence a slightly broader definition of 'pristine' was sought. A proportion of the catchment areas investigated would have only been lightly touched by human development, but the impact would vary between the kinds of land use. Simple intrusion such as forestry activities was considered most benign, while grazing animals (mostly cattle) on the land would have had greater impact, particularly via erosion potential. Fertilizer-additive land uses, such as cropping or horticulture, as well as animal production and human-urban utilisation were all considered 'intensive' uses that would have the greatest impact. By this logic, 'pristine' was defined in regard the proportion of other intruding land use, notably: <1% intensive land use, <5% grazing and/or <10% active forestry. A definition of 'near-pristine' was further defined as <2% intensive land use, <15% grazing and <15% active forestry. Some leeway was given in the 'near-pristine' category for some sites that were just slightly outside of this definition.

Table 4. Broad land use classifications and ALUM codes used in this study (Land Use Mapping at Catchment Scale, 2002).

Broad Level	Classification Title	Major ALUM classification codes included in definition
1	Conservation and natural environments	1.1 - Nature conservation 1.2 - Managed resource protection 1.3 - Other minimal use
2	Forestry production	2.2 – Production forestry 3.1 – Plantation forestry 4.1 – Irrigation plantation forestry
3	Grazing	2.1 – Grazing natural vegetation 3.2 - Grazing modified pastures 4.2 - Irrigated modified pastures
4	Intensive land use (cropping, horticulture, animal production)	3.3 - Cropping 3.4 - Perennial horticulture 3.5 - Seasonal horticulture 4.3 – Irrigated cropping 4.4 – Irrigated perennial horticulture 4.5 - Irrigated seasonal horticulture 5.1 – Intensive horticulture 5.2 – Intensive animal production
5	Urban utilisation	5.3 – Manufacturing and Industrial 5.4 – Residential 5.5 – Services 5.6 – Utilities 5.7 – Transport and communications 5.8 – Mining 5.9 – Waste treatment and disposal
6	Water features	6.1 – Lake 6.2 – Reservoir or dam 6.3 – River 6.4 – Channel/aqueduct 6.5 – Marsh/wetland 6.6 – Estuary/coastal waters

For the purpose of determining 'pristine' status, our concept of 'intensive' land use encapsulated three different categories, namely cropping/horticulture where fertilizer is applied (mostly sugarcane and banana production), intensive animal production (mostly dairy, but including cattle, poultry, pigs and aquaculture) and human-urban use (residential, services-utilities, roads, mining and waste treatment). Note that this definition of intensive land use includes 'urban' use, separately described in Maps 1-12. To aid understanding of the diversity of intensive land use, these three categories are separately listed in the land-use tables for each data set. Areas assigned as Level 6 ("Water features", including lakes, dams, rivers, channels, marsh-wetlands, and estuaries) generally only represented a very small portion of the whole, but were significant in some small sub-catchments. For consistency, the Level 6 areas of 'water features' were excluded from the total area before calculation of the broad percentage land uses.

3.3. Analysed data sets

A number of data sets were assessed for the inclusion of likely pristine sites (Table 5), covering streams from north of the Port Douglas area, south to the Rockhampton area. There was no assigned order to the numbering of the data sets, with each set number (Set 01 to Set 35) simply an identifier for a report or study that was investigated here for pristine sites or flagged for future investigation. These sites are shown in Maps 13-24, running south from the Mossman area to the Koumala area. Different symbols and colours were used to depict the different data sets. Each data set was assigned a symbol (e.g. upright triangle) and colour (e.g. blue). Pristine (Wholly Pristine and Near Pristine) sites were assigned a darker shade (e.g. dark blue) while the non-pristine sites were given a lighter shade (e.g. light blue). This example can be seen in Map 23, for the sites from Wright, 1998. A 'site name' was also constructed from the data set number, a hyphen and a numerically ordered number. For example the site name 01-02 refers to the pristine site on Little Crystal Creek sampled by Butler *et al*., 1996 (see Map 21), contained within the data set 01 (see Table 5). Descriptions of all data sites, including their locations are listed in Appendix 1. Full data from these sets are also provided in Appendix 2.

No sampled sites in the Fitzroy catchment were considered to be pristine (as defined above), so no sites from this catchment were examined. In the larger Burdekin catchment, a few pristine sites were found in streams draining to the upper Burdekin River (assumed Birthday Creek, draining to Running River and Vine, Lawyer and South Cedar Creeks draining to Wild River). However, most pristine sites were found from catchments in the Wet Tropics and the Capricornia coastal zone (Table 5).

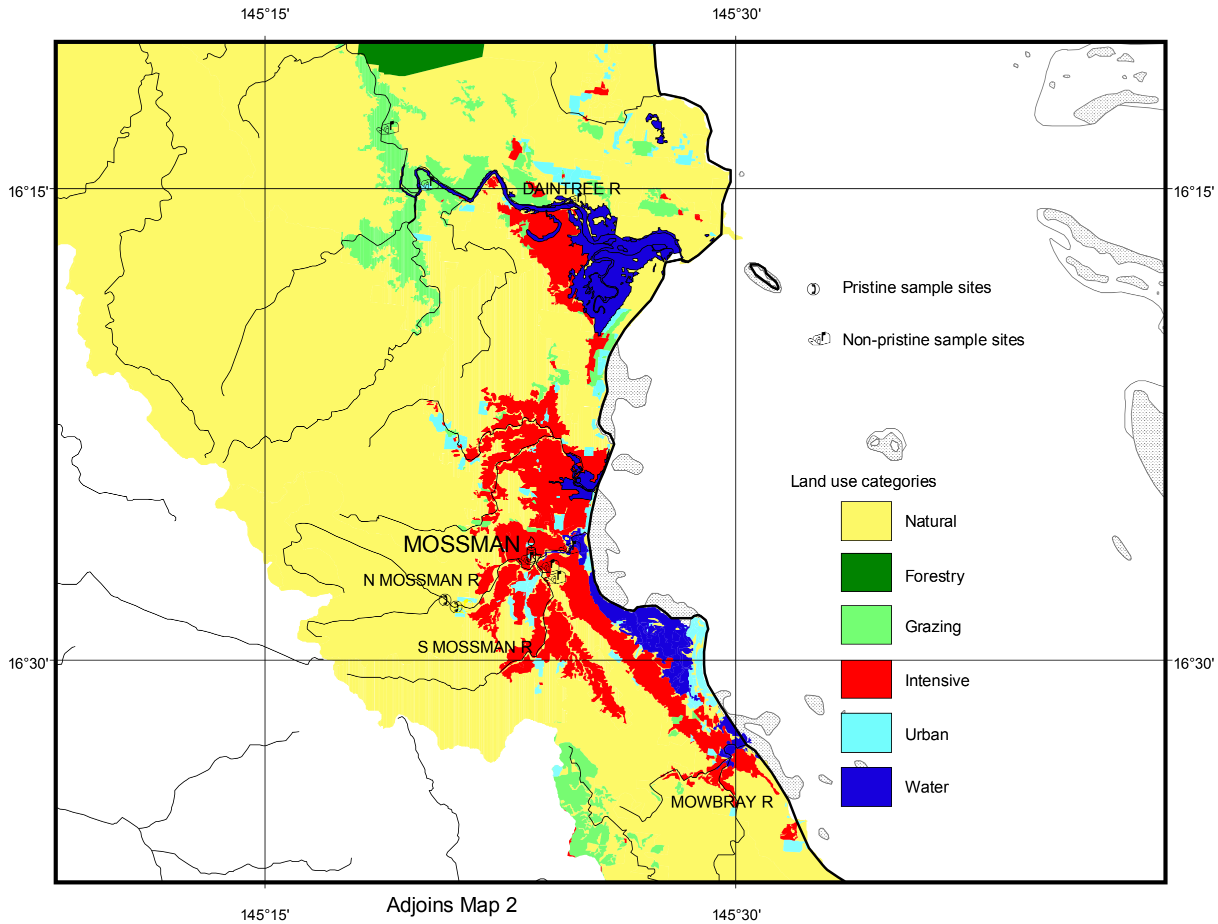
While the list clearly contains reports from which no pristine sites are likely, the purpose for their inclusion in this table is for future use, in the characterisation of nutrient conditions under broader land use categories, e.g. for forestry, grazing, cropping-horticulture and human use.

3.3.0 Note on mismatch between sampling and classification periods

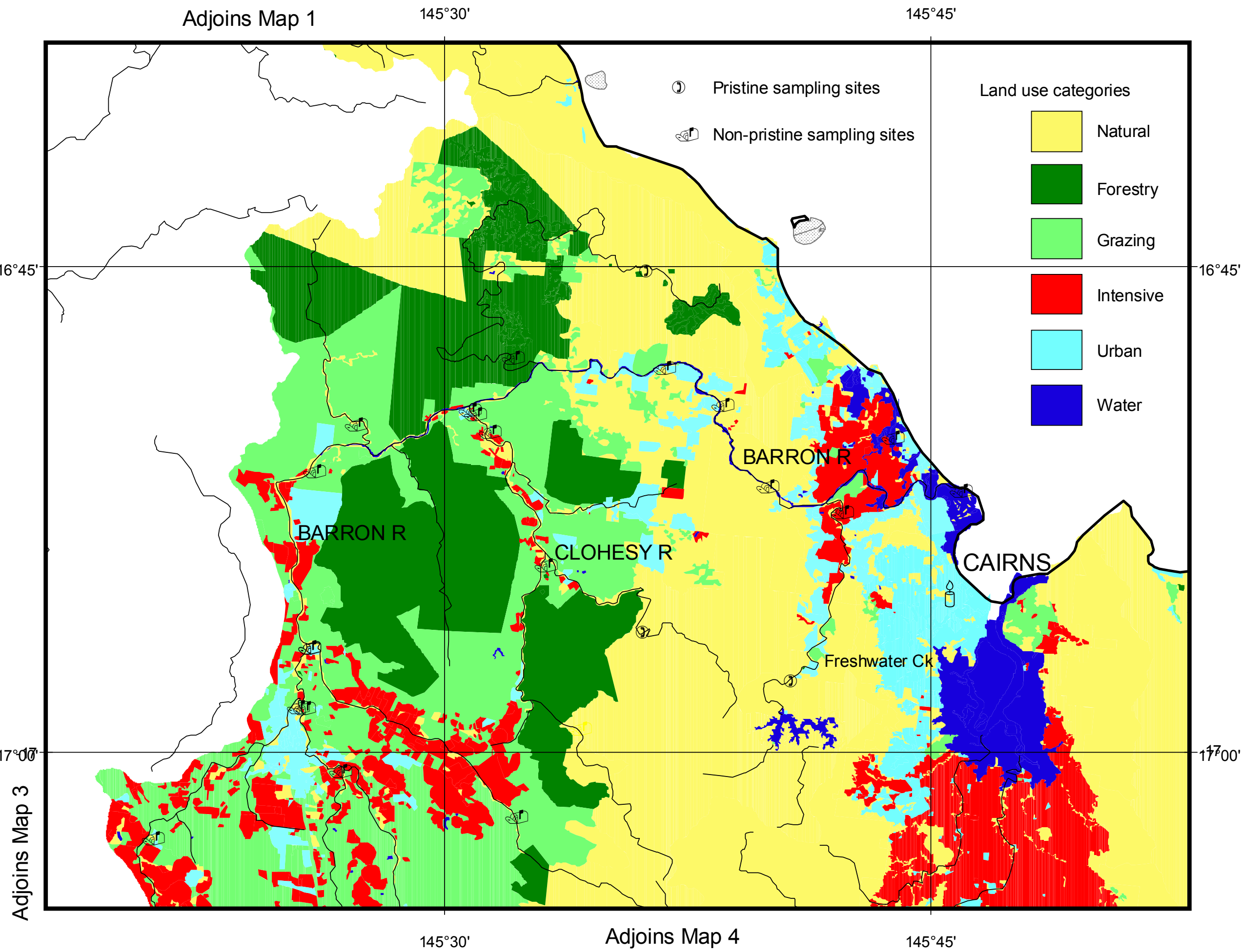
There is a time-period mismatch in that most data sets examined here were sampled in the 1990's (or earlier), some years before the QLUMP GIS classification dates (see Tables 3 and 5). However, if we assume that more development than conservation has occurred in these coastal catchments during the intervening period, then the effect of later land use estimates from QLUMP will be conservative, by reducing the natural area calculations and increasing other land uses. An exception to this trend of coastal development occurred in 1988 with the declaration of the World Heritage Area legislation, protecting areas of north Queensland such as in the Wet Tropics. After this time, some previously forested areas were protected from further logging. The QLUMP classification is confusing here with some WHA protected areas (e.g. in the Daintree River catchment) still classified as natural forestry areas (ALUM code 2.2). In such cases, some rehabilitation of the forests is assumed and these sites are given a 'near-pristine' classification.

Table 5. Data sets considered in pristine site investigation.

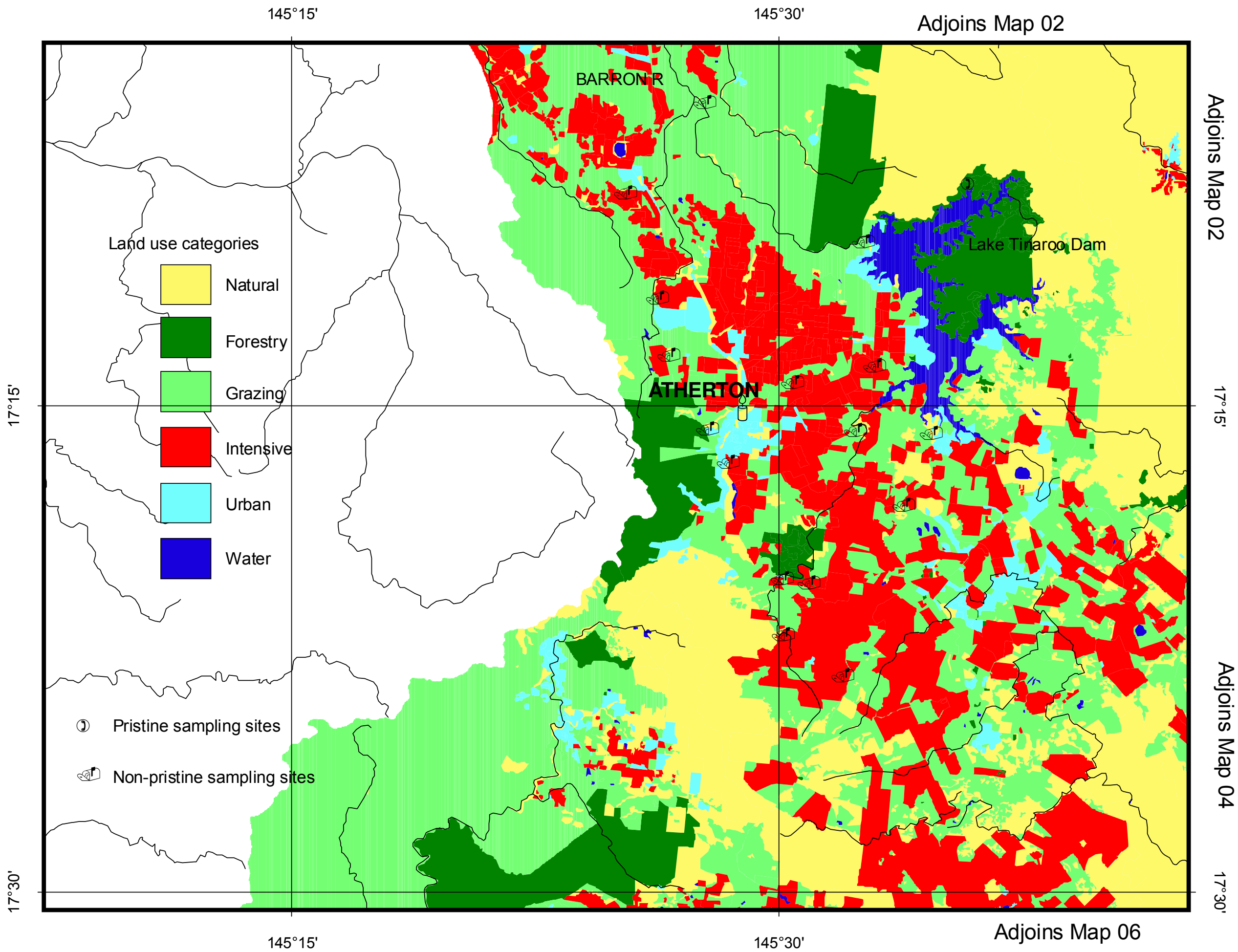
Data set	Symbols or exclusion	Organisation	Reference	Report	Catchment description	Period
1	O O	ACTFR	Butler *et al.*, 1996	ACTFR 96/11	Wet Tropics	1994-1995
2	O O	CSIRO	Bramley & Muller, 1999	CSIRO 16/99	Lower Herbert	1992-1994
3	y y	ACTFR	Pearson & Clayton, 2001	ACTFR 93/01	Teemburra Ck, CQ	1992-1993
4	5	ACTFR	Pearson & Penridge, 1992	ACTFR 92/02	Wet Tropics	1977-1978
5	y y	HEC_Tully Millstream	Faithful & Brodie, 1990	ACTFR 90/09-14	Tully basin	1990
6	5	Healthy Waterways	White, *et al.*, 2002	Report_2002	Pioneer River	2002
7	Lake	ACTFR	Faithful & Butler, 1994	ACTFR 94/07	Lake Proserpine	1992-1994
8	No pristine	ACTFR-SRDC	Pearson *et al.*, 2003	ACTFR 03/04	Lower Herbert	1998-2002
9	No pristine	ACTFR	Burrows & Faithful, 2003	ACTFR 03/12	Upper Townsville	2002-2003
10	No pristine	ACTFR-NHT	Faithful, 2002	ACTFR 02/12	Townsville/Burdekin	2001-2002
11	y	Laxton_Envir Consult	Laxton *et al.*, 1994	Priv Res Paper, Pt 1	Sarina/Broadsound	1989-1993
12	M	WaterWatch	Bensted & Wright	WW Rep Sep97	Plane Ck	1995-1997
13	M M	WaterWatch FNQ	Mitchell & Wright	WW Rep Feb03	Wet Tropics	1995-2002
14	4	AIMS-BSES	Furnas *et al.*, 2001	AIMS River Reps	Tully catchment	1987-2000
15a	5 5	WaterWatch	Wright, 1996	First WW Rep	Pioneer Catchment	1993-1996
15b	4 4	Waterwatch	Wright, 1998	Second WW Rep	Pioneer Catchment	1996-1998
16	Now #5	HEC_other data	Obtained from HEC	unreported	Tully basin	1989-1991
17	No pristine	NHT_NR&M	Ryan, Aland, Cogle	NHT 96-2005	Upper Mitchell catch	1997-1999
18	No pristine	ACTFR_LWRRDC	Congdon & Lukacs	ACTFR 95/12	Barrattas	1988-1993
19	No pristine	ACTFR	Congdon	ACTFR 91/06	Barrattas	1988-1990
20	No pristine	ACTFR_LWRRDC	Congdon & Pearson	ACTFR 92/01	Barrattas	1988-1991
21	No pristine	DNR	Noble *et al.*, ????	DELU_Fitzroy	Fitzroy basin	1993-1996
22	O O	Coast Clean Seas	Faithful, 2003	ACTFR 02/13	Whitsunday rivers	2000-2002
23	M M	NR & M	Cogle *et al.*, 2001	Nat Res Barron 2	Barron basin	1992-1999
24	Not available	NQNRM&E_WQ	Cox *et al.*, 2004	?	North Qld	?
25	No pristine	GBRMPA	Devlin, 2001	?	NQ Rivers/floods	1999
26	Not available	DNR	Hunter, ????	Johnstone model	Johnstone basin	1991-1996
27	No pristine	DNR	Anon,	Testing the waters	Qld	?
31	4	JCU – Yellowlees (Ed)	Mitchell *et al.*, 1991	Land Use Patterns…	Birthday Ck/Congdon	1998-1990
33	M	ACTFR	Pearson *et al.*, 1998	ACTFR 98/26	North Qld.	1994-1995
34	y y	ACTFR	Faithful, 2004	ACTFR ??	Whitfield Ck area	2004
35	5 5	Laxton Envir Consult	Laxton & Gittins, 2004	Private Res Proj	NQ	



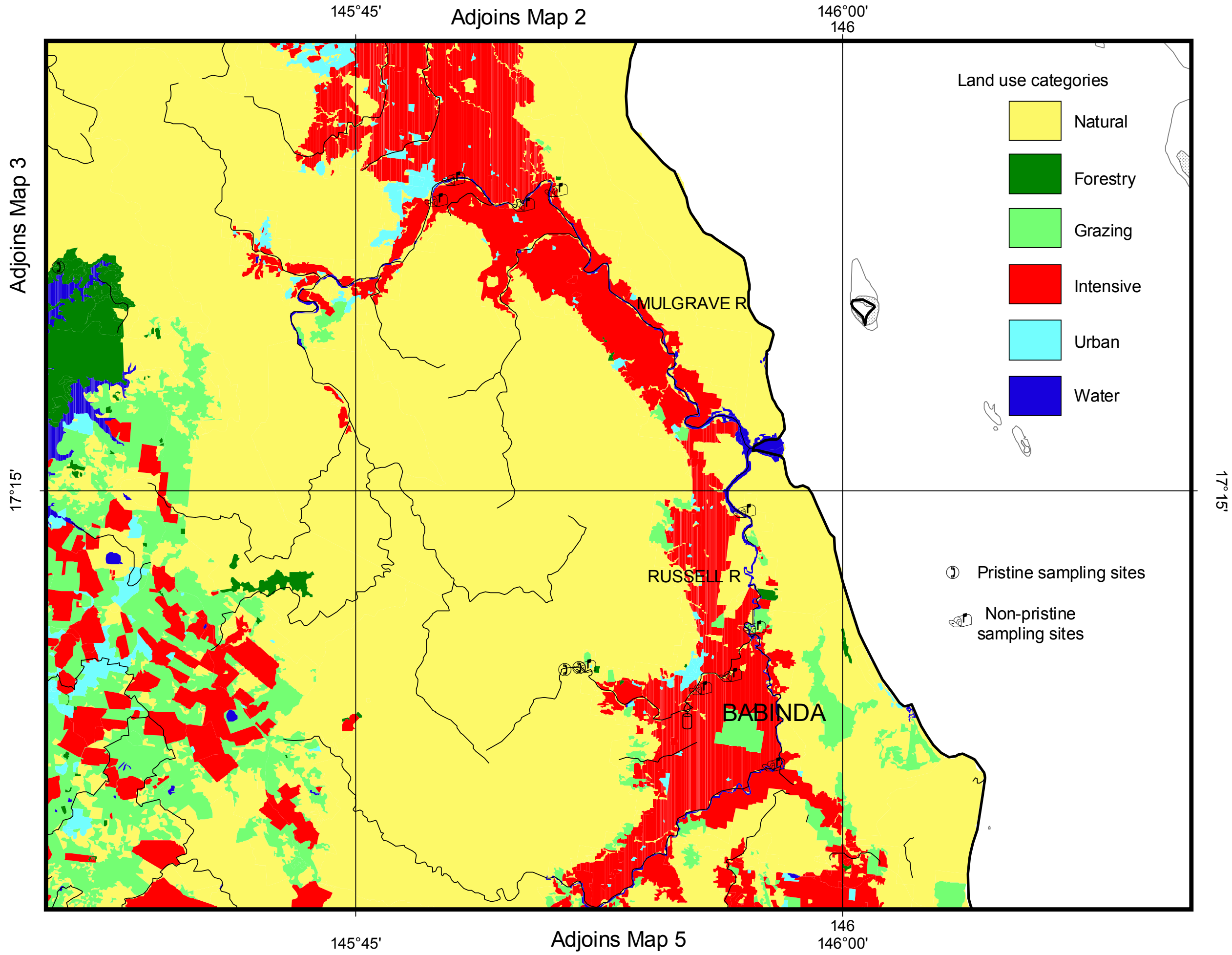
Map 1. Land use in the Mossman area



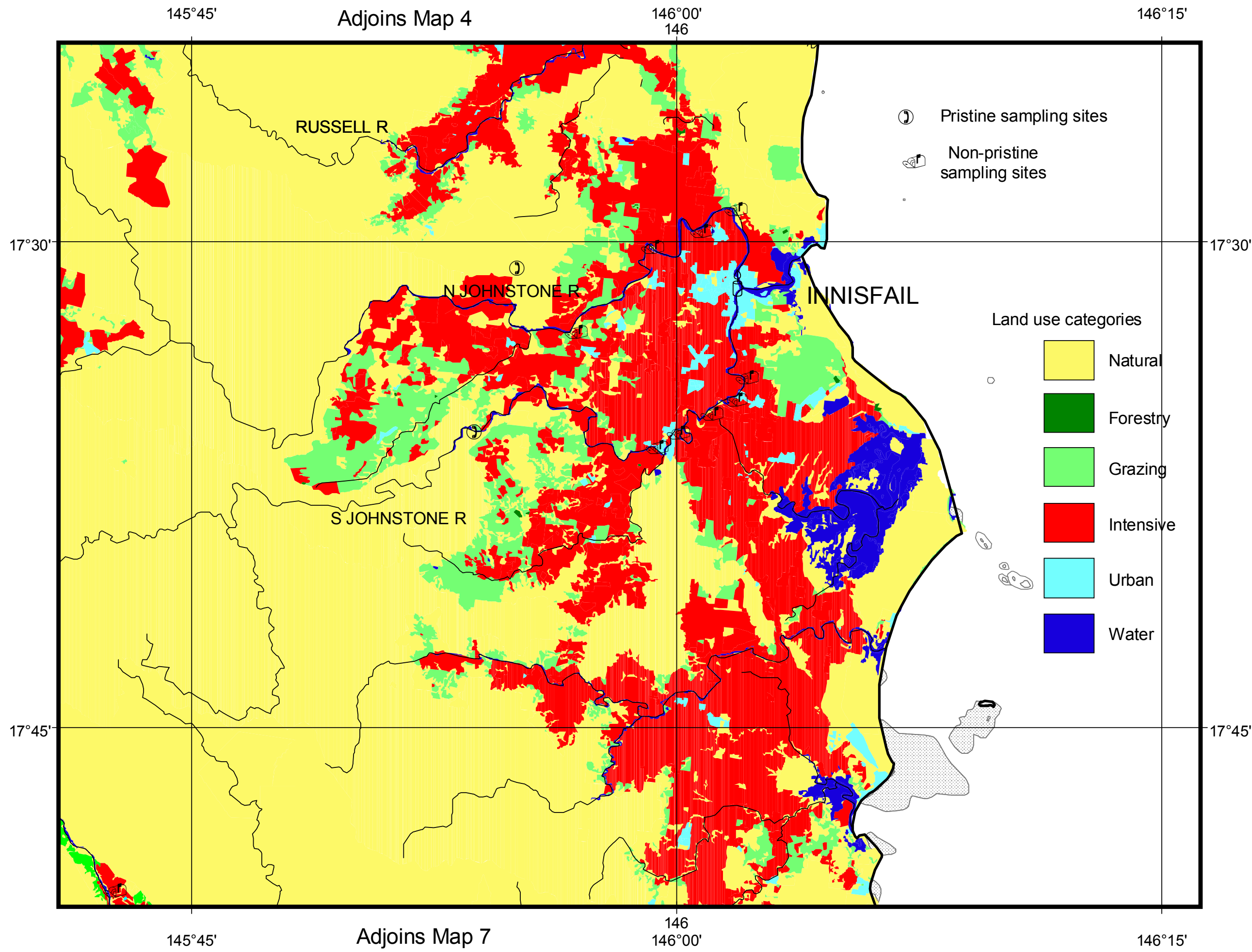
Map 2. Land use in the Cairns area



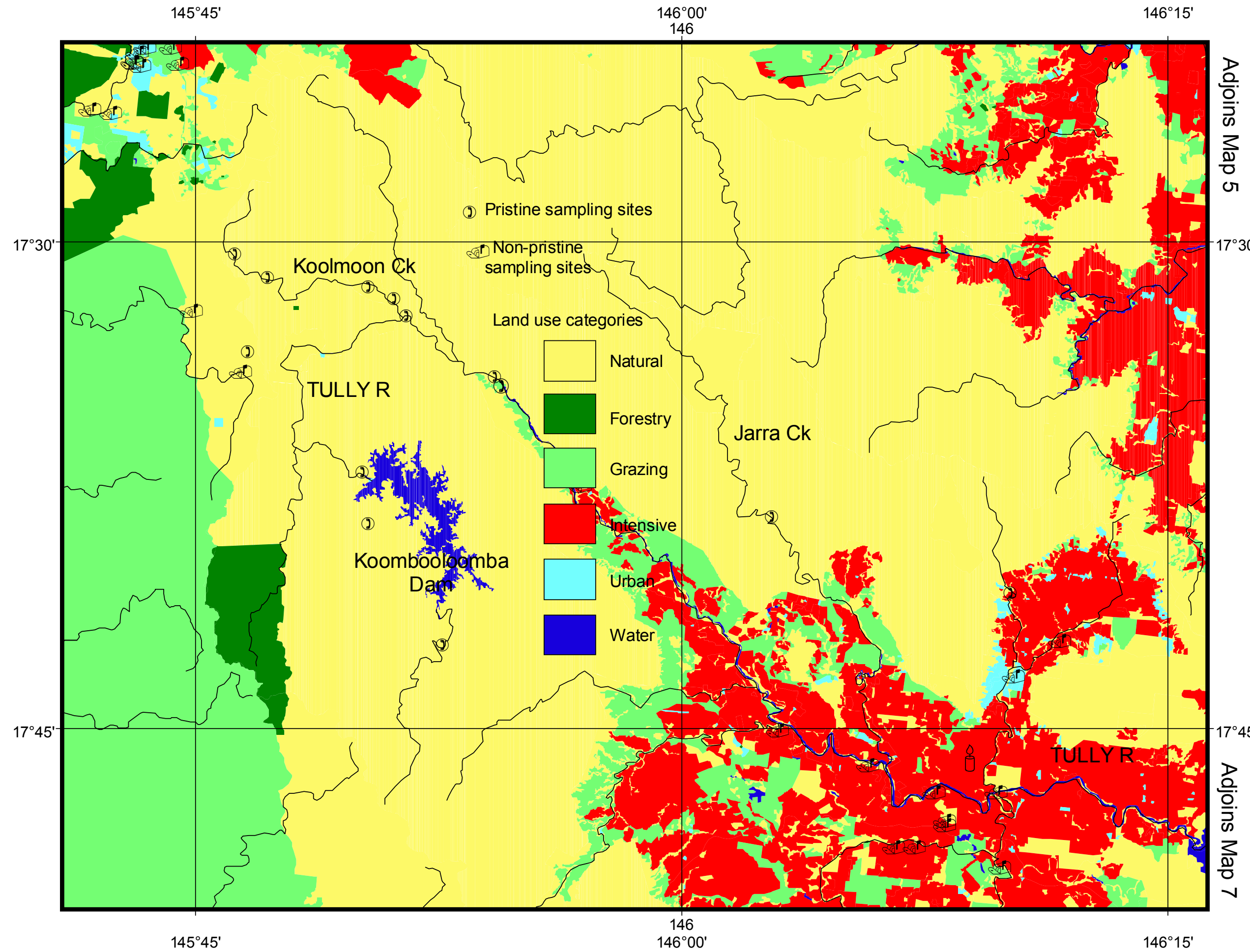
Map 3: Land use in the Mareeba area



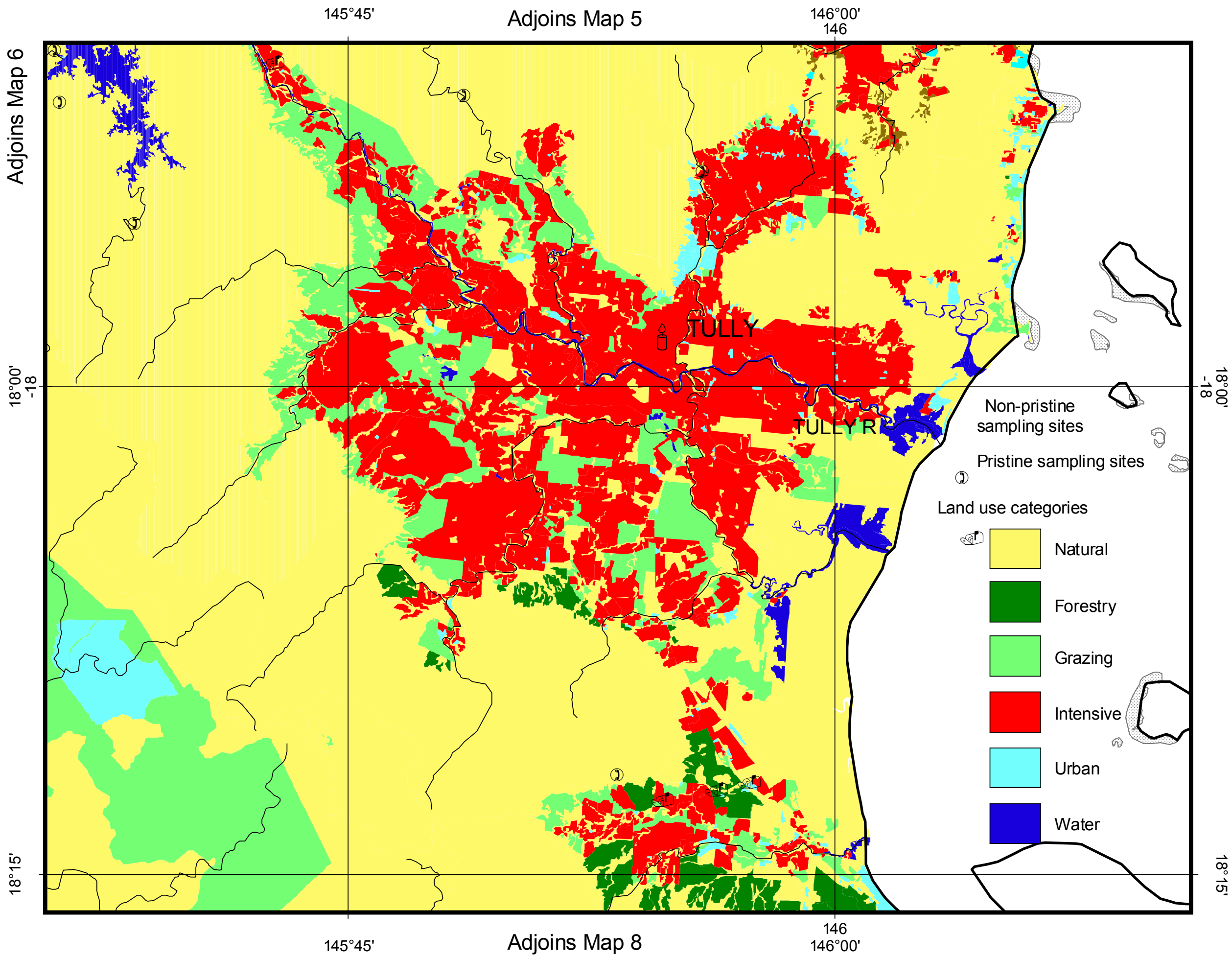
Map 4: Land use in the Babinda area



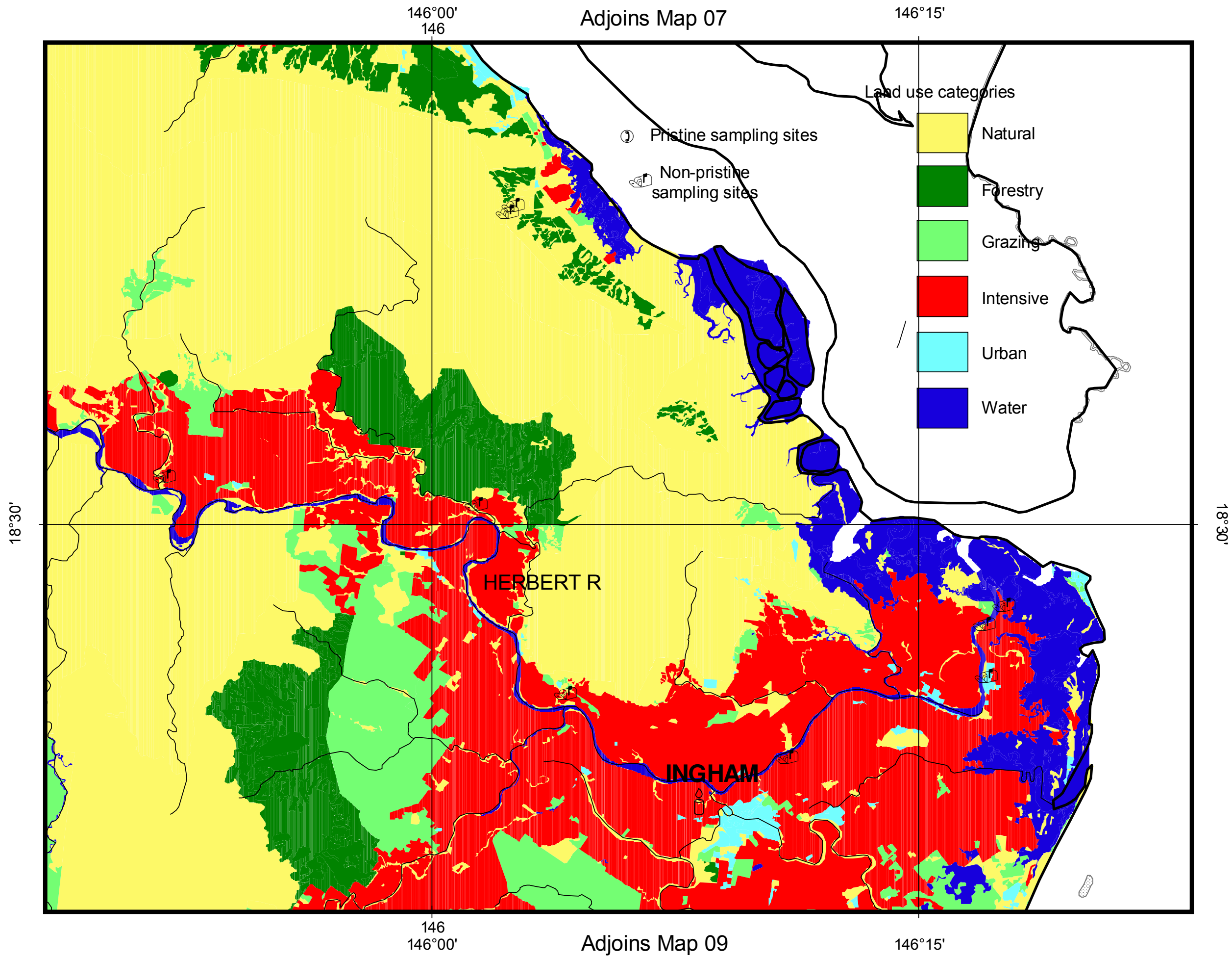
Map 5: Land use in the Innisfail area



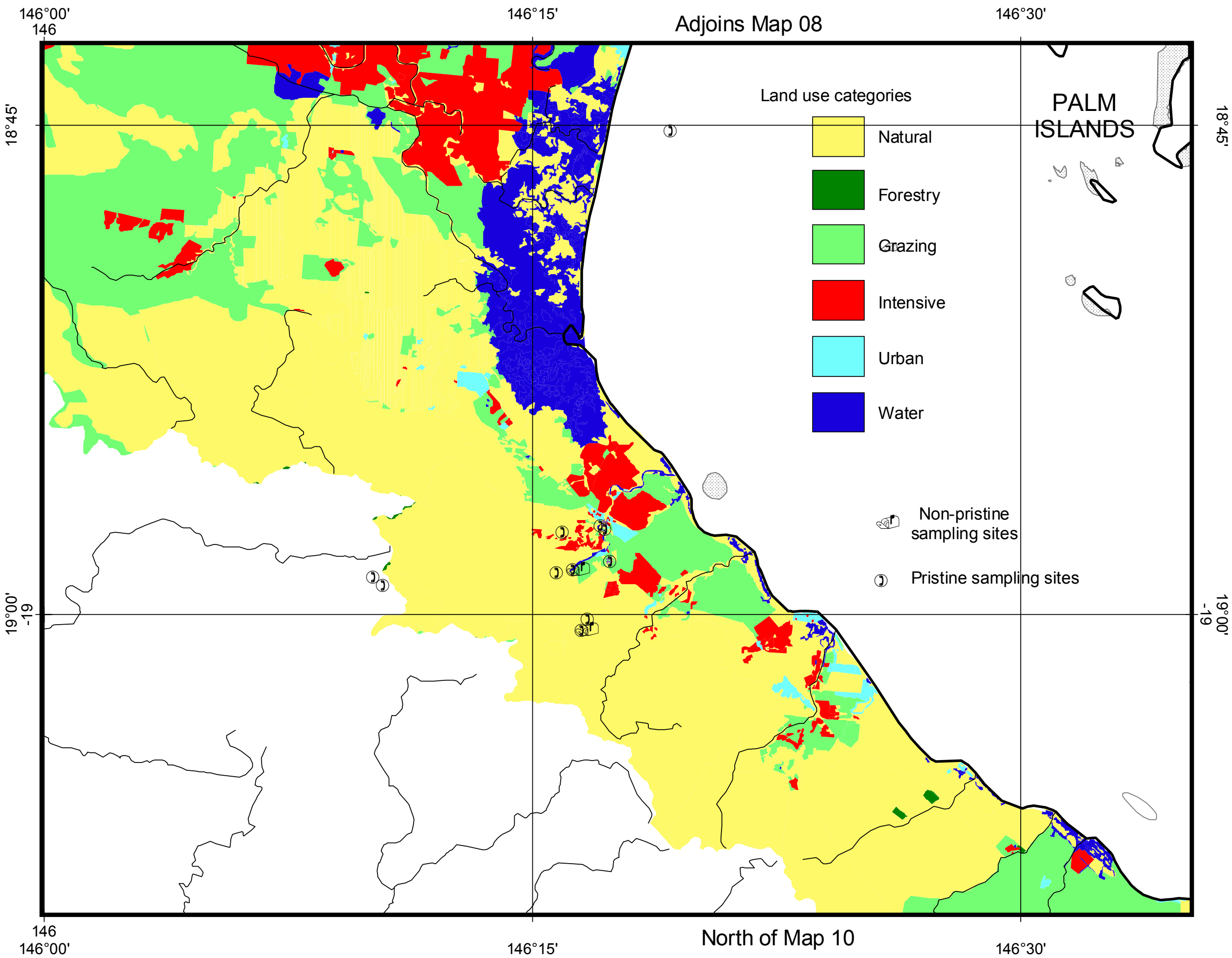
Map 6: Land use in the Koombooloomba Dam area



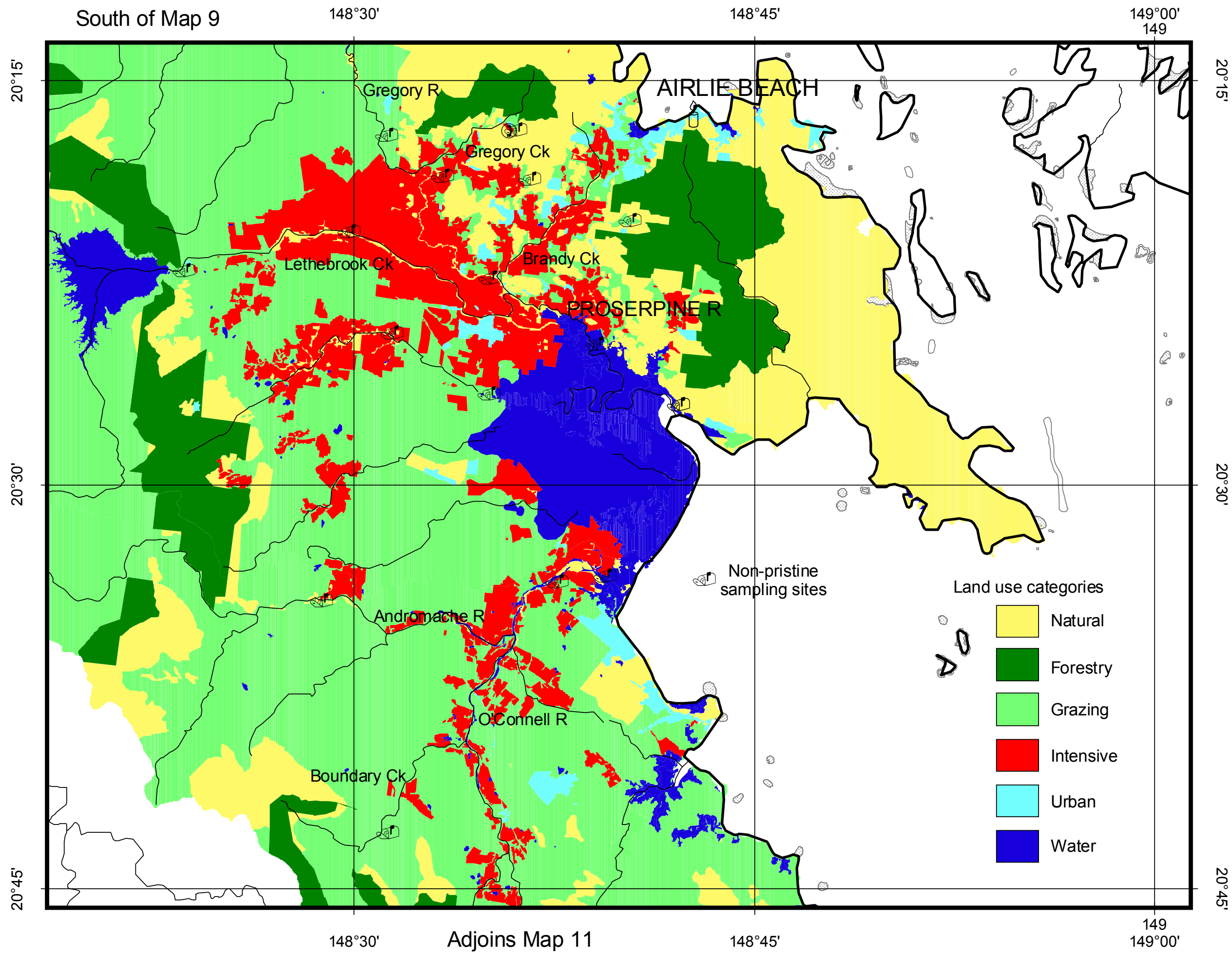
Map 7: Land use in the Tully area



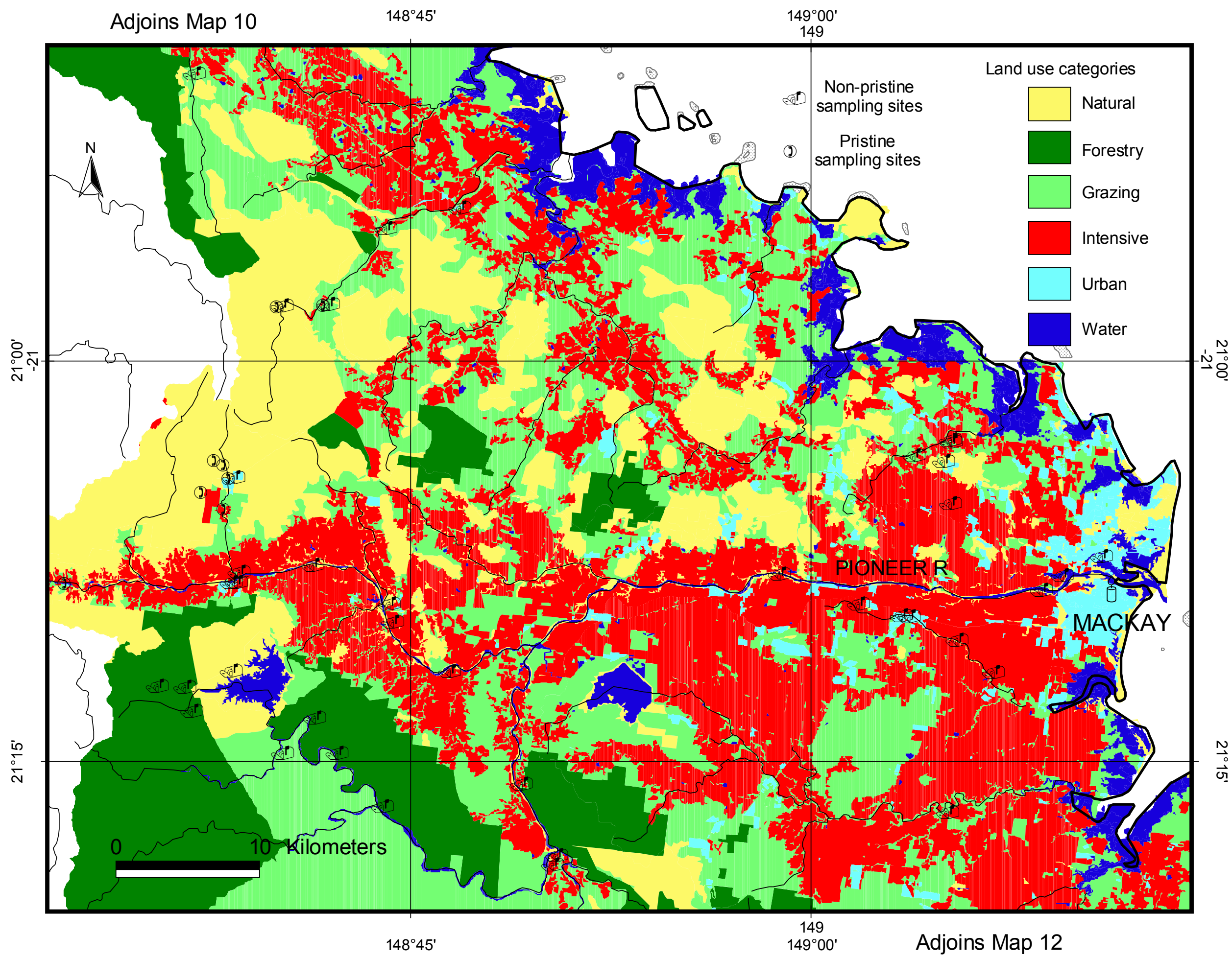
Map 8: Land use in the Ingham area



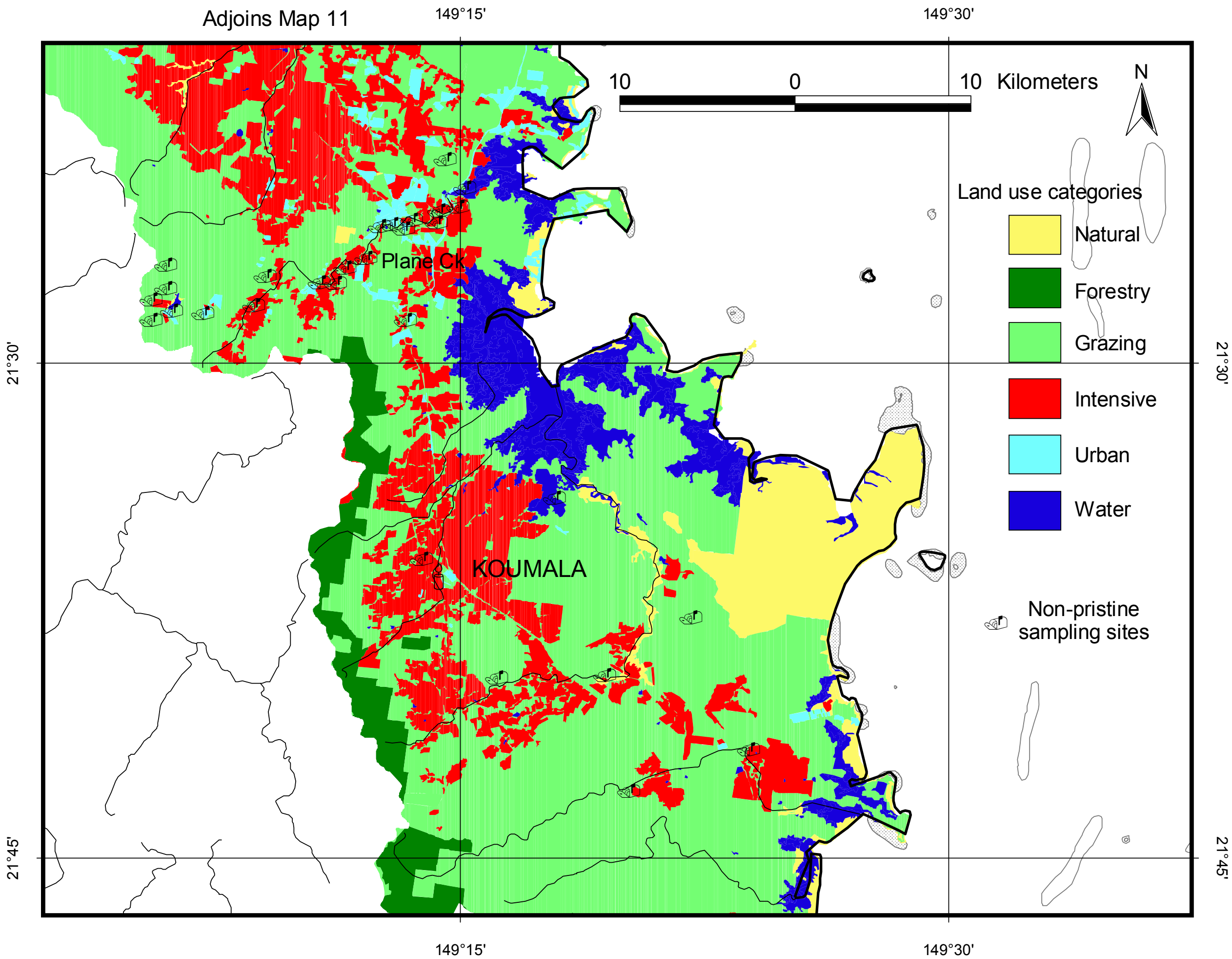
Map 9: Land use in the Palm Islands area



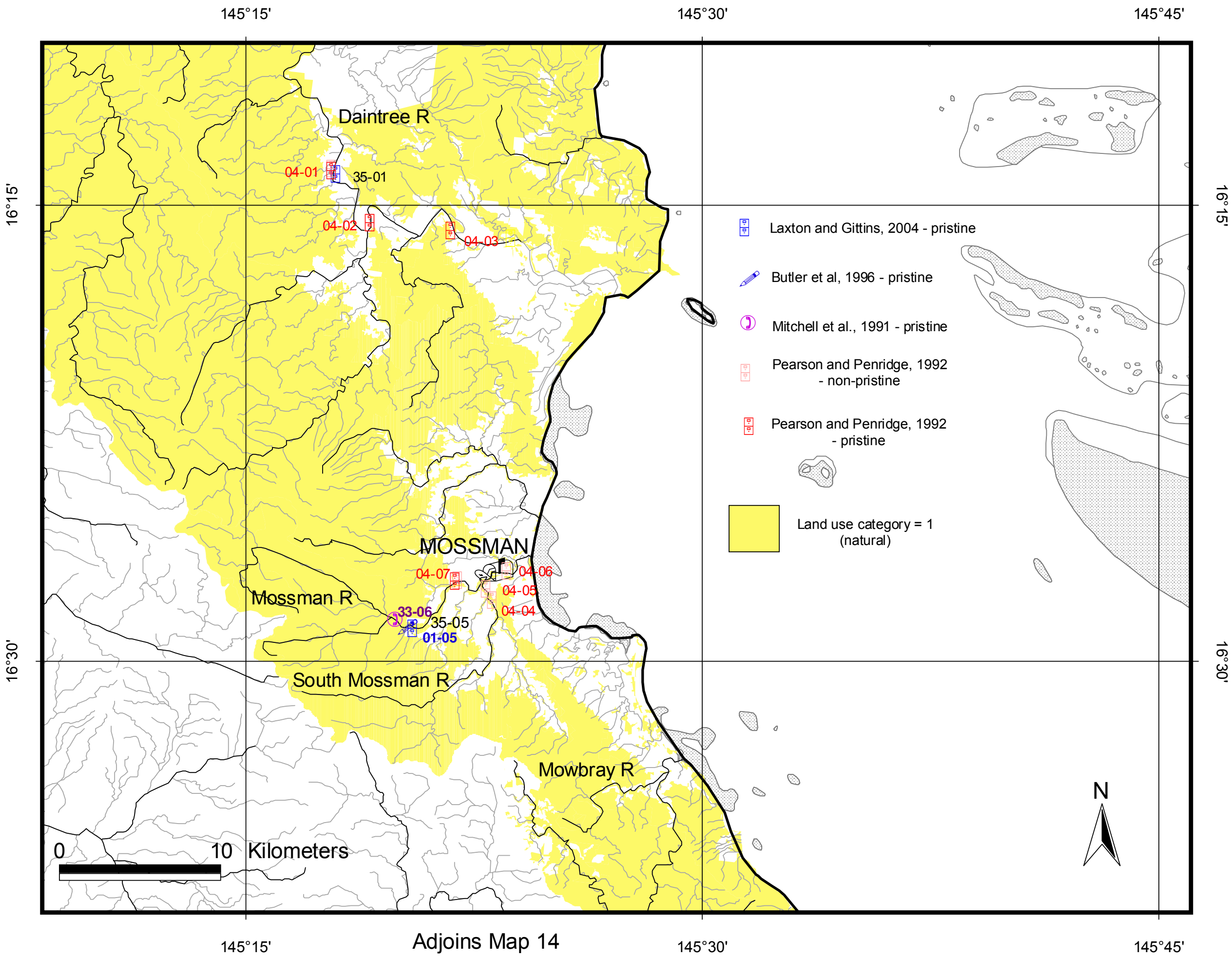
Map 10: Land use in the Airlie Beach area



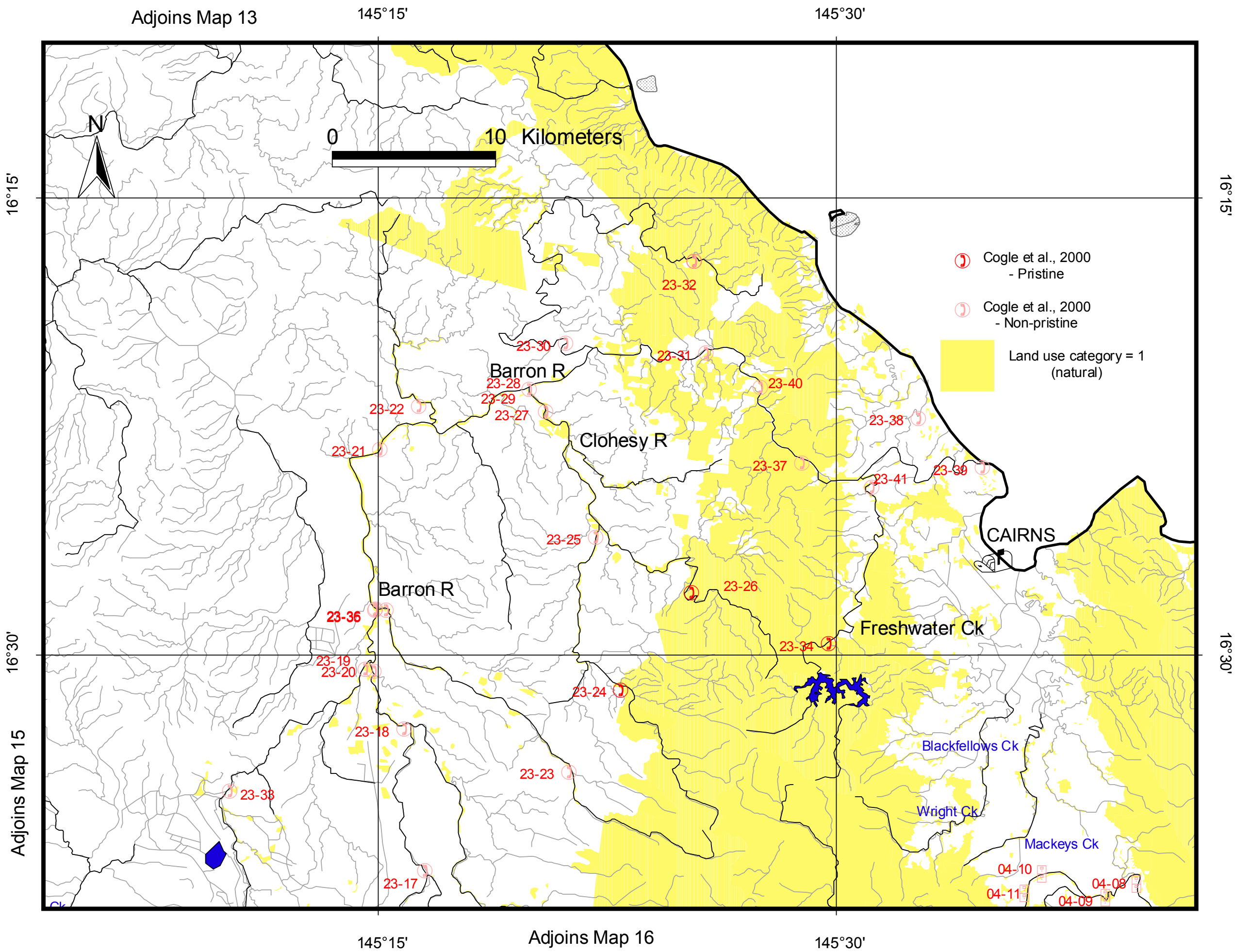
Map 11: Land use in the Mackay area



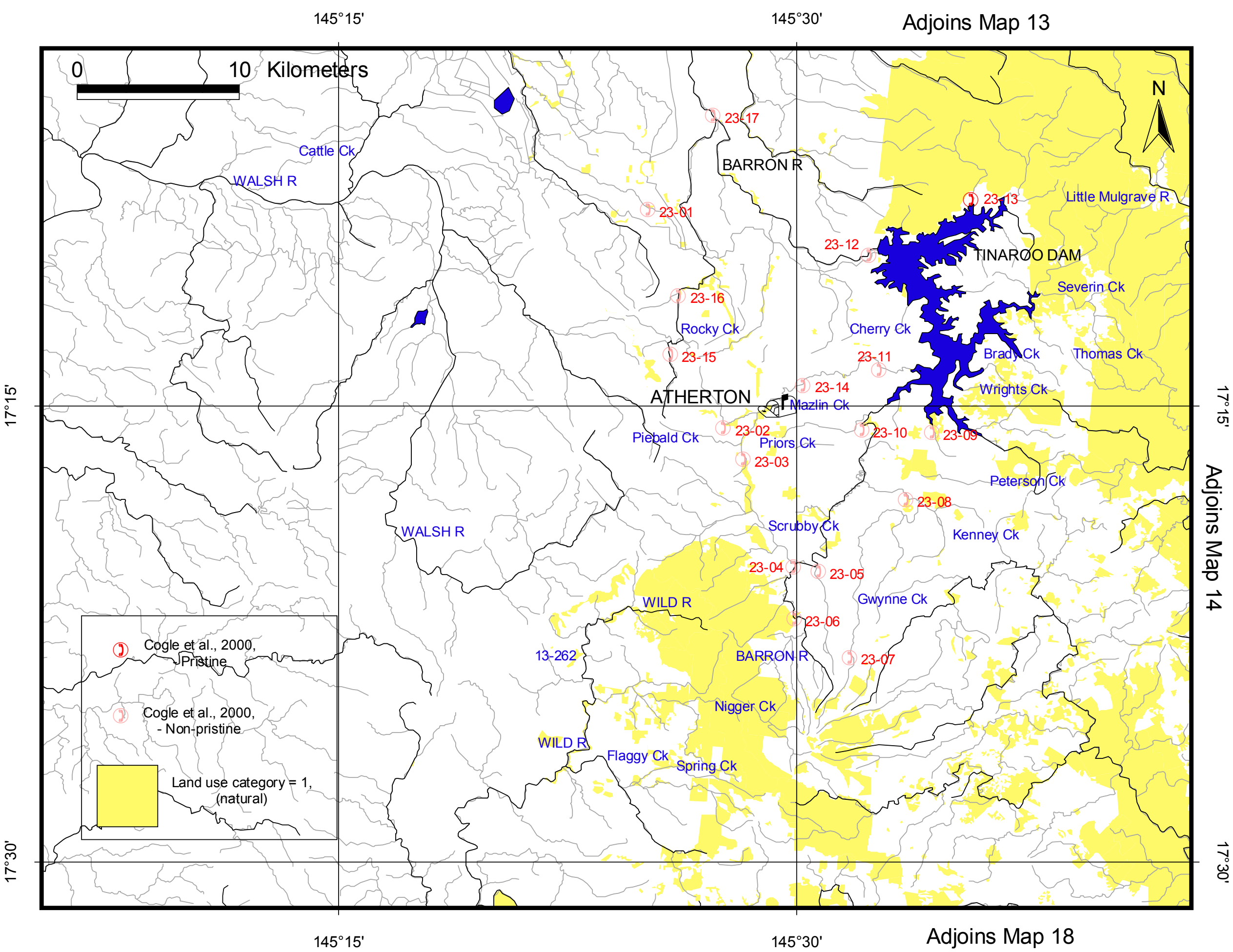
Map 12: Land use in the Koumala area



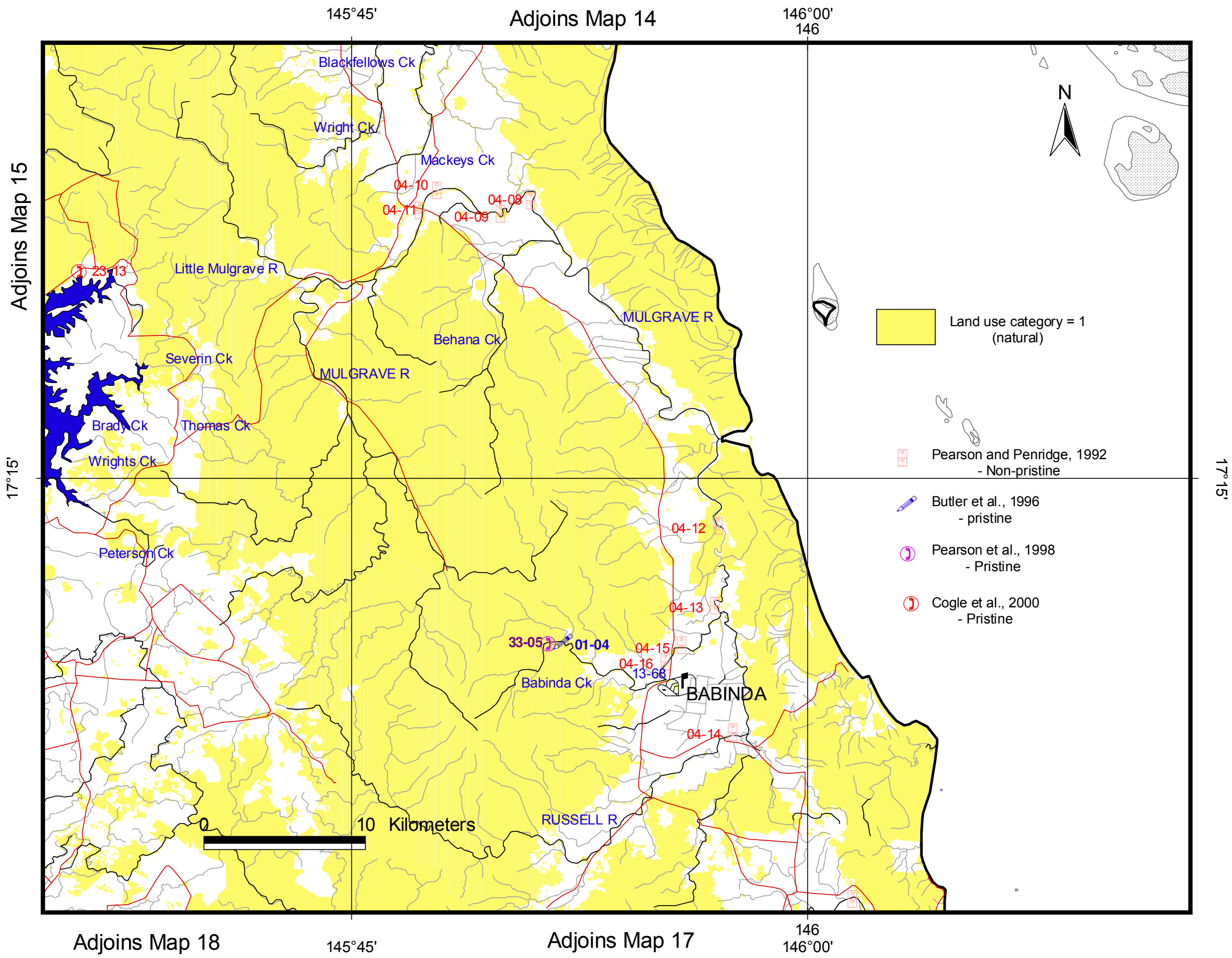
Map 13: Sampling sites from the Mossman area



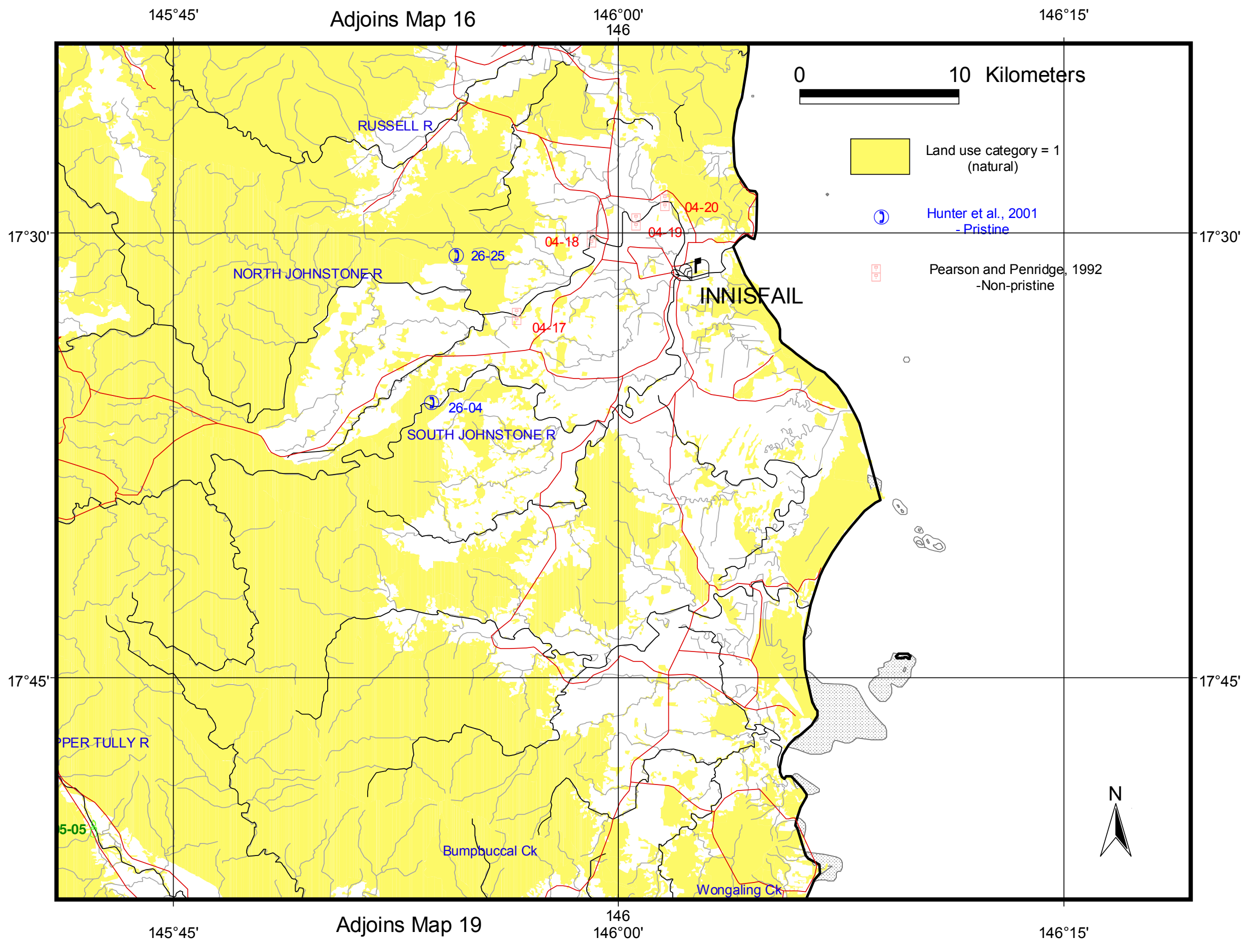
Map 14: Sampling sites from the Cairns area



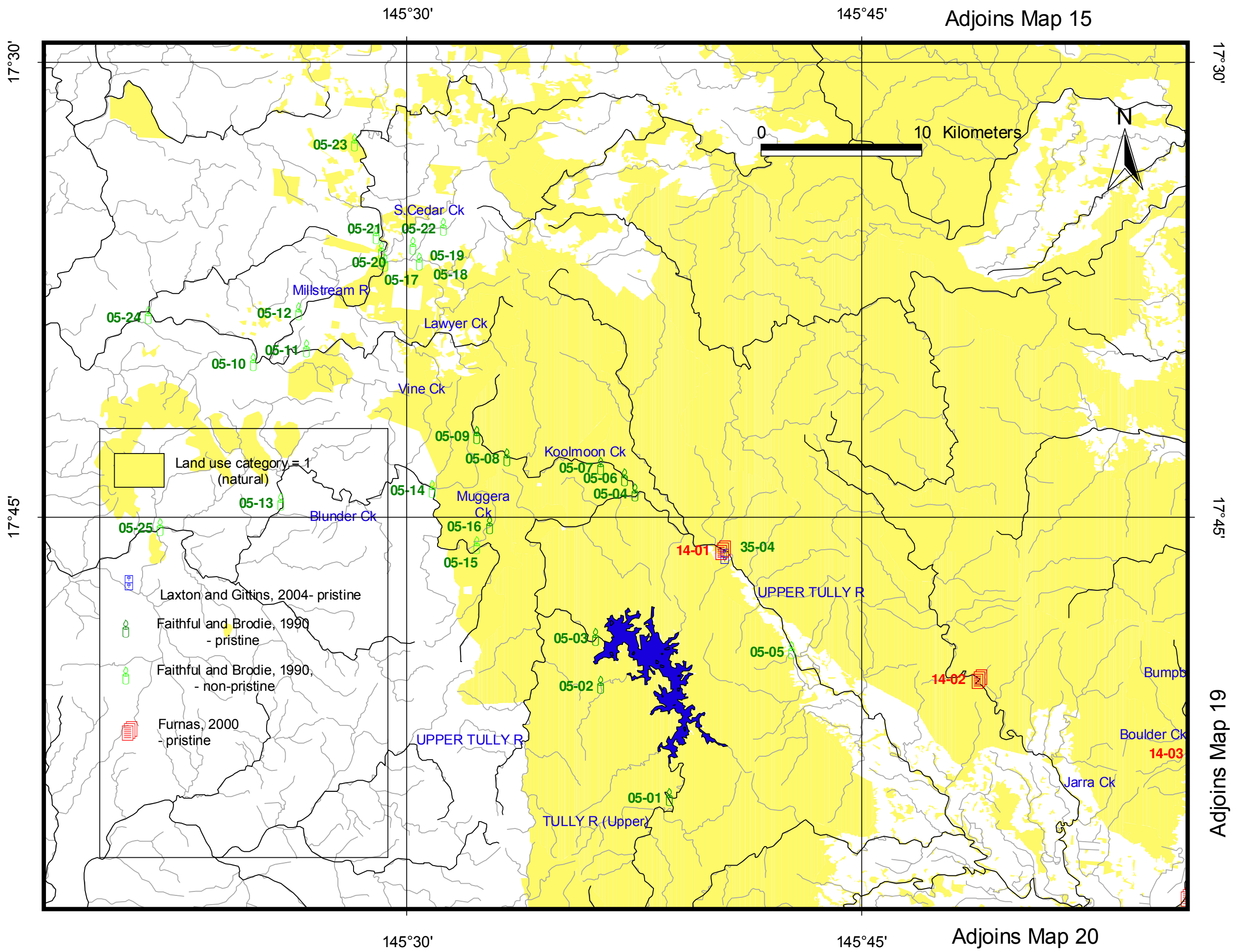
Map 15: Sampling sites from the Atherton area



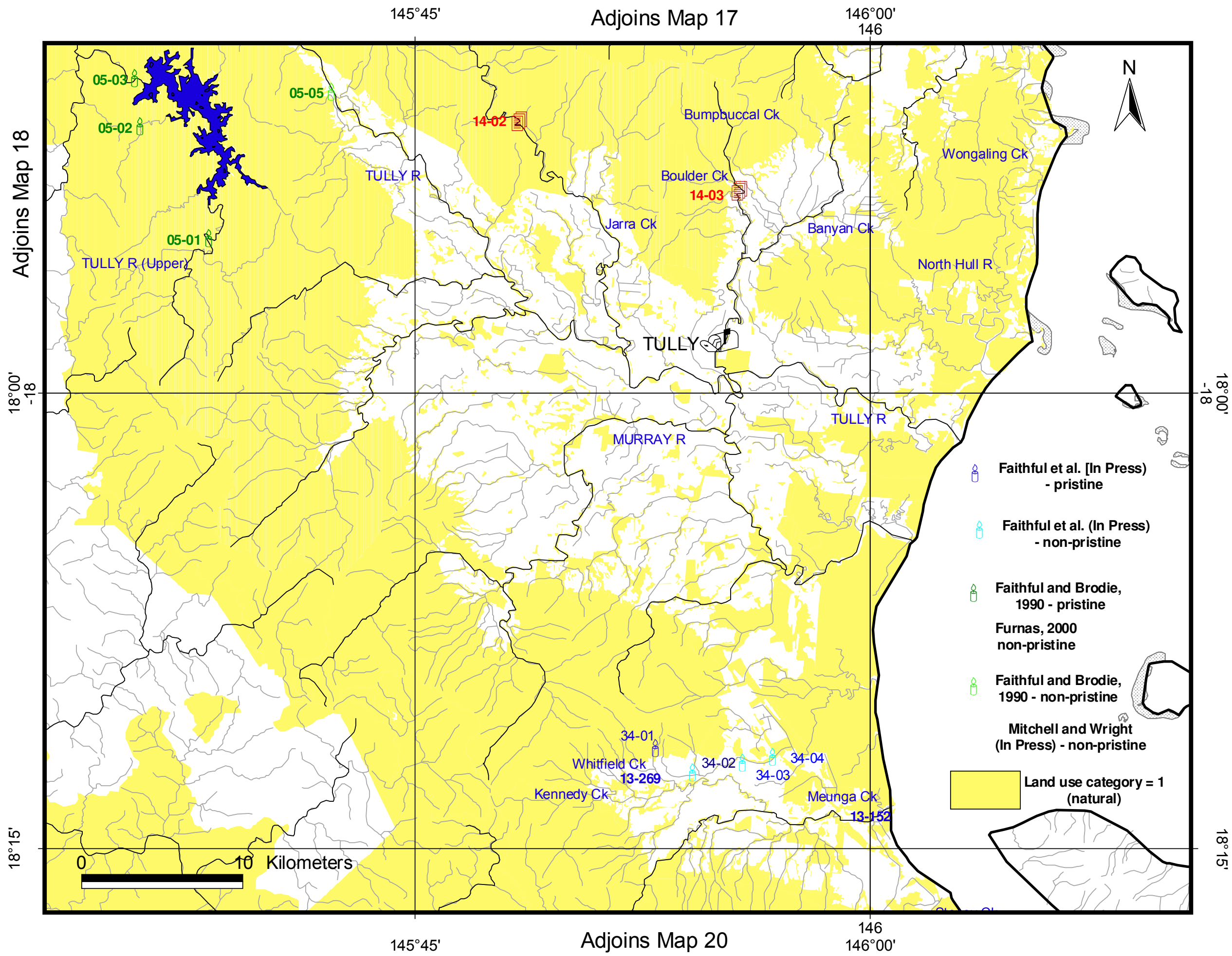
Map 16: Sampling sites from the Babinda area



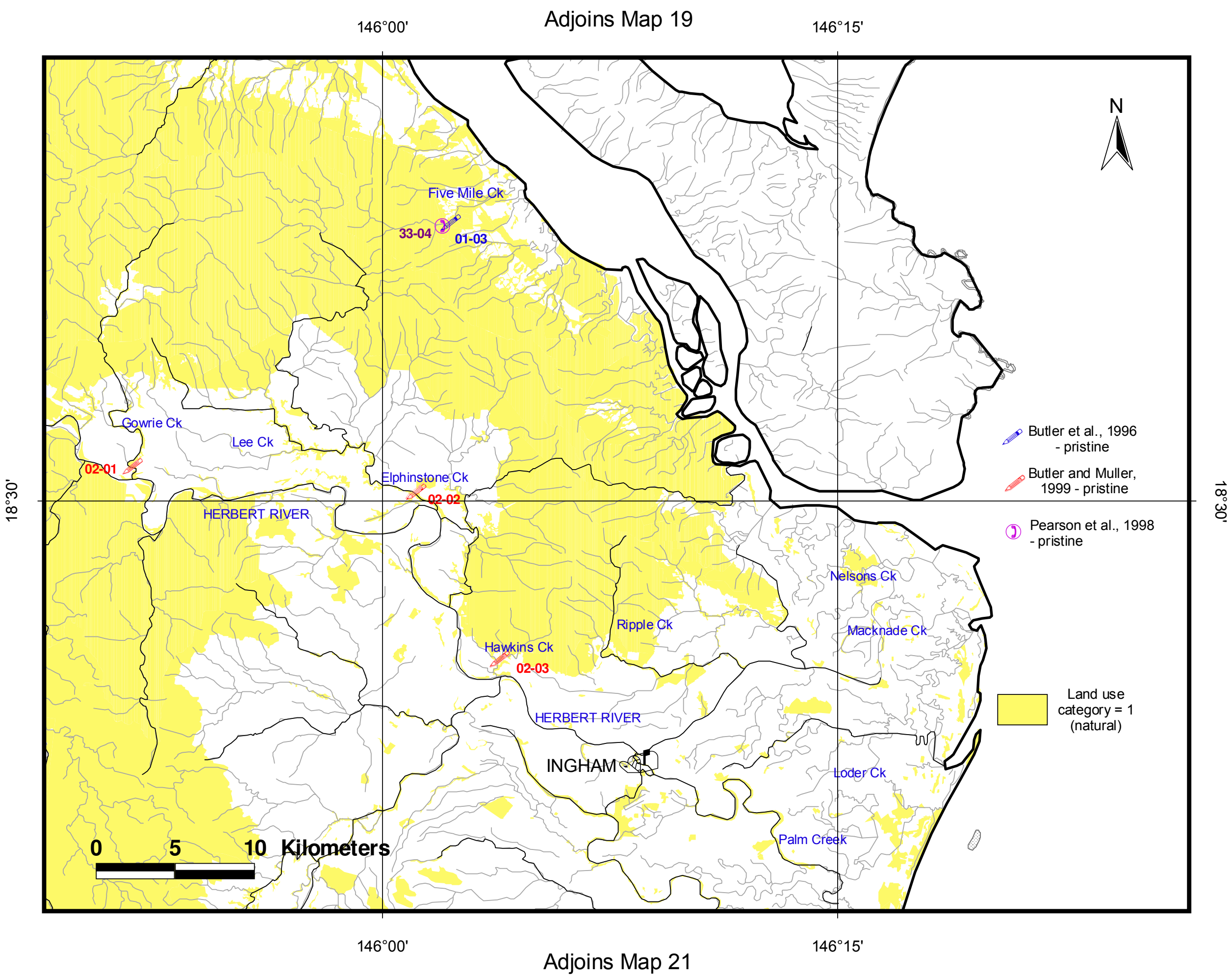
Map 17: Sampling sites in the Innisfail area



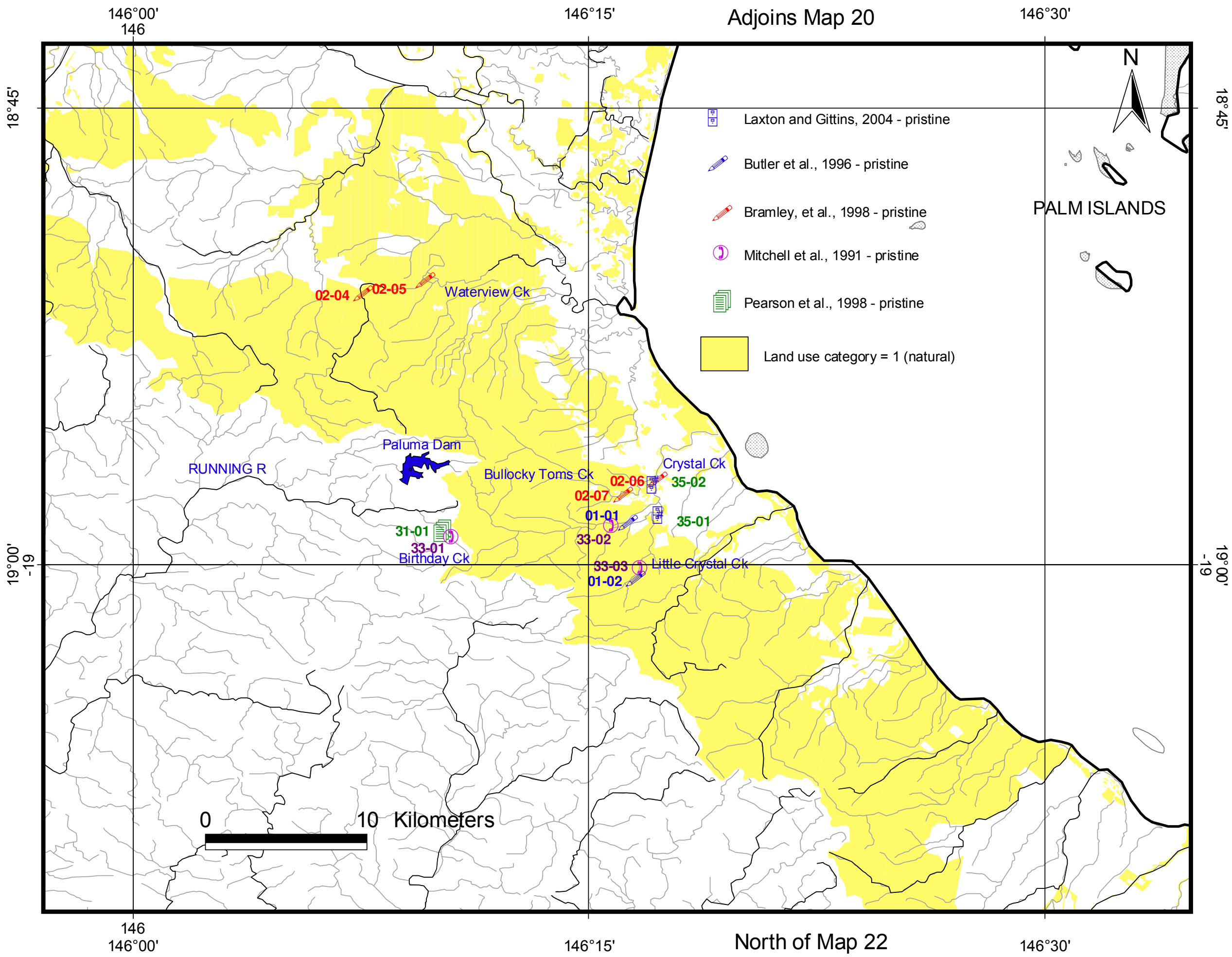
Map 18: Sampling sites in the Koombooloomba Dam area



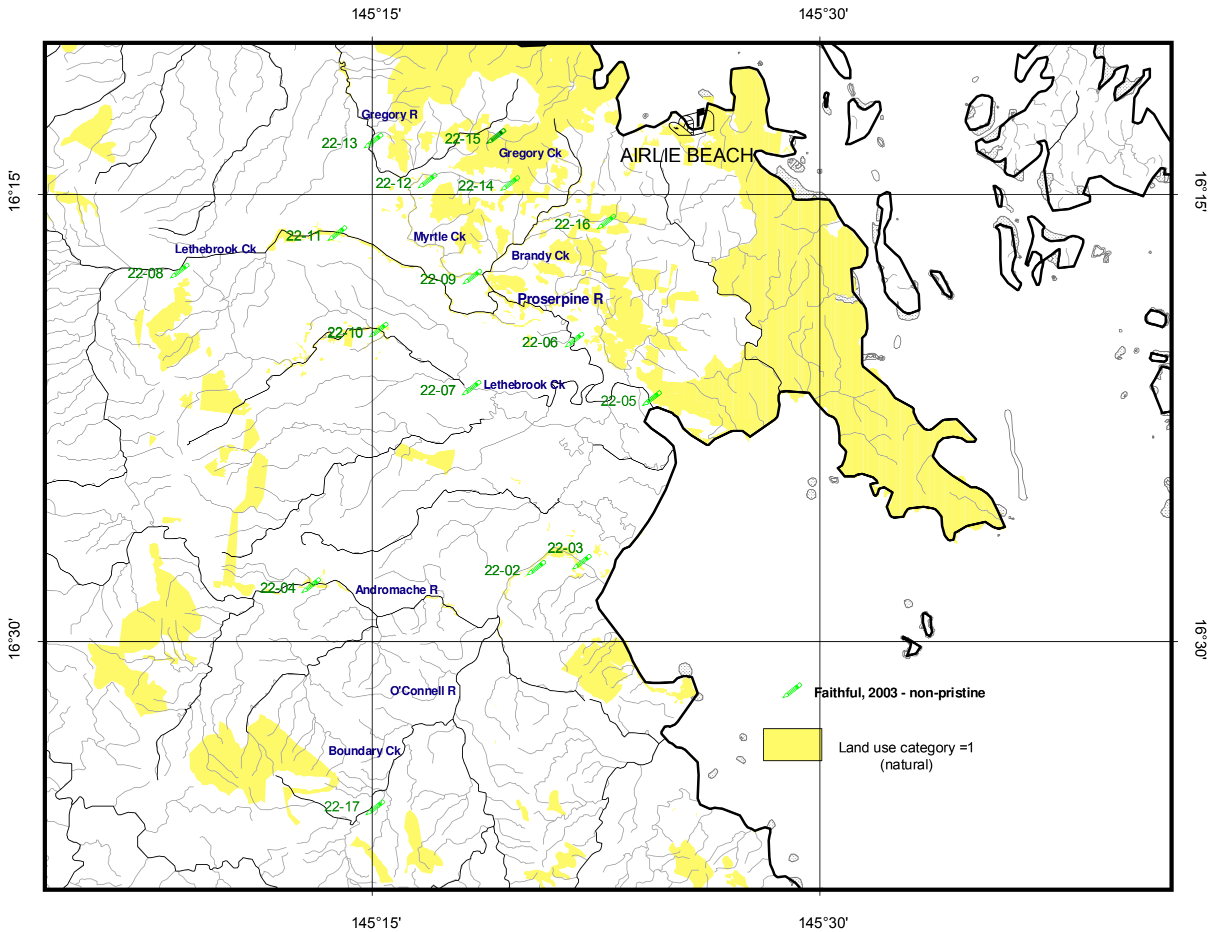
Map 19: Sampling sites in the Tully area



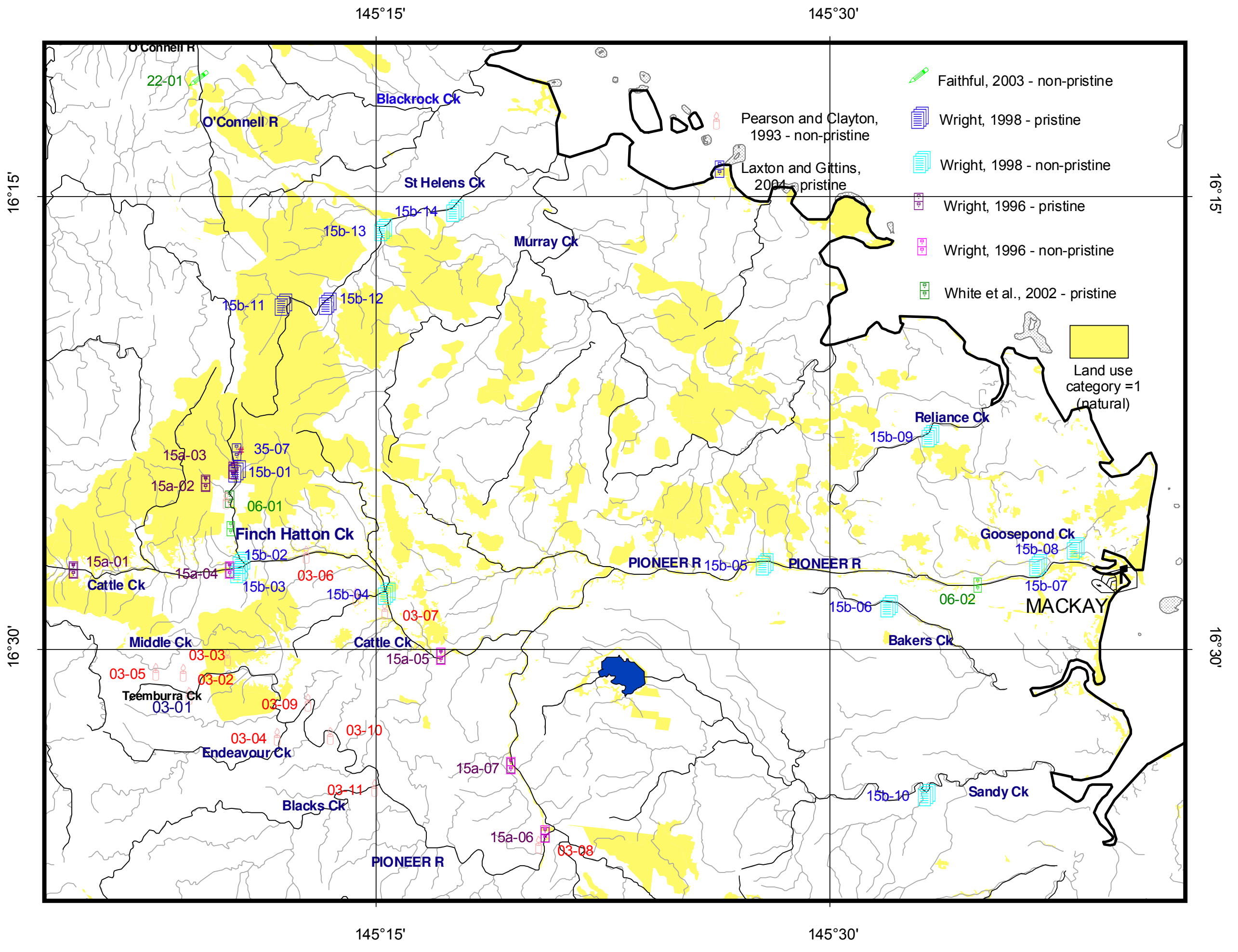
Map 20: Sampling sites in the Ingham area



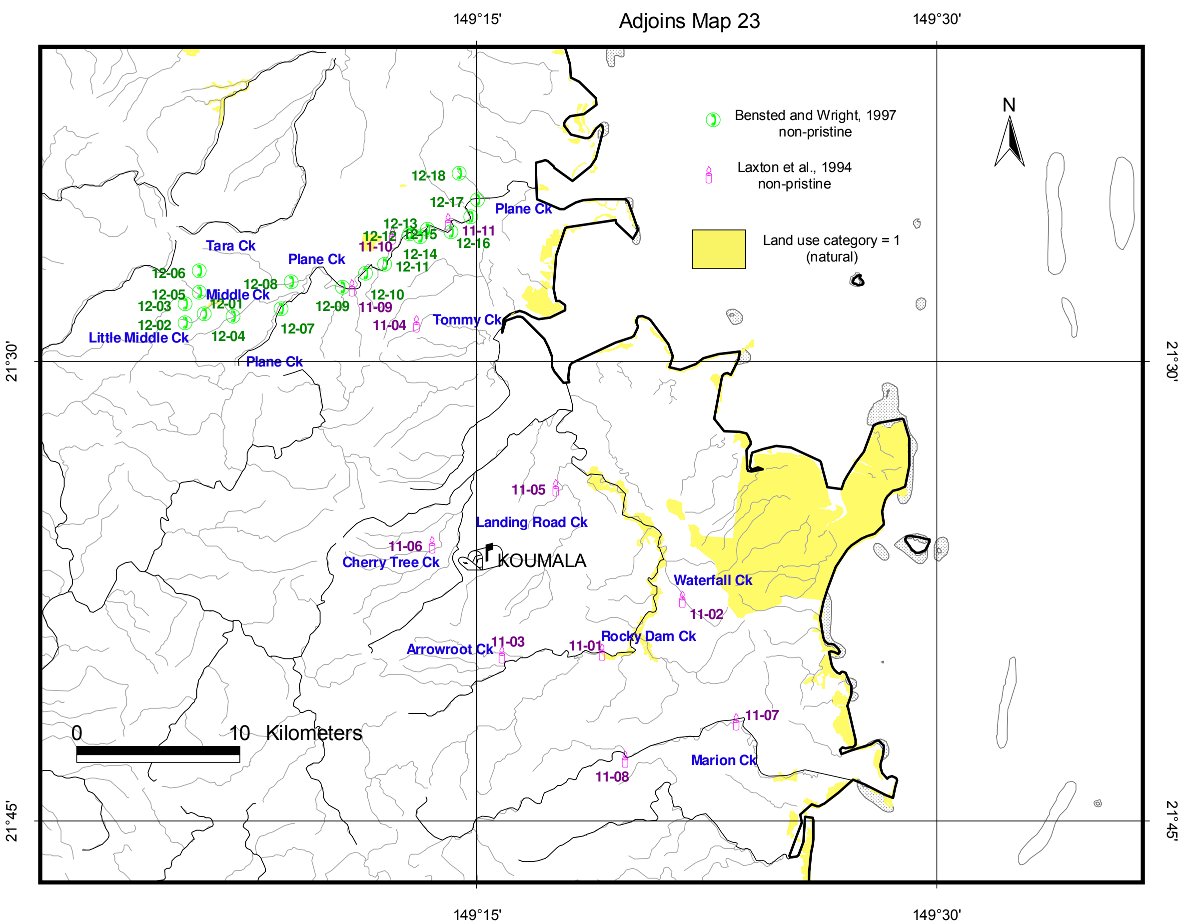
Map 21: Sampling sites from the Palm Islands area



Map 22: Sampling sites in the Airlie Beach area



Map 23: Sampling sites in the Mackay area



Map 24: Sampling sites in the Koumala area

3.3.1 [Set 1] Butler *et al*., 1996 study

This study investigated the relationships between stream-based ecotourism and environmental quality in the Wet Tropics of Queensland. The water quality immediately upstream and downstream of popular swimming holes was measured at regular times through the day for a number of days, during which times the visitor numbers and their activities were monitored. Ten study sites in relatively pristine waterways, from the Mossman River, south to Crystal Creek (Maps 13, 16, 20 and 21), were investigated. There was frequently little distance between upstream and downstream sampling locations, so for this summary, all samples are combined for five broad sites. Land use above each of the five sites to the head of its subcatchment was calculated on a percentage-area basis (Table 6). The data are summarised in Appendix 1 and graphically compared in Figure 1.

Table 6. Land use for each sample site in the Butler, *et al*., 1996 study, calculated to the top of the stream catchment and expressed as a percentage of the whole area.

Note that percentage areas of the three categories of "Crop/Hort" (cropping and horticulture), "Animal P" (animal production) and "Urban" (urban uses) are added together for the classification of 'intensive' land use. This practice is followed for all subsequent land-use tables.

Site_name	Site	Natural	Forestry	Grazing	Crop/Hort	Animal P	Urban	Classification
01-05	Mossman R	99.99%					0.01%	Pristine
01-04	The Boulders	100.00%						Pristine
01-03	Five Mile Ck	99.96%	0.04%					Pristine
01-01	Crystal Ck	99.69%	0.20%	0.11%				Pristine
01-02	L. Crystal Ck	100.00%						Pristine

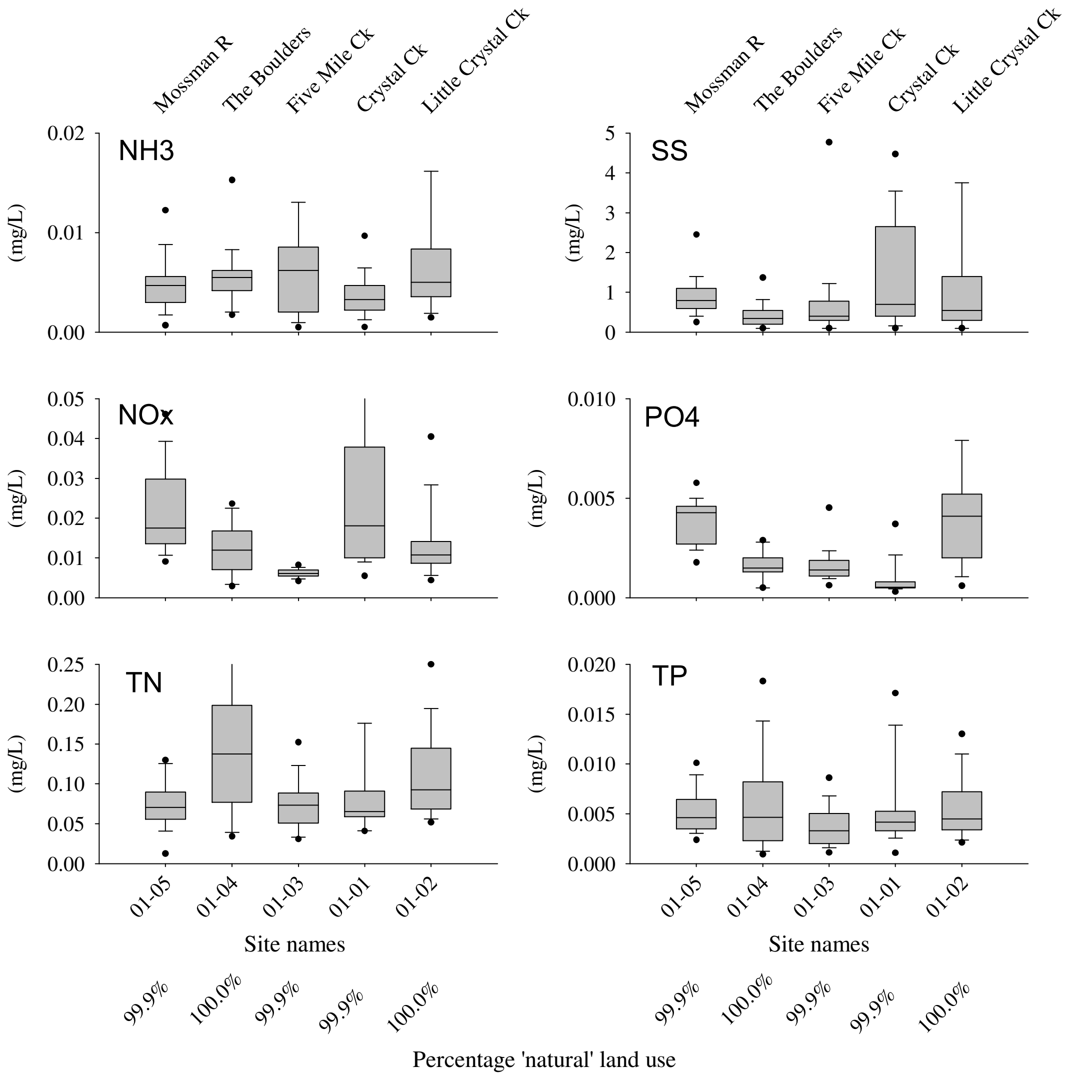


Figure 1. Box plots of N and P forms calculated from Butler *et al*. (1996) study.

NOTE ON BOX PLOT FORMAT:

Box plots graph data as a box representing statistical values. The boundary of the grey box closest to zero indicates the 25th percentile, the line within the box marks the median, and the value of the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. Closed circles above and below these represent 95th and 5th percentiles.

3.3.2 [Set 2] Bramley and Muller, 1999 study

This study was part of a CSIRO Coastal Zone program to quantify the effects of rural land use in the freshwater and near-shore zones (Bramley and Muller, 1999). Of the 37 sites sampled by CSIRO in the Herbert River basin, 7 near-pristine sites were selected for investigation in the present analysis, as having >50% estimated rainforest area in their upstream subcatchment (Maps 20 and 21). This land use mapping was constructed in 1992 (Perry, 1993 in Bramley and Muller). However, for consistency with other dataset comparisons (see **3.2.1**), the QLUMP land use GIS was used as before to calculate percentage areas of natural and other land use (Table 7). Two sites, Waterview Creek at Jourama and also at the Bruce Highway were identified as 'pristine', while Bollocky Toms Creek and Crystal Creek at the Bruce Highway were considered 'near pristine' (though slightly outside of the strict definition). As in the former section, the data are summarized in Appendix 2 and graphically compared in Figure 2.

Table 7. Land use in the Herbert River region (Bramley and Muller, 1999 study) expressed as a percentage of each stream subcatchment area, from the sampling site upstream to its headwaters. Land use for sites in Bullocky Toms Creek and Crystal Creek was taken from Bramley and Muller (1999), reconstructed from Perry (1993). Land use for all other sites was determined from the Land Use Mapping at Catchment Scale GIS, 2002.

Site_name	Stream	Natural	Forestry	Grazing	Crop/Hort	Animal	Urban	Classification
02-04	Waterview Ck (J)	99.82%	0.18%					Pristine
02-03	Hawkins Ck	93.19%		1.79%	4.71%		0.31%	Disturbed
02-07	Bollocky Toms Ck	97.38%			2.62%			Near-pristine*
02-06	Crystal Ck (H)	94.07%	0.04%	3.10%	2.38%		0.42%	Near-pristine*
02-01	Gowrie Ck	84.93%	0.46%	4.46%	10.15%			Disturbed
02-02	Elphinstone C	60.07%	18.45%	2.30%	19.18%		0.00%	Disturbed
02-05	Waterview (H)	98.52%	0.15%	1.21%	0.12%			Pristine

* Note – Cropping/Horticulture close to 'Near-pristine' condition definition (see 3.2.2), <15% grazing, <2% intensive + urban.

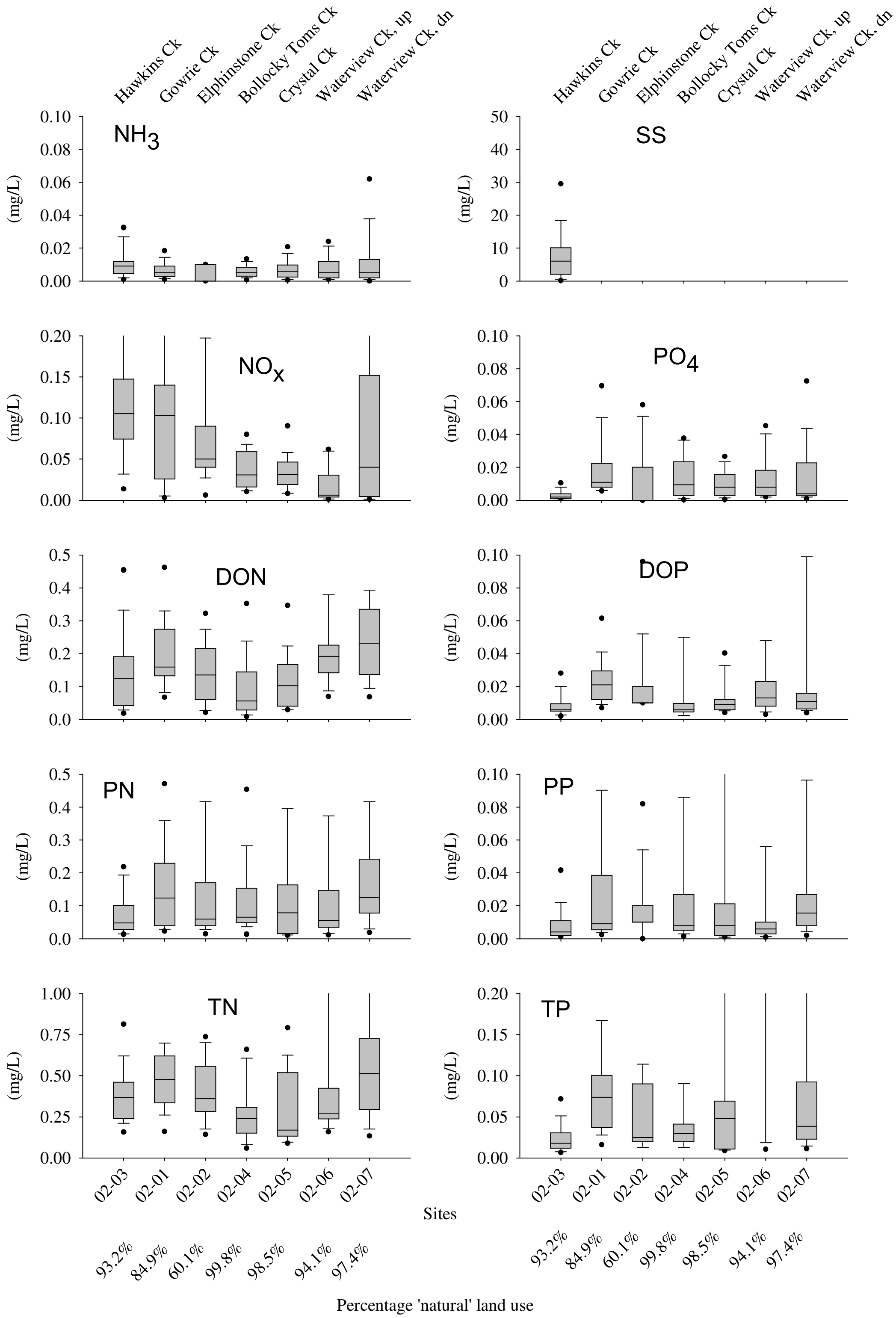


Figure 2. Box plots of N and P forms derived from the Bramley and Muller (1999) study. (See Note on box plot format, Figure 1).

3.3.3 [Set 3] Pearson and Clayton, 1993 (Teemburra Creek area study)

This report was produced for the Queensland Water Resources Commission and described the findings of various environmental surveys in the Teemburra Creek area, aimed to assess possible impacts of the proposed Teemburra Creek Dam. The study area included the proposed impoundment area and the streams downstream of the impoundment. The study timing included exceptionally dry conditions (Aug-Oct, 1992) and above-average summer rainfall conditions (Feb, 1993). All sites sampled were reviewed for land use (Table 8), with no sites identified as pristine. The nutrient data are graphically compared in Figure 3 and statistically summarised in Appendix 3.

.

Table 8. Land use in the Teemburra Dam area (Pearson and Clayton, 1993), calculated to the top of the stream catchment and expressed as a percentage of the whole area.

Site_name	Stream	Site	Natural	Forestry	Grazing	Crop/Hort	Animal	Human	Classification
03-06	Cattle Ck	7	14.05%	6.24%	20.56%	58.50%		0.65%	Disturbed
03-07	Cattle Ck	8	66.34%	4.91%	8.49%	18.33%	1.06%	0.87%	Disturbed
03-12	Palmtree Ck	6	9.78%	60.14%	30.08%				Disturbed
03-09	Teemburra Ck	10	7.14%	51.03%	41.72%	0.11%			Disturbed
03-03	Teemburra Ck	3	86.92%	13.08%					Disturbed
03-11	Blacks Ck/Teem.	12	19.80%	66.39%	13.80%				Disturbed
03-08	Blacks Ck	9	55.52%	4.37%	10.33%	28.11%	0.85%	0.82%	Disturbed
03-01	Up. Teemburra Ck	1	6.09%	93.91%					Disturbed
03-05	Upper Middle Ck	5	26.60%	72.17%	1.23%				Disturbed
03-02	Teemburra Ck	2		100.00%					Disturbed
03-04	Endeavour Ck	4		89.21%	10.79%				Disturbed

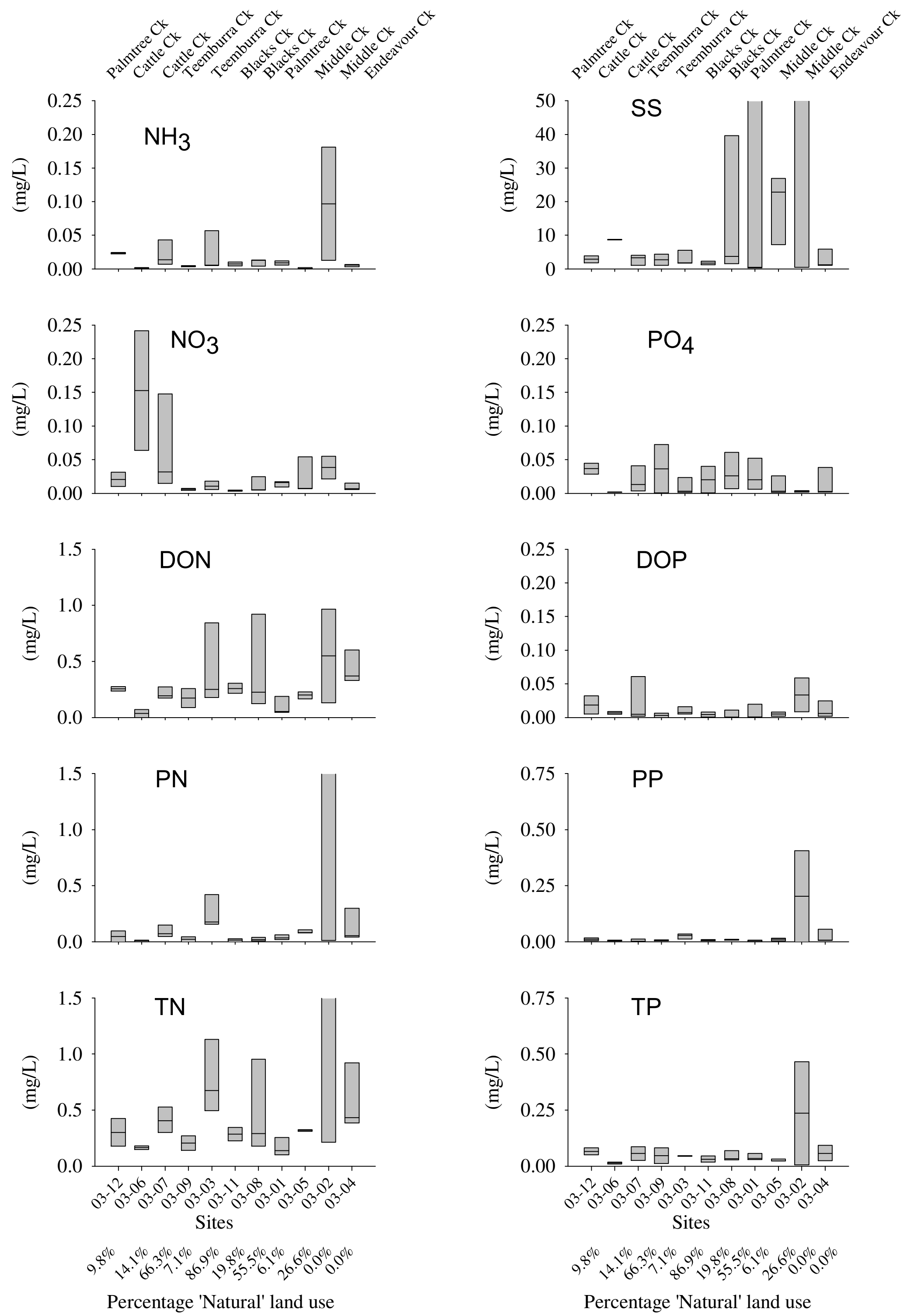


Figure 3: Box plots of N and P forms, plus suspended solids derived from the Pearson and Clayton (1993) study in the Teemburra Dam area. (See Note on box plot format, Figure 1; note also that due to low sample numbers [n=2 or 3], no outlyers are shown).

3.3.4 [Set 4] Pearson and Penridge, 1992 study (Wet Tropics).

The Northern Rivers Survey (NRS) was instituted from 1976-1977 in order to provide information to the sugar industry on the effects of sugar mill effluents on stream water quality. The survey involved northern streams from the Daintree River down to the Herbert River, but also two creeks north and south of Mackay. Ammonia, nitrate and phosphate were measured, along with suspended solids, dissolved oxygen, conductivity and other parameters. Sites along streams in the Daintree, Mossman, Russell-Mulgrave and Johnstone River systems were investigated for their levels of upstream 'natural' land use condition (Table 9). Two upstream sites in the Daintree and North Mossman Rivers were found to have 'near-pristine' upstream catchments. Sites in the Herbert River and Reliance, Amhurst and Bakers Creeks were considered not to have pristine catchments. The data are summarised in Appendix 4 and graphically compared via box plots in Figure 4. Note that the Mulgrave R sites, that were sampled once only, were not plotted.

Table 9. Land use of the Northern Rivers Survey by Pearson and Penridge (1992).

Site_name	Stream	Site	Natural	Forestry	Grazing	Crop/Hort	Animal P	Human	Classification
04-01	Daintree R	dr3	49.41%	48.26%	2.30%			0.02%	Near-pristine*
04-02	Daintree R	dr2	54.96%	41.74%	3.26%			0.04%	Near-pristine*
04-03	Daintree R	dr1	55.82%	39.85%	3.80%	0.33%		0.20%	Near-pristine*
04-04	S Mossman R	sm3	79.20%		1.04%	18.13%		1.64%	Disturbed
04-05	S Mossman R	sm4	76.83%		0.97%	19.59%		2.61%	Disturbed
04-06	N Mossman R	nm1	84.08%		0.44%	13.52%		1.96%	Disturbed
04-07	N Mossman R	nm2	96.50%			2.89%		0.61%	Disturbed
04-08	Mulgrave R	mg4	86.94%	0.64%	3.85%	6,05%	1.48%	1.48%	Disturbed
04-09	Mulgrave R	mg3	87.97%	0.66%	3.95%	4.82%	1.53%	1.53%	Disturbed
04-10	Mulgrave R	mg2	89.86%	0.68%	4.07%	2.76%	1.58%	1.58%	Disturbed
04-11	Mulgrave R	mg1	90.51%	0.68%	4.11%	2.45%	1.59%	1.59%	Disturbed
04-12	Russell R	rr3	70.23%	0.18%	5.25%	23.33%	0.34%	0.67%	Disturbed
04-13	Russell R	rr2	70.96%	0.09%	5.33%	22.57%	0.36%	0.69%	Disturbed
04-14	Russell R	rr1	77.29%	0.05%	5.41%	16.41%	0.63%	0.22%	Disturbed
04-15	Babinda Ck	bc5	79.04%	0.20%	1.16%	17.60%		2.00%	Disturbed
04-16	Babinda Ck	bc4	82.57%	0.18%	1.23%	14.94%		1.08%	Disturbed
04-17	N Johnstone R	nj4	51.81%	0.12%	19.64%	5.72%	21.41%	1.30%	Disturbed
04-18	N Johnstone R	nj3	51.21%	0.11%	19.94%	6.89%	20.55%	1.30%	Disturbed
04-19	N Johnstone R	nj2	50.06%	0.12%	19.67%	8.92%	19.91%	1.33%	Disturbed
04-20	N Johnstone R	nj1	49.77%	0.11%	19.41%	9.74%	19.58%	1.38%	Disturbed

* Note: Well outside of 'Near-pristine' definition, but since 1988, a World Heritage Area, largely historical production from native forests, minimal grazing and no intensive land use.

The Daintree River sites were tentatively allowed to be classified as near-pristine, due to the relatively undisturbed nature of this catchment after WHA legislation. However, it was recognised that during the time of sampling (1976-1977), this catchment was being logged. A review of this classification will be made later.

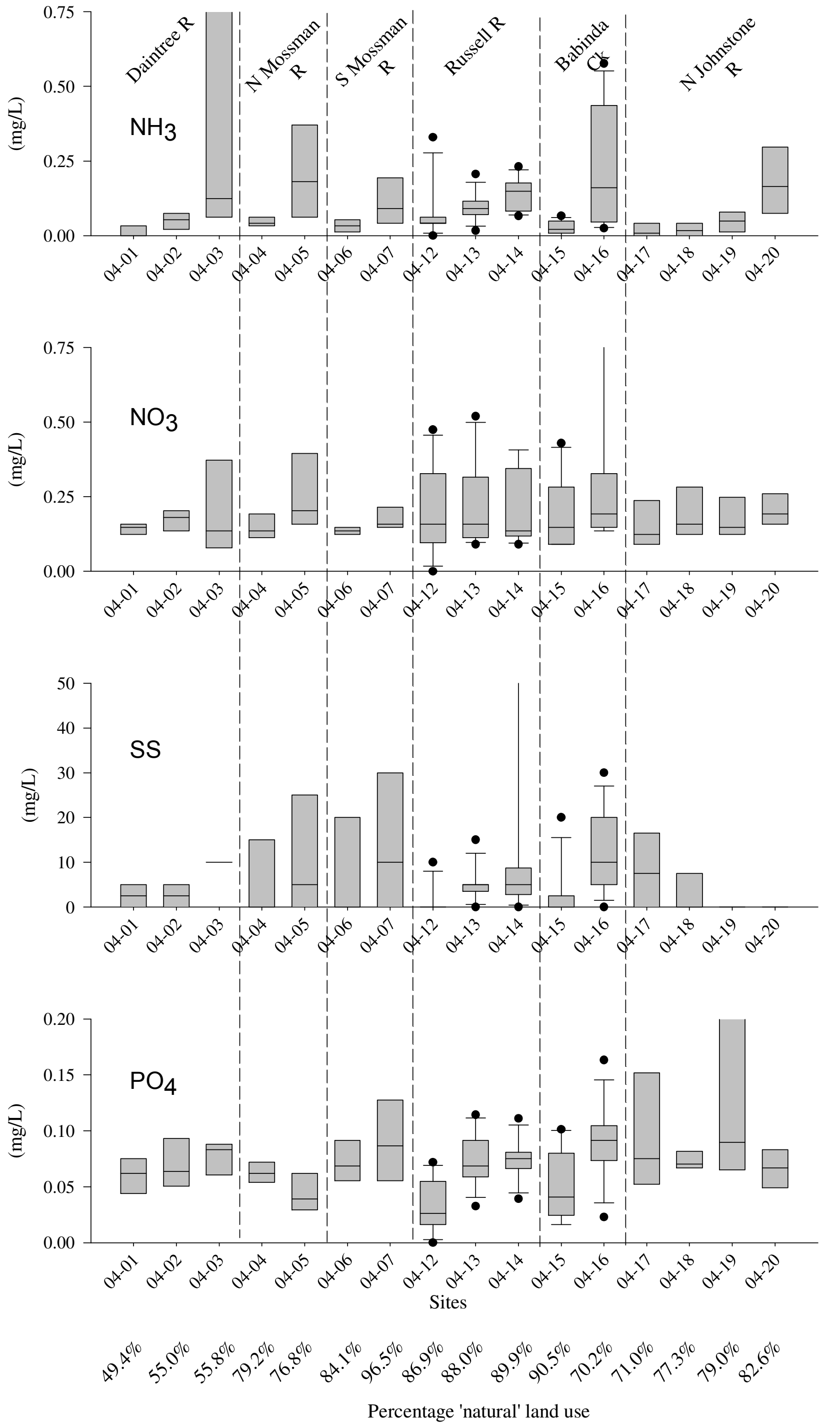


Figure 4: Box plots of N and P forms, plus suspended solids, derived from the Pearson and Penridge (1992) study. (See Note on box plot format, Figure 1; note also that due to low sample numbers [n = 4] for some sites, no outlyer percentiles are shown).

3.3.5 [Set 5] Hydroelectric Scheme Studies, Tully Millstream dam area

[Set 5a] HEC dataset, unpublished; sampling through 1989-1991

[Set 5b] Faithful and Brodie, 1990; ACTFR sampling through 1990

Two separate limnological studies were undertaken in the Tully-Millstream catchment area as preliminary work towards the construction of the Tully-Millstream Hydroelectric Scheme. The first (Set 5a), commencing in 1989, continuing through 1991 was initiated by the Hydroelectric Commission. The second study (Set 5b), commissioned by Environment Sciences and Services Consultants sampled some of the same sites, but other different ones as well.

Basic water quality parameters were measured along with sampling for the nutrients ammonia, nitrate, phosphate and Total N and P. Both sample sets were analysed by ACTFR. Sites in extreme situations, such as a site at the outfall from sewerage (Set 5b) and two sites within the Koombooloomba Dam (Set 5a) were excluded. Three superfluous sites along Millstream River, in grazing country and only sampled in Set 5a were also excluded. Land use at each site is listed in Table 10, while the data statistics are summarised in Appendix 5. The data are further graphically compared in Figure 5.

Table 10. [Sets 5 a&b] Land use of the Tully-Millstream survey by Faithful and Brodie (1990).

Code_nam	Code	Site	Set	Stream	Natural	Forestry	Grazing	Crop/Hort	Animal	Human	Classification
05-09	km1	1	a	Koolmoon Ck	100.00%						Pristine
05-08	km2	2	a,b	Koolmoon Ck	100.00%						Pristine
05-07	km3	3	a	Koolmoon Ck	99.90%	0.10%					Pristine
05-06	km4	4	a	Koolmoon Ck	99.91%	0.09%					Pristine
05-16	mc1	5	a	Muggera Ck	100.00%						Pristine
05-01	tr1	6	a,b	Tully R	100.00%						Pristine
05-02	tr2	7	a	Tully R	100.00%						Pristine
05-03	tr5	8	a	Tully R	97.84%					2.16%	Near-pristine
05-04	tr7	11	a	Tully R	91.41%	7.82%	0.74%			0.03%	Near-pristine
05-05	tr8	9	a,b	Tully R	92.90%	4.94%	1.29%	0.19%	0.67%	0.02%	Near-pristine
05-27		7b	b	Tully R	93.49%		4.58%	1.92%		0.01%	Near-pristine
05-26		3	b	Nitchaga Ck	95.59%		0.68%		3.72%		Near-pristine
05-23	ms1	10	a	Millstream R	25.07%	19.57%	30.28%	4.78%	19.64%	0.66%	Disturbed
05-14	bl2	12	a	Blunder Ck	61.77%		37.92%			0.32%	Disturbed
05-19	ms4	13	a,b	Millstream R	0.00%		24.21%	13.78%	62.01%		Disturbed
05-21	ms2	14	a	Millstream R	23.87%	30.74%	24.97%	3.65%	15.35%	1.42%	Disturbed
05-15	bl1	15	a	Blunder Ck	69.48%		29.81%			0.72%	Disturbed
05-20	ms5	16	a,b	Millstream R	25.08%	23.71%	23.67%	3.59%	19.99%	3.96%*	Disturbed
05-12	ms8	17	a	Millstream R	26.91%	26.91%	22.07%	3.04%	16.09%	4.88%*	Disturbed
05-13	bl5	18	a,b	Blunder Ck	36.20%	4.48%	59.18%			0.14%	Disturbed
05-25	bl6	19	a	Blunder Ck	20.96%	2.33%	76.57%	0.07%		0.07%	Disturbed
05-10	ms12	20	a,b	Millstream R	35.81%	24.64%	20.49%	2.12%	10.69%	6.24%*	Disturbed
05-28	ms3	8b	b	North Cedar Ck	38.95%	8.94%	15.08%		31.30%	5.73%	Disturbed
05-24	ms13	21	a,b	Millstream R	34.01%	23.33%	23.95%	2.01%	10.12%	6.58%*	Disturbed
05-11	ms9	22	a	Millstream R	64.93%	15.87%	12.56%	0.47%		6.17%	Disturbed

Note: * Sewerage inputs noted.

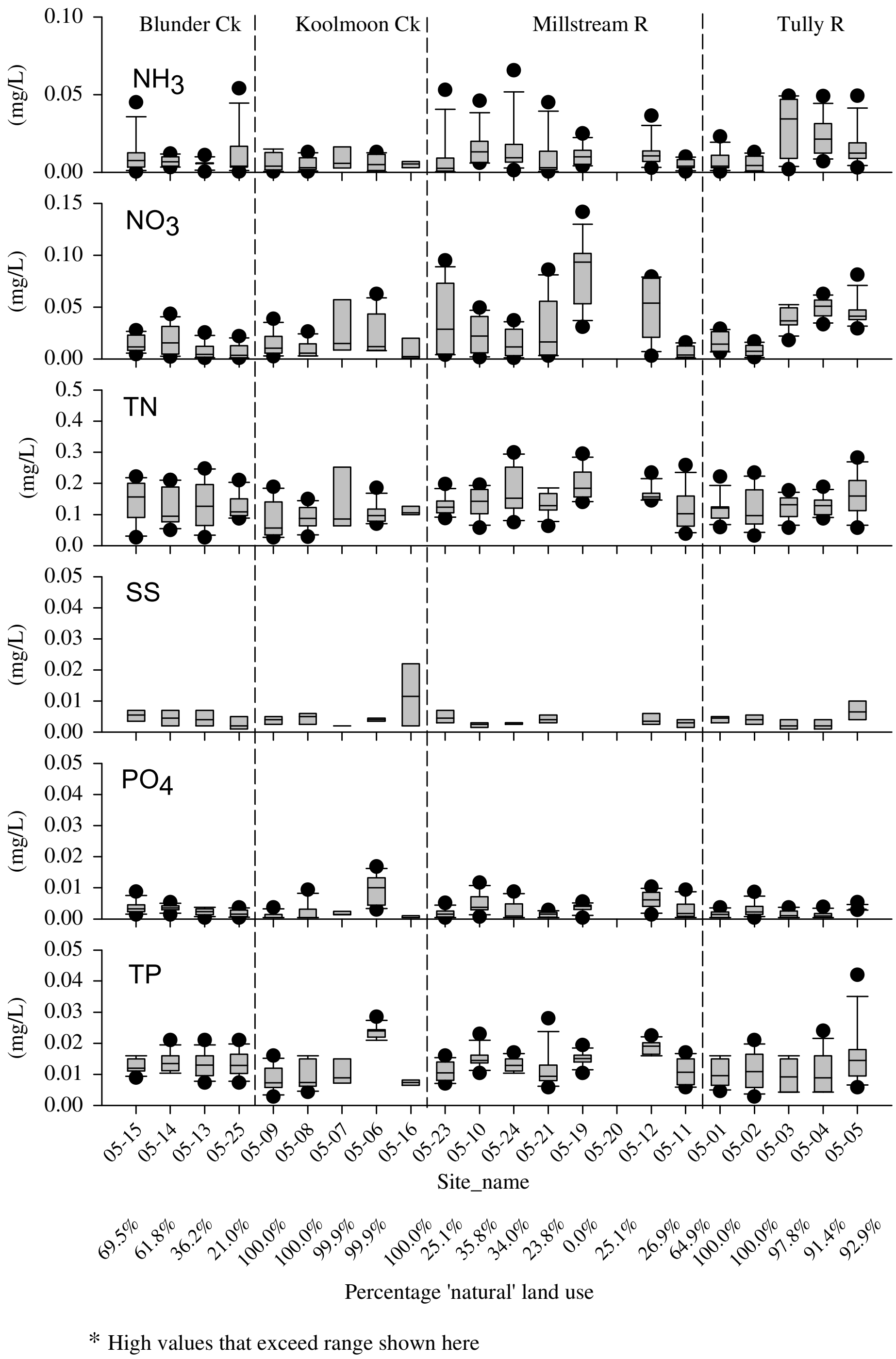


Figure 5: Box plots of N and P forms, derived from the Faithful and Brodie (1990) study. (See Note on box plot format, Figure 1; note also that low sample numbers [n = 6-8], actual outlyers rather than the 95th and 5th percentile values are shown in this graph).

3.3.6 [Set 6] White *et al*., 2002 (Healthy Waterways program, Pioneer River catchment).

The Healthy Waterways program was an initiative of the Mackay-Whitsunday regional Strategy Group to address water quality issues in this region. An attempt was made to monitor the first high-flow event of the 2001-2002 wet season in order to understand water quality in the Pioneer River catchment under wet-season flow conditions. Physical and chemical parameters were measured through this event at two sites, Finch Hatton Creek, representing the mostly undisturbed upper catchment and at Dumbleton Weir on the Pioneer River, in the lower catchment. Land use estimates for the two sites are given in Table 11. Data statistics are provided for different flow conditions in Appendix 6 and are summarised in Figure 6.

Table 11. Land use in the Pioneer River area (White *et al*., 2002), calculated to the top of the stream catchment and expressed as a percentage of the whole area.

Site_name	Stream	Site	Natural	Forestry	Grazing	Crop/Hort	Animal	Human	Classification
06-01	Finch Hatton Ck	1	78.84%		12.63%	1.52%	4.34%	2.66%	Disturbed*
06-02	Dumbleton Weir	2	20.48%	23.87%	33.16%	21.66%	0.18%	0.65%	Disturbed*

* Note – Samples taken during flow event.

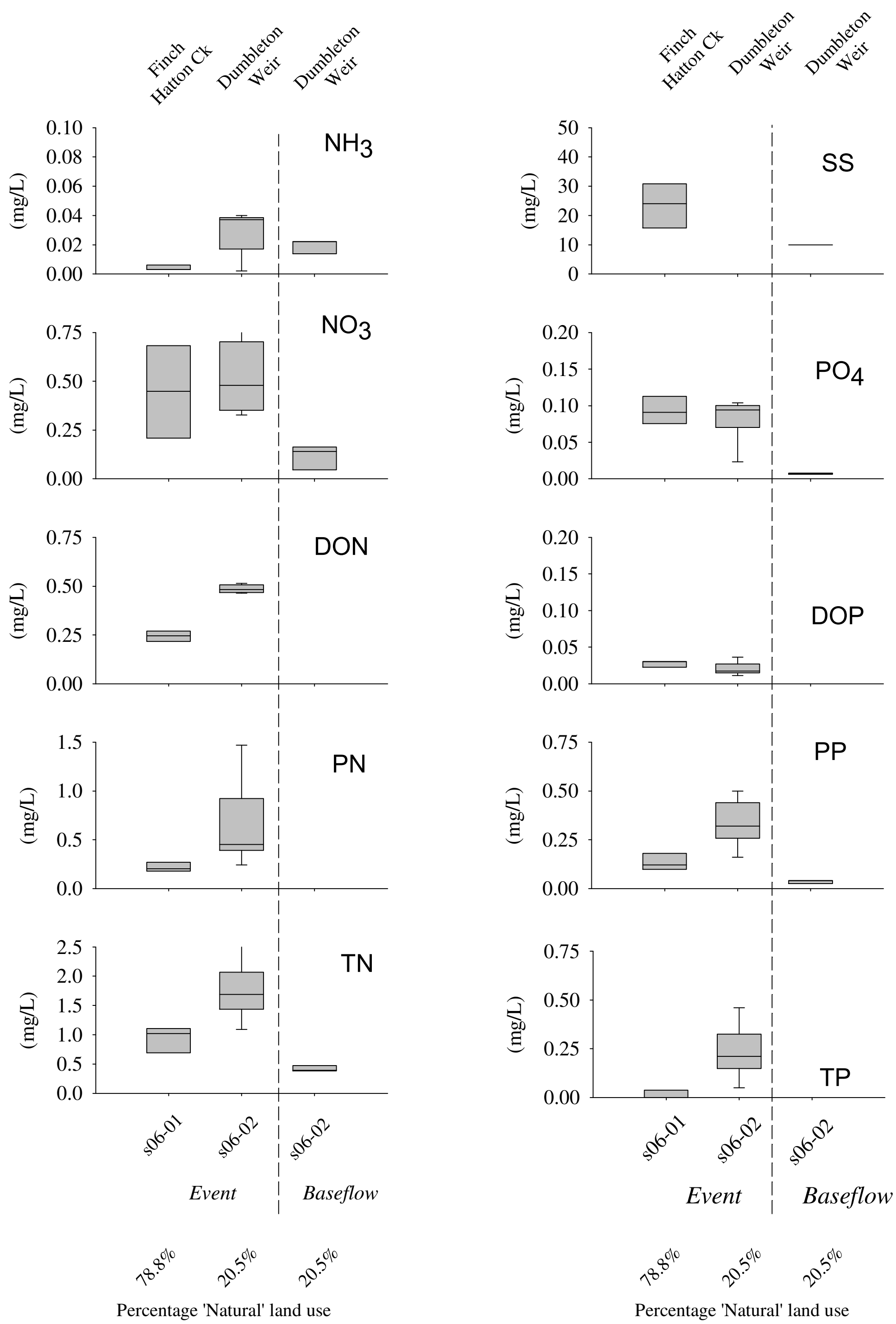


Figure 6: Box plots of N and P forms, with suspended solids from two sites in the Pioneer River catchment during event and base-flow conditions (White *et al.*, 2002 program). (See Note on box plot format, Figure 1; note also that due to low sample numbers [n = 3-5], no outlyer percentiles are shown)

3.3.7 [Set 7] Faithful and Butler, 1994. Lake Proserpine.

In 1991, ACTFR was commissioned by DPI to carry out an intensive, short-term baseline study of water quality in Lake Proserpine, soon after completion of the Peter Faust Dam that formed this storage reservoir. The reservoir was almost completely filled by the record rains generated by Cyclone Joy in the first few months of 1991. Pre and post wet-seasonal samples (Sep 1992 and Mar 1993) were taken to provide indications of likely seasonal extremes.

Somewhat mixed results were seen in the nutrient levels, with generally higher post wet-season concentrations in N forms, but lower post wet-season levels of P forms. However, for the scope of the present comparison, lake samples were not considered comparable to other samples from stream-sites and no use was made of this data set.

3.3.8 [Set 8] Pearson *et al.*, 2003. ACTFR/SRDC (Lower Herbert).

This study examined the effects of cane-field drainage on tropical waterways, so it was considered unlikely that any pristine sites were included in the data set. Hence, no analysis was made.

3.3.9 [Set 9] Burrows and Faithful, 2003. Townsville Field Training Area (TFTA), Ecological Monitoring, Nov 2002-June 2003. ACTFR Report 03/12. (Upper Townsville).

The Department of Defence commissioned ACTFR to conduct a joint monitoring exercise with CSIRO (Davies Laboratory, Townsville) of the Townsville Field Training Area to establish natural baseline levels in a range of ecological parameters. Aquatic monitoring concentrated on the ecology and water quality of local streams and permanent waterholes. Three sites in each of three systems, the Star River, Keelbottom Creek and Fanning River were sampled in the lead-up to the wet-season (Nov-Dec 2002) and in the dry-season (Apr-Jun 2003).

Four sites were considered likely to be pristine (s1, s2 and s4 in the Star River catchment and s6 in the Keelbottom Creek catchment) and two sites were considered likely to be near-pristine (s25 and s8 in the Keelbottom Creek catchment). Unfortunately, this area had not been included in the 1999 GIS survey, so no objective definition of land use in this area could be made. No analyses of these data were included in this report.

3.3.10 [Set 10] Faithful, 2002. Townsville/Burdekin (2001-2002).

No pristine sites.

3.3.11 [Set 11] Ecology of creeks in the Sarina and Broadsound shires, Central Queensland (1989-1993); Part1, water quality. Laxton *et al*., 1994. Private Research Paper, Part 1

In 1989, a four-year study of five creek systems in the Sarina and Broadsound shires was commenced, as a baseline survey of existing water quality conditions. Thirteen sites were sampled between 1989-1993. All but two sites (downstream, estuarine?) were investigated here for possible pristine status, though none were found – see land use at 11 sites in Table 12 below. A statistical summary of the Laxton *et al*. (1994) data set is provided in Appendix 7.

Table 12: Land use in the Sarina and Broadsound shires (Laxton *et al*., 1994)

Site_nam	Stream	Site	Natural	Forestry	Grazing	Crop/Hort	Animal P	Human	Classification
11-01	Cone Ck	1		12.94%	55.99%	31.07%			Disturbed
11-02	Waterfall Ck	2	7.81%		92.19%				Disturbed
11-03	Arrowroot Ck	3		21.75%	37.72%	40.54%			Disturbed
11-04	Tommy Ck	4		5.47%	91.24%	3.13%		0.16%	Disturbed
11-05	Landing Road Ck	5		12.40%	45.78%	40.69%	0.62%	0.52%	Disturbed
11-06	Cherry Tree Ck	6		70.00%	29.77%	0.23%			Disturbed
11-07	Marion Ck	7		19.18%	76.34%	4.26%		0.23%	Disturbed
11-08	Marion Ck	8		29.93%	70.07%				Disturbed
11-09	Plane Ck	9	0.16%	0.70%	81.69%	14.21%	0.63%	2.61%	Disturbed
11-10	Plane Ck	10	1.04%	0.59%	80.61%	14.14%	0.53%	3.09%	Disturbed
11-11	Plane Ck	11	0.96%	0.55%	77.28%	14.93%	0.50%	5.78%	Disturbed

There were no pristine sites seen in this data set. Grazing was found to be the dominant land use with significant cropping (mainly sugarcane) in the Plane Creek catchment. The data are summarised by box plots in Figure 7. *Note: Even though this data set contained no pristine sites, the data here have been included for comparative interest.*

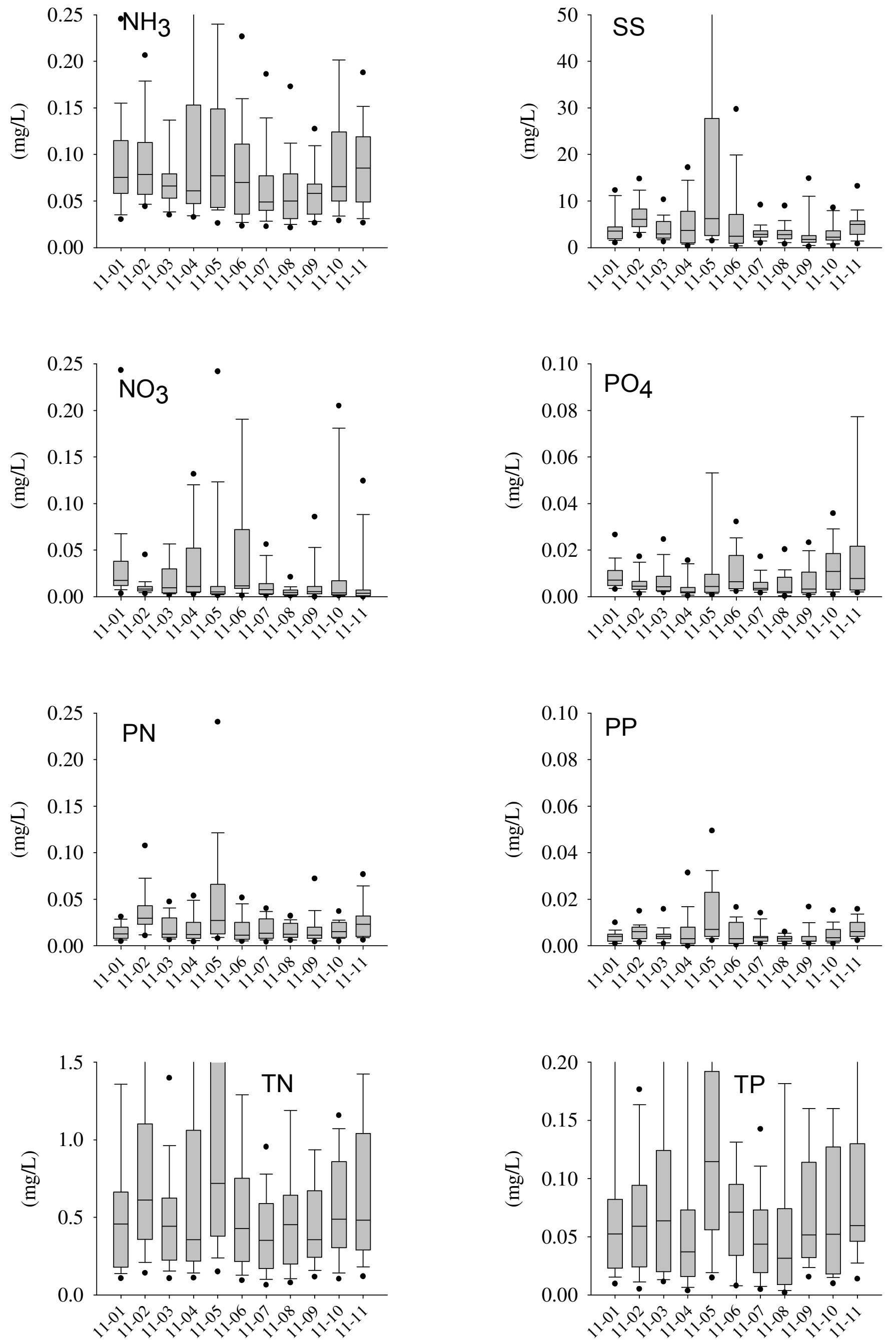


Figure 7: Box plots of N and P forms, plus suspended solids in the Plane Creek area from the Laxton *et al*. (1994) study. As very small areas of 'natural' land use were found in these catchments, no ordering of sites by land use was made. (See Note on box plot format, Figure 1).

3.3.12 [Set 12] Bensted and Wright, 1997. Waterwatch Report on sampling in the Plane Creek catchment, Nov 1995-Jun 1997.

This study was conducted by the Sarina Waterwatch group, following publication of the report on this catchment by Laxton *et al*. (1994). A GIS survey of land use throughout the entire Plane Creek catchment showed no sites with pristine upper catchments. Hence, no analyses were made of this data set.

3.3.13 Set 13] Mitchell and Wright, in press. A scientific review of Waterwatch FNQ. Large number of sites sampled throughout the Wet Tropics area.

This comprehensive data set was compiled by Waterwatch FNQ volunteers from 1995-2001in catchments throughout the Wet Tropics ranging from the Daintree River south to the Herbert River. It represents the largest single collection of water quality data from small streams of the Wet Tropics. However, in a recent, as yet unpublished review (Mitchell and Wright), nitrate was found to be the only validated nutrient measure, so only the nitrate data were considered here. The list of sites that were selected for land use evaluation represented those that appeared to lie within or near pristine areas, plus downstream sites in some of these stream sub-catchments for comparison. In general, the most upstream site or two along each stream transect were selected for land use evaluation. Many sites that were clearly outside of 'pristine' areas were excluded from this summary, along with those areas not covered by the QLUMP GIS database (Upper Mitchell, Walsh River, Mt Morgan area), aquatic (freshwater wetland) and drain sites. In total, 122 out of 286 sampled sites were evaluated, with 58 sites found to have pristine or near-pristine land use in their upstream sub-catchments.

However, the Waterwatch FNQ data set of nitrate values should be considered cautiously. Despite reasonable validation of the HACH colorimeter method, some doubts remain about the consistency of these volunteer-derived results. Furthermore, the limit of detection using this instrument was determined to be around 0.03mg/L for nitrate-N (Mitchell and Wright, In Press). Given that this detection limit is somewhat high relative to many 'pristine-level' nitrate values reviewed here, it was decided not to detail land use and box-plot trends until an overall evaluation was made. The statistics for all the nitrate samples from the 58 sites determined to have pristine and near-pristine land use are given in Table 13, below.

Table 13: Statistics for nitrate (NO_X) values from all Waterwatch FNQ samples (as mg/L N)

Statistic	Pristine sites	Near-pristine sites
Number of samples (n)	285	92
Average	0.060	0.082
Median	0.050	0.060
Minimum	0.000	0.000
Maximum	0.400	0.550

3.13.14 [Set 14] AIMS/BSES data set; Furnas *et al*., 2001

In the mid 1980s, the Australian Institute of Marine Science (AIMS) began compiling runoff information towards a nutrient budget for the GBR shelf to help understand N and P cycling in this ecosystem. At that time, AIMS quickly discovered a paucity of good data on nutrient levels in the rivers of tropical Queensland, particularly during wet-season flows when most transport to the shelf occurs. In 1987, AIMS persuaded local agencies and individuals to commence water sampling in the major river systems of north Queensland, in order to obtain reliable wet-season loads of nutrient and suspended sediment to the GBR shelf. Most of this sampling was carried out at downstream, freshwater site (end of pipe) locations, unsuitable for the present survey of pristine levels. However, upstream sites on the Tully River and in the Jarra and Boulder Creek tributaries were sampled over a long-term period (1989-2000) by a collaborative agency, BSES - Tully office (Furnas *et al*. 2001).

Data here is presented from these streams. Land use above the three upstream sites, from the QLUMP GIS is listed in Table 14. The data are summarised graphically as box plots in Figure 8 and statistically in Appendix 8.

Table 14: Land use of the Tully area pristine sites from the AIMS/BSES river sampling program (Furnas *et al*., 2001).

Site_name	Stream	Natural	Forest	Grazing	Crop/Hort	Animal P	Human	Classification
14-03	Boulder Ck	99.05%			0.69%		0.25%	Pristine
14-02	Jarra Ck	100.00%						Pristine
14-01	Upper Tully R	93.49%		4.58%	1.92%			Near-Pristine

All three sites were found to be dominated by pristine (Jarra Ck, Boulder Ck) or near-pristine (Upper Tully R) areas in their upstream catchments.

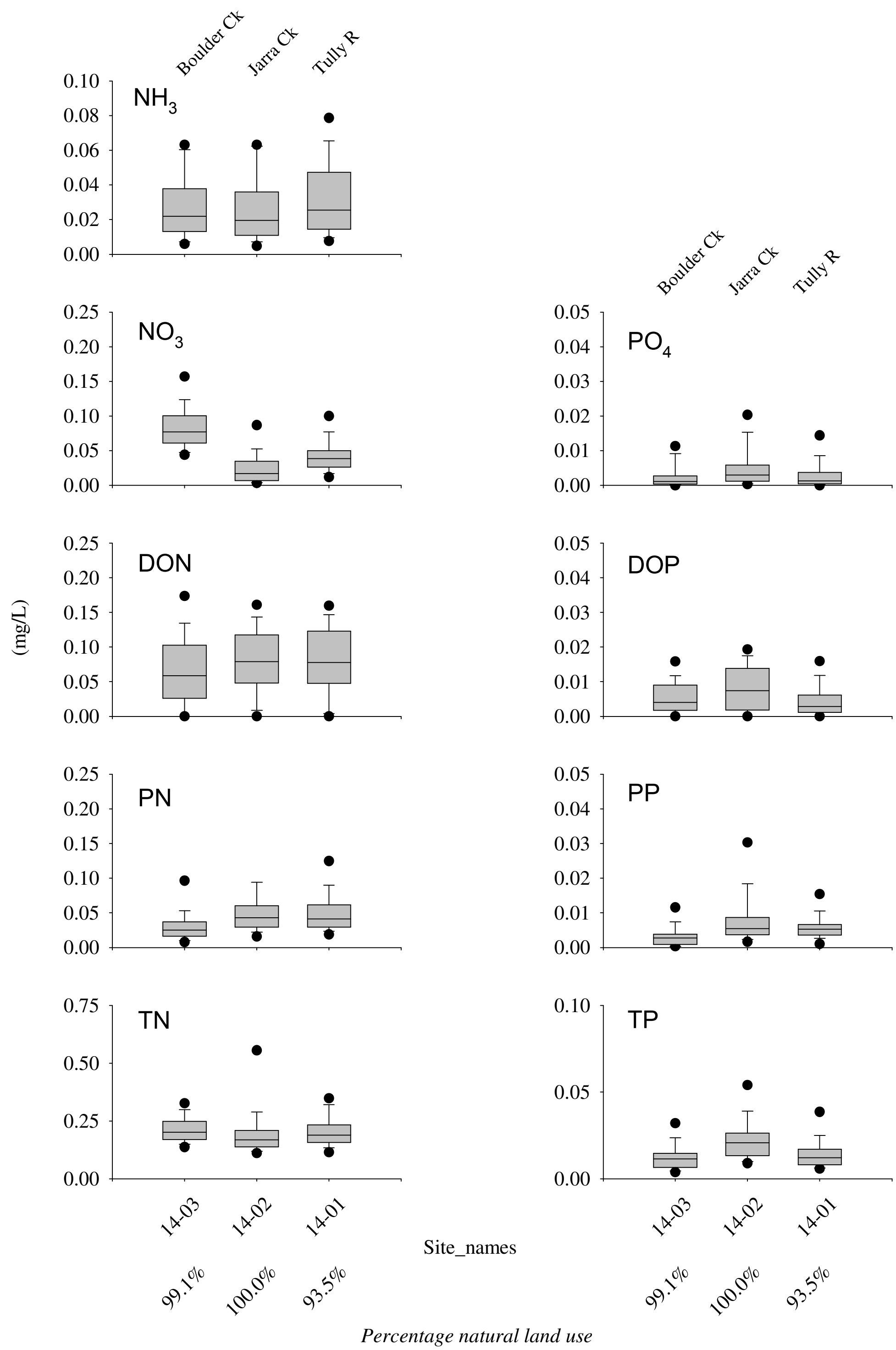


Figure 8: Box plots of N and P forms from the AIMS/BSES sampling program (Furnas *et al.*, 2001). (See Note on box plot format, Figure 1).

3.3.15 [Set 15a] Waterwatch, Pioneer Catchment Report No. 1. Wright (1996). [Set 15b] Waterwatch, Pioneer Catchment Report No. 2. Wright (1998).

These two reports detail sampling results from sites within the Pioneer River catchment between 1994-1996 (15a) and 1996-1998 (15b). Nitrate and phosphate were the only nutrients measured. Since the choice of sampling sites differed somewhat between the two data sets, they have been assessed separately here. In the first set, land use evaluation for pristine areas was only done for the five upstream sites (out of 11 sites) – see Table 15. In the second set, all sites within the Pioneer River catchment and the adjoining St Helens Creek catchment were evaluated for interest, even though the downstream sites were clearly out of pristine land use areas – see Table 16. Most site locations varied between the two data sets, but two were the same (Site 4 [15a-04] = p3 [15b-03]; Site 3 [15a-03] = p1 [15b-01]). Data statistics are summarised in Appendix 9 (15a) and Appendix 10 (15b) and the data graphed as box plots in Figure 9 (15a) and Figure 10 (15b).

Table 15: Land use for sites sampled by Waterwatch in the Pioneer River catchment from 1994-1996 (Wright, 1996).

Site_name	Stream	Site	Natural	Forestry	Grazing	Crop/Hort	Animal P	Human	Classification
15a-01	Cattle Ck	1	87.43%		2.51%	9.86%	0.12%	0.09%	Disturbed
15a-02	Palm Ck	2	99.83%					0.17%	Pristine
15a-03	Finch Hatton Ck	3	100.00%						Pristine
15a-04	Cattle Ck	4	71.57%	5.72%	4.91%	16.87%	0.69%	0.24%	Disturbed
15a-05	Cattle Ck	5	51.23%	6.04%	10.99%	30.24%	0.82%	0.69%	Disturbed

Table 16: Land use for sites sampled by Waterwatch in the Pioneer River catchment from 1996-1998 (Wright, 1998).

Site_name	Stream	Site	Natural	Forestry	Grazing	Crop/Hort	Animal P	Human	Classification
15b-01	Finch Hatton Ck	p1	99.54%					0.46%	Pristine
15b-02	Finch Hatton Ck	p2	71.28%		14.78%	7.55%	4.01%	2.38%	Disturbed
15b-03	Cattle Ck	p3	71.84%	5.80%	4.89%	16.64%	0.46%	0.38%	Disturbed
15b-04	Cattle Ck	p4	56.22%	4.22%	10.23%	27.75%	0.82%	0.77%	Disturbed
15b-05	Pioneer R	p5	20.55%	25.08%	34.35%	19.35%	0.19%	0.47%	Disturbed
15b-06	Bakers Ck	p6	0.98%		18.64%	67.49%		12.89%	Disturbed
15b-07	Gooseponds Ck	p7	8.99%		10.63%	73.79%		6.59%	Disturbed
15b-08	Gooseponds Ck	p8	11.12%		12.11%	54.20%		22.57%	Disturbed
15b-09	Reliance Ck	p9	19.67%		18.41%	57.89%		4.03%	Disturbed
15b-10	Sandy Ck	p10	2.61%	9.35%	35.43%	50.29%		2.32%	Disturbed
15b-11	St Helens Ck	h1	98.53%	1.47%					Pristine
15b-12	St Helens Ck	h2	96.53%	0.41%	2.08%	0.58%			Pristine
15b-13	St Helens Ck	h4	76.67%	1.75%	17.88%	3.70%			Disturbed
15b-14	St Helens Ck	h3	70.64%	1.56%	20.30%	7.41%		0.10%	Disturbed

Two pristine sites were discovered from the first program, while three pristine sites were found from the second data set.

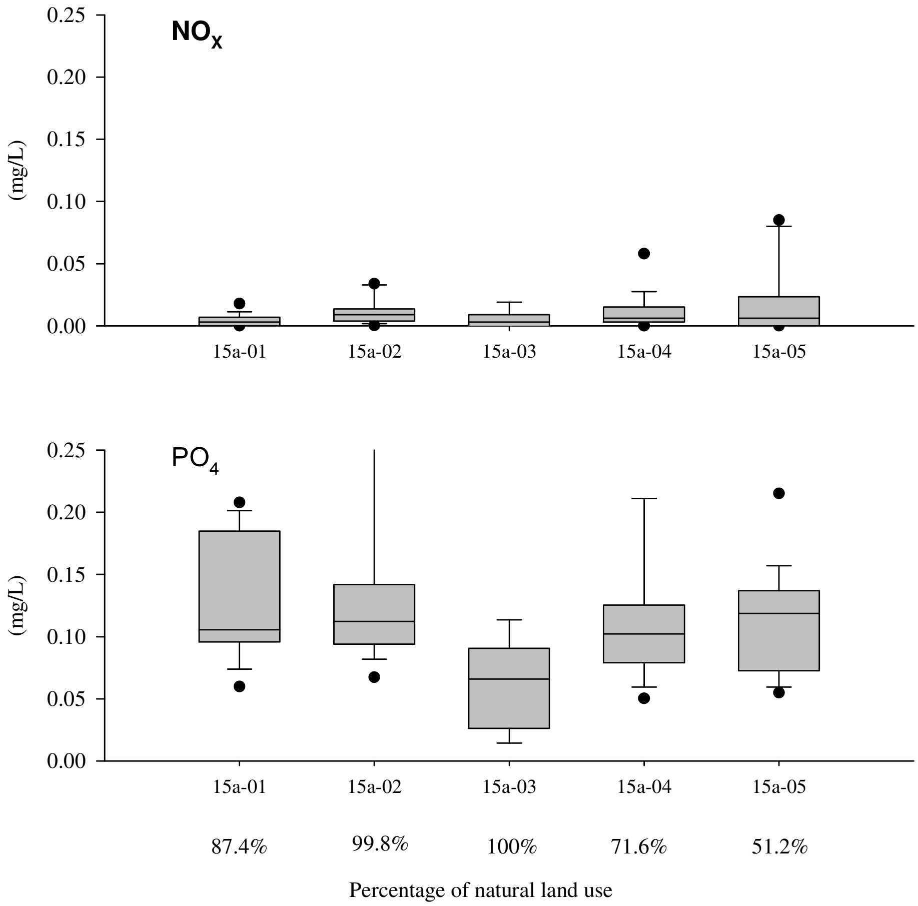


Figure 9: Box plots of the first Pioneer River data set collected by Waterwatch (Wright, 1996). (See Note on box plot format, Figure 1)

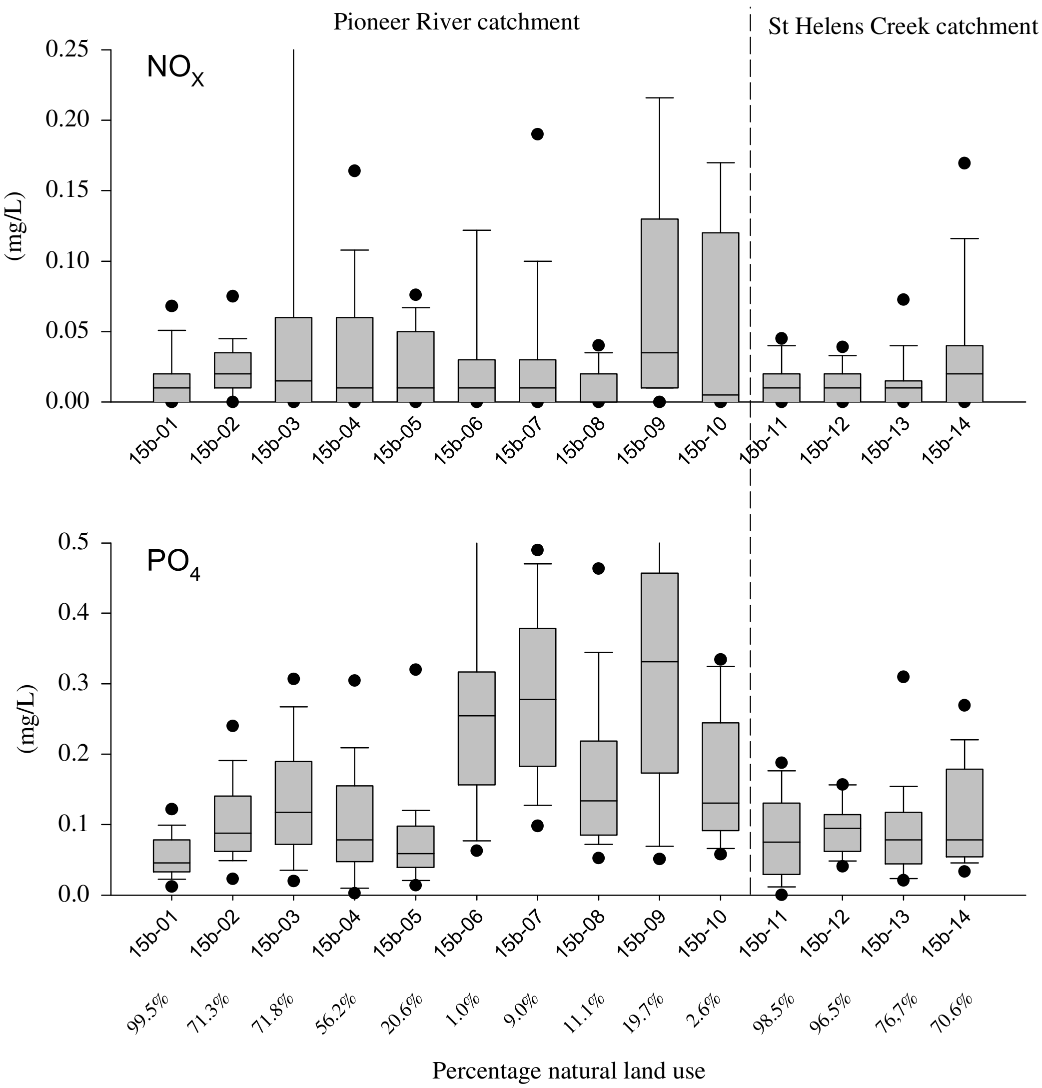


Figure 10: Box plots of the second Pioneer River data set collected by Waterwatch (Wright, 1998). (See Note on box plot format, Figure 1).

3.3.16 [Set 16] HEC data – original HEC study.

Now included in Set 5.

3.3.17 [Set 17] Environmental conditions of the Upper Mitchell River system; Water quality and ecology, Ryan *et al*., 2002.

QLUMP GIS land use analysis not available for this area.

3.3.18 [Set 18] Limnology and classification of tropical floorplain wetlands, with particular reference to the effects of irrigation drainage. LWRRDC/QDPI-WR Partnership, Rep No 95/12. Congdon, *et al*., 1995.

No pristine sites.

3.3.19 [Set 19] Effects of irrigation discharge on the Barrattas wetlands, rep No. 91/06. Congdon (1991).

No pristine sites.

3.3.20 [Set 20] Limnology and classification of tropical floodplain wetlands, with particular reference to the effects of irrigation drainage. LWRRDC/QWRC Partnership Project, Rep No. 92/01. Congdon and Pearson, 1992.

This is the earlier progress report to Set 18 – no pristine sites.

3.3.21 [Set 21] Downstream effects of land use in the Fitzroy catchment; summary report, 1993-1996. Noble *et al*., 1996.

None of the sampled sites in this study were considered to be pristine, so no investigation was undertaken at this time.

3.3.22 [Set 22] Coast and Clean Seas Project. Water Quality in the Whitsunday Rivers catchment. Faithful (2003).

The main aim of the monitoring program was to obtain water quality data for the four main river systems in the Whitsunday Rivers region. Major objectives were to identify gaps in water quality information and to improve knowledge of the differences between the wet and dry seasons in this coastal catchment area.

Land use was investigated at all sites sampled, though none were found to have pristine subcatchments. The land uses for each site are listed in Table 18, while the data are summarised statistically in Appendix 12 and by box plots in Figure 11.

Table 18: Land use for sites in the Whitsunday Rivers study (Faithful, 2003).

Site_name	Stream	Site_code	Natural	Forest	Grazing	Crop/Hort	Animal P	Urban	Classification
s22-01	O'Connell R	1	19.14%	46.69%	34.10%	0.08%			Disturbed
s22-02	Proserpine R	6	11.86%	17.98%	63.26%	6.71%		0.18%	Disturbed
s22-03	Proserpine R	6b	11.91%	17.79%	62.78%	7.34%		0.18%	Disturbed
s22-04	Andromache R	8	22.05%	9.77%	68.18%				Disturbed
s22-05	Proserpine R	20b	13.92%	12.54%	50.91%	21.11%	0.00%	1.51%	Disturbed
s22-06	Proserpine R	18	15.02%	9.00%	50.76%	23.28%	0.01%	1.95%	Disturbed
s22-07	Lethebrook Ck	9	6.58%	10.62%	51.88%	29.89%		1.03%	Disturbed
s22-08	Proserpine R	14	3.84%	13.12%	83.04%				Disturbed
s22-09	Myrtle Ck	23	25.20%		12.44%	59.81%	0.06%	2.55%	Disturbed
s22-10	Lethebrook Ck	12	12.55%	21.35%	39.83%	25.96%		0.31%	Disturbed
s22-11	Proserpine R	16	6.87%	11.95%	75.55%	5.61%		0.03%	Disturbed
s22-12	Myrtle Ck	30	38.56%	0.00%	17.51%	42.13%	0.16%	1.80%	Disturbed
s22-13	Gregory R	28	34.24%	33.07%	14.32%	17.97%		0.41%	Disturbed
s22-14	Myrtle Ck	24	70.31%		27.70%	1.99%			Disturbed
s22-15	Gregory Ck	25	94.80%	1.44%	2.84%	0.92%			Near-pristine
s22-16	Brandy Ck	22	42.37%	48.25%	8.88%			0.50%	Disturbed
s22-17	Boundary Ck	3	8.55%	35.83%	55.23%	0.39%			Disturbed

One near-pristine site was found in Gregory Creek.

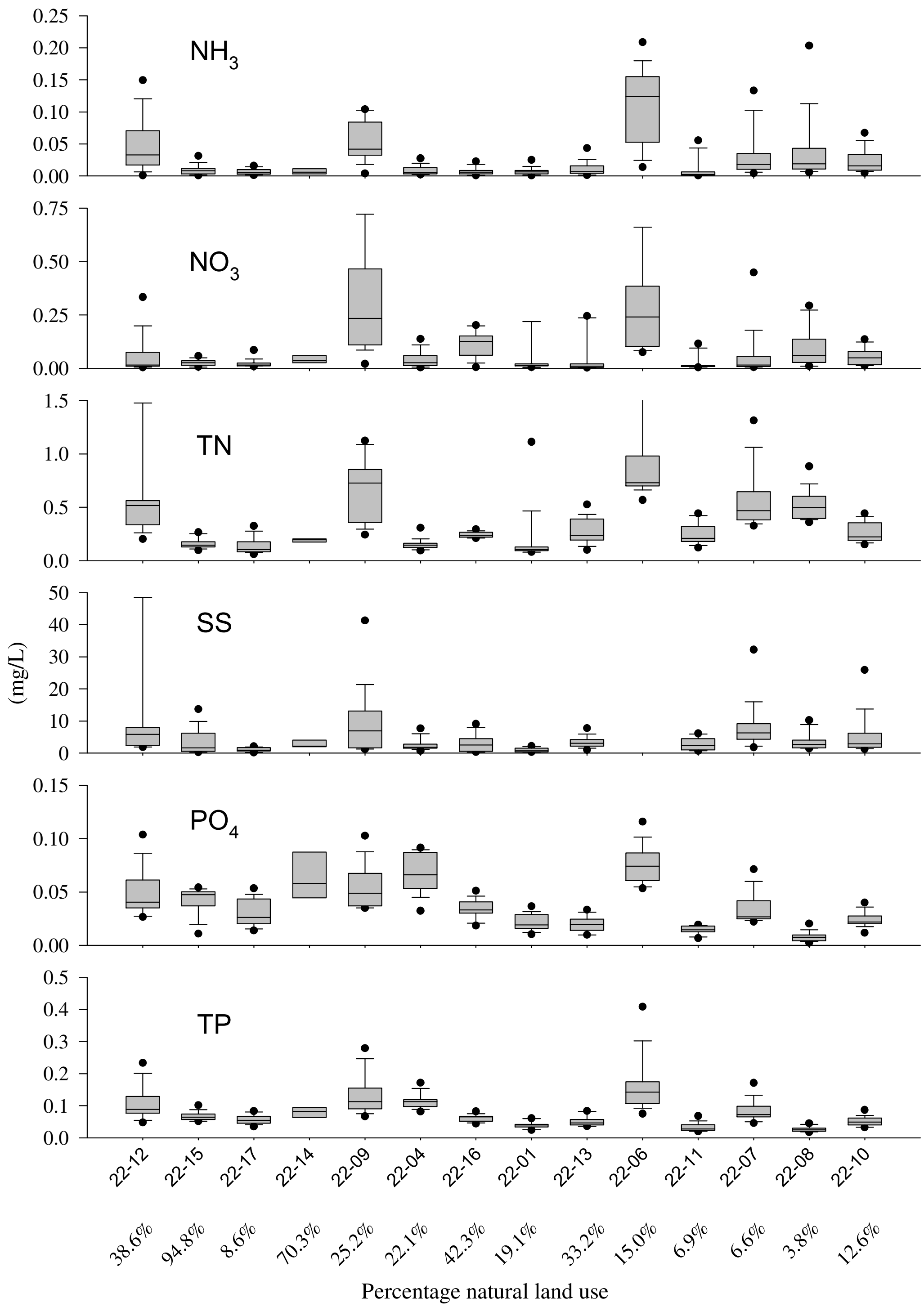


Figure 11: Box plots of the Whitsunday Rivers dataset (Faithful, 2003). (See Note on box plot format, Figure 1).

3.3.23 [Set 23] Natural resources of the Barron River catchment 2; Water quality, land use and management. Cogle *et al*. (2000).

This study was a major investigation of the Barron River catchment to provide quality baseline information to assist in formulating and implementing management strategies. Forty-three sites within the Barron River basin across twelve sub-catchments were regularly sampled, between 1992 and 1999. Extensive wet-season sampling was undertaken in the last year of the project.

Seventeen sites were evaluated for land use, with five shown to drain pristine sub-catchments. The land uses for each of these sites are ordered by the percentage natural land use and listed in Table 19. The data are summarised statistically in Appendix 13 and as box plots in Figures 12-13.

Table 19: Land uses at selected sites within the Barron River basin (Cogle *et al*., 2000).

Site_nam	Stream	Site_code	Natural	Forestry	Grazing	Crop/Hort	Animal P	Human	Classification
23-26	Clohesy R	27	100.00%						Pristine
23-34	Freshwater Ck	35	99.89%		0.02%			0.08%	Pristine
23-24	Davies Ck	25	96.72%	3.28%					Pristine
23-13	Kauri Ck	13	94.65%	5.35%					Near-pristine
23-32	Flaggy Ck	33	76.03%	23.97%					Disturbed
23-23	Emerald Ck	24	64.32%	10.91%	24.77%				Disturbed
23-04	Scrubby Ck	4	51.92%	0.06%	25.88%	0.74%	21.40%		Disturbed
23-30	Flaggy Ck	31	50.67%	41.26%	8.07%				Disturbed
23-06	Barron R	6	44.27%	0.10%	26.11%		29.53%		Disturbed
23-22	Shanty Ck	23	26.11%	42.50%	31.34%			0.05%	Disturbed
23-07	Gwynne Ck	7	23.02%		50.77%		26.21%		Disturbed
23-09	Peterson Ck	9	18.68%	7.98%	33.69%	7.53%	26.75%	5.36%	Disturbed
23-15	Rocky Ck	15	7.13%	29.36%	52.20%	11.30%			Disturbed
23-03	Piebald Ck	3	6.64%	32.92%	13.35%	20.75%	13.47%	12.87%	Disturbed
23-08	Leslie Ck	8	5.49%	0.24%	35.86%	5.40%	50.12%	2.89%	Disturbed
23-38	Thomatis Ck	39	4.07%		1.16%	88.77%	4.68%	1.32%	Disturbed
23-02	Mazlin Ck	2	1.86%	35.77%	46.48%	9.21%	6.68%		Disturbed

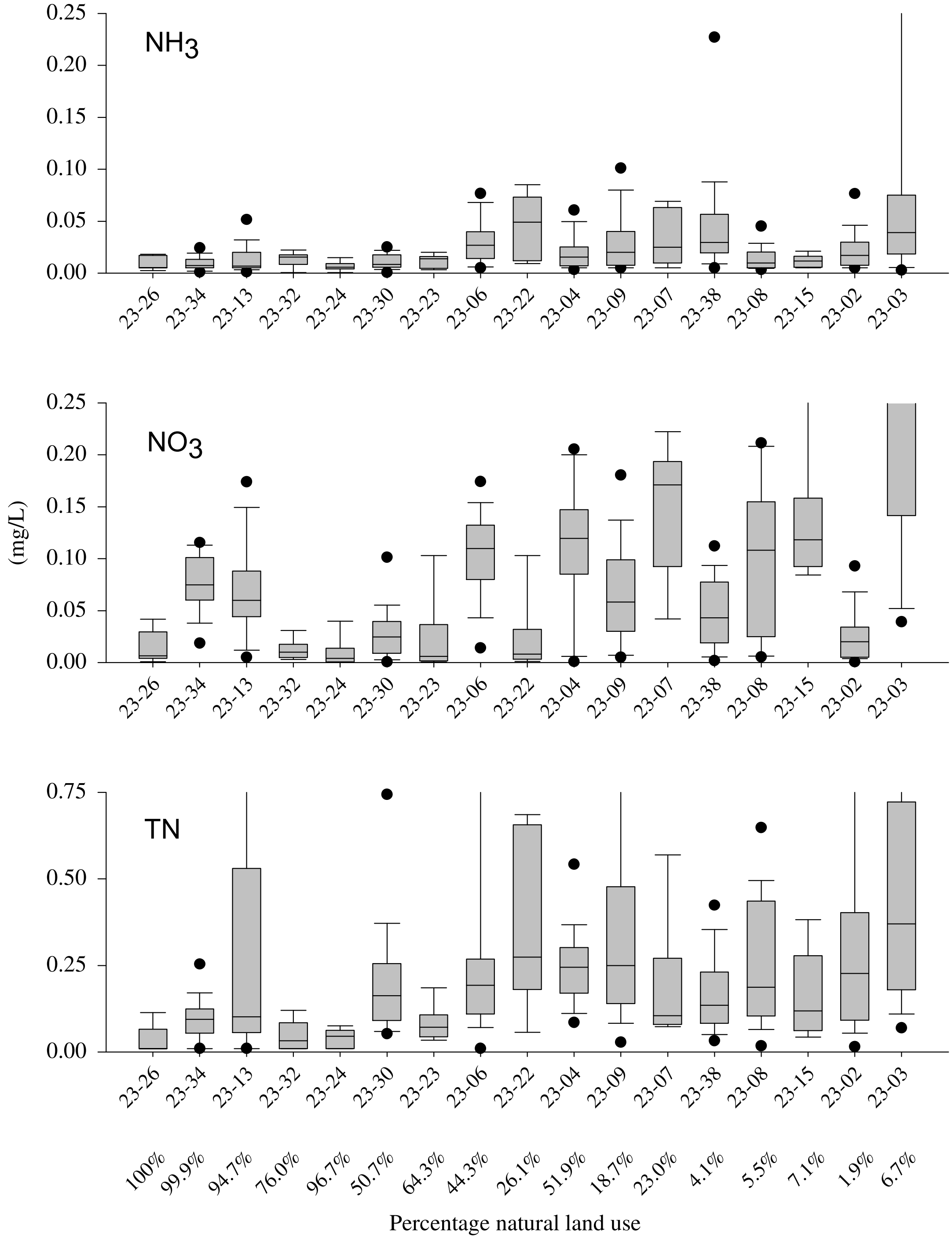


Figure 12: Box plots of Cogle *et al*.'s (2000) data from the Barron basin, ammonia, nitrate and Total N forms. (See Note on box plot format, Figure 1).

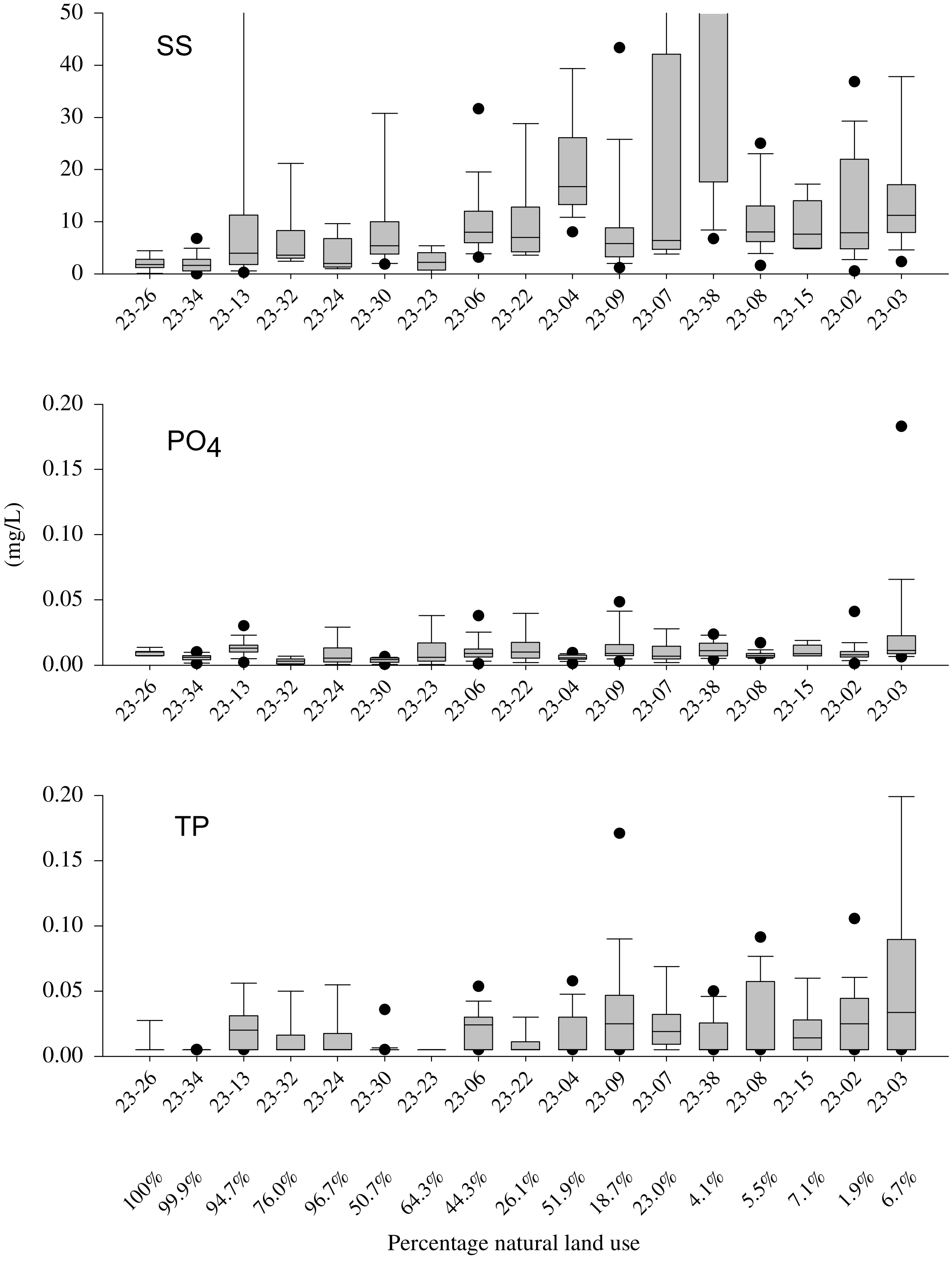


Figure 13: Box plots of Cogle *et al.*'s (2000) data from the Barron basin, suspended solids, phosphate and total phosphorus forms. (See Note on box plot format, Figure 1).

3.3.24 [Set 24] North Queensland NRM&E (analysis of new and historical data). Cox *et al.*, 2004.

The data set was not available at the time of writing.

3.3.25 [Set 25] Stream sampling associated with flood-plume studies of Devlin, 2001.

The sites sampled in this study from the Russell-Mulgrave and Barron Rivers were in agricultural rather than pristine areas.

3.3.26 [Set 26] Johnstone Rivers study of DNR. Hunter *et al.*, 2001.

This major study of water management in the Johnstone River basin between 1991 and 1996 included two 'reference' sites in predominantly rainforest catchments. Although access was only available to median values and percentiles for an incomplete set of nutrient forms, this large data set was regarded as too important to ignore. Land uses calculated from QLUMP for the two sites are listed in Table 20 and the median values given in Table 21.

Table 20: Land uses at reference sites within the Johnstone Basin study (Hunter *et al.*, 2001).

Site_name	Code	Stream	Natural	Forestry	Grazing	Crop/Hort	Animal P	Urban	Classification
s26-04	SC	S Johnstone R	95.29%		1.61%	0.06%	3.04%		Near-pristine
s26-25	TW	Taylor Ck	98.22%		0.13%	1.34%		0.30%	Near-pristine

The animal production at the South Johnstone River site was dairy activity, not considered as intensive land use as say cropping, so allowance was made for its slightly high overall 'intensive' land-use percentage.

Table 21: Nutrient statistics at reference sites within the Johnstone Basin study (Hunter *et al.*, 2001). (Nutrient concentrations in mg/L).

Site	Statistic	NO_X	NH_3	TDN	DON	PO_4	TDP	DOP
SC	n	77	77	63	*	77	64	*
	median	**0.006**	**0.007**	**0.084**	**0.071**	**0.009**	**0.020**	**0.011**
	20%ile	0.003	0.005	0.031		0.007	0.010	
	80%ile	0.015	0.010	0.148		0.011	0.029	
TW	n	527	233	355	*	233	361	*
	median	**0.025**	**0.008**	**0.100**	**0.066**	**0.006**	**0.020**	**0.014**
	20%ile	0.015	0.005	0.030		0.004	0.010	
	80%ile	0.034	0.012	0.190		0.007	0.020	

Note: * Calculated by difference.

The very large number of samples that were taken at the Taylor Creek (site TW) endows these median values with a high degree of confidence.

3.3.27 [Set 27] Testing the Waters, DNR publication of their long-term data collection, 1999.

Unfortunately, serious questions regarding the efficacy of early sample storage (not frozen) and methodology (water samples not filtered; relatively high limits of detection for analyses) make this data set somewhat unreliable for pristine comparisons.

3.3.28 [Set 28] Water quality assessment for sustainable agriculture (Tully-Murray rivers catchment area and Granite Creek on the Atherton Tablelands); ACTFR Rep No. 03/18, Feb 2004. Faithful and Finlayson (2004).

This report summarises the findings of a relatively intensive survey of paddock scale farm runoff after rain events in north Queensland. No pristine sites.

3.3.29 [Set 29] River health in the Fitzroy catchment – Community ownership; Jan 1997-Dec 1999. (Ed.) Noble, 2000.

No pristine sites were likely to have been sampled in the Fitzroy basin in this study.

3.3.30 [Set 30] Nutrient control strategy for tropical catchments; Final report of the NLP funded project. Cogle *et al.*, 1998.

Same sites as in Set 23 of Cogle *et al.*, 2001 – data can be accessed from DNR&M.

3.3.31 [Set 31] Mitchell, A., Rasmussen, C., Blake, S., Congdon, R., Reghenzani, J., Saffigna, P. and Sturmey, H. (1991) Nutrient status and trends in waters of the Great Barrier Reef Marine Park. In: 'Landuse Patterns and Nutrient Loading of the Great Barrier Reef Region'. (Ed.) D. Yellowlees, Proceedings of Workshop, Nov. 1990, James Cook University, Townsville. pp. 108-161.

Statistics published for Birthday Creek, but outside of the 1999 GIS QLUMP boundaries.

3.3.32 [Set 32] Miscellaneous far-north and north Queensland stream investigations, mostly estuarine sampling.

- **Studies of FNQ estuaries – Eyre and Davies, 1996; Davies and Eyre, 2005**

Estuarine sampling only. The water quality at estuarine sites is regularly affected by seawater dilution, so no estuarine sites were considered in this study.

- **AIMS studies in FNQ estuaries (unpublished).** Estuatine sampling only – see above.
- **AIMS sampling in Normanby River (unpublished, though statistics reported in Furnas, 2001)** – data unavailable for analyses.
- **AIMS sampling in Murray River (unpublished)**. Estuarine sampling only.

3.3.33 [Set 33] Stream ecosystems as monitors of tropical forest catchments; LWRRDC Project: JCU8; ACTFR Rep No. 98/26. Pearson *et al.*, 1998.

Essentially the same data as in Butler *et al.*, 1996 (see 3.3.1).

3.3.34 [Set 34] Nutrient concentrations in runoff draining from a pine plantation in the Whitfield Creek catchment, located in the Wet Tropics of north Queensland, Australia in the 2003/04 wet season. John Faithful, Jon Brodie, Ken Bubb and Craig Armstrong, ACTFR Draft report 05/02, in press.

The objective of this recent study was to quantify losses from nutrients and sediment from a plantation estate in the Wet Tropics. The one pristine site was located in the upper catchment, at an exit point from the World Heritage Area, supposedly before entering the plantation area. Land use at these catchment sites is listed in Table 22. The nutrient and suspended sediment data are statistically summarised in Appendix 13 and graphically presented in Figure 14.

Table 22: Land uses at sites within the Whitfield Ck study (Faithful *et al*., 2005).

Site_nam	Stream	Site_stn	Natural	Forestry	Grazing	Crop/Hort	Animal P	Human	Classification
34-01	Whitfield Ck	1	100.00%						Pristine
34-02	Whitfield Ck	2	60.80%	39.20%					Disturbed**
34-03	Whitfield Ck	3	53.47%	18.71%	5.40%	22.14%	0.12%	0.16%	Disturbed**
34-04	Whitfield Ck	4	49.20%	26.03%	4.64%	19.59%	0.10%	0.43%	Disturbed**

Note: ** Forestry all pine plantation.

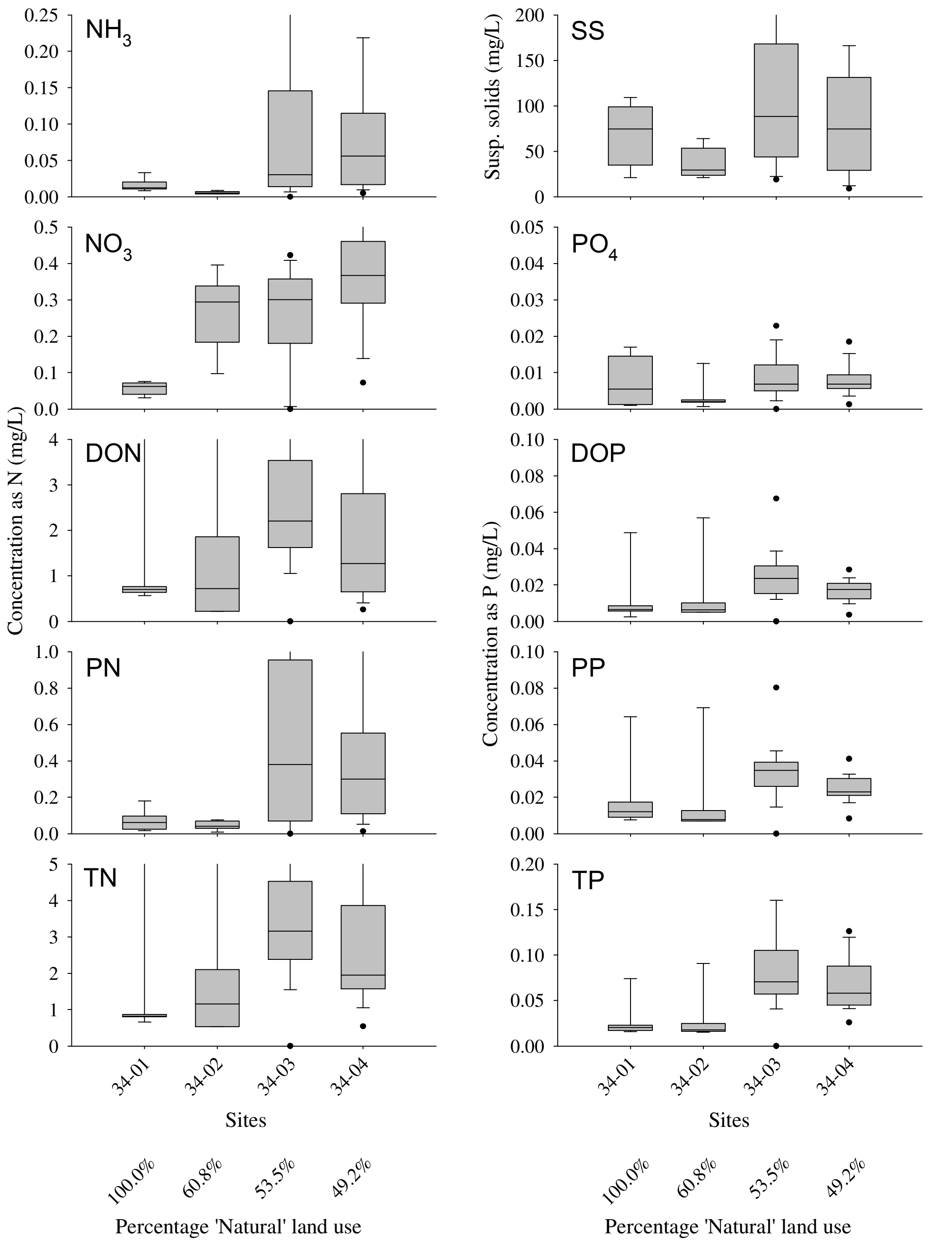


Figure 14: Box plots of Faithful *et al*. (2005) data from the Whitfield Creek area. (See Note on box plot format, Figure 1).

3.3.35 [Set 35] Water Quality of Pristine Sections of Rivers of Eastern Australia Draining to the Tasman Sea. Private Research Project. John H. Laxton and R. Gittins, October 2004.

The aim of this project was to determine the water quality in streams draining from pristine or undisturbed sections of the upper catchments of rivers along the east coast of Australia and to compare it with that draining from land in the lower catchments that had been only moderately disturbed by forestry, grazing, agriculture and residential development. Estimates were made by the author as to the relative pristine nature of the sub-catchments above each sampling site.

For the present study, only selected sites in the Laxton and Gittins data set were investigated, with the QLUMP GIS to objectively quantify this land use. Sites were chosen that were likely to be pristine, located in the area from the Daintree River in the north, to the Pioneer River, in the south. Sites in the North and South Johnstone River were quickly seen to be affected by intensive land use and were excluded on this basis. Sites in the Fitzroy basin were also excluded to be consistent with earlier decisions not to investigate streams in this generally disturbed large catchment. Just seven sites were investigated here and six were identified as either 'pristine' or 'near-pristine' (Table 23). The nutrient and suspended sediment data at theses sites are compared by box plots in Figure 15 and statistically summarised in Appendix 14.

Table 23: Land uses at selected sites in central and north Queensland (Laxton and Gittins, 2004).

Site_nam	Stream	Site_stn	Same site	Natural	Forestry	Grazing	Crop/Hort	Animal P	Human	Classification
35-07	Finch Hatton Ck	28		100.00%						Pristine
35-05	Mossman R	38	01-05	99.99%					0.01%	Pristine
35-04	Upper Tully R	34	14-01	93.49%		4.58%	1.92%		0.43%	Near-pristine
35-02	Crystal Ck	31	02-06	94.07%	0.04%	3.10%	2.38%		0.42%	Near-pristine*
35-01	Little Crystal Ck	30		91.99%		6.18%	1.81%		0.02%	Near-pristine
35-06	Upper Daintree R	41	04-01	49.41%	48.26%	2.30%				Near-pristine**
35-03	Upper Herbert R	32		18.85%	2.84%	76.28%	0.28%	0.42%	1.14%	Disturbed

* Note – Slightly outside 'Near-pristine' condition, but allowed.
** Note – The land uses here lie outside of the 'Near-pristine' definition, determined by the QLUMP GIS as having considerable forestry production from native forests. See note re WHA (Section 3.3.0).

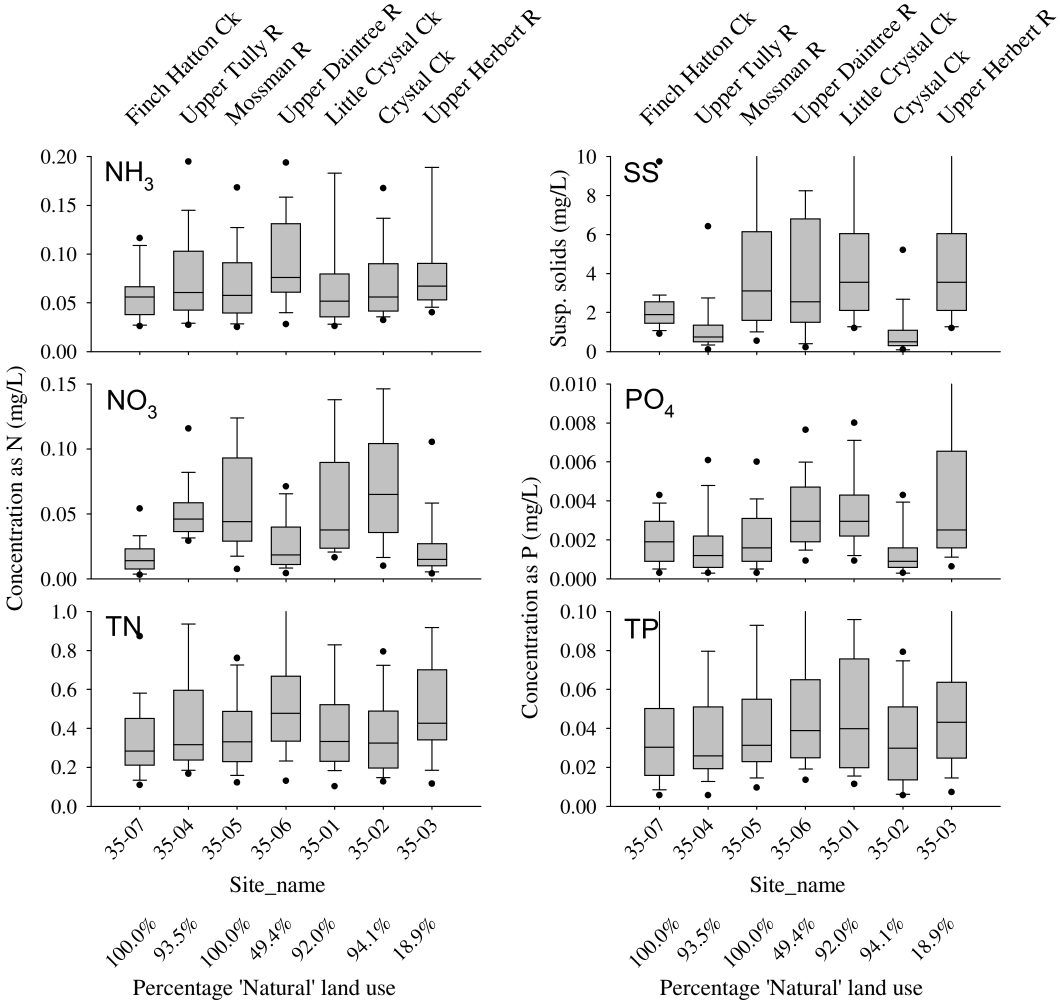


Figure 15: Box plots of Laxton and Gittins (2004) data from north Queensland. (See Note on box plot format, Figure 1).

3.4 Summary of water quality from pristine sites

3.4.1 Review of data sets and sites selected for pristine status

Since the objective of this report was to define the baseline levels of nutrients and suspended sediment in pristine and near-pristine streams, it was argued that any clearly outlying data should be identified. To this end, the data sets in this collective 'pristine' series were analysed for outliers and removed if objective reasons could be found for their exclusion (see Figures 16-19).

3.4.1.1 Ammonia

For the N forms, all six sites from Set 35 (Figures 15, 16) showed ammonia (NH_3) results that were substantially elevated, compared to the other data sets. During transportation to the laboratory, an unspecified time period, but likely to be some days, these samples were apparently kept at room temperature (Laxton and Gittins, 2004). Furthermore, unfiltered water samples were analysed, raising the possibility of some contamination by particulate material in the analyses. Given that ammonia is the nutrient most easily contaminated or changed by procedural delays (experience of AIMS laboratory), this set has been excluded. Set 04 is examined in the nitrate section below.

3.4.1.2 Nitrate

The nitrate data from Set 13 (Waterwatch FNQ) was only presented as a statistical summary of the data from identified pristine and near-pristine sites (Table 13). However, it is clear that the average values 0.060 - 0.082 mg/L and median values 0.050 – 0.060 mg/L are considerably higher than the average/median values of most other sets (Figure 16). Given the analytical issue discussed earlier (high limit of detection of 0.030 mg/L with the HACH photometer) and uncertainty over volunteer consistency, this set has been excluded. In the other Waterwatch set (Set 15) from the Pioneer River catchment, a somewhat more reliable photometer (Palintest) was used, though this instrument was also found to have a similar, relatively high detection limit compared to typical laboratory methods (see Mitchell and Wright, in press). Despite the apparent low levels of nitrate shown in Figure 16, many values in this data set were listed as 'zero', a somewhat nebulous result that would have greatly affected these statistics. On this basis, these results are also removed.

The old data in Set 04 (Daintree River) were elevated for all nutrient forms, ammonia, nitrate and phosphate (Figures 18, 19). These sites were previously allowed a near-pristine classification, due to the perceived undisturbed nature of the Daintree catchment. From these 1976-1977 results, it appears that logging activities at the time were having an impact on runoff and so all of these results have been removed. However, the data of site 35-06 in the Daintree River (same position as 04-01) were from a recent sampling program (1998-2003). This catchment might be assumed to have been somewhat rehabilitated after logging ceased in 1988 (WHA listing), so these data (minus the ammonia results) have been retained as near-pristine. The methods used in the 1976-77 results also appear to be comparable to those used in more recent studies.

3.4.1.3 DON

The smaller collection of DON values had one obvious outlying site from Set 34, possibly related to some plantation forestry activities in the upper catchment not identified, either by the author (Faithful *et al.*, in press) or by the QLUMP GIS. However, since high DON levels are sometimes seen to emanate from natural forests, these data were not excluded.

3.4.1.4 TN

For TN, there was no obvious explanation for the variability of this cumulative N component, except for the elevation to a relatively small degree by ammonia in the Laxton data set. No exclusions were made from the TN data sets.

3.4.1.5 Phosphate

The Waterwatch data of Set 15 was excluded due to the instrumental high detection limit (3.1.4.2) and the Daintree data of Set 04 was excluded due to logging activities at the time (3.1.4.2).

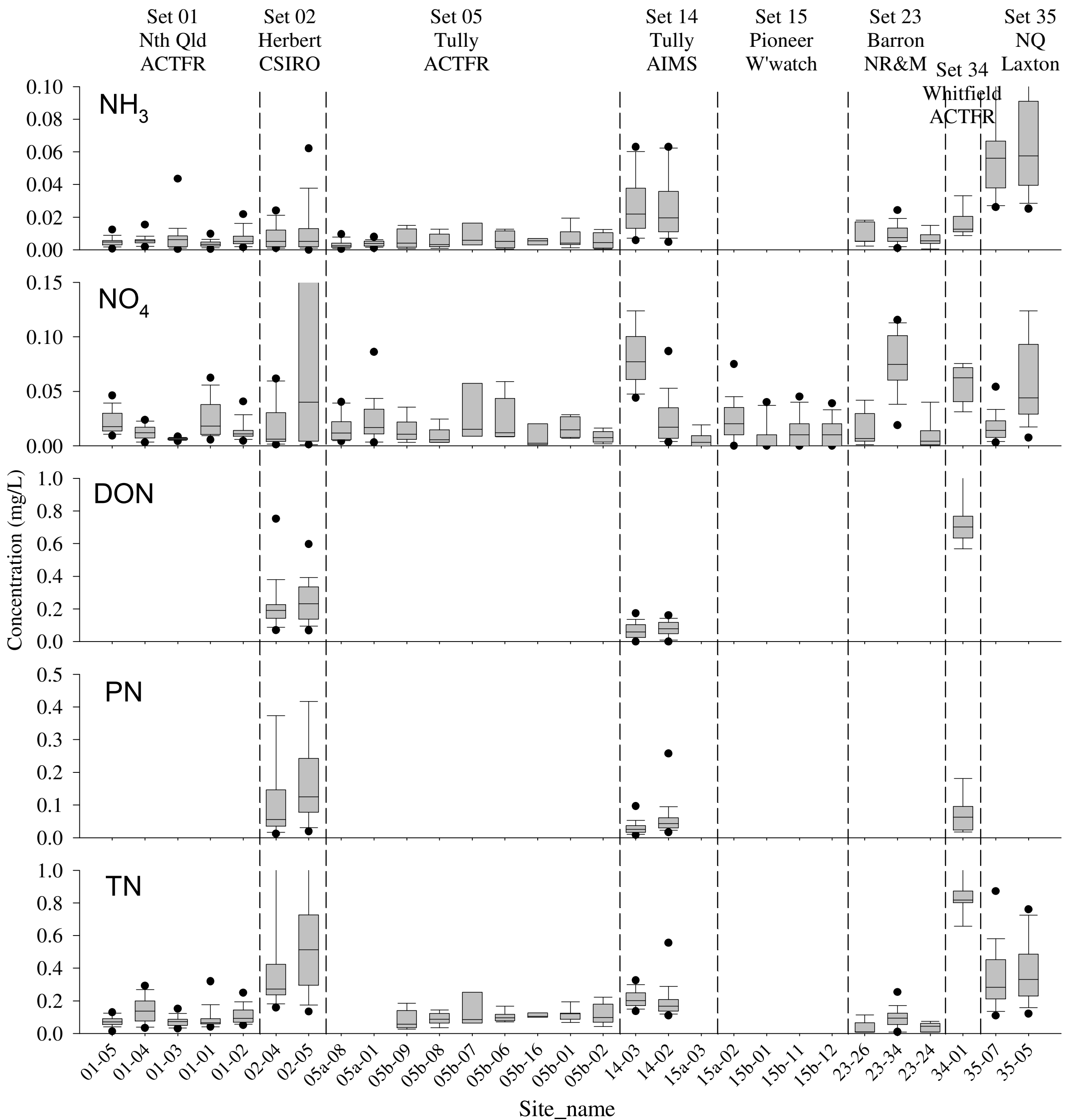


Figure 16: Summary of N forms from 'Pristine' sites. (See Note on box plot format, Figure 1).

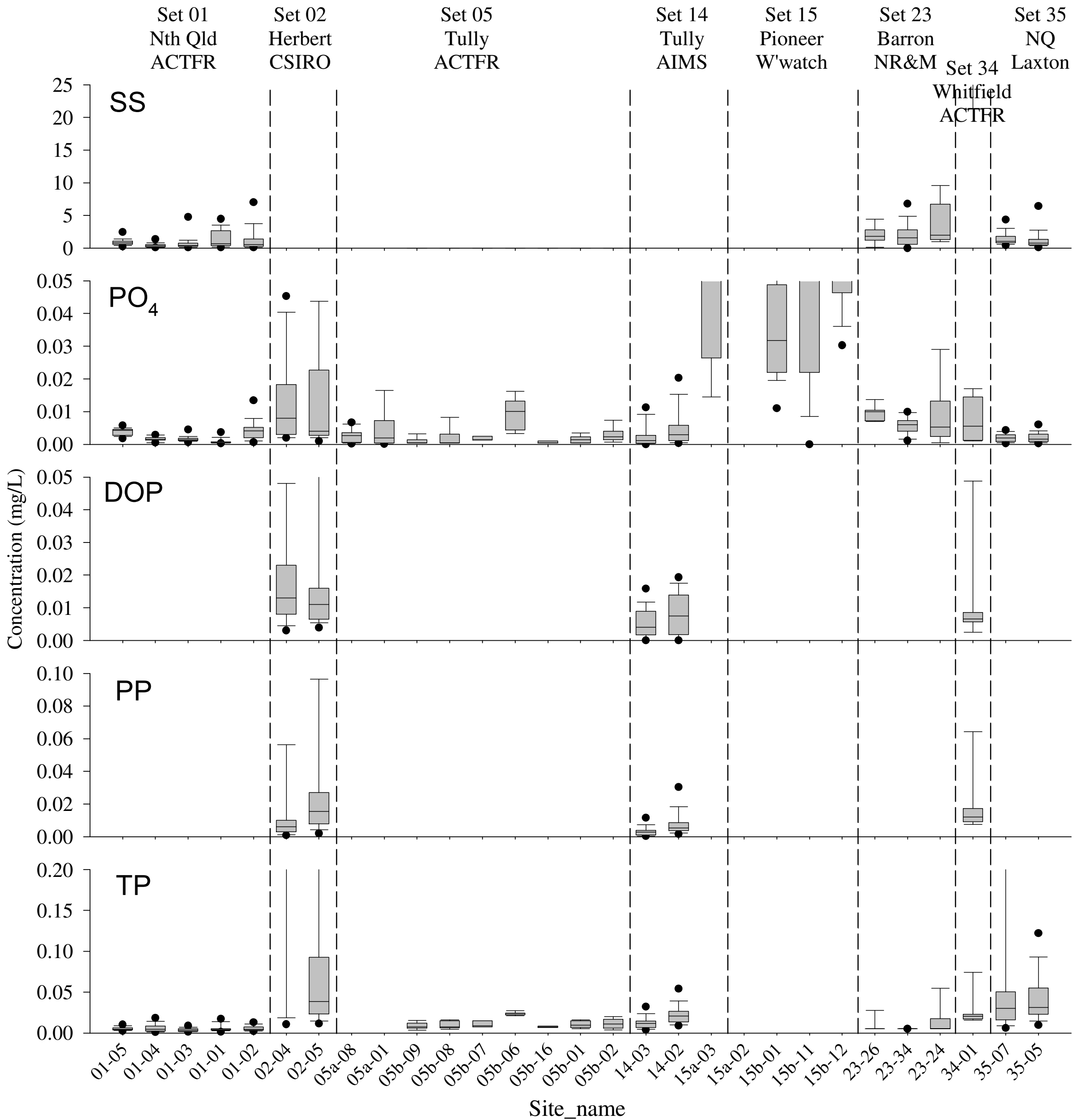


Figure 17: Summary of SS and P forms from 'Pristine' sites. (See Note on box plot format, Figure 1).

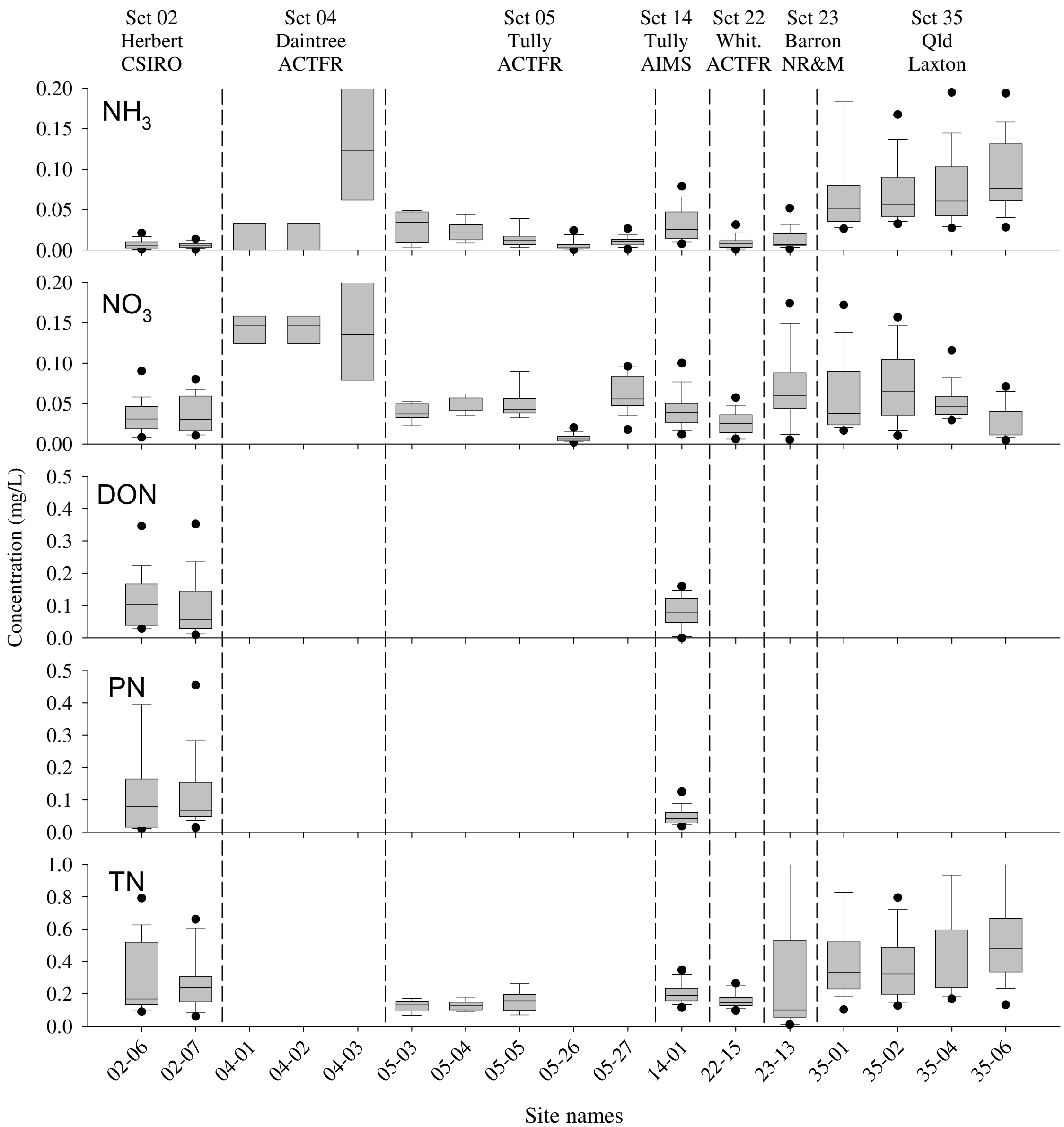


Figure 18: Summary of N forms from 'Near-pristine' sites. (See Note on box plot format, Figure 1).

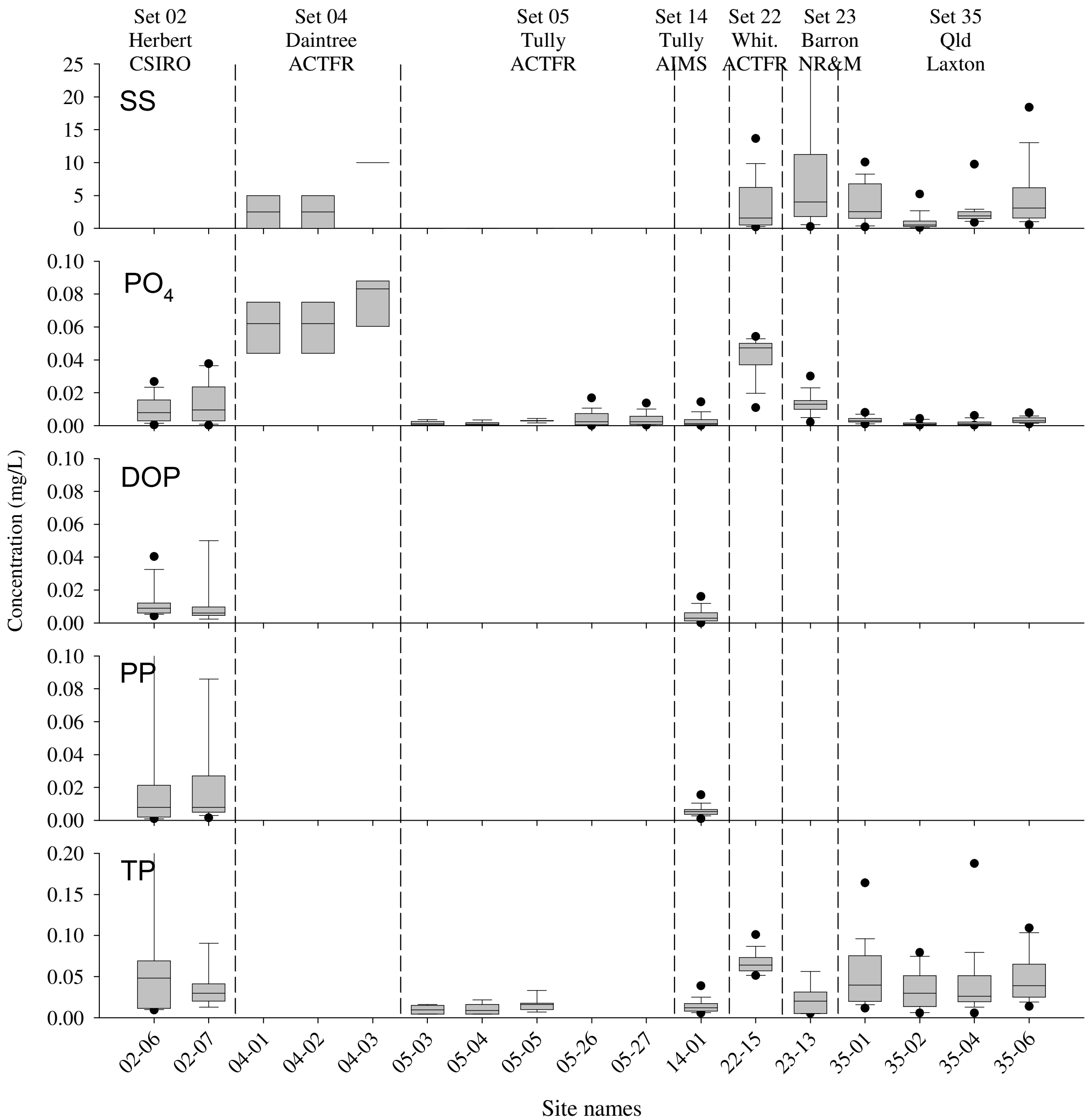


Figure 19: Summary of SS and P forms from 'Near-pristine' sites. (See Note on box plot format, Figure 1).

3.4.2 Summary of data selected for pristine status

To summarise, data exclusions included the sites from Set 35 for ammonia, from Set 13 (Waterwatch-FNQ) for nitrate, from Set 15 (Waterwatch-Pioneer) for both nitrate and phosphate and from Set 04 (Pearson and Penridge – Daintree River) for ammonia, nitrate and phosphate. These excluded data may be appropriate for investigations of disturbed land uses, though not for the purpose here of defining pristine levels. All remaining pristine data were combined into two sets, pristine and near-pristine and data-weighted statistics calculated for each set (Table 23) below.

Table 24: Statistics for nutrient and suspended sediment samples from reviewed pristine and near-pristine sites (All measurements in mg/L).

Classification	Statistic	NH3	NOx	DON	PN	TN	TSS	PO4	DOP	PP	TP
Pristine	n	636	695	241	257	614	383	695	232	265	610
	average	0.014	0.037	0.155	0.077	0.213	2.5	0.005	0.011	0.014	0.021
	median	0.007	0.019	0.092	0.038	0.144	0.7	0.003	0.007	0.004	0.009
	20%ile	0.003	0.007	0.036	0.021	0.070	0.2	0.001	0.002	0.002	0.004
	80%ile	0.021	0.064	0.163	0.085	0.258	1.7	0.006	0.014	0.011	0.023
	min	0.000	0.000	0.000	0.003	0.010	0.0	0.000	0.000	0.001	0.001
	max	0.100	0.316	7.440	1.557	7.750	111.2	0.537	0.298	0.795	1.358
Near-pristine	n	297	425	130	134	373	223	425	122	135	367
	average	0.021	0.053	0.090	0.073	0.372	9.5	0.007	0.006	0.013	0.037
	median	0.012	0.042	0.080	0.044	0.215	2.0	0.003	0.004	0.006	0.020
	20%ile	0.005	0.021	0.033	0.028	0.121	0.5	0.001	0.001	0.003	0.008
	80%ile	0.032	0.070	0.133	0.083	0.502	6.6	0.012	0.009	0.009	0.046
	min	0.000	0.002	0.000	0.006	0.000	0.0	0.000	0.000	0.000	0.001
	max	0.180	0.900	0.381	0.584	5.462	261.2	0.060	0.060	0.257	0.671

It is noteworthy that all of the sites found here to be pristine, except one in upper Finch Hatton Creek (s35-07) in the Pioneer River catchment, were from upper catchments of the Wet Tropics area. Few other catchments of northern Queensland are either undisturbed or have been sampled in their upper reaches. In support of the values determined in Table 23, we see similar nutrient levels at well-sampled pristine sites in the Johnstone River basin, one major catchment of the Wet Tropics for which only median and percentile values were made available (see Table 21; N lower, P higher). While the concentrations estimated for dissolved organic and particulate forms are affected by relatively low sample counts, we contend that the concentrations tabled here for dissolved inorganic and total N and P forms are reasonable, new estimates of levels in pristine streams.

In summary from the results reviewed in this study, waters draining pristine rainforest and woodlands in northern Australia have moderate concentrations of dissolved organic nitrogen (DON) and phosphorus (DOP) (DON average 0.155; median 0.092 mg/L as N and DOP average 0.011; median 0.007 mg/L respectively), low to moderate concentrations of particulate nitrogen (PN) and phosphorus (PP) (PN average 0.077; median 0.038 mg/L and PP average 0.014; median 0.004 mg/L respectively) and low concentrations of dissolved inorganic nitrogen (DIN) and phosphorus (DIP) (DIN average 0.037; median 0.019 mg/L and DIP average 0.005; median 0.003 mg/L respectively) (Table 21). Nitrogen speciation is dominated by DON with only significant spikes of PN in first flush events when land slips and roads contribute suspended sediments. Occasional spikes of DIN, mainly nitrate, in some areas may be associated with groundwater discharge to the stream, often after the main peak flow. In savannah woodlands and grasslands with low grazing intensity, nitrogen speciation is also dominated by DON and phosphorus by DOP and PP. Concentrations of DIN and DIP are generally low except where groundwater inputs are involved.

It is believed that savannah systems yield far less total nitrogen and individual nitrogen species than forest-dominated areas (Lewis *et al*., 1999) due to the relationship between runoff and vegetation type. Limited data is available for ungrazed savannah/woodlands in northern Australia as it is normally impossible to verify that such landscapes have not been subjected to beef grazing at some time over the last 150 years. Magela Creek in the Northern Territory, with little gazing on its catchment but some mining activity has low concentrations of nitrate (0.007 – 0.030 mg/L) and SS (< 50 mg/L) in wet season flows (Hart and McGregor, 1980; Hart *et al*., 1987a; 1987b), although nitrate built up to quite high concentrations in no flow conditions in the dry season.

3.4.3 Comparison with broader published data on pristine levels

The concentrations of nitrogen species exported from pristine tropical Australian systems are not dissimilar to those seen elsewhere in the tropics (Lewis *et al*., 1999). Nitrate losses seem in general a little lower with mean concentrations of the order of 0.037 mg/L compared to estimates of 0.075 mg/L (Meybeck, 1982) globally or 0.120 mg/L (Lewis *et al*., 1999) in the Americas. Mean DON in northern Australian pristine systems (0.155 mg/L) is also slightly lower than Lewis *et al*.'s values in the Americas (0.162 mg/L), while mean PN in tropical Australia (0.077 mg/L) is considerably lower (115 μg/L in Americas). However all comparisons of means of this type are fraught with problems associated with the skewed nature of the data sets. Comparison of northern Australian 'pristine' mesic (moderate-high rainfall and runoff) catchments with xeric (low rainfall and runoff) catchments supports the conclusions of studies from other parts of the world that xeric catchments lose less nutrients overall than mesic catchments (Caraco and Cole, 2001; Puckridge *et al*., 1998).

4. Suspended sediments and nutrients in waters draining land dominated by low intensity land uses (rangeland grazing, selective forestry)

As catchment development proceeds and low intensity land uses such as grazing (eg rangeland beef grazing) and selective forestry (not clear felling) replace pristine forest/woodland/grasslands, the fluxes of N and P lost from the landscape increase and the forms of N and P exports change (excluding large anthropogenic atmospheric inputs). The principal change is to higher rates of soil erosion through hillslope, gully and streambank erosion and hence to increased concentrations of PN and PP in runoff. As PN and PP are mobilized into the water column, some desorption of species such as ammonia and phosphate occurs and so DIN and DIP concentrations rise, albeit slightly, compared to pristine conditions. Forestry operations increase particulate matter exports greatly through widespread soil disturbance. Thus, suspended solids loads and associated particulate nitrogen and phosphorus loads increase relative to the natural export of primarily dissolved organic carbon, nitrogen and phosphorus. Suspended sediment concentrations typically increase substantially as the forests are being actively harvested. Limited data from south-eastern Queensland supports the prediction that runoff from forests under selective forestry has moderate concentrations of PN and PP, moderate concentrations of DON and DOP and low concentrations of DIN and DIP (Bubb *et al*., 2000; 2001).

Unaltered savannas have high ground cover and low rates of runoff and erosion (Ludwig and Tongway, 2002). Rangeland beef grazing in many parts of northern Australia has involved wide-scale clearance or thinning of woodland vegetation for conversion to pasture (Tothill and Gillies, 1992). The principal consequence of beef grazing on catchments is greatly increased soil erosion and sediment discharge (Ciesiolka, 1987; Gardiner *et al*., 1990; Prosser *et al*., 2002). Soil erosion increases arise from woodland removal; overgrazing, especially in drought conditions, where pasture vegetation cover falls below 40% (McIvor *et al*., 1995; Scanlan *et al*., 1996; Ludwig and Tongway, 2002); streambank erosion when cattle have direct access to streams (Finlayson and Brizga, 1993); and stock trampling (Greene *et al*., 1994). Estimates of the increase in soil erosion from natural conditions to modern conditions, with poorly managed vegetation cover, range from 0.9 tonnes per hectare per year on catchments with minor gully erosion, 1.6 tonnes from one active gully and 27-30 tonnes under severe gully-erosion conditions (Ciesiolka, 1987; Rayment and Neil, 1997). Nutrients may escape from this system to waterways at high rates compared to those from undisturbed woodlands (Schmidt and Lamble, 2002).

For land under rangeland beef grazing, a number of studies are available at a small catchment scale from which the concentrations of SS and nutrients in runoff can be derived (Prove and Hicks, 1991; O'Reagain *et al*., 2001). In addition, many medium or large catchments of northern Australia have > 90 % of their area used for grazing and in these cases the complete catchment runoff can be considered representative of runoff from grazing lands with little or no contribution of nutrients from any other source. This is the case for some of the largest river catchments, for example the Burdekin and Western Australian Fitzroy, as well as many sub-catchments of the Burdekin (eg the Belyando), Queensland Fitzroy (eg the Issacs) and Herbert (eg the Wild) catchments. In grazed systems, the added factor (besides increased soil erosion) of an increased rate of mineralization of N and P due to digestion and excretion of vegetation means that increased losses of dissolved nutrients also occur compared to pristine. Thus, runoff from grazed systems has moderate to high concentrations of PN (0.3 – 3.0 mg/L) and PP (0.1 – 2.0 mg/L), moderate concentrations of DON (0.2 – 0.6 mg/L) and DOP (0.005 – 0.030 mg/L) and low/moderate concentrations of DIN (0.1 – 0.8 mg/L) and DIP (0.01 – 0.10 mg/L) (Brodie and Mitchell, 2005).

Other factors besides land use also have a large effect on the concentrations of SS and nutrients in grazed systems. Catchment geology, geomorphology, soil type, vegetation community type and topography can combine to produce dramatic differences in SS and nutrient concentrations between sub-catchments which all have similar grazing intensity. This is evident in results for the Burdekin where SS and nutrient concentrations in event flows are very high in the Burdekin itself above Charters Towers and in the Bowen sub-catchment (eg peak-flow SS concentrations of 4000 mg/L; TN of 4 mg/L; and TP of 2 mg/L); moderate in the Belyando (eg SS of 1500 mg/L; TN of 3 mg/L; and TP of 1 mg/L) and Suttor sub-catchments and low in the Cape-Campaspe sub-catchment (eg SS of 500 mg/L; TN of 1 mg/L; and TP of 0.3 mg/L) (Brodie *et al*., 2004).

McCulloch *et al*. (2003) have shown the sharp increase in soil erosion and suspended sediment flux accompanying the introduction of grazing (sheep and cattle) on the Burdekin Catchment. Using coral cores from reefs near the Palm Island group more than 100km from the Burdekin River mouth they showed that the concentration of barium in the corals, a signal of sediment discharge, increased sharply after 1870 at just the time sheep and cattle were introduced to the Burdekin Catchment. High sedimentation in the Ord River system (Western Australia) due to grazing land management has led to infilling of Lake Argyle at an average rate of 24 million cubic metres per year, which by 1998 (dam built in 1971) constituted 10% of the original volume of the reservoir (Environment Western Australia, 1998). Rehabilitation of areas of the Ord catchment degraded by grazing activities and subject to severe erosion has been ineffective. In the Mary River (Northern Territory), where cattle grazing occurs during the dry season, the river in flow has peak total Kjeldahl nitrogen concentrations of 1.5 mg/L, total phosphorus of 0.2 mg/L and filterable reactive phosphorus of 0.07 mg/L (Townsend and Edwards, 2003).

Grazing in Wet Tropics catchments is quite different to the Dry Tropics as pasture cover never falls to low levels, so erosion levels are generally low. For this land use, soil erosion is typically associated with streambank erosion due to cattle access. Loss of suspended solids and nutrients from dairy grazing on the upper Johnstone Catchment (southern Atherton Tableland) was studied experimentally by Prove *et al*. (1996). Losses were low compared to losses from sugarcane and bananas in the same study (Moody *et al*., 1996). These relatively low losses were confirmed by Hunter's catchment-scale studies in the Johnstone (see Tables 4 and 6, Hunter and Walton, 1997; Hunter *et al*., 2001).

5. Suspended sediments and nutrients in waters draining lands with a significant proportion of intensive land uses

5.1 Background

In general only about 40% of applied fertiliser N and P is incorporated into that part of the crop removed from the field for use (Moody *et al*., 1996; Reghenzani *et al*., 1996). The remainder may be left in the field as crop residues (stubble, trash), in the plant itself if it is a multi-year crop (sugarcane roots/stalks in ratoon crops; the trees themselves in tree crops) and in the soil (Robertson and Thorburn, 2000); or lost from the field to the atmosphere through volatilisation (mostly of ammonia from N fertilisers) and denitrification (loss of nitrogen gas or nitric oxide) (Freney *et al*., 1994); leaching to subsurface or groundwater (commonly as nitrate) (Weier, 1999; Bohl *et al*., 2000); or as runoff (all forms of N and P) (Faithful and Finlayson, 2003). Thus cropping systems tend to export high concentrations and produce large fluxes of N and P, often as DIN and DIP, as well as high soil erosion in some cases producing high runoff concentrations of PN and PP. In consequence, overall runoff from fertilised cropping contains high concentrations of PN (0.1 – 1.0 mg/L) and PP (0.05 – 0.15 mg/L), moderate concentrations of DON (0.1 – 1.0 mg/L) and DOP (0.01 – 0.1 mg/L) and high/very high concentrations of DIN (1 – 15 mg/L) and moderate/high concentrations of DIP (0.05 – 0.5 mg/L) (Brodie and Mitchell, 2005).

5.2 Sugarcane cultivation

Currently, sugarcane is harvested from over 400,000 ha on the Queensland and northern NSW coast with a small area on the Ord irrigation area (WA). Accelerated soil erosion in canelands was first recognised as a major source of sediment in a number of river systems when cane was predominantly burnt and hand-harvested. Annual soil loss rates up to 500 tonnes per ha were measured in sloping Johnstone River canelands under conventional tillage, burning and harvesting practices (Prove and Hicks, 1991; Prove *et al*., 1995) and 42-227 tonnes per ha around Mackay (Sallaway, 1979). With the move to green cane harvesting/trash blanketing (GCTB) with minimum tillage, soil erosion rates have dropped dramatically with average losses now less than 15 tonnes/ha/year (Prove and Hicks, 1991; Rayment and Neil, 1997; Rayment, 2003). Most of the cane grown in Queensland now uses GCTB (Rayment, 2003). Nutrient loss associated with soil erosion is also minimised under GCTB cultivation making losses of N and P associated with fertiliser the major source of nutrients from canelands in recent times. Soil loss in new cane lands can be severe and this has been anecdotally noted in the expansion lands of the Tully-Murray catchment during the 1990s. Such losses may partly explain the major rise in particulate nitrogen concentrations in the Tully River during the 1990s (Mitchell *et al*., 2001).

Sugarcane cultivation is the major user of fertiliser in northern Australia. With both increasing cultivation area and increasing rates of fertiliser application, the total amounts of fertiliser applied have increased rapidly since 1950 (Pulsford 1996). This expansion in fertiliser use mirrors that found globally associated with intensive agriculture (Vitousek *et al*., 1997). The efficiency of use of applied fertiliser, i.e. the proportion which is actually taken up by the crop, is often low (Bristow *et al*., 1998). High application rates of more mobile nutrients like N may be reflected in elevated nutrient concentrations in the water of receiving streams and rivers. However, the actual nutrient loading in the rivers depends on additional factors such as flow rate and status of wetlands, aquatic and riparian vegetation, which are in a poor state in some catchments (eg the Herbert see Johnson *et al.* 1999). Sugarcane receives most of the fertiliser applied to crops in northern Australia. Between 1950 and 1990, applications of nitrogen in fertiliser in Queensland have increased ten fold and phosphorus six fold (Pulsford, 1996). In the Tully region nitrogen fertiliser use increased from about 2090 tonnes per year (of N) in 1989 to 4750 tonnes in 1999 (Mitchell *et al*., 2001) associated with both increased cane planting, on lands which were before 1989 primarily used for beef grazing, and greatly increased banana cultivation.

Of the about 180 kg/ha/year of fertiliser N applied to sugar about 70 kg is taken up by the crop (Moody *et al*., 1996; Reghenzani *et al*., 1996) and goes to the mill. The remaining 110 kg/ha/year ends up in a number of environmental compartments including the atmosphere (volatilisation and denitrification) (Freney *et al*., 1994), groundwater (Bohl *et al*., 2000), runoff (Faithful and Finlayson, 2003) and soil storage (including trash storage) (Robertson and Thorburn, 2000). The proportion lost to each compartment depends on climate, weather, soil type, cultivation practices, fertiliser application practices and hydrology (McShane *et al*., 1993; Moody *et al*., 1996). A large fraction of the lost nitrogen reaches adjacent streams and rivers. This has been shown in the Johnstone River (Hunter *et al*., 1996; Hunter, 1997); Herbert River (Mitchell *et al*., 1997; Bramley and Roth, 2002); Burdekin River Irrigation Area (Congdon and Lukacs, 1996); the Pioneer River (Mitchell *et al*., 2005); the Tully River (Mitchell *et al*., 2001); the Russell-Mulgrave River (Devlin *et al*., 2001b); the Moresby River (Eyre, 1995); and the Mitchell River (Atherton Tableland) (Hunter and Armour, 2001).

Mitchell *et al.* (1997) note that there is potential for large nutrient exports from agricultural land during high intensity runoff events. Hunter and colleagues (Hunter and Walton, 1997; Hunter, 1997; Hunter *et al*., 1996; 2001) have shown that land use can have a marked effect on the discharge of sediments and nutrients in the Johnstone River catchment. Their results demonstrate that the export of sediments and nutrients from sugar growing areas can be "disproportionately high" (Table 25). It has been found that 35% of the total nitrogen load and 48% of the nitrate load came from sugarcane lands which occupy only 11.5% of the area of the catchment.

Table 25. Estimates of suspended sediment and nutrient load from the Johnstone River catchment (Hunter and Walton 1997).

	Catchment area (%)	Sediment load (%)	P load (%)	Total N load (%)	Nitrate-N load (%)
Rainforest	52	41	43	36	11
Sugar Cane	11.5	36	32	35	48
Bananas	1.9	8	7	8	14
Unsewered Residential	0.5	0.5	0.5	4	15
Pasture (beef)	20.1	12	14	11	0.001
Pasture (diary)	7.9	3	4	6	12

The information in Table 25 is supported by other studies, including CSIRO work on the Herbert (Johnson *et al*., 2001; Bramley and Muller, 1999; Bramley and Roth, 2002) that found that concentrations of nutrients in streams draining sugar cane were higher than for other land use types. Sugarcane production was found to have the most significant impact on riverine water quality compared to grazing and forestry as shown by higher concentrations of nitrogen, phosphorus and suspended solids in streamwaters draining lands primarily under sugarcane compared to the other landuses. The impacts on total nitrogen, total phosphorus and suspended solids for the three land uses are summarised in Table 26 (modified from Figure 5 of Bramley and Roth, 2002).

Table 26. **Herbert catchment SS and nutrient concentrations from different landuses (data from Bramley and Roth, 2002).**

Landuse (mainly)	Total nitrogen (mg/L)		Total phosphorus (mg/L)		Suspended solids (mg/L)	
	Median	**Range**	**Median**	**Range**	**Median**	**Range**
Forestry	0.15	0.05 – 0.7	10	.007 – 0.50	8	0 - 35
Grazing	0.60	0.1 – 1.5	40	0.01 – 0.17	10	0 - 75
Sugarcane	1.00	0.4 – 3.7	80	0.03 – 0,23	32	3 - 160

Work by the Australian Centre for Tropical Freshwater Research (ACTFR) (Congdon and Lukacs, 1996) in the Burdekin River Irrigation Area shows that nutrient concentrations downstream of sugarcane lands are higher than those upstream, with highest concentrations in established cane growing areas. Similar results were seen in the Mitchell catchment (Cattle Creek sub-catchment) on the Atherton Tableland (Hunter and Armour, 2001) where loads of N and P in streams receiving cane runoff were closely linked to irrigation runoff and fertiliser applications. Total nitrogen in event flows peaked above 24 mg/L N and 1 mg/L P with about 75% of the nitrogen present as dissolved N.

In the Herbert catchment, studies on runoff from sub-catchments dominated by sugarcane showed median DIN concentrations in flow events of 2 – 5 mg/l (Bramley and Muller, 1999). In cane drains and small streams, where the flow was completely made up of caneland runoff, DIN concentrations were in the range 9 – 11 mg/L (Pearson *et al*., 2003), with dominance by ammonium in some events and nitrate in others. In contrast, in adjacent small streams draining rainforest, DIN concentrations were around 0.06 mg/L, just 1-3% of the concentrations of runoff from sugarcane land. The difference in P concentrations between the rainforest and cane drainage streams was not as marked; 0.03 mg/L PO_4-P in cane runoff versus 0.015 mg/L PO_4-P from rainforest (50%). Similarly in the Tully catchment runoff from cane fields in drains and small streams had median concentrations of DIN (mostly nitrate) of 3.2 mg/L but with low concentrations of TP (median 0.06 mg/L) and FRP (median 0.004 mg/L) (Faithful and Finlayson, 2004).

N fertiliser is used by the majority of farmers at rates above the recommended rates for fallow plant cane while on replant and ratoon cane it is being applied in excess of recommendations by 45% and 44% of farmers respectively (Schroeder *et al.*, 1998; Rayment, 2003). Trash retention, the practice of cutting cane green (unburnt) and leaving the leaves (trash) on the soil as a trash blanket is now the primary means of cultivation in north and central Queensland. After about five years of trash retention about 50 kg/ha/year of N begins to be returned to the soil, and potentially, the crop and off-farm environment (Robertson and Thorburn, 2000; Thorburn *et al*., 2000). In some areas (Sarina/Mackay), dunder (a waste from alcohol distilling) is also added to sugarcane soils, as is millmud (a waste from sugar mill operations) in areas close to mills (Barry *et al*., 1998). These materials also contain N and P and along with the N and P from trash mineralisation, means substantial over-fertilisation is now occurring in many districts (Schroeder *et al*., 1998; Rayment, 2003). In many instances there is also an over-application of P fertiliser on cane lands (Bloesch *et al*., 1997; Bramley *et al*., 1998), an observation supported by soil test data from Queensland canelands (Rayment 2003). Around 80% of canegrowers have over-supplied P to their soils.

Fertiliser use can also profoundly change the status of nutrients in groundwater. Significant quantities of groundwater underlie many of the coastal river floodplains of the northern Australian coast. Elevated nitrate levels have been observed in groundwaters in many catchments underlying sugarcane, e.g. Burdekin (Brodie *et al*., 1984; Bauld *et al*., 1996; Keating *et al*., 1996; Biggs *et al*., 2001), Pioneer (Biggs *et al*., 2001; Baskeran *et al*., 2002), Johnstone (Rasiah and Armour, 2001; Rasiah *et al*., 2002; 2003), Herbert (Bohl *et al*., 2000; 2001), Burnett (Keating *et al*., 1996; Biggs *et al*., 2000). Weier (1999) sampled in excess of 1000 bores in sugarcane areas between northern NSW and the Mossman region for nitrate and found many had elevated nitrate concentrations and 33 exceeded the drinking water standard (50 mg/L of nitrate). An isotopic investigation revealed that the majority of nitrate contamination in groundwater was from inorganic sources, probably from surface applied N fertilisers.

Comment [GR1]: The research only separated organic from inorganic sources. It is a reasonable assumption that the inorganic source was originally from fertilizers but it could also derive from nitrification of soil N.

While natural sources of nitrate in groundwater do exist, groundwaters with nitrate concentrations > 1 mg/l NO_3 – N are generally a sign of fertiliser or sewage effluent contamination. Laurence (1983) found nitrate in some bores at concentrations above 10 mg/L NO_3 – N in most coastal Queensland areas in data collected before 1983 and Brodie *et al* (1984) found widespread high nitrate concentrations in the Burdekin delta area in 1976-1977. More recent sampling has confirmed the persistence of these elevated levels (Keating *et al*., 1996; Biggs *et al*., 2001). Biggs *et al*. (2001) note that although nitrate concentrations in the Mackay and Burdekin regions discussed in their study are generally high, mostly > 20 mg/L NO_3 (i.e. > 4.5 mg/L NO_3 – N) their trend analysis shows that concentrations do not appear to have generally increased over the period 1997 – 2000. They also point out that nitrate concentrations are so high in many of the bores used for irrigation in the Mackay and Burdekin regions that the water, given the irrigation volumes used, is a significant source of 'fertiliser' nitrogen. They calculate that a water application of 15 ML/ha with groundwater nitrate concentrations of 50 mg/L NO_3 (a frequent concentration) represents an input of N equivalent to 170kg/ha. This is in fact equal to or above the total required N fertiliser for sugarcane.

The Nutrient Balance project on the Johnstone Catchment showed that a considerable proportion of applied nitrogen fertiliser passed below the root zone (>0.75m) of sugarcane and banana crops. For sugarcane the losses to drainage average 30 to 50 kg N/ha/year and for bananas 70 to 130 kg N/ha/year. (Moody *et al*., 1996; Prove *et al*., 1996). This nitrate is believed to be the source of the 'nitrate bulge' found at some depth (4 - 10 m) in many parts of the Johnstone Catchment (Rasiah and Armour, 2001; Rasiah *et al*., 2002a; 2003). Concentrations of nitrate in soil of up to 72.5 mg/kg NO_3 – N have been found in this 'bulge' under sugarcane compared to concentrations of only up to 0.31 mg/kg NO_3 – N under rainforest. Over-application of nitrogen fertilisers on sugarcane crops can lead to substantial leaching of nitrate below the root zone (Verberg *et al*., 1998). Significant leaching of nitrate in alluvial soils in the Herbert floodplain is reported (Bohl *et al*., 2000; 2001) and believed to be a significant contribution to elevated levels of nitrate in streams after horizontal flow of nitrate rich subsurface flow in to streams. Over-application of fertiliser continues despite theoretical studies showing better returns to farms at lower fertiliser rates (Mallawaarachchi *et al*., 2002).

5.3 Horticulture

Only a few published studies have examined runoff or leaching of suspended solids and nutrients from northern Australian horticultural systems and their contributions to stream water quality. Overuse of fertiliser in horticulture is a well-recognised problem (Rayment, 1994) but usage on, for example, bananas in north Queensland has been decreasing greatly over the last decade (D. Pollock, pers. com.). Prove and colleagues studied nutrient budgets and losses of nutrients at the plot scale for bananas in the Johnstone catchment. Sugarcane and dairy pasture were also examined with a rainforest plot used as a control (Moody *et al*., 1996; McShane *et al*., 1993; Prove *et al*., 1996). Large leaching losses of nitrate (38 – 152 kg/ha/year) were recorded under bananas with the losses particularly high in the plant crop. Runoff of particulate nitrogen was a much smaller component of the total nitrogen loss. The major loss pathway for phosphorus was via suspended sediment in runoff. As suspended solids loads in runoff were generally low, phosphorus losses were small (Prove *et al*., 1996). More recent studies have shown (Faithful and Finlayson, 2004) considerable loss of N and P from banana cultivation. In studies of runoff events median concentrations of nitrate were 1.6 mg/L, TP 0.24 mg/L and FRP 0.08 mg/L.

At the catchment scale, Hunter and colleagues studied water quality in the Johnstone catchment and were able to allocate exports per unit area of suspended solids, nitrogen and phosphorus from various landuses, including rainforest, sugarcane, bananas, dairy pasture, beef pasture and unsewered residential (Hunter, 1997; Hunter and Walton, 1997; Hunter *et al*., 1996; 2001). Table 27 taken from Table 3.5 in Hunter *et al.* (2001) shows the annual exports for the different landuses. Bananas, which occupy 2% of the Johnstone land area are responsible for 8% of the suspended solids export, 7% of the phosphorus, 8% of the nitrogen and 14% of the nitrate (Hunter and Walton, 1997; Hunter *et al*., 2001).

Table 27. Annual average exports per unit area for various landuses in the Johnstone Catchment (from Hunter *et al*., 2001).

Landuse	Coast SS (t/ha/y)	TN (kg/ha/y)	TP (kg/ha/y)	Tablelands SS (t/ha/y)	TN (kg/ha/y)	TP (kg/ha/y)
Rainforest	1.2	8.9	2.3	0.3	3.0	0.8
Sugarcane	3.9	38.1	6.6	n/a	n/a	n/a
Bananas	4.0	42.2	6.8	n/a	n/a	n/a
Pasture (dairy)	n/a	n/a	n/a	0.3	6.3	0.8
Pasture (beef)	1.2	8.3	2.4	0.3	2.9	0.8
Unsewered residential	1.2	72.0	2.4	0.3	25.0	0.8

In the Tully basin a large increase in the use of nitrogen fertiliser has occurred as grazing lands have been converted to bananas and sugarcane in the period 1989 to 2000. This is reflected in an increase in particulate nitrogen concentrations by 100% and nitrate concentrations by 16% in the Tully River over the period 1987 – 1999 (Mitchell *et al*., 2001). During this period, the area under bananas and sugarcane doubled, while fertiliser nitrogen use increased by 130% (from 2090 tonnes to 4750 tonnes of N).

5.4 Cotton and grains

The influence of tillage methods on water balance and soil erosion on grain crops in central and southern Queensland has been studied for many years (eg Freebairn and Broughton, 1981; Freebairn and Wockner, 1986). Stubble left on the soil surface and no tillage reduced both runoff and the sediment concentration of runoff with soil erosion from no-tilled areas averaging 2 tonnes/ha/year compared to 30 – 60 tonnes/ha/year from bare fallow (Freebairn *et al*., 1996).

On cotton, considerable quantities of suspended sediments and nutrients are presently lost from fields that can be detected in the streamwaters of the Fitzroy catchment (particularly the Dawson sub-catchment) (Noble *et al*., 1997; Noble and Collins, 2000). Techniques such as retention of surface cover and controlling wheel traffic are known to minimise soil erosion and high – sediment runoff from cotton fields (Silburn and Glanville, 2002) but these are not widely adopted in the cotton industry on the Fitzroy catchment as yet. Irrigation tailwater capture and recycling are also known to reduce nutrient and sediment movement from cotton lands to streams (Rummenie and Noble, 1996). Considerable unpublished data are available for runoff from cotton on the Fitzroy catchment (Carroll, pers. com.; Noble, unpublished) and, along with the published studies of water quality in the Fitzroy (Noble *et al*., 1997; Noble and Collins, 2000; Carroll *et al*., 1992), these data can be used to increase our understanding of runoff from cotton. Nitrate concentrations in runoff from irrigated cotton can be large (10 – 100 mg/L NO_3 – N, Noble, unpublished), but as the runoff tailwater is often reused several times before eventual release to the river, fluxes of nitrogen are considerably less than estimated from the runoff concentration data alone (Bob Noble, pers. comm.).

6. River transformations and transport of materials through waterways

Australian rivers have, in general, highly irregular flow regimes (Finlayson and McMahon, 1988) and transport of materials, such as suspended sediments, nutrients and pesticide residues, in both dissolved and particulate forms occurs almost completely in major flow conditions (Furnas and Mitchell, 2001). In these conditions, while some trapping of coarser washload sediments may occur within the catchment, there is almost no trapping of the finer sediments, with their PP and PN component, or dissolved nutrients. Rivers flush fresh to the sea in the major flow events (in sub-tropics rivers see Eyre, 1998; McKee *et al*., 2000; for the Burdekin, Wolanski and Jones, 1981; for the GBR rivers, Devlin *et al*., 2001a). A large proportion of nutrients mobilised in the catchments in major flood events are therefore completely exported to the ocean. Some trapping of finer sediments from the washload occurs in the estuary of rivers eg in the Pioneer (Goulay and Hacker, 1986), Johnstone (Arakel *et al*., 1989) and Normanby (Bryce *et al*., 1998) but the Burdekin, for example, essentially has no traditional estuary. For the Burdekin, most silt and sand is deposited in a sub-tidal delta seaward of the main mouths (Pringle, 1991).

The forms of nutrients vary in downstream transport due to instream processes such as carbon metabolism, sedimentation, species transformations mediated by bacterial action and denitrification (Downing, 1997; Behrendt and Opitz, 2000). Many of these processes require considerable time and thus may be a minor factor in many northern Australian rivers due to their fast flow in major events and subsequent lack of time for such processes to occur. Probable river transit times in north-eastern Australian rivers range from about 12 days maximum for the Burdekin and Fitzroy Rivers to only one to two days for the smaller coastal rivers. Harris (2001) has shown removal of DIN (as shown in DIN:TN ratios) down the Murray River in southern Australia but residence times are of the order of many weeks in this system. In anoxic conditions (in sediments or bottom waters) DON is converted to ammonia and then to nitrate and is exported downstream. Reservoirs export nitrate which has originally entered the reservoir as PN or DON and, in time, been converted to nitrate in the reservoir (Harris, 2001). Reservoirs thus often export nitrate in far greater concentrations than the intake water. Evidence for this occurring in northern Australian reservoirs is seen in data from Teemburra Dam on the Pioneer River (Brodie, 2004) and Peter Faust Dam on the Proserpine River (Faithful, 2002).

Queensland Wet Tropics catchments are relatively small (compared to, for example, the Burdekin) and will discharge most of their load of fine sediments and dissolved material completely to the mouth in significant flow events. This behaviour has been shown for Australian east coast sub-tropical rivers such as the Richmond (Hossain *et al*., 2002) and Brisbane River (McKee *et al*., 2000). Prosser (1996) noted that the vast majority of sediment eroded from agricultural lands in the Johnstone River catchment is not stored within the catchment but is quickly delivered to the mouth of the river. Wasson (1997) used Prosser's results to estimate a sediment 'delivery ratio' of 34%.

The delivery ratio is a useful measure, a function of the great variation between the delivery of different sized sediment particles due to differential trapping. Total delivery (of fine-size sediments) and no trapping is given a ratio of 100%, while total sequestration (of course-size sediments) is given a ratio of 0%. There will be a high delivery ratio of 'fines' (fine sediment particles) to the river mouth, principally in the washload (suspended sediments), and a low delivery ratio of coarse sediments, principally in the bedload. The 34% delivery ratio is a mean of these two extremes and will be principally composed of fines.

Fines, organics and clays are transported with delivery ratios of ~ 100% (Novotny & Chesters, 1989), while it is known that pollutants (eg phosphates, ammonium and many pesticides) associated with soil particles contained in runoff sediments may be present in higher concentrations than in the parent soil. This difference is termed the enrichment ratio (Novotny and Chesters, 1989). Almost all of the nitrogen lost from catchment lands will be in fine particulate or dissolved form and thus the delivery ratio for nitrogen to the river mouth will be very high. In many Wet Tropics catchments much of the nitrogen is sourced from fertiliser or sewage discharge and thus a large proportion will be in dissolved form, particularly as nitrate and ammonia. Delivery of this form of nitrogen in significant flow events, when most of the export occurs, will be almost 100%. Almost all phosphorus lost from Wet Tropics catchment lands will be in fine particulate or dissolved form and as such also have a high delivery ration to the river mouth (Pailles and Moody, 1996). In contrast to nitrogen, the proportions of phosphorus in particulate form compared to dissolved forms will be higher and the catchment and the estuary may trap more phosphorus than nitrogen (Pailles and Moody, 1992; Pailles *et al*., 1996). Thus, a large proportion of nitrogenous forms of nutrients mobilised in the catchments in major flood events are completely exported to coastal waters (Brodie *et al*., 2003).

7. Overall river concentrations in northern Australia

The large quantities of sediment, nitrogen, phosphorus and significant amounts of pesticides lost from agricultural systems are easily measurable in northern Australian rivers where monitoring has occurred. River discharge from catchments dominated by agriculture typically have, for example, dissolved inorganic nitrogen (nitrate and ammonia) concentrations in flood flow 30 times that of rivers with undeveloped catchments (0.14 – 1.4 mg/L compared to 0.014–0.070 mg/L) (Eyre and Davies, 1996; Faithful, 1990; Faithful and Brodie, 1990; Hunter *et al*., 1996; Noble *et al*., 1997; Mitchell *et al*., 1997; Mitchell *et al*., 2001; Bramley and Roth, 2002; Furnas, 2003). Furnas (2003) shows data comparing the Normanby River, with low intensity grazing (about 2 animals per km^2), with the Burdekin and Fitzroy Rivers, with moderate to high intensity rangeland grazing (about 10 animals per km^2) but all three catchments with a 'dry tropics' climate regime. Median and mean concentrations in the rivers (Table 28) show the elevation of nitrate (large) and PN (moderate) in the rivers with more intensive grazing regimes, i.e. more cattle per ha (Furnas, 2003).

Table 28. Nitrogen species concentrations in Queensland dry tropics rivers (data from Furnas, 2003)

River	Ammonium (mg/L)		Nitrate (mg/L)		DON (mg/L)		PN (mg/L)	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Normanby	0.025	0.020	0.010	0.010	0.250	0.220	0.270	0.250
Burdekin	0.025	0.015	0.150	0.120	0.150	0.160	0.650	0.250
Fitzroy	0.020	0.015	0.220	0.210	0.140	0.150	0.550	0.370

In rivers where the upper catchment is undeveloped, lightly developed or used for rangeland grazing flood waters from this part of the catchment have low concentrations of dissolved inorganic nutrients (e.g. 0.014–0.140 mg/L for nitrogen). In contrast, waters discharging from the same catchment, after passing through cropping and urban dominated lower catchment and floodplain, have high concentrations of dissolved inorganic nutrients (e.g. 0.140– 1.400 mg/L for nitrogen) (Furnas, 2003).

Rivers discharging into northern Australian coastal waters can reveal catchment landuse by the concentrations of various forms of nutrients present in their flood flow (as has been already mentioned this type of relationship has been carried out using nitrate for world rivers (Caraco and Cole, 1999)). Furnas (2003) shows the percentage of nitrogen present as nitrate and the percentage of phosphorus present as orthophosphate at a number of stations in Queensland rivers over a number of years. The rivers of the Wet Tropics (South Johnstone, Tully and lower Herbert), with a considerable proportion of fertilised agriculture in their catchments, have high proportions of nitrate – generally above 30%. Rivers in the Dry Tropics (upper Herbert, Burdekin and Fitzroy), with a low proportion of fertiliser use in the catchment have lower proportions, generally less than 30% for nitrate. The effect is probably also increased by the difference in rainfall between the two groups of rivers. The pattern is not clear for orthophosphate.

In general, rivers with substantial catchment development have concentrations of SS of 50 – 2000 mg/L; TN of 0.2 – 3.0 mg/L; TP of 0.2 – 1.0 mg/L; and nitrate 0.05 – 1.0 mg/L NO_3 – N. The biggest difference in rivers with limited or no catchment development is that nitrate concentrations are far lower, often in the range 0.001 – 0.50 mg/L NO_3 – N. The concentrations of N and P in the rivers with substantial catchment development during major flow conditions are similar to large overseas rivers that are substantially polluted (Turner *et al*., 2003). In the Tully River mean PN concentrations have increased by 100% from about 0.1 to 0.2 µg/L in the period 1987 to 2000 while mean nitrate concentrations rose by 16% in the same period (Mitchell *et al*., 2001). Rivers with substantial proportions of sugar generally have poor water quality in terms of nutrients and exceed ANZECC trigger values (ANZECC and ARMCANZ, 2000; Wilhelm, 2001; Hunter *et al*., 2003). In addition to surface runoff sub-surface flows are considered to be an important mechanism conveying dissolved nutrients to rivers and streams. Concentrations of DIN and DIP in sub-surface and groundwaters in sugarcane lands are similar to concentrations in surface runoff event flows.

8. Implications for aquatic ecosystems

The information presented in this review indicates that changes in the nutrient status of northern Queensland streams following agricultural development are not dissimilar to changes seen in other parts of the world. With increased grazing pressure soil erosion increases and concentrations of PN and PP increase greatly in runoff. While not all the released N and P is bioavailable (particularly the case for PP where mineral P may form a substantial proportion of the PP) large increases in the amount of bioavailable N and P available to downstream ecosystems occurs. With increased fertilised cropping large losses of dissolved inorganic nitrogen occur and also increased phosphorus losses. The N and P lost are highly bioavailable in contrast to the DON and DOP lost from 'natural' systems. Thus overall, catchment agricultural development has led to both greatly increased losses of N and P to downstream aquatic ecosystems and an increase in the proportion of bioavailable N and P in the export. The stoichiometry of C:N:P (and possibly to Si) will probably have also changed but data from northern Queensland are too limited at present to perform this analysis.

The effects of these changes in nutrient export are now being realised. Freshwater ecosystems such as lakes, reservoirs, billabongs and wetlands are showing signs of eutrophication and, in combination with the introduction of exotic weeds, degraded. This has been reported for floodplain wetlands on the north – east Queensland coast (Finlayson and Lukacs, 2003), reservoirs with significant cyanobacteria bloom problems (Bormans *et al*., 2004) and estuaries. At a larger scale, some coral reefs of the inner-shelf of the Great Barrier Reef have suffered degradation associated with increased nutrient (and sediment) discharge from the land associated with agricultural development in the GBR catchment (Brodie, 2002; van Woesik *et al*., 1999; Fabricius and De'ath, 2004; Fabricius *et al*., 2005). There is concern in many places that further cropping development with minimal farm runoff management will cause further degradation. Continued agricultural development, especially fertilised cropping, without adequate management of nutrient losses, is likely to exacerbate these problems in northern Australia.

9. Data set references

Set 1 **Butler, B., Birtles, A., Pearson, R. and Jones, K.** (1996) Ecotourism, Water Quality and Wet Tropics Streams. ACTFR Report No. 96/11.

Set 2 **Bramley, R.G.V. and Muller, D.E.** (1999) Water Quality in the Lower Herbert River – The CSIRO dataset. CSIRO Land and Water, Technical Report 16/99.

Set 3 **Pearson, R. and Clayton, P.** (1993) Teemburra Creek Dam Study, Part A. Hydrological, Biological and Water Quality Surveys. ACTFR Report No. 93/01.

Set 4 **Pearson, R.G. and Penridge, L.K.** (1992) An Ecological Survey of Selected Rivers in Queensland. With Particular Reference to the Effects of Sugar Mill Effluents. ACTFR Report No. 92/02.

Set 5a **Faithful, J and Brodie, J.** (1990) Tully-Millstream Hydroelectric Scheme. Water Quality Sampling and Testing Program. Post Wet-Season Monitoring Program. Technical Report No. 90/09.

Set 5b **Anonymous (1991)** Tully-Millstream Hydroelectric Scheme. Water Quality Sampling and Testing Program. Unpublished data.

Set 6 **White, I., Brodie, J. and Mitchell, C.** (2002) Pioneer River catchment event-based water quality sampling. Healthy waterways Program, Mackay-Whitsunday Regional Strategy Group.

Set 7 **Faithful, J.W. and Butler, B.M.** (1994) A Limnological Assessment of Lake Proserpine with reference to management implication. ACTFR Final Report, No. 94/07.

Set 8 **Pearson, R., Crossland, M., Butler, B. and Manwaring, S. (2003)** Effects of cane-field drainage on the ecology of tropical waterways. ACTFR Report No. 3/04 – 1. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Set 9 **Burrows, D.W. and Faithful, J. (2003)** Townsville Field Training Area (TFTA) Ecological Monitoring - Monitoring of aquatic ecology, water and sediment quality on the Townsville Field Training Area, November 2002 to June 2003. ACTFR Report No. 03/12

Set 10 **Faithful, J. (2002)** Water quality in the Townsville/Burdekin Dry Tropics Region. ACTFR Report No. 02/12

Set 11 **Laxton, J.H., Hansen, M.M. and Duell, J.D. (1994)** Ecology of creeks in Sarina and Broadsound shires, Central Queensland (1989-1993). Part 1 – Water quality. Private Research Paper, J.H. & E.S. Laxton – Environmental Consultants P/L, St Ives, NSW, 91pp.

Set 15a **Wright, M. (1997)** Waterwatch Report, Pioneer Catchment. Data collected by community volunteers. 29pp.

Set 15b **Wright, M. (1998)** Second Waterwatch Report, Pioneer Catchment. Data collected by community volunteers, 1 Jan 1996 to 1 Jan 1998. 39pp.

Set 15c **Bensted, P. and Wright, M. (1997)** Waterwatch Report, Plane Creek Catchment. Data collected from November 1995 to June 1997. 28pp.

Set 16 **Set now renamed as Set 5b.**

Set 17 **Ryan, T.J., Aland, G. and Cogle, A.L. (2002)** Environmental Condition of the Upper Mitchell River system. Water quality and ecology. A report prepared for the National Heritage Trust (Ref No.: 96-2005), Queensland Department of Natutral resources and Mines and the Queensland department of Primary Industries. 103pp.

Set 18 **Congdon, R.A. and Lukacs, G.P (1995)** Limnology and Classification of Tropical Floodplain Wetlands, with particular reference to the effects of irrigation drainage. Part 1. Temporal changes in water quality. LWRRDC/QDPI-WR Partnership Project; LWRRDC R & D Project JCUI. ACTFR Report No. 95/12.

Set 19 **Congdon, R.A. (1991)** Effects of Irrigation Discharge on the Barrattas Wetlands. ACTFR Report No. 91/06.

Set 20 **Congdon, R.A. and Pearson, R.G. (1992)** Limnology and Classification of Tropical Floodplain Wetlands, with particular reference to the effects of irrigation drainage. Milestone Report No. 1, January, 1992. LWRRDC/QDPI-WR Partnership Project: ACTFR Report No. 92/01.

Set 21 **Noble, R.M., Duivenvoorden, Rummenie, S.K., Long, P.E. and Fabbro, L.D. (1997)** Downstream effects of land use in the Fitzroy catchment. November 1993 to December 1996. Summary Report, December 1996. 97pp.

Set 22 **Faithful, J. (2003) Water quality in the Whitsunday Rivers catchments. Surface Water Quality – December 2000 to August 2002, Volume 1 – Main Report, Report No. 02/13 (2003)** Coastand Clean Seas Project. A report to WhitsundayRivers Integrated Catchment Management Association, Proserpine, Queensland.

Set 23 **Cogle, A.L., Langford, P.A., Kistle, S.E., Ryan, T.J., McDougall, A.E., Russell, D.J. and Best, E. (2000)** Natural Resources of the Barron River Catchment 2; Water Quality, Land Use and Land Management interactions. DPI Queensland, Natural Heritage Trust. Information Series Q100033. 87 pp.

Set 24 **M.E. Cox, A. Moss and G. K. Smyth (2005)** Water quality condition and trend in North Queensland waterways. Marine Pollution Bulletin 51, 89-98.

Set 25 **Devlin, M., Waterhouse, J., Taylor, J., Brodie, J.** (2001a) Flood plumes in the Great Barrier Reef: spatial and temporal patterns in composition and distribution. GBRMPA Research Publication No 68, Great Barrier Reef Marine Park Authority, Townsville, Australia.

Set 26 **Hunter, H., Sologinkin, S., Choy, S., Hooper, A., Allen, W., Raymond, M., Peeters, J.** (2001) Water management in the Johnstone Basin. Queensland Department of Natural Resources and Mines, Brisbane.

Set 27 **Anon (2000)** Testing the Waters, DPI Report.

Set 28 **Faithful, J. and Finlayson, W. (2004)** Water Quality Assessment for Sustainable Agriculture (Tully-Murray Rivers Catchment Area and Granite Creek on the Atherton Tablelands). NRM Board (Wet Tropics) Inc, Innisfail. ACTFR Report No. 03/18.

Set 29 **Noble, R.M. (2000)** River Health in the Fitzroy Catchment, Community Ownership, January 1997 – December 1999. DNR, Rockhampton.

Set 30 **Cogle, L., Gourley, J, Herbert, B. and Best, E. (1998)** Nutrient Control Strategy for Tropical Catchments. Final Report of NLP funded Project. DNR Mareeba.

Set 31 **Mitchell, A., Rasmussen, C., Blake, S., Congdon, R., Reghenzani, J., Saffigna, P. and Sturmey, H. (1991)** Nutrient status and trends in waters of the Great Barrier Reef Marine Park. In: 'Landuse Patterns and Nutrient Loading of the Great Barrier Reef Region'. (Ed.) D. Yellowlees, Proceedings of Workshop, Nov. 1990, James Cook University, Townsville. pp. 108-161.

Set 32 **Taylor, J.P. (1991)** An Investigation of Riverine Nutrient Dynamics as a Potential Source of Nutrients to the Marine Environment. PhD Thesis submitted plus Appendices, JCU Townsville. 172 pp.

Set 33 **Pearson, R., Butler, B, Nolen, J. Christidis, F., Connolly, N., Cairns, A. and Davis, L. (1998)** Stream Ecosystems as Monitors of Tropical Forest Catchments. LWRRDC Project: JCU8, Final Report. ACTFR Report No. 98/26.

Set 34 **Faithful, J., Brodie, J., Bubb, K. and Armstrong, C. (2005)** Water Quality of Runoff Draining from Pine Plantation, Native Forest and Agricultural Crops in the Whitfield Creek Catchment, Located in the Wet Tropics of North Queensland, Australia in the 2003/04 Wet Season.. Draft ACTFR Report No. 05/02.

Set 35 **Laxton, J.H. and Gittins, R. (2004)** Water Quality of Pristine sections of Rivers of Eastern Australia draining to the Tasman Sea. Private research Project, October 2004. J.H. & E.S. Laxton – Environmental Consultants P/L, Sydney. 204 pp.

10. References

Accad, A., Neldner, V.J., Wilson, B.A., Niehus, R.E. (2001) Remnant vegetation in Queensland: Analysis of pre-clearing, remnant 1997-1999 regional ecosystem information. Queensland Herbarium, Environmental Protection Agency, Mount-Cootha, Brisbane.

Aitkenhead, J.A. and McDowell, W.H. (2000) Soil C:N ratio as a predictor of annual riverine DOC flux at local and global scales. *Global Biogeochemical Cycles* **14,** 127-138

Arakel, A.V., Hill, C.M., Piorewicz, J. and Connor, T.B. (1989) Hydro-sedimentology of the Johnstone River estuary. *Hydrobiologia* **176/177**, 51-60.

Arthington, A.H., Marshall, J.C., Rayment, G.E., Hunter, H.M. and Bunn, S.E. (1997). Potential impact of sugar cane production in riparian and freshwater environments. In: Keating, B.A., Wilson, J.R. (eds). Intensive sugarcane production: Meeting the challenges beyond 2000. CAB International, Wallingford, UK. Pp 403-421.

Baldwin, C. (1990). *Impact of elevated nutrients in the Great Barrier Reef.* GBRMPA Research Publication No 20, GBRMPA, Townsville.

Barry, G.A., Price, A.M. and Lynch, P.J. (1998). Some implications of the recycling of sugar industry by-products. *Proceedings of the Australian Society of Sugar Cane Technologists* **20,** 52-55.

Barson, M., Randall, L., Bordas, V. (2000) Land cover change in Australia: Results of the collaborative Bureau of Rural Sciences - State Agencies on the remote sensing of agricultural land cover changes. Bureau of Rural Sciences, Canberra

Baskeran, S., Brodie, R.S., Budd, K.L., Plazinska, A.J. (2001) Assessment of groundwater quality and origin of saline groundwaters in the coastal aquifers of Bowen area, North Queensland. Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Canberra.

Baskeran, S., Budd, K.L., Larsen, R.M., Bauld, J. (2002) A groundwater quality assessment of the lower Pioneer Catchment, Queensland. Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Canberra.

Bauld, J., Leach, L.L. and Sandstrom, M.W. (1996) Impact of land use on groundwater quality in the Burdekin River Delta and the Burdekin River Irrigation Area (Abstract only). In: Hunter, H. M., Eyles, A. G., and Rayment, G. E (eds.). *Downstream Effects of Land Use*. Queensland Department of Natural Resources, Brisbane, Australia. pp. 195-196.

Beaulac, M.N. & Reckhow, K.H. (1982) An examination of land use – nutrient export relation-ships. *Water Resources Bulletin* **18,** 1013–1024

Behrendt, H. and Opitz, D. (2000) Retention of nutrients in river systems: dependence on specific runoff and hydraulic load. *Hydrobiologia* **410,** 111-122

Bell, P. R. F. & Elmetri, I. (1995). Ecological indicators of large-scale eutrophication in the Great Barrier Reef lagoon. *Ambio* **24,** 208-215.

Bennell, N. (1979) Coastal land development - a shadow over the Great Barrier Reef. *Australian Parks and Recreation Nov, 1979*, 41-45.

Biggs, J., Keating, B., Thorburn, P. (2000) Time trends of nitrate in groundwaters under intensive agriculture in the Bundaberg region. *Proceedings of the Australian Society of Sugar Cane Technologists* **22,** 296-301.

Biggs, J., Thorburn, P., Weier, K.L., Hopp, M.L. (2001) Nitrate in groundwaters in Mackay and Burdekin regions. *Proceedings of the Australian Society of Sugar Cane Technologists* **23,** 77-83.

Bloesch, P.M., Rayment, G.E., Pulsford, J.S. (1997) Regional total phosphorus budgets for sugar production in Queensland. *Proceedings of the Australian Society of Sugar Cane Technologists* **19,** 213-220.

Boesch, D.F., R.B. Brinsfield, and R.E. Magnien. (2001) Chesapeake Bay eutrophication: Scientific understanding, ecosystem restoration, and challenges for agriculture. *Journal of Environmental Quality* **30,** 303-320.

Bohl, H.P., Mitchell, D.C., Penny, R.S., Roth, C.H. (2000) Nitrogen losses via subsurface flow from sugar cane on floodplain soils in the Australian wet tropics. *Proceedings of the Australian Society of Sugar Cane Technologists* **22,** 302-307.

Bohl, H.P., Roth, C.H., Tetzlaff, D., Timmer, J. (2001) Estimation of groundwater recharge and nitrogen leaching under sugarcane in the Ripple creek catchment, lower Herbert. *Proceedings of the Australian Society of Sugar Cane Technologists* **23,** 84-89.

Boormans, M., Ford, P.W., Fabbro, L. and Hancock, G. (2004) Onset and persistence of cyanobacterial blooms in a large impounded tropical river, Australia. *Marine and Freshwater Research* **55,** 1-15.

Bramley, R. and Roth, C. (2002) Land-use effects on water quality in an intensively managed catchment in the Australian humid tropics. *Marine and Freshwater Research* **53,** 931-940.

Bramley, R., Edis, R., White, R. and Wood, A. (1998). Environmentally sound phosphorus management for sugarcane soils. Final report on SRDC Project No. CSS3S. (Australian Sugar research and development Corporation: Brisbane, Australia).

Bramley, R.G.V. and Muller, D.E. (1999) Water Quality in the Lower Herbert River - The CSIRO Dataset. CSIRO Land and Water Technical Report 16/99, CSIRO, Canberra.

Bristow, K.L., Thorburn, P.J., Sweemey, C.A. and Bohl, H.P. (1998). Water and nitrogen balance in natural and agricultural systems in the Wet Tropics of north Queensland: a review. Occasional paper RAPPS03/98, Land and Water Resources Research and Development Corporation, Canberra.

Brodie, J.E. (1995) The problems of nutrients and eutrophication in the Australian marine environment. In: Zann, L.P., Sutton D.C. (Eds.). The State of the Marine Environment Report for Australia. Technical Annex 2: Pollution. Department of Environment, Sports and Territories Special Report, Canberra. 39 pp.

Brodie, J.E. (2002). Keeping the wolf from the door: managing land-based threats to the Great Barrier Reef. In: *Proceedings of the 9th International Coral Reef Symposium*. October, 2000, Bali, Indonesia. **2,** 705-714.

Brodie, J. (2004). Mackay Whitsunday Region: State of the Waterways. ACTFR Technical Report No. 02/03, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Brodie, J.E., Hicks, W.S., Richards, G.N., Thomas, F.G. (1984) Residues related to agricultural chemicals in the groundwaters of the Burdekin River delta, north Queensland. *Environmental Pollution (Series B)* **8,** 187-215.

Brodie, J.E., Christie, C., Devlin, M., Haynes, D., Morris, S., Ramsay, M., Waterhouse, J., Yorkston, H. (2001a) Catchment management and the Great Barrier Reef. *Water Science and Technology* **43(9),** 203-211.

Brodie, J.E., McKergow, L.A., Prosser, I.P., Furnas, M., Hughes, A.O. & Hunter, H. (2003). Sources of sediment & nutrient exports to the Great Barrier Reef World Heritage Area. ACTFR Report No. 03/11, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville. 191 p.

Brodie, J., Faithfull, J. and Cullen, K. (2004). Community water quality monitoring in the Burdekin River catchment and estuary: 2002 – 2003. ACTFR Technical Report No. 04/15, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Bryce, S., Larcombe, P. and Ridd, P.V. (1998) The relative importance of landward-directed tidal sediment transport versus freshwater flood events in the Normanby River estuary, Cape York Peninsula, Australia. *Marine Geology* **149,** 55-78.

Bubb, K.A., Yu, B., Cakurs, U., Costantini, A. (2000) Impacts of site preparation techniques on runoff, soil and nitrogen losses during the establishment phase in hoop pine plantations of southeast Queensland. *Australian Forestry* **63,** 239-245.

Bubb, K.A., Frayne, P.F., Wittmer, T.R. (2001) Impacts on stream and groundwater quality during the inter-rotation phase of a Pinus plantation in the coastal lowlands of south-east Queensland. *Australian Forestry* **65,** 38-46.

Butler, B., Birtles, A., Pearson, R., Jones, K. (1996) Ecotourism, WQ and Wet Tropics Streams. ACTFR Technical Report No. 96/11, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Cappo, M., Alongi, D., Williams, D. and Duke, N. (1998). A review and synthesis of Australian fisheries habitat research. Volume 2: Scoping review. Australian Institute of Marine Science, Townsville, Australia.

Caraco, N. F. and J. J. Cole. (1999). Human impact on nitrate export: An analysis using major world rivers. *Ambio* **28(2),** 167-170.

Caraco, N.F., J.J. Cole. (2001) Human influence on nitrogen export: a comparison of mesic and xeric catchments. *Marine and Freshwater Research* **52,** 119-125.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smith, V.H. (1998) Non point pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* **8,** 559-568

Carroll, C., Lawrence, P.A., Silburn, D.M., Ciesolka, C.A.A., Halpin, M. (1992) Impact of agricultural land use on inputs to the Fitzroy River system. In: Duivenvoorden, L. J., Yule, D. F., Fairweather, L., Lawrie, G. (Eds.). Proceedings of the Fitzroy Catchment Symposium, 12-13 November, 1992, University of Central Queensland, Rockhampton.

Ciesiolka, C. (1987) Catchment management in the Nogoa watershed. Australian Water Resource Council Research Project 80/129. Queensland Department of Primary Industry, Brisbane, 204 p

Clayton, P., Pearson, R. (1992) Instream effects of dunder application to canefields in the Sarina region, Queensland. ACTFR Report No. 92/17, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Cloern, J.E. (2001). Review. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series* **210,** 223-253.

Cogle, A.L., Langford, P.A., Kistle, S.E., Sadler, G., Ryan, T.J., McDougall, A.E., Russell, D.J., Best, E. (2000) Natural Resources of the Barron River Catchment 2 - Water Quality, land use and land management interactions. Department of Primary Industries, Brisbane. http://www.barronriver.com.au/Barron_Report_2.pdf

Congdon RA, Lukacs GP (1996) Water quality aspects of irrigation runoff from the Burdekin River irrigation area. In: Hunter, H.A., Eyles, A.G., Rayment, G.E. (Eds.) Downstream Effects of Land Use. Queensland Department of Natural Resources, Brisbane, pp 73-76

Correll, D.L. (1998). The role of phosphorus in the eutrophication of receiving waters: A review. *Journal of Environmental Quality* **27,** 261–66.

Dahm, C.N., Baker, M.A., Moore, D.I. and Thibault, J.R. (2003). Coupled biogeochemical and hydrological response of streams and rivers to draught. *Freshwater Biology* **48,** 1219-1231.

Devlin, M., Waterhouse, J., Brodie, J. (2001) Community and connectivity: Summary of a community based monitoring program set up to assess the movement of nutrients and sediments into the Great Barrier Reef during high flow events. *Water Science and Technology* **43(9),** 121-131.

Dillon, P.J. and Kirchner, W.B. (1975). The effect of geology and land use on the export of phosphorus from watersheds. *Water Research*, **9,** 135-148.

Dillon, P.J. and Molot, L.A. (1997) Effect of landscape form on export of dissolved organic carbon, iron and phosphorus from forested stream catchments. *Water Resources Research* **33,** 2591-2600

Dilshad, M., Motha, J.A., Peel, L.J. (1996) Surface runoff, soil and nutrient losses from farming systems in the Australian semi-arid tropics. *Australian Journal of Experimental Agriculture* **36,** 1003-1012.

Downing, J.A. (1997). Marine nitrogen:phosphorus stoichiometry and the global N:P cycle. *Biogeochemistry* **37,** 237-252.

Downing JA, McClain ME, Twilley R, Melack JM, Elser J, Rabalais NN, Lewis WM, Turner RE, Corredor J, Soto D, Yanez-Aranciba A, Kopaska JA & Howarth RW. (1999). The impact of accelerating land-use change on the N-cycle of tropical aquatic ecosystems: Current conditions and projected changes. *Biogeochemistry* **46,** 109-148.

Environment Western Australia (1998). Western Australian State of the Environment Report, Department of Environmental Protection, Perth, Australia. 125 p.

Eyre, B. (1995) A first-order nutrient budget for the tropical Moresby Estuary and catchment, north Queensland, Australia. *Journal of Coastal Research* **11(3),** 717-732.

Eyre, B.D. (1998) Transport, retention and transformation of material in Australian estuaries. *Estuaries* **21,** 540-551.

Eyre B, and Davies P (1996) A preliminary assessment of suspended sediment and nutrient concentrations in three far north Queensland catchments. In: Hunter, H.A., Eyles, A.G., Rayment, G.E. (Eds.) Downstream Effects of Land Use, Queensland Department of Natural Resources, Brisbane, pp 57–64.

Eyre, B.D. and Pepperell, P. (1999). A spatially intensive approach to water quality monitoring in the Rous River catchment, NSW, Australia. *Journal of Environmental Management* **56,** 97-118.

Fabricius, K.E. and De'ath, G. (2004). Identifying ecological change and its causes: A case study on coral reefs. *Ecological Applications* **14,** 1448-1465.

Fabricius, K., De'ath, G., McCook, L., Turak E. and Williams. D.B. (2005). Changes in algal, coral and fish assemblages along water quality gradients on the inshore Great Barrier Reef. *Marine Pollution Bulletin* **51(1-4),** 384-398.

Faithful, J. (1990) Tully-Millstream hydroelectric scheme: Water quality sampling and testing program. Dry season monitoring program. ACTFR Technical report No. 90/14, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Faithful, J. (2002) Water quality in the Whitsunday Rivers catchments. ACTFR Technical report No. 02/13, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Faithful, J. and Finlayson, W. (2004) Water quality assessment for sustainable agriculture: Tully-Murray Rivers catchment area and Granite Creek, Atherton Tablelands. ACTFR Technical report No. 03/18, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Faithful J., Brodie J. (1990) Tully-Millstream hydroelectric scheme: Water quality sampling and testing program. ACTFR Technical report No. 90/09, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville

Fenn, M.E., Poth, M.A., Aber, J.D., Baron, J., Bormann, B., Johnson, D., Lemly, A., McNulty, S., Ryan, D. and Stottlemyer, R.. (1998) Nitrogen excess in northern American ecosystems – predisposing factors, ecosystem responses and management strategies. *Ecological Applications* **8,** 706-733

Finlayson, B.L. and Brizga, S.O. (1993). Anastomosing channels and arroyo development on the Nogoa River, Central Queensland, Australia. *Sedimentary Geology* **85,** 179-190.

Finlayson, B.L., McMahon, T.A. (1988) Australia v the World: A comparative analysis of streamflow characteristics. In; Warner, R.F. (Ed.) Fluvial Geomorphology of Australia. Academic Press.

Finlayson, C.M. and Lukacs, G.P. (2003). Status of wetlands in northern Australia. In: Dawson, N., Brodie, J., *et al*., (Eds.) Proceedings of the 2nd National Conference on Aquatic Environments: Sustaining our aquatic environments- Implementing solutions. Queensland Department of Natural Resources and Mines, Brisbane, Australia.

Freebairn, D. and Broughton, W. (1985). Hydrological effects of crop residue management practices. *Australian Journal of Soil Research* **23,** 23-35.

Freebairn, D. and Wockner, G.H. (1986) A study of soil erosion on vertisols of the eastern Darling Downs, Queensland. II. The effect of soil, rainfall and flow conditions on suspended sediment losses. *Australian Journal of Soil Research* **24,** 159-172.

Freebairn, D., Truong, P., Miles, R., Ciesiolka, C., Titmarsh, G. and Norrish, S. (1996). Practical measures to counter soil erosion. In: Hunter, H.A., Eyles, A.G., Rayment, G.E. (Eds.) Downstream Effects of Land Use. Queensland Department of Natural Resources, Brisbane, pp 213-219.

Freeny, J.R., Denmead, O.T., Wood, A.W., Saffigna, P.G. (1994) Ammonia loss following urea addition to sugar cane trash blankets. *Proceedings of the Australian Society of Sugar Cane Technologists* **16,** 114-121.

Furnas, M. (2003) Catchments and Corals: Terrestrial Runoff to the Great Barrier Reef. Australian Institute of Marine Science and CRC Reef Research Centre, Townsville, 334 pp.

Furnas, M., Mitchell, A. (2001) Runoff of terrestrial sediment and nutrients into the Great Barrier Reef World Heritage Area. In: Wolanski, E. (Ed.) Oceanographic Processes of Coral reefs: Physical and Biological Links in the Great Barrier Reef. CRC Press, Boca Raton. pp 37-51.

Gardiner, C.J., McIvor, J.G. and Williams, J. (1990). Dry tropical rangelands: solving one problem and creating another. *Proceedings of the Ecological Society of Australia* **16,** 279-286.

Gilbert, M. and Brodie, J. (2001) Population and major land use in the Great Barrier Reef catchment area: spatial and temporal trends. Great Barrier Reef Marine Park Authority, Townsville.

Goulay, M.R. and Hacker, J.L.F. (1986). *Pioneer River Estuary Sedimentation Studies*. Department of Civil Engineering, University of Queensland, Brisbane.

Greene, R.S.B., Kinnell, P.I.A., Wood, J.T. (1994) Role of plant cover and stock trampling on runoff and soil erosion from semi-arid wooded rangeland. *Australian Journal of Soil Research* **32,** 953-973.

Harris, G. (1995) Eutrophication – Are Australian waters different from those overseas. *Water* **May/June,** 9 – 12.

Harris, G.P. (1999) Comparison of the Biogeochemistry of lakes and estuaries: ecosystem processes, functional groups, hysteresis effects and interactions between macro- and microbiology. *Marine and Freshwater Research* **50,** 791-811

Harris, G.P. (2001) Biogeochemistry of nitrogen and phosphorus in Australian catchments, river and estuaries: effects of land use and flow regulation and comparisons with global patterns. *Marine and Freshwater Research* **52,** 139-149.

Hart, B.T., Ottaway, E.M. and Noller, B.N. (1987a) Magela Creek system, Northern Australia. I 1982-83 wet season water quality. *Australian Journal of Marine and Freshwater Research* **38,** 261-288

Hart, B.T., Ottaway, E.M. and Noller, B.N. (1987b) Magela Creek system, Northern Australia. II Material budget for the floodplain. *Australian Journal of Marine and Freshwater Research* **38,** 861-876

Haynes, D. and Michalek-Wagner, K. (2000). Water quality in the Great Barrier Reef World Heritage Area: past perspectives, current issues and new research directions. *Marine Pollution Bulletin* **41(7-12),** 428-434.

Haynes, D., Brodie, J., Christie, C., Devlin, M., Michalek-Wagner, K., Morris, S., Ramsay, M., Storrie, J., Waterhouse, J., Yorkston, H. (2001) Great Barrier Reef water quality: Current issues. Great Barrier Reef Marine Park Authority, Townsville.

Holland, E.A., Braswell, B.H., Lamarque, J.F., Townsend, A., Sulzman, J., Muller, J-F., Dentener, F., Brasseur, G., Levy, H.II, Penner, J.E. and Roelofs, G-J. (1997). Variations in the predicted distribution of atmospheric nitrogen deposition and their impact on carbon uptake by terrestrial ecosystems. *Journal of Geophysical Research* **102 D13,** 15849-15866

Holloway, J.M., Dahlgren, R.A., Hansen, B. and Casey, W.H. (1998). Contribution of bedrock nitrogen to high nitrate concentrations in stream waters. *Nature* **395,** 785-788.

Hopkinson, C.S. and Vallino, J.J. (1995). The nature of watershed perturbations and their influence on estuarine metabolism. *Estuaries* **18,** 598-621.

Hossein, S., Eyre, B. and McConchie, D. (2002) Spatial and temporal variations of suspended sediment responses from the subtropical Richmond River catchment, NSW, Australia. *Australian Journal of Soil Research* **40,** 419-432.

Howarth, R.W. (1998) An assessment of human influences on fluxes of nitrogen from the terrestrial landscape to the estuaries and continental shelves of the North Atlantic Ocean. *Nutrient Cycling in Agroecosystems* **52,** 213-223.

Howarth, R.W., G. Billen, D. Swaney, A. Townsend, N. Jowarski, K. Lajtha, J.A. Downing, R. Elmgren, N. Caraco, T. Jordan, F. Berendse, J. Freney, V. Kudeyarov, P. Murdoch, and Z.-L. Zhu. 1996. Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: Natural and human influences. *Biogeochemistry* **35,** 75-139.

Hunter H.M. (1997) Nutrients and suspended sediment discharged from the Johnstone River catchment during cyclone Sadie. In: Steven, A. (Ed.) Cyclone Sadie flood plumes in the Great Barrier Reef lagoon: Composition and consequences. Workshop Series No. 22, Great Barrier Reef Marine Park Authority, Townsville, pp 1-8.

Hunter, H.M., Armour, J.D. (2001) Offsite movement of nutrients: Contrasting issues at three Australian study sites. In: Offsite movement of agrochemicals in tropical sugarcane production. Proceedings of workshop, Bundaberg, 8-9 May, 2001. Australian Centre for International Agricultural Research, Canberra, pp 69-76.

Hunter, H.M., Walton, R.S. (1997) From land to river to reef lagoon. Land use impacts on water quality in the Johnstone Catchment. Queensland Department of Natural Resources, Indooroopilly. 10pp

Hunter H.M., Walton R.S., Russell D.J. (1996) Contemporary water quality in the Johnstone River catchment. In: Hunter, H.A., Eyles, A.G., Rayment, G.E. (Eds.) Downstream Effects of Land Use. Queensland Department of Natural Resources, Brisbane, pp 339-345.

Hunter, H., Sologinkin, S., Choy, S., Hooper, A., Allen, W., Raymond, M., Peeters, J. (2001) Water management in the Johnstone Basin. Queensland Department of Natural Resources and Mines, Brisbane, 105 pp.

Hunter, H., Witting, N., Clarke, R. and Raymond, M. (2003). Water quality in sugarcane catchments in Queensland, Report No. 3, Department of Natural Resources and Mines, Brisbane, Australia.

Jaworski, N.A., R.W. Howarth, and L.J. Hetling. 1997. Atmospheric deposition of nitrogen oxides onto the landscape contributes to coastal eutrophication in the northeast United States. *Environmental Science and Technology* 31:1995–2004.

Johnson AKL, Ebert SP, Murray AE (1999) Distribution of coastal freshwater wetlands and riparian forests in the Herbert River catchment and implications for management of catchments adjacent to the Great Barrier Reef Marine Park. *Environmental Conservation*, 26(3): 229-235.

Johnson, A.K.L., Bramley, R.G.V., Roth, C.H. (2001) Landcover and water quality in river catchments of the Great Barrier Reef Marine Park. In: Wolanski E. (Ed.) Oceanographic Processes of Coral reefs: Physical and Biological Links in the Great Barrier Reef. CRC Press, Boca Raton. pp 19-37.

Justic, D. (1987). Long-term eutrophication of the Northern Adriatic Sea. *Marine Pollution Bulletin* **18,** 281-284.

Kaiser, J. (2001). The other global pollutant: nitrogen proves tough to curb. *Science* **294,** 1268-1269.

Keating, B.A., Bauld, J., Hillier, J., Ellis, R., Weier, K.L., Sunners, F., Connell, D. (1996) Leaching of nutrients and pesticides to Queensland groundwaters. In: Hunter, H.M., Eyles A.G., Rayment, G.E. (Eds.) Downstream effects of land use. Department of Natural Resources, Brisbane. pp 151-163.

Laurence, C.R. (1983). Nitrate-rich groundwaters of Australia. AWRC Technical Paper No. 79, Australian Water Resources Council, Canberra, Australia.

Lewis WM Jr (2002) Yield of nitrogen from minimally disturbed watersheds of the United States. *Biogeochemistry* **57/58:** 375–385

Lewis, W.M. Jr., Melack, J.M., McDowell, W.H., McClain, M. and Richey, J.E. (1999). Nitrogen yields from undisturbed watersheds in the Americas. *Biogeochemistry* **46,** 149-162

Likens, G.E. (2001). Biogeochemistry, the watershed approach: some uses and limitations. *Marine and Freshwater Research* **52,** 5 – 12.

Ludwig, J.A., Tongway, D.J. (2002) Clearing savannas for use as rangelands in Queensland: Altered landscapes and water erosion processes. *Rangelands Journal* **24(1),** 83-95.

Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. (1997) Agricultural intensification and ecosystem properties. *Science* **277,** 504-509.

McCulloch, Fallon, S., Wyndham, T., Lough, J., Barnes, D. (2003) Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. *Nature* **421,** 727-730.

McIvor, J.G., Williams, J., Gardner, C.J. (1995) Pasture management influences runoff and soil movement in the semi-arid tropics. *Australian Journal of Experimental Agriculture* **35,** 55-65.

McKee, L., Eyre, B. D and Hossain, S. (2000) Transport and retention of nitrogen and phosphorus in the sub-tropical Richmond River estuary, Australia. *Biogeochemistry* **50,** 241-278.

McKee, L., Eyre, B. D., Hossain, S., Pepperell, P.R. (2001) Influence of climate, geology, and humans on spatial and temporal nutrient geochemistry in the subtropical Richmond River catchment, Australia. *Marine and Freshwater Research* **52,** 235-248.

McShane, T.J., Reghenzani, J.R., Prove, B.G., Moody, P.W. (1993) Nutrient balances and transport from sugarcane land – a preliminary report. *Proceedings of the Australian Society of Sugar Cane Technologists 15th Conference*. pp 268-275.

Mallawaarachchi, T., Moneypenny, R. and Rayment, G. (2002). An integrated strategy to enhance profitability and environmental compliance in the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists 24th Conference*. pp 99-106.

Meybeck, M. (1982) Carbon, nitrogen and phosphorous transport by world rivers. *American Journal of Science* **282,** 401-450.

Mitchell, A. W., Furnas, M. J. (2001) River loggers - a new tool to monitor riverine suspended particle fluxes. *Water Science and Technology* **43(9),** 115-120.

Mitchell, A. W., Bramley, R. G. V., Johnson, A. K. L. (1997) Export of nutrients and suspended sediment during a cyclone-mediated flood event in the Herbert River catchment, Australia. *Marine and Freshwater Research* **48,** 79-88.

Mitchell, A. Reghenzani, J.R., Furnas, M. (2001) Nitrogen levels in the Tully River – a long-term view. *Water Science and Technology* **43(9),** 99-105.

Mitchell, C., Brodie J. and White, I. (2005). Sediments, nutrients and pesticide residues in event flow conditions in streams of the Mackay Whitsunday Region, Australia. *Marine Pollution Bulletin.* **51(1-4),** 23-36.

Moody P.W., Reghenzani J.R., Armour J.D., Prove B.G., McShane T.J. (1996) Nutrient balances and transport at farm scale- Johnstone River catchment. In: Hunter, H.A., Eyles, A.G., Rayment, G.E. (Eds.) Downstream Effects of Land Use. Queensland Department of Natural Resources, Brisbane, pp 347-351.

Morecroft, M.D., Burt, T.P., Taylor, M.E. and Rowland, A.P. (2000). Effects of the 1995-1997 drought on nitrate leaching in lowland England. *Soil Use and Management* **16,** 117-123.

Noble ,R., Collins, C. (2000) Physical and chemical water quality of the Dawson River. In: Noble, R. (Ed.) River health in the Fitzroy Catchment: Community ownership. Queensland Department of Natural Resources, Brisbane, pp 25-39.

Noble R.M., Duivenvoorden L.J., Rummenie S.K., Long P.E., Fabbro L.D. (1997) Downstream effects of land use in the Fitzroy catchment. Queensland Department of Natural Resources, Brisbane, 97 pp.

Novotny, V. and Chesters, G. (1989). Delivery of sediments and pollutants from non-point sources: A water quality perspective. *Journal of Soil and Water Conservation* Nov.-Dec., 1989: 568-576.

Oliver, R.L., Hart, B.T., Douglas, G.B. and Beckett, R. (1993). Phosphorus speciation in the Murray and Darling Rivers. *Water: Official Journal of the Australian Water and Wastewater Association* **20,** 24-26 & 29

O'Reagain, P., Bushell. J., Allen, R. (2001) The effect of grazing management on soil and nutrient loss in the tropical savannas of north Queensland. Report to the Great Barrier Reef Marine Park Authority, Department of Primary Industries, Charters Towers, 42pp.

Paerl, H.W. (1997). Coastal eutrophication and harmful algal blooms: Importance of atmospheric deposition and groundwater as "new" nitrogen and other nutrient sources. *Limnology and Oceanography* **42(5),** 1154-1165.

Pailles, C., Moody, P.W. (1996) Phosphorus dynamics of sediments from the Johnstone Rivers. In: Hunter, H. M., Eyles, A. G. & Rayment, G. E. (Eds.) Downstream effects of land use, Department of Natural Resources, Brisbane. pp 359-365.

Pailles, C., Moody, P. W. (1992) Phosphorus sorption-desorption by some sediments of the Johnstone Rivers Catchment, Northern Queensland. *Australian Journal of Marine and Freshwater Research* **43,** 1535-1545.

Pearson, R., Butler, B., Nolen, J., Christidis, F., Connolly, N., Cairns, A., Davis, L. (1998) Stream ecosystems as monitors of tropical forest catchments. ACTFR Technical report No. 98/26, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Pearson, R., Crossland, M., Butler, B., Manwaring, S. (2003) Effects of cane-field drainage on the ecology of tropical waterways. ACTFR Report No. 3/04 – 1. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Peierls, B.L., Caraco, N.F., Pace, M.L., Cole, J.J. (1991) Human influence on river nitrogen. *Nature* **350 (6317),** 386-387.

Perakis, S.S. (2002). Nutrient limitation, hydrology and watershed nitrogen loss. *Hydrological Processes* **16,** 3507-3511.

Perakis, S.S., Hedin, L.O. (2001) Fluxes and fate of nitrogen in soil of an unpolluted old growth temperate forest, southern Chile. *Ecology* **82,** 2245-2260.

Perakis, S.S., Hedin, L.O. (2002) Nitrogen from unpolluted South American forests mainly via dissolved organic compounds. *Nature* **415,** 416-419.

Prosser, I. (1996). Using riparian zones to control sediment, nutrients and erosion in the Johnstone River, Far North Queensland. Paper presented at the Johnstone River Riparian Workshop, Johnstone River Catchment Coordinating Committee, Innisfail, Queensland.

Prosser, I. P. Moran, C. J. , Lu, H., Scott, A., Rustomji, P., Stevenson, J., Priestley, G., Roth C. H., Post, D. (2002). Regional Patterns of Erosion and Sediment Transport in the Burdekin River Catchment. CSIRO Land and Water Technical Report 05/02, Canberra, Australia. http://www.clw.csiro.au/publications/technical

Pringle, A.W. (1991) Fluvial sediment supply to the north-east Queensland coast, Australia. *Australian Geographic Studies* **29,** 114-138.

Prove, B.G. and Hicks, W.S. (1991) Soil and nutrient movements from rural lands of north Queensland. In: Yellowlees, D. (Ed.). Land Use Patterns and Nutrient Loading of the Great Barrier Reef Region. James Cook University of North Queensland, Townsville, pp 67-76.

Prove, B.G., Doogan, V.J. & Truong, P.N.V. (1995) Nature and magnitude of soil erosion in sugarcane land on the wet tropics coast of north-eastern Queensland. *Australian Journal of Experimental Agriculture* **35,** 641-649.

Prove, B.G., McShane, T.J., Reghanzani, J.R., Armour, J.D., Sen, S. and Moody, P.W.(1996) Management options to reduce loss of applied nitrogen fertilisers in the major rural industries in the Johnstone River catchment. In: Measurement and management of nitrogen losses for groundwater protection in agricultural production systems. Workshop proceedings (E. Bond, ed) LWRRDC Occasional paper 08/96, Land and Water Australia, Canberra.

Puckridge, J.T., Sheldon, F., Walker, K.F., Boulton, A.J. (1998) Flow variability and the ecology of large rivers. *Marine and Freshwater Research*, **49,** 55-72

Pulsford, J.S. (1996) Historical nutrient usage in coastal Queensland river catchments adjacent to the Great Barrier Reef Marine Park. Research Publication No. 40, Great Barrier Reef Marine Park Authority, Townsville

Rabalais, N.N., R.E. Turner, D. Justic, Q. Dortch, W.J. Wiseman Jr., and B.K. Sen Gupta. (1996). Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. *Estuaries* **19,** 386-407.

Rasiah, V., Armour, J.D. (2001) Nitrate accumulation under cropping in the Ferrosols of Far North Queensland wet tropics. *Australian Journal of Soil Research* **39,** 329-341.

Rasiah, V., Armour, J.D., Menzies, N.W., Heiner, D.H., Don, M.J., Mahendrarajah, S. (submitted –2002a) Retention and environmental association of the nitrate leached below sugarcane root-zone in Queensland wet tropics. *Australian Journal of Soil Research.*

Rasiah, V., Armour, J.D., Yamamoto, S., Mahendrarajah, S., Heiner, D.H. (Accepted – 2002b) Nitrate dynamics in groundwater under sugarcane in the Australian wet tropics. *Water, Air and Soil Pollution Journal.*

Rayment, G.E. (1994). Excessive levels of nutrients in horticultural soil and vegetables. In: Hunter, M.N. and Eldershaw, V.J. (Eds.) Nutrition in Horticulture, Proceedings of a review workshop, Gatton 4-6 May, 1993. DPI Conference and Workshop Series QC94003, Department of Primary Industries, Brisbane, Australia. pp. 55-70.

Rayment, G.E. (2003) Water quality in sugar catchments of Queensland. *Water Science and Technology* **48,** 35-47.

Rayment, G.E., Neil, D.T. (1997) Sources of material in river discharge. In: Turia, N., Dalliston, C. (Eds.). The Great Barrier Reef: science, use and management. Great Barrier Reef Marine Park Authority, Townsville, Australia. pp 42-58.

Reghenzani, J.R., Armour, J.D., Prove, B.G., Moody P.W., McShane, T. (1996) Nitrogen balances for sugarcane plant and first ratoon crops in the wet tropics. In: Wilson, J.R., Hogarth, D.M., Campbell, J.A., Garside, A.L (Eds.). Sugarcane research towards efficient and sustainable production. CSIRO Division of Tropical Crops and Pasture, Brisbane. pp 275-277.

Riegman, R., Noordeloos, A. and Cadee, G. (1992) Phaeocystis blooms and eutrophication of the continental coastal zones of the North Sea. *Marine Biology* **112,** 479-484.

Robertson, F.A. and Thornburn, P.J. (2000). Trash management – consequences for soil carbon and nitrogen. *Proceedings of the Australian Society of Sugar Cane Technologists* **22,** 225-229.

Rummenie, S and Noble, B. (1996) Drainage and tailwater recycling reduces nutrient and sediment movement. *The Australian Cotton Grower* **17,** 30-37.

Russell, D.J., Hales, P.W., Helmke, S.A. (1996a) Fish resources and stream habitat of the Moresby River catchment. Information Series, Queensland Department of Primary Industries, Brisbane

Russell, D.J., Hales, P.W., Helmke, S.A. (1996b) Stream habitat and fish resources in the Russell and Mulgrave rivers catchment. Information Series, Queensland, Department of Primary Industries, Brisbane

Russell, D. and Hales, P.W. (1994). Stream habitat and fisheries resources of the Johnstone River catchment. Information Series, Queensland Department of Primary Industries, Cairns.

Sallaway, M.M. (1979) Soil erosion studies in the Mackay district. In: Egan, B.T. (Ed) *Proceedings of the Australian Society of Sugar Cane Technologists*. pp 322-327

Sanden, P. and Rahm, L. (1993) Nutrient trends in the Baltic Sea. *Environmetrics* **4,** 75-103.

Scanlan, J. C., Pressland, A. J., Myles, D. J. (1996) Run-off and soil movement on mid-slopes in north-east Queensland grazed areas. *Rangelands Journal* **18,** 33-46.

Schmidt, S., Lamble, R.E. (2002) Nutrient dynamics in Queensland savannas: Implications for the sustainability of land clearing for pasture production. *Rangelands Journal* **24(1),** 96-111.

Schroeder, B.L., Wood, A.W., Kingston, G. (1998) Re-evaluation of the basis for fertiliser recommendations in the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists* **20,** 239-247

Seitzinger, S. and Sanders, R. (1997). Contribution of dissolved organic nitrogen from rivers to estuarine eutrophication. *Marine Ecology Progress Series* **159,** 1-12.

Silburn, D.M., Glanville, S.F. (2002) Management practices for control of runoff losses from cotton furrows under storm rainfall. I Runoff and sediment on a black Vertosol. *Australian Journal of Soil Research* **40,** 1-20.

Smith, S. and Hollibaugh, J. (1997). Coastal metabolism and the oceanic organic carbon balance. *Reviews of Geophysics* **31,** 75-89

Tatara, K. (1991). Utilization of the biological production in eutrophicated sea areas by commercial fisheries, and the environmental quality standard for fishing ground. *Marine Pollution Bulletin* **23,** 315-319.

Thorburn, P.J., Keating, B.A., Robertson, F.A. and Wood, A.W. (2000). Long-term changes in soil carbon and nitrogen under trash blanketing. *Proceedings of the Australian Society of Sugar Cane Technologists* **22,** 217-224.

Timperley, M.H. (1983). Phosphorus in spring waters of the Taupo Volcanic Zone, North Island, New Zealand. *Chemical Geology* **38,** 287-306.

Tothill, J.C. and Gillies, C. (1992). The pasture lands of northern Australia. Their condition, productivity and sustainability. Tropical Grasslands Society of Australia. Occasional Paper No. 5.

Townsend, S.A. and Edwards, C.A. (2003). A fish kill event, hypoxia and other limnological impacts associated with early wet season flow into a lake on the Mary River floodplain, tropical northern Australia. *Lakes and Reservoirs: Research and Management* **8,** 169-176.

Turner, R.E., Rabalais, N.N., Justic, D. and Dortch, Q. (2003) Global patterns of dissolved N, P and Si in large rivers. *Biogeochemistry* **64,** 297-317.

van Breeman, N. (2002). Natural organic tendency. *Nature* **415,** 381-382.

van Cuylenberg, H.R.M. (1985) Land management and erosion survey, N.T. croplands (1984-89). In: Fergus, I.F. (ed.) Proceedings of the Fourth Soil Conservation Conference. Standing Committee on Soil Conservation, Canberra. Pp. 206-207.

van Woesik, R., Tomascik, T., Blake, S. (1999) Coral assemblages and physico-chemical characteristics of the Whitsunday Islands: evidence of recent community changes. *Marine and Freshwater Research* **50,** 427-440.

Verberg, K., Keating, B.A., Probert, M.E., Bristow, K.L., Huth, N.I. (1998) Nitrate leaching under sugarcane: Interactions between crop yield, soil type and management strategies. In: Michalk, D.L., Pratley, J.E. (Eds.) Agronomy – growing greener future. *Proceedings of the 9th Australian Agronomy Conference, Wagga Wagga, NSW.* pp 717-720.

Vitousek, P.M., Aber, J.D., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H., Tilman D.G. (1997) Human alteration of the global nitrogen cycle: sources and consequences. *Ecological Applications* **7,** 737-750.

Vollenweider, R.A. (1975) Input–output models, with special reference to the phosphorus loading concept in limnology. *Schweizerische Zeitzschrift fur Hydrologie* **37,** 53-82

Wasson, R.J. (1997) Run-off from the land to the rivers and the sea. In: The Great Barrier Reef: Science, Use and Management. James Cook University, 25-29 November 1996, Townsville. Volume 1 pp 23-41.

Weier, K.L. (1999) The quality of groundwater beneath Australian sugarcane fields. *Australian Sugarcane* **3(2),** 26-27.

Wilhelm, G. (2001) Water quality report for catchments containing sugar cane in Queensland. Queensland Department of Natural Resources and Mines, Brisbane.

Williams, M.R. and Melack, J.M. (1997) Solute export from forested and partially deforested catchments in the central Amazon. *Biogeochemistry* **38,** 67-102

Winter, D. and Wild, A. (1995). *Current distribution and historical comparisons of intertidal vegetation communities and saltpans in the Mackay region (Shoal Point to Hay Point).* Department of Management Studies, University of Queensland, Gatton College.

Wolanski, E. and Jones, M. (1981). Physical properties of Great Barrier Reef Lagoon waters near Townsville. I. Effects of Burdekin River Floods. *Australian Journal of Marine and Freshwater Research* **32,** 305-319.

Young, W.J., Marston, F.M., Davis, J.R. (1996) Nutrient exports and land use in Australian catchments. *Journal of Environmental Management* **47,** 165-183

Zaitsev, Y.P. 1991. Cultural eutrophication of the Black Sea and other European seas. *La Mer* **29,** 1-7.

Appendix 1. Concentrations of nutrients in streams of the Wet Tropics investigated by ACTFR, 1994-1995 (Butler *et al*., 1996).

Site	Measure	Susp Solids	NO_3 [a]	NO_2 [a]	NH_3	DIN [b]	TN [c]	DIP	TP [c]
Mossman R	n	66	57	57	67	57	63	57	54
	Average	1.1	20.8	1.1	5.1	27.3	79.1	3.9	5.4
	Median	0.8	16.2	1.2	4.7	22.4	70.0	4.3	4.6
	Range	0.1–1.8	1.7–46.1	0.5-1.2	0.5-18.6	5.3-54.5	124-179.0	0.5-5.9	0.5-17.5
The Boulders (Babinda Ck)	n	32	34	34	37	34	36	34	36
	Average	0.4	11.5	1.1	5.8	18.0	143.6	1.6	5.9
	Median	0.4	10.7	1.0	5.5	17.8	137.5	1.5	4.7
	Range	0.1-1.4	1.5-17.0	0.6-1.6	1.4-18.2	4.6-25.3	26.9-354.0	0.3-3.6	0.5-11.6
Five Mile Ck	n	23	23	23	23	23	20	23	23
	Average	1.0	4.6	1.6	10.0	16.2	77.0	1.7	3.8
	Median	0.4	4.5	1.6	6.2	12.3	73.1	1.4	3.3
	Range	0.1-11.2	3.5-7.0	0.4-2.3	0.5-98.9	5.6-104.0	30.3-175.0	0.3-3.4	0.9-9.9
Crystal Ck	n	30	29	29	30	24	30	30	31
	Average	1.4	25.3	1.0	3.7	26.7	98.3	2.6	6.0
	Median	0.7	17.2	0.9	3.3	20.7	66.6	0.5	4.2
	Range	0.1-4.7	2.2-60.0	0.3-2.0	0.5-10.2	6.1-65.8	40.0-459.0	0.3-3.7	0.5-26.5
Little Crystal Ck	n	90	90	90	81	79	90	90	90
	Average	1.3	12.3	1.6	7.1	21.6	111.0	4.5	5.6
	Median	0.6	9.2	1.5	5.0	16.8	92.7	4.1	4.5
	Range	0.1-8.0	0.5-68.5	0.3-2.9	0.2-27.5	3.7-73.7	34.0-383.0	0.2-18.6	1.5-14.0

Notes: [a] Calculated separately; [b] DIN = $NO_3 + NO_2 + NH_3$; [c] TN and TP determined separately

Appendix 2. Concentrations of nutrients in selected streams of the Herbert River area, investigated by CSIRO, 1992-1995 (Bramley and Muller, 1999).

Site	Measure	NO_3 [a]	NH_3	DIN [b]	TKN	DON [c]	PN	TN [d]	DIP	TKP	PP	TP [e]
Bollocky Toms Ck	n	16	16	16	12	12	15	11	16	7	15	6
	Average	37.3	5.9	43.2	104.2	97.6	121.1	273.4	13.4	13.9	24.4	38.0
	Median	30.5	5.0	37.0	60.5	56.0	66.0	239.0	9.5	6.0	8.0	29.5
	Range	10-85	0-14	10-87	13-377	8-371	6-511	57-665	0-38	2-60	1-123	12-96
Crystal Ck (Hwy)	n	19	19	19	14	14	18	14	19	11	19	11
	Average	34.7	7.3	42.1	132.1	123.9	128.1	306.5	9.7	12.7	34.7	70.6
	Median	31.0	6.0	37.0	109.0	103.0	79.0	169.0	8.0	9.0	8.0	48.0
	Range	8-114	0-23	8-116	34-390	29-381	9-584	87-839	0-28	4-41	1-257	9-268
Elphinstone Ck	n	14	14	14	12	12	14	11	14	11	14	8
	Average	87.5	3.4	90.9	149.3	146.1	148.8	400.0	14.6	19.0	17.3	50.5
	Median	52.0	3.5	53.5	137.0	134.5	60.0	363.0	4.0	13.0	8.0	25.0
	Range	1-441	1-8	2-444	22-335	21-329	7-567	139-744	1-59	5-96	1-92	14-117
Gowrie Ck	n	29	29	29	23	23	23	19	29	20	24	17
	Average	152.1	6.7	158.8	204.7	198.1	152.6	552.4	20.7	23.9	32.0	81.1
	Median	103.0	5.0	106.0	164.0	159.0	124.0	477.0	11.0	21.0	9.0	74.0
	Range	2-1394	1-25	6-1419	42-549	41-524	14-556	86-2524	1-101	6-75	1-197	10-226
Hawkins Ck	n	40	36	36	32	31	33	27	39	32	34	27
	Average	144.1	12.3	158.5	169.8	151.9	74.0	385.4	3.3	12.6	9.6	26.5
	Median	105.5	9.0	111.0	158.0	125.0	48.0	368.0	2.0	6.0	4.0	18.0
	Range	1-771	1-75	13-782	12-592	6-591	8-286	109-825	1-12	2-141	1-53	5-144
Waterview Ck (Highway)	n	29	29	29	25	25	25	24	29	19	26	16
	Average	84.4	13.7	98.1	267.4	253.4	190.4	541.3	30.0	33.4	37.7	80.1
	Median	40.0	5.0	58.0	244.0	232.0	125.0	513.6	4.0	11.0	15.5	38.5
	Range	0-316	0-100	0-416	34-753	27-751	16-629	111-1073	0-537	3-298	2-254	10-345
Waterview Ck (Jourama)	n	29	29	29	21	21	26	19	29	20	27	20
	Average	19.2	7.7	27.0	245.0	237.2	171.2	460.6	13.4	25.6	41.7	80.0
	Median	6.0	5.0	19.0	193.0	192.0	55.5	272.0	8.0	13.0	6.0	28.5
	Range	1-94	1-24	3-97	73-1164	67-1160	8-1557	152-1755	1-51	3-206	0-795	7-813

Notes: [a] Nitrate determined as $NO_3 + NO_2$; [b] DIN = $NO_3 + NH_3$; [c] DON = TKN – NH_3; [d] TN = DIN + DON + PN; [e] TP = DIP + DOP + PP

Appendix 3. Statistics on the nutrient and suspended sediment concentrations in streams of the Teemburra Creek area (Pearson and Clayton, 1993).

Site Name	Description	Measure	Site	SS	NO2	NO3	NOx	NH3	DIN	TON	DON	PN	TN	PO4	DOP	PP	TP
03-01	Upper Teemburra Ck	n	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Average		25.9	0.001	0.012	0.014	0.009	0.022	0.151	0.110	0.041	0.173	0.028	0.009	0.005	0.042
		Median		0.5	0.001	0.015	0.016	0.009	0.025	0.127	0.054	0.034	0.138	0.020	0.001	0.006	0.034
		Min		0.2	0.001	0.006	0.007	0.005	0.012	0.059	0.044	0.015	0.089	0.001	0.001	0.000	0.028
		Max		77.0	0.001	0.016	0.018	0.013	0.030	0.268	0.234	0.073	0.293	0.063	0.026	0.007	0.064
03-02	Teemburra Ck	n	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Average		482.8	0.002	0.036	0.038	0.097	0.135	2.260	0.549	1.711	2.395	0.003	0.034	0.203	0.236
		Median		482.8	0.002	0.036	0.038	0.097	0.135	2.260	0.549	1.711	2.395	0.003	0.034	0.203	0.236
		Min		0.5	0.002	0.020	0.021	0.013	0.068	0.144	0.132	0.012	0.212	0.002	0.008	0.000	0.006
		Max		965.0	0.002	0.053	0.055	0.181	0.202	4.376	0.965	3.411	4.578	0.004	0.059	0.405	0.466
03-03	Teemburra Ck	n	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Average		1.7	0.001	0.003	0.004	0.005	0.009	0.326	0.249	0.177	0.435	0.003	0.004	0.036	0.044
		Median		1.7	0.001	0.003	0.004	0.005	0.009	0.326	0.249	0.177	0.435	0.003	0.004	0.036	0.044
		Min		1.7	0.001	0.003	0.004	0.005	0.009	0.326	0.249	0.177	0.435	0.003	0.004	0.036	0.044
		Max		1.7	0.001	0.003	0.004	0.005	0.009	0.326	0.249	0.177	0.435	0.003	0.004	0.036	0.044
03-04	Endeavour Ck	n	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Average		3.2	0.001	0.009	0.010	0.005	0.015	0.613	0.456	0.157	0.628	0.018	0.012	0.028	0.059
		Median		1.2	0.001	0.006	0.007	0.006	0.014	0.422	0.369	0.053	0.433	0.003	0.006	0.006	0.057
		Min		1.0	0.001	0.004	0.005	0.002	0.011	0.356	0.318	0.038	0.370	0.001	0.001	0.006	0.014
		Max		7.4	0.003	0.015	0.018	0.007	0.020	1.062	0.681	0.381	1.082	0.050	0.031	0.072	0.105
03-05	Upper Middle Ck	n	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Average		17.7	0.001	0.027	0.028	0.001	0.029	0.289	0.197	0.091	0.317	0.012	0.005	0.009	0.027
		Median		22.8	0.001	0.006	0.007	0.001	0.009	0.313	0.201	0.082	0.321	0.003	0.005	0.011	0.023
		Min		2.0	0.001	0.006	0.006	0.001	0.008	0.237	0.153	0.076	0.305	0.001	0.001	0.000	0.023
		Max		28.2	0.001	0.069	0.070	0.002	0.070	0.316	0.237	0.115	0.325	0.033	0.009	0.017	0.034
03-12	Palmtree Ck	n	6	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Average		2.9	0.001	0.020	0.021	0.023	0.044	0.262	0.255	0.048	0.301	0.037	0.019	0.011	0.066
		Median		2.9	0.001	0.020	0.021	0.023	0.044	0.262	0.255	0.048	0.301	0.037	0.019	0.011	0.066
		Min		1.8	0.001	0.009	0.010	0.023	0.034	0.155	0.236	0.000	0.179	0.029	0.005	0.004	0.051
		Max		3.9	0.001	0.030	0.031	0.024	0.054	0.369	0.274	0.095	0.423	0.045	0.032	0.017	0.081

Appendix 3 continued. Statistics on the nutrient and suspended sediment concentrations in streams of the Teemburra Creek area.

Site Name	Description	Measure	Site	SS	NO2	NO3	NOx	NH3	DIN	TON	DON	PN	TN	PO4	DOP	PP	TP
03-06	Cattle Ck	n	7	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Average		8.7	0.041	0.112	0.153	0.001	0.154	0.051	0.036	0.006	0.165	0.002	0.007	0.005	0.014
		Median		8.7	0.041	0.112	0.153	0.001	0.154	0.051	0.036	0.006	0.165	0.002	0.007	0.005	0.014
		Min		8.6	0.001	0.062	0.064	0.001	0.064	0.018	0.001	0.000	0.148	0.001	0.005	0.003	0.009
		Max		8.8	0.081	0.161	0.242	0.002	0.243	0.084	0.071	0.013	0.181	0.002	0.009	0.008	0.018
03-07	Cattle Ck	n	8	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Average		2.6	0.001	0.075	0.076	0.024	0.099	0.313	0.218	0.095	0.413	0.021	0.028	0.006	0.056
		Median		3.3	0.001	0.031	0.032	0.014	0.062	0.368	0.194	0.071	0.405	0.013	0.005	0.002	0.056
		Min		0.3	0.001	0.008	0.009	0.005	0.037	0.204	0.164	0.040	0.266	0.001	0.001	0.001	0.015
		Max		4.3	0.002	0.184	0.186	0.053	0.200	0.368	0.297	0.174	0.568	0.050	0.080	0.016	0.096
03-08	Blacks Ck	n	9	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Average		27.7	0.000	0.004	0.005	0.007	0.012	0.645	0.621	0.025	0.657	0.036	0.007	0.010	0.054
		Median		27.7	0.000	0.004	0.005	0.007	0.012	0.645	0.621	0.025	0.657	0.036	0.007	0.010	0.054
		Min		3.7	0.000	0.004	0.004	0.001	0.005	0.134	0.088	0.003	0.140	0.001	0.000	0.009	0.026
		Max		51.6	0.001	0.005	0.005	0.013	0.018	1.156	1.153	0.046	1.174	0.072	0.015	0.011	0.081
03-09	Teemburra Ck	n	10	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Average		2.8	0.000	0.006	0.006	0.004	0.010	0.196	0.173	0.023	0.205	0.036	0.003	0.007	0.046
		Median		2.8	0.000	0.006	0.006	0.004	0.010	0.196	0.173	0.023	0.205	0.036	0.003	0.007	0.046
		Min		1.1	0.000	0.004	0.004	0.003	0.007	0.134	0.088	0.001	0.140	0.001	0.000	0.005	0.012
		Max		4.4	0.001	0.007	0.007	0.005	0.012	0.258	0.257	0.044	0.270	0.072	0.006	0.009	0.081
03-10	Teemburra Ck	n	3A	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Average		4.3	0.001	0.015	0.016	0.040	0.055	0.924	0.598	0.325	0.979	0.015	0.013	0.018	0.046
		Median		4.3	0.001	0.015	0.016	0.040	0.055	0.924	0.598	0.325	0.979	0.015	0.013	0.018	0.046
		Min		1.8	0.001	0.010	0.011	0.005	0.016	0.657	0.155	0.149	0.673	0.001	0.007	0.007	0.044
		Max		6.8	0.001	0.020	0.020	0.074	0.094	1.190	1.041	0.502	1.284	0.030	0.019	0.029	0.048
03-11	Blacks Ck/Teem.	n	12	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Average		1.8	0.000	0.003	0.004	0.007	0.011	0.273	0.259	0.014	0.284	0.020	0.004	0.007	0.031
		Median		1.8	0.000	0.003	0.004	0.007	0.011	0.273	0.259	0.014	0.284	0.020	0.004	0.007	0.031
		Min		1.2	0.000	0.002	0.003	0.004	0.009	0.216	0.214	0.002	0.225	0.001	0.001	0.004	0.018
		Max		2.3	0.001	0.005	0.005	0.010	0.013	0.330	0.304	0.026	0.343	0.040	0.008	0.009	0.045

Appendix 4. Statistics on the nutrient and suspended sediment concentrations from Pearson and Penridge (1992)

Statistics	Site_name	Stream	Site	NH3	NO3	SS	PO4
n	04-01	Daintree R	DR3	4	4	4	4
avg				0.02	0.63	2.50	0.18
med				0.00	0.65	2.50	0.19
min				0.00	0.50	0.00	0.09
max				0.08	0.70	5.00	0.26
n	04-02	Daintree R	DR2	4	4	4	4
avg				0.06	0.75	2.50	0.22
med				0.07	0.80	2.50	0.20
min				0.00	0.50	0.00	0.14
max				0.10	0.90	5.00	0.35
n	04-03	Daintree R	DR1	4	4	4	4
avg				0.53	1.00	10.00	0.23
med				0.15	0.60	10.00	0.26
min				0.00	0.30	10.00	0.13
max				1.80	2.50	10.00	0.27
n	04-04	S Mossman R	SM3	4	4	4	4
avg				0.14	0.80	15.00	0.28
med				0.11	0.70	10.00	0.27
min				0.00	0.60	0.00	0.09
max				0.35	1.20	40.00	0.50
n	04-05	S Mossman R	SM4	4	4	4	4
avg				0.04	0.60	10.00	0.23
med				0.04	0.60	0.00	0.21
min				0.00	0.50	0.00	0.13
max				0.08	0.70	40.00	0.35
n	04-06	N Mossman R	NM1	4	4	4	4
avg				0.26	1.23	12.50	0.14
med				0.22	0.90	5.00	0.12
min				0.06	0.60	0.00	0.08
max				0.55	2.50	40.00	0.24
n	04-07	N Mossman R	NM2	4	4	4	4
avg				0.06	0.68	7.50	0.19
med				0.05	0.60	0.00	0.19
min				0.03	0.50	0.00	0.15
max				0.10	1.00	30.00	0.24
n	04-08	Mulgrave R	MG4	1	1	1	1
avg				0.06	0.80	10.00	0.25
n	04-09	Mulgrave R	MG3	1	1	1	1
avg				0.10	0.60	10.00	0.38
n	04-10	Mulgrave R	MG2	1	1	1	1
avg				0.17	0.70	5.00	0.30
n	04-11	Mulgrave R	MG1	1	1	1	1
avg				0.07	0.60	10.00	0.15

n	04-12	Russell R	RR3	6	6	6	6
avg				0.12	1.02	1.67	0.12
med				0.06	0.70	0.00	0.11
min				0.05	0.40	0.00	0.04
max				0.40	2.10	10.00	0.22
n	04-13	Russell R	RR2	8	8	8	8
avg				0.12	0.99	5.25	0.22
med				0.11	0.70	5.00	0.21
min				0.02	0.40	0.00	0.10
max				0.25	2.30	15.00	0.35
n	04-14	Russell R	RR1	7	7	7	7
avg				0.17	0.91	12.43	0.23
med				0.18	0.60	5.00	0.23
min				0.08	0.40	0.00	0.12
max				0.28	1.80	60.00	0.34
n	04-15	Babinda Ck	BC5	8	8	8	8
avg				0.03	0.86	3.13	0.16
med				0.03	0.65	0.00	0.13
min				0.00	0.40	0.00	0.05
max				0.08	1.90	20.00	0.31
n	04-16	Babinda Ck	BC4	8	8	8	8
avg				0.29	1.69	12.50	0.28
med				0.20	0.85	10.00	0.28
min				0.03	0.60	0.00	0.07
max				0.70	7.00	30.00	0.50
n	04-17	N Johnstone R	NJ4	4	4	4	4
avg				0.03	0.73	8.25	0.31
med				0.01	0.55	7.50	0.23
min				0.00	0.30	0.00	0.09
max				0.08	1.50	18.00	0.70
n	04-18	N Johnstone R	NJ3	4	4	4	4
avg				0.03	0.90	3.75	0.23
med				0.02	0.70	0.00	0.22
min				0.00	0.50	0.00	0.20
max				0.06	1.70	15.00	0.28
n	04-19	N Johnstone R	NJ2	4	4	4	4
avg				0.06	0.83	0.00	0.48
med				0.06	0.65	0.00	0.28
min				0.00	0.50	0.00	0.20
max				0.10	1.50	0.00	1.17
n	04-20	N Johnstone R	NJ1	4	4	4	4
avg				0.23	0.93	0.00	0.20
med				0.20	0.85	0.00	0.21
min				0.00	0.70	0.00	0.10
max				0.50	1.30	0.00	0.30

Appendix 5: [Sets 5a,b] Statistics on the nutrient and suspended sediment concentrations in streams in the QEC Hydro-Electric Dam area at Koombooloomba (Faithful and Brodie, 1990)

Site_Name	Stream	Site	Statistic	NH3	NOx	TN	SS	PO4	TP
05-15	Blunder Ck	BL1	n	8	8	8	4	8	8
			Average	0.012	0.015	0.143	5.3	0.004	0.013
			Median	0.008	0.012	0.157	5.5	0.003	0.012
			Minimum	0.001	0.005	0.026	2.0	0.001	0.009
			Maximum	0.045	0.028	0.222	8.0	0.009	0.016
05-14	Blunder Ck	BL2	n	6	8	8	4	8	8
			Average	0.007	0.019	0.123	4.5	0.004	0.014
			Median	0.007	0.015	0.095	4.5	0.004	0.013
			Minimum	0.003	0.002	0.050	1	0.001	0.010
			Maximum	0.012	0.044	0.210	8	0.005	0.021
05-13	Blunder Ck	BL5	n	7	8	8	4	8	8
			Average	0.006	0.008	0.131	4.5	0.002	0.013
			Median	0.006	0.004	0.127	4	0.002	0.013
			Minimum	0.001	0.001	0.026	1	0.000	0.007
			Maximum	0.011	0.026	0.247	9	0.004	0.021
05-13b	Blunder Ck	5	n	14	14			14	
			average	0.006	0.015			0.004	
			median	0.006	0.009			0.003	
			min	0.001	0.002			0.000	
			max	0.011	0.046			0.011	
05-25	Blunder Ck	BL6	n	8	8	8	4	8	8
			Average	0.013	0.007	0.126	3	0.002	0.013
			Median	0.004	0.004	0.108	2	0.002	0.013
			Minimum	0.001	0.001	0.087	1	0.000	0.007
			Maximum	0.054	0.022	0.210	7	0.004	0.021
05-09	Koolamoon Ck	KM1	n	7	7	7	4	7	7
			Average	0.006	0.015	0.082	3.75	0.001	0.009
			Median	0.004	0.011	0.056	4	0.000	0.007
			Minimum	0.001	0.003	0.026	1	0.000	0.003
			Maximum	0.015	0.039	0.189	6	0.004	0.016
05-08	Koolamoon Ck	KM2	n	7	7	7	4	7	7
			Average	0.005	0.009	0.091	4.25	0.002	0.010
			Median	0.003	0.006	0.087	5	0.000	0.007
			Minimum	0.001	0.003	0.028	1	0.000	0.004
			Maximum	0.013	0.026	0.149	6	0.009	0.016
05-08b	Koolmoon Ck	4	n	14	14			14	
			average	0.003	0.017			0.003	
			median	0.002	0.012			0.003	
			min	0.000	0.004			0.000	
			max	0.010	0.040			0.007	
05-07	Koolamoon Ck	KM3	n	3	3	3	2	3	3
			Average	0.009	0.031	0.150	2	0.002	0.011
			Median	0.006	0.015	0.085	2	0.001	0.009
			Minimum	0.002	0.007	0.057	2	0.001	0.007
			Maximum	0.020	0.071	0.308	2	0.003	0.017

05-06	Koolamoon Ck	KM4	n	8	8	8	4	8	8
			Average	0.006	0.025	0.105	4	0.009	0.024
			Median	0.005	0.012	0.097	4	0.010	0.024
			Minimum	0.001	0.008	0.070	3	0.003	0.021
			Maximum	0.013	0.064	0.185	5	0.017	0.029
05-16	Muggera Ck	MC1	n	8	4	8	4	8	8
			Average	0.005	0.010	0.113	12	0.001	0.007
			Median	0.005	0.002	0.105	11.5	0.000	0.007
			Minimum	0.002	0.001	0.095	1	0.000	0.006
			Maximum	0.007	0.037	0.147	24	0.002	0.009
05-23	Millstream R	MS1	n	8	8	8	4	8	8
			Average	0.010	0.039	0.129	5	0.002	0.011
			Median	0.003	0.029	0.123	4.5	0.002	0.010
			Minimum	0.001	0.004	0.088	3	0.000	0.007
			Maximum	0.053	0.095	0.198	8	0.005	0.016
05-10	Millstream R	MS12	n	8	8	8	4	8	8
			Average	0.016	0.024	0.138	2.25	0.005	0.015
			Median	0.013	0.022	0.142	2.5	0.004	0.014
			Minimum	0.006	0.002	0.057	1	0.001	0.010
			Maximum	0.046	0.050	0.196	3	0.012	0.023
05-24	Millstream R	MS13	n	7	8	8	4	8	8
			Average	0.017	0.016	0.178	2.75	0.003	0.013
			Median	0.010	0.012	0.152	3	0.001	0.013
			Minimum	0.001	0.001	0.075	2	0.000	0.010
			Maximum	0.066	0.037	0.299	3	0.009	0.017
05-24b	Millstream R	14	n	3	3			3	16
			average	0.059	0.064			0.005	0.014
			median	0.011	0.086			0.005	0.010
			min	0.003	0.012			0.003	0.004
			max	0.163	0.094			0.006	0.060
05-21	Millstream R	MS2	n	8	8	8	4	8	8
			Average	0.010	0.030	0.134	4.25	0.001	0.012
			Median	0.003	0.017	0.129	4	0.002	0.009
			Minimum	0.001	0.003	0.063	3	0.000	0.006
			Maximum	0.045	0.086	0.185	6	0.003	0.028
05-19	Millstream R	MS4	n	8	8	8		8	8
			Average	0.011	0.084	0.199		0.004	0.015
			Median	0.010	0.094	0.184		0.004	0.015
			Minimum	0.004	0.030	0.140		0.000	0.010
			Maximum	0.025	0.143	0.295		0.006	0.019
05-20	Millstream R	MS5	n	8	8	8		8	8
			Average	3.964	10.137	22.440		2.960	3.911
			Median	3.940	9.571	19.905		3.380	3.760
			Minimum	1.050	7.949	15.750		0.870	3.260
			Maximum	7.700	16.769	32.000		5.200	5.200
05-20b	Millstream R	10	n	3	3			3	17
			average	0.020	0.179			0.027	0.042

			median	0.023	0.143			0.008	0.036
			min	0.011	0.096			0.001	0.011
			max	0.026	0.300			0.073	0.092
05-12	Millstream R	MS8	n	7	8	8	4	8	8
			Average	0.013	0.048	0.166	4.25	0.006	0.019
			Median	0.011	0.054	0.156	3.5	0.006	0.019
			Minimum	0.003	0.003	0.145	2	0.001	0.016
			Maximum	0.036	0.080	0.234	8	0.010	0.023
05-11	Millstream R	MS9	n	8	8	8	4	8	8
			Average	0.005	0.007	0.118	2.75	0.003	0.011
			Median	0.004	0.004	0.103	3	0.002	0.011
			Minimum	0.001	0.001	0.038	1	0.000	0.006
			Maximum	0.010	0.016	0.259	4	0.009	0.017
05-26b	Nichaga Ck	3	n	14	14			14	
			average	0.006	0.008			0.004	
			median	0.004	0.006			0.002	
			min	0.000	0.002			0.000	
			max	0.025	0.021			0.018	
16-08	N Cedar Ck	8	n	3	3			3	17
			average	0.011	0.093			0.008	0.019
			median	0.011	0.128			0.007	0.015
			min	0.008	0.005			0.004	0.008
			max	0.014	0.146			0.014	0.046
05-01	Tully R	TR1	n	8	8	8	4	8	8
			Average	0.007	0.017	0.119	4	0.002	0.010
			Median	0.004	0.014	0.121	4.5	0.001	0.010
			Minimum	0.001	0.007	0.059	2	0.000	0.005
			Maximum	0.023	0.029	0.222	5	0.004	0.016
05-01b	Tully R	6	n	14	14			14	
			average	0.004	0.024			0.009	
			median	0.004	0.017			0.002	
			min	0.001	0.003			0.000	
			max	0.008	0.098			0.083	
05-02	Tully R	TR2	n	8	8	8	4	8	8
			Average	0.006	0.008	0.120	4	0.003	0.011
			Median	0.004	0.007	0.097	4	0.002	0.011
			Minimum	0.001	0.002	0.032	2	0.000	0.003
			Maximum	0.013	0.017	0.234	6	0.009	0.021
05-03	Tully R	TR5	n	8	8	8	4	8	8
			Average	0.029	0.039	0.124	2.5	0.002	0.010
			Median	0.035	0.037	0.132	2	0.001	0.009
			Minimum	0.002	0.017	0.057	1	0.000	0.004
			Maximum	0.049	0.053	0.177	5	0.004	0.016
05-04	Tully R	TR7	n	8	8	8	4	8	8
			Average	0.023	0.049	0.128	2.5	0.001	0.011
			Median	0.021	0.050	0.129	2	0.001	0.009
			Minimum	0.007	0.033	0.087	1	0.000	0.004
			Maximum	0.049	0.065	0.189	5	0.004	0.024

05-05	Tully R	TR8	n	5	8	5	5	5	5
			Average	0.017	0.045	0.163	7	0.003	0.016
			Median	0.013	0.041	0.160	6.5	0.003	0.014
			Minimum	0.003	0.029	0.057	2	0.003	0.006
			Maximum	0.049	0.081	0.283	13	0.005	0.042
05-27b	Tully R	7	n	14	14			14	
			average	0.011	0.060			0.004	
			median	0.010	0.056			0.002	
			min	0.000	0.013			0.000	
			max	0.028	0.096			0.015	

Appendix 6: Statistics on data collected in the Pioneer River area under the Healthy Waterways project ((White *et al*., 2002)

Site_Name	Location	Condition	Measure	SS	NOx	NH3	DIN	DON	PN	TN	PO4	DOP	PP	TP
06-01	Finch Hatton	Event	n	3	3	3	3	3	3	3	3	3	3	3
			mean	23	0.446	0.004	0.450	0.243	0.220	0.913	0.094	0.027	0.017	0.137
			median	24	0.449	0.003	0.452	0.245	0.200	1.020	0.091	0.030	0.000	0.121
			min	13	0.128	0.003	0.135	0.206	0.170	0.580	0.070	0.020	0.000	0.090
			max	33	0.761	0.007	0.764	0.278	0.290	1.140	0.120	0.030	0.050	0.200
06-02	Dumbleton Weir	Baseflow	n	3	3	3	3			3	3			3
			mean	10	0.108	0.018	0.127			0.423	0.007			0.033
			median	10	0.140	0.022	0.162			0.390	0.007			0.040
			min	10	0.015	0.011	0.026			0.380	0.006			0.020
			max	10	0.170	0.022	0.192			0.500	0.008			0.040
06-02	Dumbleton Weir	Event	n	4	5	5	5	5	5	5	5	5	5	5
			mean	272	0.536	0.028	0.618	0.486	0.668	1.772	0.081	0.021	0.236	0.338
			median	210	0.479	0.037	0.686	0.482	0.450	1.690	0.094	0.017	0.210	0.320
			min	49	0.327	0.002	0.328	0.464	0.240	1.090	0.023	0.011	0.050	0.160
			max	620	0.867	0.040	0.907	0.513	1.470	2.660	0.104	0.036	0.460	0.500

Appendix 7: Statistics on [Set 11] sites in the Sarina/Broadsound area … (Laxton *et al*., 1994).

Site_name	Description	Stn	Date	TSS	Oxid N	NH3	DIN	Org N	Part Tot N	Tot N	PO4	Part Tot P	Tot P
11-01	Rocky Dam/Cone Ck	1	n	18.0	18	18	18	18	18	18	18	18	18
			average	4.4	0.043	0.092	0.135	0.410	0.015	0.545	0.009	0.004	0.102
			median	3.5	0.018	0.076	0.093	0.287	0.013	0.458	0.007	0.004	0.053
			Minimum	0.8	0.001	0.028	0.029	0.009	0.004	0.088	0.003	0.001	0.006
			Max	13.1	0.358	0.299	0.657	1.593	0.033	1.673	0.032	0.012	0.801
11-02	Waterfall Ck	2	n	18.0	18	18	18	18	18	18	18	18	18
			average	6.8	0.012	0.094	0.105	0.655	0.037	0.760	0.006	0.006	0.072
			median	6.1	0.008	0.079	0.087	0.518	0.030	0.612	0.005	0.006	0.059
			Minimum	2.4	0.003	0.043	0.046	0.027	0.011	0.097	0.001	0.001	0.002
			Max	15.7	0.064	0.222	0.286	1.523	0.126	1.606	0.018	0.019	0.183
11-03	Arrowroot/Turnor Ck	3	n	18.0	18	18	18	18	18	18	18	18	18
			average	4.3	0.042	0.084	0.126	0.382	0.019	0.508	0.007	0.005	0.112
			median	3.0	0.010	0.066	0.076	0.291	0.013	0.442	0.004	0.004	0.064
			Minimum	1.1	0.001	0.033	0.034	0.039	0.006	0.092	0.002	0.001	0.011
			Max	12.5	0.457	0.329	0.786	1.109	0.051	1.639	0.027	0.021	0.699
11-04	Tommy Ck	4	n	18.0	18	18	18	18	18	18	18	18	18
			average	5.2	0.035	0.166	0.201	0.590	0.020	0.791	0.004	0.007	0.085
			median	3.7	0.011	0.061	0.072	0.261	0.012	0.355	0.002	0.003	0.037
			Minimum	0.2	0.002	0.032	0.034	0.049	0.004	0.092	0.000	0.000	0.002
			Max	17.7	0.134	1.076	1.210	2.170	0.057	2.760	0.016	0.041	0.586
11-05	Landing Road Ck	5	n	18.0	18	18	18	18	18	18	18	18	18
			average	16.4	0.037	0.131	0.168	1.021	0.055	1.188	0.018	0.014	0.131
			median	6.3	0.005	0.077	0.082	0.654	0.027	0.719	0.004	0.007	0.115
			Minimum	1.4	0.001	0.017	0.018	0.044	0.008	0.095	0.001	0.002	0.012
			Max	61.4	0.309	0.804	1.113	3.381	0.316	4.494	0.182	0.059	0.401
11-06	Cherry Tree Ck	6	n	18.0	18	18	18	18	18	18	18	18	18
			average	6.2	0.058	0.085	0.143	0.452	0.018	0.595	0.011	0.005	0.075
			median	2.4	0.012	0.070	0.082	0.349	0.012	0.428	0.006	0.003	0.071
			Minimum	0.2	0.000	0.022	0.022	0.045	0.005	0.091	0.002	0.000	0.008
			Max	34.0	0.394	0.269	0.663	1.934	0.054	2.321	0.036	0.019	0.250

Site_name	Description	Stn	Date	TSS	Oxid N	NH3	DIN	Org N	Part Tot N	Tot N	PO4	Part Tot P	Tot P
11-07	Marion Ck (E)	7	n	18.0	18	18	18	18	18	18	18	18	18
			average	3.2	0.013	0.066	0.080	0.312	0.017	0.392	0.005	0.004	0.052
			median	2.8	0.008	0.049	0.057	0.289	0.014	0.352	0.004	0.004	0.044
			Minimum	0.8	0.001	0.019	0.020	0.006	0.003	0.049	0.002	0.001	0.004
			Max	11.8	0.061	0.213	0.274	0.907	0.041	1.058	0.021	0.015	0.157
11-08	Marion Ck (W)	8	n	18.0	18	18	18	18	18	18	18	18	18
			average	3.4	0.006	0.064	0.069	0.445	0.016	0.515	0.005	0.003	0.064
			median	2.8	0.005	0.050	0.055	0.412	0.013	0.453	0.002	0.003	0.032
			Minimum	0.7	0.001	0.019	0.020	0.030	0.006	0.065	0.000	0.001	0.002
			Max	11.0	0.028	0.213	0.241	1.692	0.035	1.712	0.025	0.006	0.352
11-09	Plane Ck V-notch	9	n	18.0	18	18	18	18	18	18	18	18	18
			average	3.3	0.015	0.059	0.074	0.591	0.018	0.666	0.007	0.004	0.105
			median	1.8	0.006	0.058	0.064	0.294	0.012	0.355	0.003	0.002	0.052
			Minimum	0.2	0.000	0.026	0.026	0.074	0.004	0.102	0.000	0.001	0.012
			Max	16.4	0.101	0.133	0.234	4.203	0.091	4.385	0.025	0.020	0.708
11-10	Plane Ck Neilsons	10	n	18.0	18	18	18	18	18	18	18	18	18
			average	3.1	0.036	0.094	0.130	0.441	0.018	0.572	0.012	0.005	0.075
			median	2.3	0.004	0.066	0.070	0.444	0.015	0.488	0.011	0.004	0.052
			Minimum	0.3	0.001	0.027	0.028	0.009	0.003	0.085	0.000	0.001	0.007
			Max	8.8	0.217	0.352	0.569	1.047	0.043	1.194	0.038	0.018	0.268
11-11	Plane Ck Apex Pk	11	n	18.0	18	18	18	18	18	18	18	18	18
			average	5.0	0.017	0.088	0.106	0.734	0.027	0.839	0.023	0.007	0.112
			median	5.0	0.004	0.086	0.089	0.410	0.023	0.481	0.008	0.006	0.060
			Minimum	0.7	0.000	0.025	0.025	0.057	0.005	0.096	0.002	0.002	0.007
			Max	16.3	0.128	0.207	0.335	4.415	0.084	4.662	0.146	0.017	0.616

Appendix 9 (Set 15a): Data statistics for the first set of Waterwatch data collected in the Pioneer River, 1994-1996 (Wright, 1996).

Site_name	Stream	Location	Site	Measure	NOX	PO4
15a-01	Cattle Ck	Netherdale	1	n	17	17
				average	0.004	0.131
				median	0.003	0.106
				min	0.000	0.053
				max	0.021	0.211
15a-02	Cattle Ck	FHG_PalmCk	2	n	11	11
				average	0.012	0.178
				median	0.009	0.112
				min	0.000	0.066
				max	0.034	0.733
15a-03	Finch Hatton Ck	FHG_FHCk	3	n	8	9
				average	0.006	0.062
				median	0.003	0.066
				min	0.000	0.007
				max	0.022	0.119
15a-04	Cattle Ck	FHT_Cattle	4	n	26	26
				average	0.014	0.131
				median	0.006	0.102
				min	0.000	0.040
				max	0.130	0.733
15a-05	Cattle Ck	Septimus_Cattle	5	n	23	23
				average	0.022	0.113
				median	0.006	0.119
				min	0.000	0.046
				max	0.094	0.284

Appendix 10 (Set 15b): Data statistics for the second set of Waterwatch data collected in the Pioneer River, 1996-1998 (Wright, 1998).

Site_name	Stream	Location	Site	Measure	NOx-N	PO4-P
15b-01	Finch Hatton Ck	Gorge	p1	n	16	16
				Average	0.008	0.036
				Median	0.000	0.032
				Min	0.000	0.007
				Max	0.040	0.073
15b-02	Finch Hatton Ck	above Cattle Ck	p2	n	20	19
				Average	0.025	0.083
				Median	0.020	0.068
				Min	0.000	0.034
				Max	0.100	0.210
15b-03	Cattle Ck	Showgrounds	p3	n	22	22
				Average	0.094	0.105
				Median	0.015	0.088
				Min	0.000	0.007
				Max	0.550	0.266
15b-04	Cattle Ck	Gargett Bridge	p4	n	14	14
				Average	0.036	0.089
				Median	0.010	0.083
				Min	0.000	0.007
				Max	0.180	0.251
15b-05	Pioneer R	Marian Bend	p5	n	18	15
				Average	0.022	0.060
				Median	0.010	0.044
				Min	0.000	0.007
				Max	0.080	0.337
15b-06	Bakers Ck	Walkerston	p6	n	22	23
				Average	0.04	0.19
				Median	0.01	0.19
				Min	0.00	0.03
				Max	0.40	0.43
15b-07	Gooseponds Ck	blw Sport Complex	p7	n	30	30
				Average	0.041	0.219
				Median	0.010	0.207
				Min	0.000	0.039
				Max	0.420	0.635
15b-08	Gooseponds Ck	behind swim pool	p8	n	30	30
				Average	0.023	0.127
				Median	0.000	0.100
				Min	0.000	0.020
				Max	0.430	0.386
15b-10	Sandy Ck	Palm Tree Ck crossing	p10	n	26	26
				Average	0.073	0.127
				Median	0.005	0.098
				Min	0.000	0.039
				Max	0.550	0.273
15b-11	St Helens Ck	Hunters Farm	h1	n	20	20
				Average	0.013	0.063
				Median	0.010	0.056

Site_name	Stream	Location	Site	Measure	NOx-N	PO4-P
				Min	0.000	0.000
				Max	0.050	0.149
15b-12	St Helens Ck	below Pig Ck	h2	n	12	12
				Average	0.012	0.070
				Median	0.010	0.071
				Min	0.000	0.029
				Max	0.040	0.117
15b-13	St Helens Ck	Cameron's Pocket	h3	n	17	17
				Average	0.015	0.072
				Median	0.010	0.059
				Min	0.000	0.015
				Max	0.090	0.293
15b-14	St Helens Ck	Caravan Park Kolijo	h4	n	19	19
				Average	0.037	0.088
				Median	0.020	0.059
				Min	0.000	0.017
				Max	0.210	0.222

Appendix 12: (Set 22) Data statistics for water quality in the Whitsunday Rivers catchment (Faithful, 2003).

Site_name	Location	Site	Statistic	NH3	NOx	TN	SS	PO4	TP
22-12	Myrtle Ck	30	n	11	11	11	11	11	11
			avg	0.048	0.059	0.627	14.2	0.049	0.107
			med	0.033	0.015	0.518	5.8	0.040	0.088
			min	0.001	0.004	0.196	1.8	0.026	0.047
			max	0.152	0.345	1.920	104.4	0.105	0.236
22-15	Patullo Rd	25	n	11	11	11	11	11	11
			avg	0.009	0.027	0.163	3.6	0.042	0.066
			med	0.008	0.025	0.146	1.6	0.047	0.064
			min	0.001	0.006	0.095	0.2	0.010	0.051
			max	0.032	0.058	0.266	14.0	0.054	0.102
22-17	Boundary Ck	3	n	13	13	13	13	13	13
			avg	0.007	0.023	0.137	1.1	0.030	0.057
			med	0.005	0.016	0.105	0.9	0.026	0.054
			min	0.001	0.009	0.056	0.1	0.013	0.033
			max	0.016	0.094	0.334	2.0	0.055	0.083
22-14	Bates Rd	24	n	3	3	3	3	3	3
			avg	0.007	0.042	0.189	2.9	0.065	0.079
			med	0.006	0.036	0.195	2.1	0.058	0.082
			min	0.002	0.022	0.165	1.9	0.040	0.056
			max	0.013	0.067	0.207	4.6	0.097	0.098
22-09	Cantemessa's Cr	23	n	13	13	13	13	13	13
			avg	0.053	0.314	0.681	10.0	0.055	0.133
			med	0.042	0.234	0.726	6.9	0.049	0.112
			min	0.001	0.005	0.229	1.1	0.035	0.064
			max	0.104	0.957	1.130	45.9	0.106	0.286
22-04	Moxham's B	8	n	13	13	13	13	13	13
			avg	0.009	0.042	0.152	2.5	0.066	0.114
			med	0.005	0.026	0.146	1.8	0.066	0.112
			min	0.002	0.002	0.092	0.5	0.029	0.079
			max	0.029	0.143	0.328	8.0	0.092	0.175
22-16	Brandy Ck	22	n	11	11	11	11	11	11
			avg	0.008	0.110	0.242	2.9	0.034	0.061
			med	0.006	0.125	0.236	2.5	0.033	0.065
			min	0.001	0.003	0.209	0.3	0.018	0.043
			max	0.023	0.202	0.293	9.1	0.051	0.082
22-01	Cathu Forest	1	n	13	13	13	13	13	13
			avg	0.007	0.090	0.206	1.0	0.022	0.039
			med	0.007	0.014	0.105	0.7	0.019	0.040
			min	0.001	0.005	0.080	0.3	0.010	0.023
			max	0.027	1.002	1.260	2.1	0.038	0.060
22-13	Collingvale Rd	28	n	13	13	13	13	13	13
			avg	0.011	0.046	0.281	3.3	0.020	0.051
			med	0.007	0.010	0.237	3.0	0.019	0.046
			min	0.001	0.003	0.091	0.8	0.010	0.035
			max	0.047	0.246	0.547	8.1	0.034	0.083

22-06	River Landing	18	n	13	13	13	13	13	13
			avg	0.110	0.290	0.891	218.7	0.076	0.164
			med	0.124	0.241	0.729	131.2	0.074	0.142
			min	0.011	0.074	0.544	69.6	0.053	0.070
			max	0.215	0.983	1.740	541.0	0.119	0.433
22-11	Spruce's Cr	16	n	13	13	13	13	13	13
			avg	0.010	0.024	0.252	2.8	0.014	0.033
			med	0.002	0.010	0.208	2.3	0.015	0.027
			min	0.001	0.004	0.116	0.6	0.006	0.019
			max	0.058	0.119	0.446	6.1	0.019	0.071
22-07	Lethebrook B	9	n	13	13	13	13	13	13
			avg	0.034	0.063	0.584	8.4	0.035	0.084
			med	0.018	0.015	0.469	6.3	0.027	0.072
			min	0.004	0.005	0.321	1.7	0.022	0.044
			max	0.140	0.510	1.370	35.9	0.074	0.179
22-08	DPI Station	14	n	13	13	13	13	13	13
			avg	0.041	0.098	0.518	3.6	0.008	0.026
			med	0.019	0.060	0.497	2.7	0.008	0.024
			min	0.006	0.010	0.354	1.4	0.002	0.017
			max	0.224	0.298	0.920	10.5	0.022	0.045
22-10	B Lee B	12	n	13	13	13	13	13	13
			avg	0.024	0.056	0.263	5.6	0.024	0.050
			med	0.016	0.048	0.224	2.8	0.022	0.049
			min	0.004	0.012	0.147	1.2	0.010	0.032
			max	0.070	0.138	0.448	28.7	0.041	0.090

Appendix 13: (Set 23) Data statistics for the Barron River water quality study (Cogle *et al*., 2000)

Site_nam	Sites	Site_no	Statistics	NH3	NOx	TN	SS	PO4	TP
23-26	Clohesy R	27	n	6	6	6	6	6	6
			average	0.009	0.015	0.037	2.0	0.010	0.009
			median	0.005	0.007	0.010	1.8	0.010	0.005
			min	0.002	0.001	0.010	0.0	0.007	0.005
			max	0.018	0.043	0.119	4.6	0.014	0.030
23-34	Freshwater Ck	35	n	34	34	34	34	34	34
			average	0.009	0.077	0.100	2.1	0.006	0.006
			median	0.007	0.075	0.094	1.6	0.006	0.005
			min	0.001	0.005	0.010	0.0	0.001	0.005
			max	0.033	0.124	0.320	9.0	0.026	0.030
23-13	Kauri Ck	13	n	89	90	90	72	90	90
			average	0.016	0.072	0.516	22.8	0.014	0.038
			median	0.007	0.060	0.101	4.0	0.013	0.020
			min	0.001	0.005	0.000	0.0	0.002	0.005
			max	0.180	0.290	5.462	261.2	0.060	0.620
23-32	Flaggy Ck	33	n	5	5	5	5	5	5
			average	0.013	0.012	0.049	6.9	0.003	0.014
			median	0.015	0.010	0.032	3.6	0.003	0.005
			min	0.001	0.003	0.010	2.4	0.001	0.005
			max	0.022	0.031	0.120	21.2	0.007	0.050
23-24	Davies Ck	25	n	5	5	5	5	5	5
			average	0.007	0.010	0.040	4.0	0.009	0.015
			median	0.006	0.004	0.045	2.0	0.005	0.005
			min	0.001	0.001	0.010	1.0	0.001	0.005
			max	0.015	0.040	0.075	9.6	0.029	0.055
23-30	Flaggy Ck	31	n	34	34	34	34	34	34
			average	0.011	0.030	0.210	12.9	0.004	0.008
			median	0.008	0.025	0.162	5.4	0.004	0.005
			min	0.001	0.001	0.010	1.0	0.001	0.005
			max	0.029	0.112	0.823	90.0	0.023	0.040
23-23	Emerald Ck	24	n	5	5	5	5	5	5
			average	0.011	0.025	0.084	2.4	0.012	0.005
			median	0.014	0.006	0.071	2.2	0.006	0.005
			min	0.003	0.001	0.033	0.0	0.001	0.005
			max	0.020	0.103	0.185	5.4	0.038	0.005
23-06	Barron R	6	n	58	58	58	58	58	58
			average	0.034	0.104	0.359	11.2	0.012	0.022
			median	0.027	0.110	0.193	8.0	0.009	0.024
			min	0.001	0.005	0.010	1.0	0.001	0.005
			max	0.228	0.216	3.485	79.0	0.080	0.086
23-22	Shanty Ck	23	n	5	5	5	5	5	5
			average	0.045	0.025	0.377	10.3	0.014	0.010
			median	0.049	0.008	0.274	7.0	0.010	0.005
			min	0.009	0.001	0.057	3.6	0.002	0.005
			max	0.085	0.103	0.686	28.8	0.040	0.030

23-04	Scrubby Ck	4	n	36	36	36	36	36	36
			average	0.020	0.117	0.264	22.5	0.006	0.017
			median	0.015	0.120	0.244	16.7	0.006	0.005
			min	0.001	0.001	0.010	6.2	0.001	0.005
			max	0.070	0.294	1.290	76.6	0.011	0.066
23-09	Peterson Ck	9	n	82	83	81	66	83	83
			average	0.033	0.070	0.462	13.5	0.015	0.045
			median	0.020	0.058	0.250	5.8	0.009	0.025
			min	0.004	0.005	0.010	0.6	0.001	0.002
			max	0.248	0.390	2.590	204.4	0.080	0.397
23-07	Gwynne Ck	7	n	5	5	5	5	5	5
			average	0.034	0.146	0.200	28.7	0.010	0.025
			median	0.025	0.171	0.105	6.4	0.007	0.019
			min	0.005	0.042	0.073	3.8	0.002	0.005
			max	0.069	0.222	0.569	108.4	0.028	0.069
23-38	Thomatis Ck	39	n	36	36	36	36	36	36
			average	0.052	0.049	0.169	65.7	0.012	0.016
			median	0.030	0.043	0.135	54.0	0.011	0.005
			min	0.002	0.001	0.010	4.0	0.002	0.005
			max	0.337	0.147	0.440	204.0	0.027	0.064
23-08	Leslie Ck	8	n	35	35	35	34	35	35
			average	0.015	0.099	0.276	10.9	0.008	0.033
			median	0.010	0.108	0.186	8.0	0.007	0.005
			min	0.003	0.003	0.010	0.8	0.003	0.005
			max	0.054	0.216	1.290	44.0	0.020	0.166
23-15	Rocky Ck	15	n	5	5	5	5	5	5
			average	0.012	0.138	0.171	9.5	0.011	0.020
			median	0.011	0.118	0.119	7.6	0.009	0.014
			min	0.005	0.084	0.043	4.8	0.007	0.005
			max	0.021	0.271	0.382	17.2	0.019	0.060
23-02	Mazlin Ck	2	n	54	54	54	54	54	54
			average	0.029	0.027	0.366	15.3	0.011	0.031
			median	0.017	0.020	0.227	7.9	0.008	0.025
			min	0.005	0.001	0.010	0.0	0.001	0.005
			max	0.390	0.111	1.840	107.0	0.080	0.170
23-03	Piebald Ck	3	n	37	37	37	37	37	37
			average	0.133	0.595	0.543	18.2	0.032	0.066
			median	0.039	0.317	0.370	11.2	0.011	0.034
			min	0.002	0.033	0.010	0.0	0.005	0.005
			max	1.095	4.207	1.947	110.0	0.220	0.291

Appendix 14: (Set 34) Data statistics for the Whitfield Creek study (Faithful *et al*., 2005)

Site_name	Stream	Site	Statistic	NH3	NOx	DON	PN	TN	TSS	PO4	DOP	PP	TP
34-01	Whitfield Ck	1	n	7	7	7	7	7	7	7	7	7	7
			average	0.017	0.055	1.645	0.072	1.789	67.771	0.007	0.014	0.021	0.029
			median	0.013	0.062	0.703	0.062	0.818	74.800	0.006	0.007	0.012	0.020
			min	0.008	0.029	0.554	0.016	0.623	18.800	0.001	0.002	0.007	0.016
			max	0.036	0.076	7.440	0.200	7.750	111.200	0.017	0.059	0.076	0.087
34-02	Whitfield Ck	2	n	6	6	6	6	6	6	6	6	6	6
			average	0.006	0.267	3.185	0.044	3.501	37.067	0.004	0.016	0.020	0.032
			median	0.005	0.295	0.723	0.040	1.153	29.600	0.002	0.006	0.008	0.018
			min	0.004	0.088	0.217	0.006	0.534	20.800	0.001	0.005	0.007	0.015
			max	0.009	0.402	15.363	0.076	15.530	65.200	0.014	0.062	0.076	0.098
34-03	Whitfield Ck	3	n	24	24	24	24	24	24	24	24	24	24
			average	0.118	0.257	3.075	0.594	4.044	114.567	0.009	0.026	0.035	0.096
			median	0.031	0.301	2.204	0.380	3.155	88.250	0.007	0.024	0.035	0.071
			min	0.000	0.000	0.000	0.000	0.000	12.000	0.000	0.000	0.000	0.000
			max	0.726	0.440	9.284	2.400	12.100	491.500	0.028	0.111	0.129	0.514
34-04	Whitfield Ck	4	n	23	23	23	23	23	23	23	23	23	23
			average	0.090	0.372	2.284	0.622	3.369	85.569	0.008	0.017	0.025	0.069
			median	0.056	0.367	1.272	0.300	1.950	74.670	0.007	0.018	0.023	0.058
			min	0.000	0.000	0.000	0.000	0.000	8.000	0.000	0.000	0.000	0.000
			max	0.497	0.693	12.541	5.420	13.440	256.400	0.021	0.033	0.054	0.137

Appendix 15: (Set 35) Data statistics for selected sites from Laxton and Gittins (2004) research.

Site_name	Stream	Site	Statistic	NH_3	NO_X	TN	SS	PO_4	TP
35-07	Finch Hatton Ck	28	n	32	32	32	32	32	32
			average	0.058	0.019	0.362	1.522	0.002	0.098
			median	0.056	0.014	0.285	1.050	0.002	0.030
			min	0.022	0.002	0.077	0.200	0.000	0.002
			max	0.123	0.113	1.386	7.200	0.006	1.358
35-04	Upper Tully R	34	n	32	32	32	32	32	32
			average	0.078	0.076	0.454	2.566	0.002	0.057
			median	0.061	0.046	0.317	1.900	0.001	0.026
			min	0.016	0.028	0.122	0.800	0.000	0.002
			max	0.219	0.900	1.616	14.700	0.009	0.671
35-05	Mossman R	38	n	32	32	32	32	32	32
			average	0.069	0.067	0.477	1.584	0.002	0.043
			median	0.058	0.044	0.331	0.750	0.002	0.031
			min	0.020	0.005	0.117	0.000	0.000	0.007
			max	0.192	0.313	3.904	16.000	0.011	0.169
35-06	Upper Daintree R	41	n	32	32	32	32	32	32
			average	0.095	0.028	0.560	5.694	0.004	0.051
			median	0.076	0.019	0.478	3.100	0.003	0.039
			min	0.024	0.002	0.121	0.500	0.000	0.013
			max	0.209	0.079	1.673	42.200	0.013	0.202
35-01	Little Crystal Ck	30	n	32	32	32	32	32	32
			average	0.079	0.058	0.494	3.336	0.003	0.056
			median	0.065	0.030	0.359	3.450	0.003	0.042
			min	0.017	0.011	0.091	0.100	0.001	0.008
			max	0.377	0.383	2.299	11.100	0.010	0.587
35-03	Upper Herbert R	32	n	32	32	32	32	32	32
			average	0.089	0.028	0.537	7.044	0.005	0.069
			median	0.067	0.015	0.427	3.550	0.003	0.043
			min	0.026	0.002	0.104	1.100	0.001	0.004
			max	0.214	0.223	1.540	49.100	0.020	0.333