WATER QUALITY MONITORING OF THE BLACK ROSS BASINS: 2007/08 WET SEASON

Report No. 08/04

for the Black Ross WQIP

August 2008

Water quality monitoring of the Black Ross Basins: 2007/08 Wet Season.

Interim report for the Black Ross Water Quality Improvement Plan

ACTFR Report No. 08/04

Prepared by Stephen Lewis, Zoe Bainbridge, Jon Brodie, Barry Butler and Mirjam Maughan

Australian Centre for Tropical Freshwater Research
James Cook University, Qld, 4811
Phone: (07) 47814262
Fax: (07) 47815589
Email: actfr@jcu.edu.au

Executive summary

Event-based water quality monitoring was conducted in the Black Ross Water Quality Improvement Plan (WQIP) Region in the 2007/08 wet season as a continuation on the previous 2006/07 campaign reported in Liessmann et al. (2007). The 2007/08 monitoring was designed to build upon the data gathered in the previous wet season in order to examine water quality signals from catchments draining different land uses, to calculate event mean concentrations of the various land uses in the region and to assist water quality model development. The monitoring sites were scaled down in the 2007/08 wet season to target specific land uses (developing urban: hillslopes and coastal plain, established urban and light industrial) in the Black Ross WQIP Region. The major catchments (Black, Bohle and Ross Rivers) were also monitored in the 2007/08 wet season to calculate sediment and nutrient loads. Pesticide samples were collected at the Alligator Creek downstream site to further investigate the presence of endosulfan residues which were detected in the previous 2006/07 wet season. Water quality data from sewage treatment plants (STP) were also obtained to examine their contribution to the total nutrient loads from the Bohle River. Broadly, four rainfall events which triggered catchment flows were sampled in the 2007/08 wet season including two smaller ‘first flush’ events and two large monsoonal rainfall events.

Similarly to the previous 2006/07 wet season, catchments draining different land uses displayed strong water quality signals in the Black Ross WQIP Region in the 2007/08 wet season. Catchments draining developing urban sites contained highly elevated suspended sediment concentrations, with exceptionally high concentrations at sampling sites draining hillslope developments. Suspended sediment concentrations were at least 40-50 fold (and up to 130 fold) higher in the developing urban (hillslope) waterways compared to the adjacent comparison sites draining the nearby hillside. The runoff of suspended sediments from developing urban sites is therefore a water quality concern in the Black Ross WQIP Region. High variability in the event mean concentrations (EMC) of suspended sediments were found in the Ross and Bohle Rivers over the two successive wet seasons. Interestingly, the trends in the EMC for particulate nitrogen and phosphorus did not conform to the trends observed for the suspended sediments in these larger catchments. This result is perplexing and may reflect the erosion of different soils within the catchment areas. The EMC for particulate nitrogen were comparable or higher in the established urban sites compared to the developing urban sites. The large difference in the suspended sediment EMC and particulate nitrogen EMC between these two land uses would be related to the runoff of more fertile soils from the established urban lands. The ANNEX model appears to considerably overestimate the loads of particulate nutrients from the major catchments of Black Ross Region; this is probably due to the soils database in the model which does not account for the nutrient poor soils in these broader landscapes.

Suspended sediment loads for the major catchments of the Black Ross Region showed interesting trends over the two wet seasons. The Black River loads were comparable over the two wet seasons with 33,000 tonnes and 41,000 tonnes of sediment discharged in the 2006/07 and 2007/08 wet seasons, respectively. The sediment load from the Bohle River was higher in 2007/08 (35,100 tonnes) compared to 2006/07 (22,000 tonnes) while the load from the Ross River in 2007/08 (14,500 tonnes) was much lower than the previous wet season (26,500 tonnes) despite the larger total discharge in 2007/08. The raising of the Ross River Dam spillway which was completed before the onset of the 2007/08 wet season may account for this difference where more sediment is being trapped by the dam.

Waterways draining urban lands contained elevated dissolved organic nitrogen (DON) concentrations and may be sourced to the leakage of DON from urban gardens. The light industrial site contained highly elevated dissolved organic phosphorus (DOP) contents; the DOP may be sourced to the runoff of an unknown type of industrial chemical. Water courses draining established urban lands also contained elevated DOP concentrations and could be

linked to the runoff of animal excreta and garden fertilisers. The runoff of DON is a lower water quality concern in the Black Ross WQIP Region as this species of nitrogen is considered to be less bioavailable compared to dissolved inorganic nitrogen. The potential effects of DOP at this stage are unknown as the specific sources of DOP could not be resolved.

Waterways draining the urban sites and the rural residential and light industrial lands had high inorganic forms of nitrogen (oxidised nitrogen: NO_x and ammonia). This result suggests the use of some fertilisers in these land uses as well as more fertile soils in these areas (e.g. from top dressings). The sites draining urban and light industrial lands had highly elevated filterable reactive phosphorus (FRP) concentrations and are of concern in the Black Ross WQIP Region. The sources of the elevated FRP would include the runoff of industrial effluent (light industry) cleaning detergents (both light industry and urban lands), animal excreta (e.g. dogs), phosphorus-based fertilisers and wastewater (urban lands).

The loads calculated for the STP suggest that they may contribute a considerable proportion to the nutrient loads discharged from the Black Ross Region. It is likely that little of these nutrients are transported very far into the marine environment but may pose a risk to the estuarine environment. The residence and cycling times of the nutrient-rich effluent discharge requires further research to evaluate ecological risk. Data from the Cleveland Bay STP show that plant upgrades have the potential to considerably reduce the loads of bioavailable nitrogen and phosphorus discharged from the STP.

No pesticide residues were detected in the Alligator Creek site in the 2007/08 wet season. Additional research into the pesticide products applied and their properties (fate, transport potential and half lives) in the Black Ross WQIP Region is required to better assess the risk of pesticide runoff in the region.

As there was considerable variability in the loads (and EMC) of sediments and nutrients in the major catchments of the Black Ross WQIP Region over the two successive wet seasons, we recommend that the monitoring of these waterways (Black, Ross and Bohle Rivers, Alligator and Bluewater Creeks) continue into the 2008/09 wet season. The results of this monitoring would further strengthen the water quality dataset and help produce better estimations of catchment loads in the Black Ross WQIP Region. The monitoring of the light industrial site (Hills Street Drain), which was established in the 2007/08 wet season, should also continue into the 2008/09 wet season to obtain two years of monitoring data. We also recommend that this site be monitored into the 2008/09 wet season to determine the constituents of the brown sludge observed in the previous wet season. The fate of nutrients discharged from the STP in the Bohle River would be another valuable study. In particular, the knowledge of residence times of the effluent would be important to evaluate the ecological risk of this discharge.

Table of Contents

1. INTRODUCTION

Over the last two wet seasons (2006/07 and 2007/08), the Australian Centre for Tropical Freshwater Research (ACTFR) has conducted an event water quality monitoring program for the Black Ross Water Quality Improvement Plan (WQIP). The water quality monitoring undertaken during the first wet season (2006/07) was designed as a pilot investigation to examine the water quality issues from the various catchments in the region and included a suite of parameters such as total suspended sediments, nutrients (full speciation of nitrogen and phosphorus), pesticide residues, trace metals and oil and grease residues. The results from this wet season and a thorough background to the study are reported in Liessmann et al. (2007).

A more focused monitoring approach was conducted in the following 2007/08 wet season, which assessed sediment and nutrient runoff from catchments dominated by the established urban, developing urban and light industrial land uses. The three largest waterways in the region (Black River, Bohle River and Ross River) were also monitored in the 2007/08 wet season so that sediment and nutrient loads could be calculated and compared to the previous 2006/07 wet season. One of the key aims of this monitoring approach is to provide event mean concentration (EMC) data for each of these land use types and larger end-of-river sites for use by catchment modellers. In addition, Alligator Creek was monitored to investigate the presence of pesticide residues, particularly endosulfan, which was detected in the previous 2006/07 wet season.

This report presents the results from the 2007/08 event water quality monitoring program and builds on the water quality dataset collected in the previous 2006/07 wet season. We present EMC for suspended sediments and nutrients (ammonia, nitrate, nitrite, dissolved organic nitrogen, particulate nitrogen, filterable reactive phosphorus, dissolved organic phosphorus and particulate phosphorus) from the different land uses in the region using the data from both wet seasons and calculate loads for the major catchments in the region. The load data from the major waterways have been adjusted to mean annual flows and compared with the latest SedNet and ANNEX models. We calculate loads for the sewage treatment plants (STP) which discharge into the major rivers of the Black Ross WQIP Region to investigate their relative contribution to the annual loads of nitrogen and phosphorus. Finally, we investigate the analysis of pesticide residues from the Alligator Creek site.

The specific objectives of this project are to:

- Obtain data that will aid the identification of sub-catchments and land uses responsible for the fluvial exportation of sediments, nutrients and pesticides from the Black Ross WQIP Region;
- Augment the baseline data that will be needed to support regional and local target-setting, and the Black Ross WQIP;
- Improve the ability to predict loads and concentrations of sediments, nutrients and pesticides being exported to the GBR lagoon; and
- Increase awareness of water quality and aquatic ecosystem issues within the Black Ross WQIP Region.

2. 2007/08 FLOW EVENTS AND SAMPLING TIMING

Four rainfall events occurred in the Black Ross WQIP Region during the 2007/08 wet season and the effects on regional stream flows are illustrated in the flow hydrograph of the Bohle River (Fig. 1). As can be seen events occurred in late December (26th-29th: small first flush, Fig. 2), early January (7th-13th: larger 'first' flush, Fig. 3), mid January (13th-17th January: large event 1, Fig. 4), and mid February (10th-22nd February: large event 2, Fig. 5). There was no significant stream flow in the catchment during the months prior to these events, with less than 30 mm rainfall being registered in the catchment between September and December 25, 2007. The events in mid January and mid February were driven by monsoonal rain depressions and generated the largest stream flows of the 2007/08 wet season.

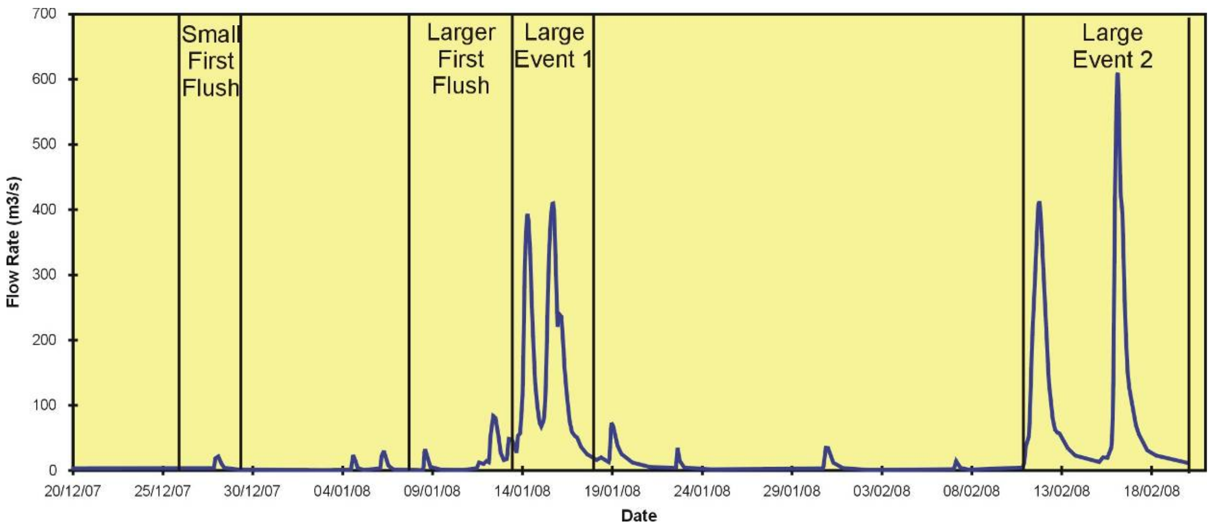


Figure 1. Hydrograph of the Bohle River over the 2007/08 wet season. The key flow events sampled are outlined.

The large events were sampled on the rise, peak and fall of the hydrographs so loads and concentration ranges could be estimated. The smaller first flush events were characterised by overnight rainfall which triggered small flashy flows and were largely only sampled on the falling stages.

The combined discharge of these events is considerable when compared to historical flow records (NRW Watershed). Stream discharge volume recorded at Bohle River gauge (118003A: Bohle River at Hervey Range Road, approximately 8 km upstream of the sampling site) was 154,200 ML which was the 2nd largest annual discharge for the 22 year gauged record (since 1985/86).

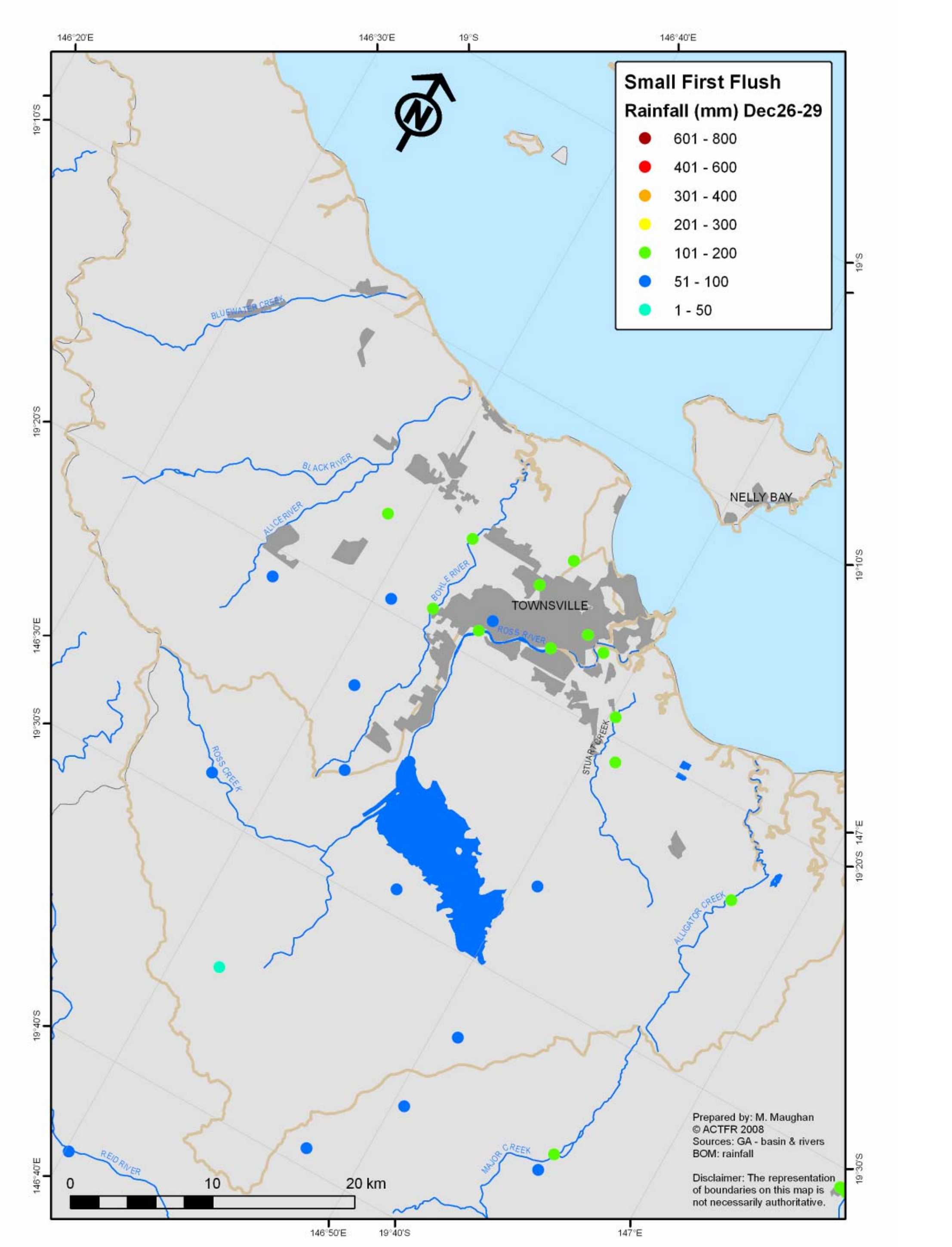


Figure 2. Map showing the rainfall distribution during the small first flush event (26th-29th December) monitored in the 2007/08 wet season.

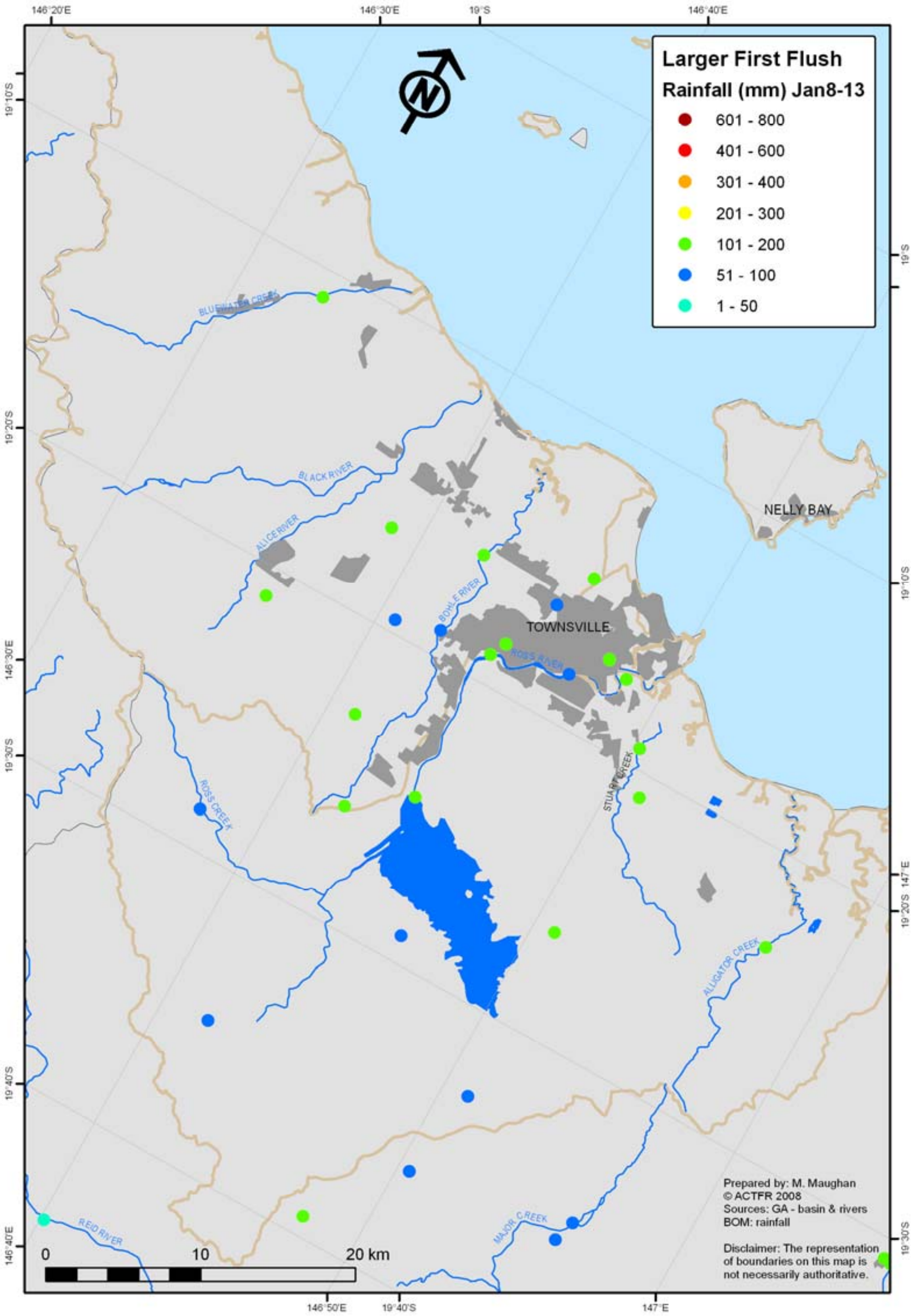


Figure 3. Map showing the rainfall distribution during the larger first flush event (8th-13th January) monitored in the 2007/08 wet season.

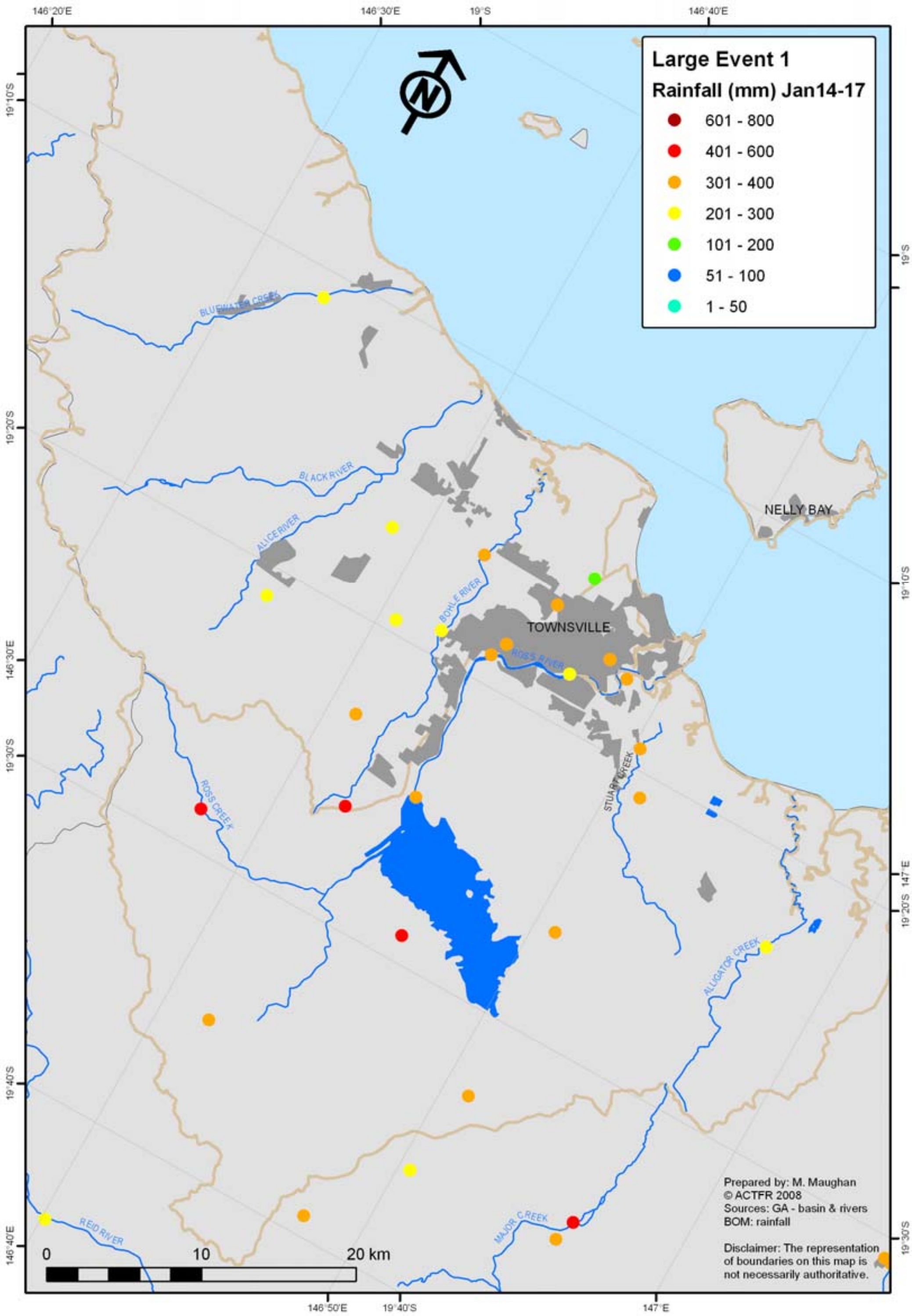


Figure 4. Map showing the rainfall distribution during the 1st large event (14th-17th January) monitored in the 2007/08 wet season.

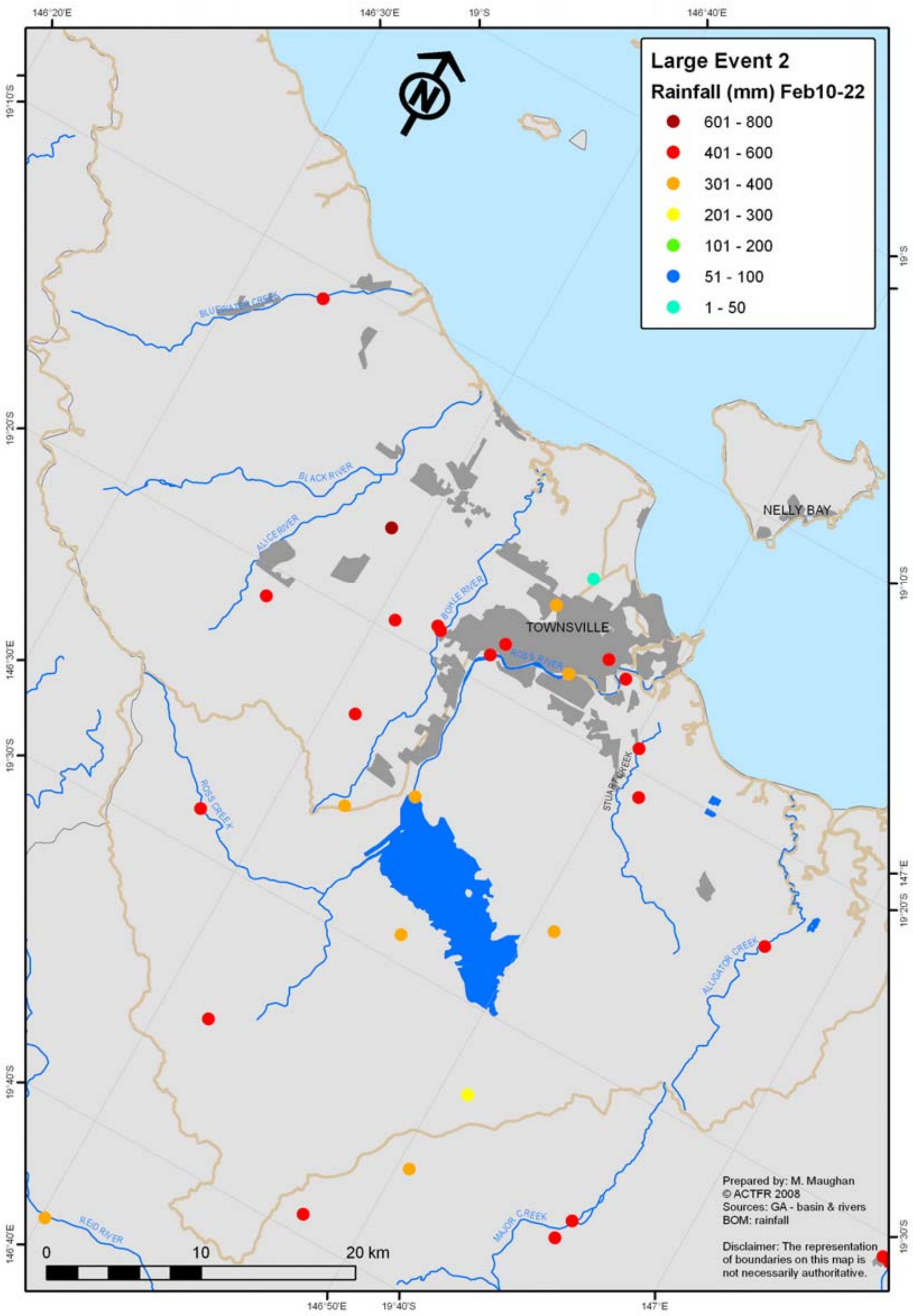


Figure 5. Map showing the rainfall distribution during the 2nd large event (10th-22nd February) monitored in the 2007/08 wet season.

3. METHODS

3.1 Site Selection

The sites sampled in the previous 2006/07 wet season were scaled back for the 2007/08 water year to particularly focus on the developing urban (both coastal plain and hillslope), established urban and light industrial land uses in the Black Ross WQIP Region (Table 1). These sites included the Woolcock Street Drain, Gordon Creek, Kern Drain and Riverside Creek which were all sampled in the 2006/07 season while an additional site to examine the effects of light industry land use was established in the 2007/08 wet season (Hills Street Drain) (Fig. 6). An extra three waterways adjacent to Riverside Creek were also sampled in the 2007/08 wet season to compare suspended sediment concentrations across developing and undeveloped lands on hillslopes. The major catchment sites (Ross River, Bohle River and Black River) were all sampled in the 2007/08 wet season while the Alligator Creek site was sampled only for pesticide residues in 2007/08. Table 1 outlines the sites, parameters and events sampled in the 2007/08 wet season as well as the number of samples collected.

3.2 Sampling Methods

Sampling was conducted exclusively by ACTFR project staff in the 2007/08 wet season. Project staff were trained in the correct sampling and quality assurance procedures.

The monitoring strategy was to sample throughout the duration of the flow hydrograph at each site, including the rising, peak and falling stages. Surface samples (top 50 cm of the water column) from all sites were collected with a sampling pole where the sample was collected directly into the appropriate container. Where it was not possible to collect the sample using a sampling pole, samples were collected in a bucket which was rinsed with water from the site prior to sample collection. The sediment and nutrient samples were then sub-sampled into the appropriate containers.

Samples were collected from the centre of the channel flow were possible. Where this was not possible every effort was made to ensure samples were collected from the main flow, away from the backwash at the riverbank. Nutrient samples were filtered at the time of sampling using a 0.45µm sterile filter cartridge (Sartorius MiniSart) and stored on ice with the unfiltered nutrient samples before being frozen. Total suspended solid (TSS) samples were stored on ice before being refrigerated. Pesticide samples were collected in amber glass bottles and stored on ice before being transported to the Queensland Health and Scientific Services laboratory for analysis.

Where flow or stream height data were unavailable for the ACTFR monitored sites, the water depth was measured opportunistically with a height stick at the time when samples were collected (sites include: Kern Drain, Woolcock St Drain and Gordon Creek). This measurement allowed trends between the water quality data and stream flow stage (i.e. rising, peaking, falling) to be investigated. Unfortunately, material loads could not be calculated in these catchments due to the lack of flow speed data, although estimates of the event mean concentrations can be used as model input data.

Table 1. Details of the sites sampled in the 2007/08 wet season including events samples (refer to Fig. 1) and total number of samples collected

Waterway	Sample Location	Sample collection	Events sampled	Parameters	Collection Method	Landuse (Dominant)	No of samples collected
1. Major Waterway Sites							
Black River (downstream)	Hwy	ACTFR	3 events (larger first flush and large events 1 and 2)	TSS and nutrients	Grab sampling	Grazing/ rural residential	13 (TSS and nutrients)
Bohle River (downstream)	Bruce Hwy (access across road from Bohle Barn)	ACTFR	All 4 events	TSS and nutrients	Grab sampling	Industrial/urban	18 (TSS and nutrients)
Ross River	Aplin's Weir footbridge	ACTFR	3 events (larger first flush and large events 1 and 2)	TSS and nutrients	Grab sampling	Grazing/ rural residential/urban	17 (TSS and nutrients)
2. Pesticide investigation							
Alligator Ck (downstream)	Bruce Hwy	ACTFR	3 events (small and large first flush and large event 1)	Pesticides only (5 samples)	Grab sampling	Pristine, rural residential	5 (Pesticide samples) and 1 (TSS and Nutrients)
3. Smaller Urban Creek/Drain sites							
Woolcock St Drain (near Hyde Park shopping centre	Woolcock St (Drains through Mindham Park/ Anderson Park)	ACTFR	3 events (small and large first flush and large event 1)	TSS and nutrients	Grab sampling	urban	10 (TSS and nutrients)
Gordon Ck	Abbott St (Fairfield Waters plus)	ACTFR	3 events (small and large first flush and large event 1)	TSS only	Grab sampling	Urban/ developing urban/ sewage	9 (TSS only)
Kern Drain (Trib to Bohle R)	Darlymple/Shaws Rd (Thuringowa / Kelso area)	ACTFR	3 events (small and large first flush and large event 1)	TSS and nutrients	Grab sampling	Urban/ developing urban	10 (TSS and nutrients)
Riverside Ck	Riverside Gardens	ACTFR	3 events (small and large first flush and large event 1)	TSS only	Grab sampling	Urban/ developing urban	10 (TSS only* includes some comparison sites)
Light industrial site	Tributary to Louisa Creek (Hills St, Garbutt)	ACTFR	All 4 events	TSS and nutrients	Grab sampling	Light industry	9 (TSS and nutrients)

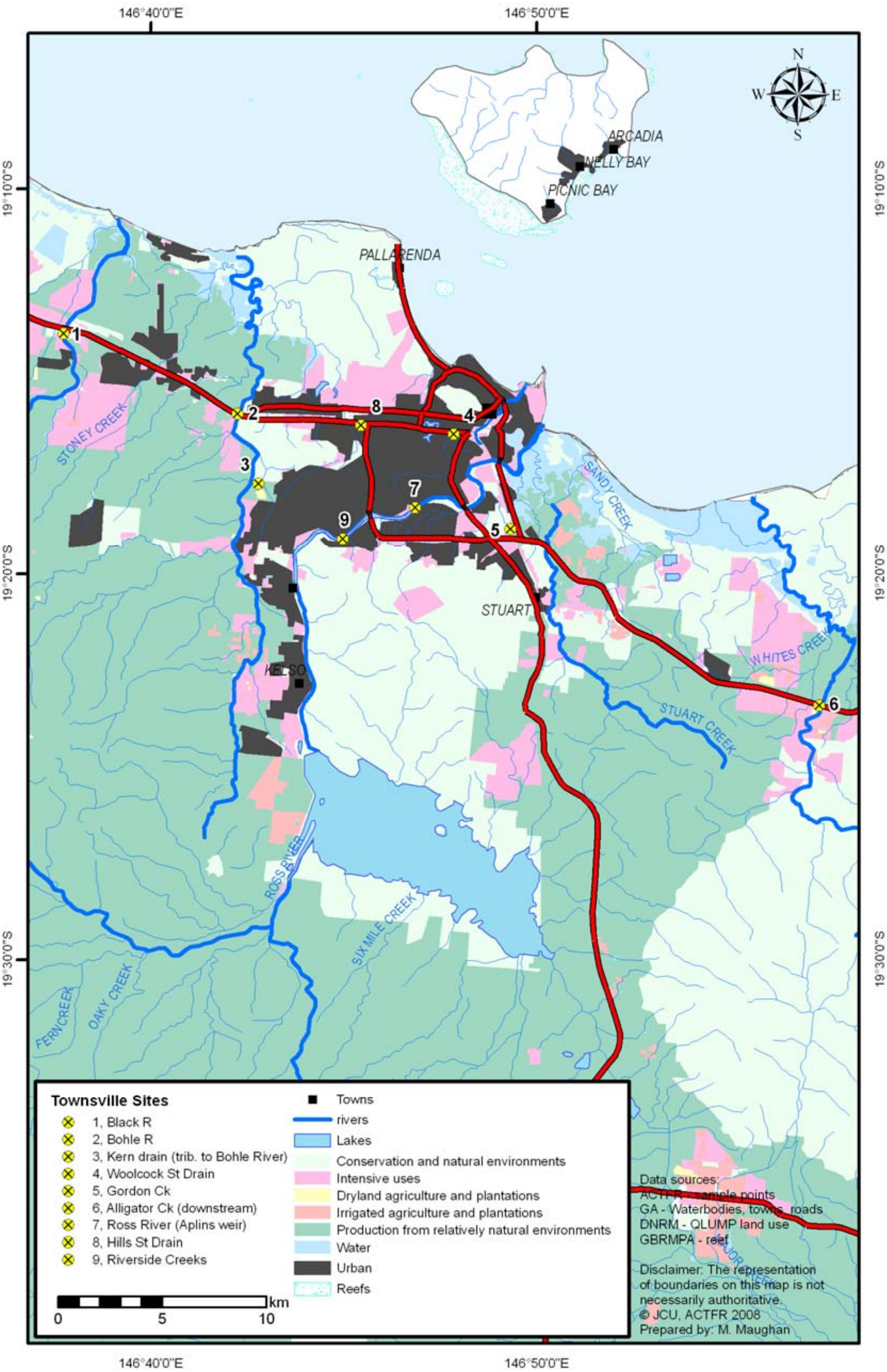


Figure 6. Map showing the locations of the water quality monitoring sites in the 2007/08 wet season.

3.3 Analytical Methods

Samples collected for TSS, electrical conductivity and nutrients were analysed at the Australian Centre for Tropical Freshwater Research (ACTFR) Water Quality Laboratory, James Cook University (JCU), Townsville. Samples collected for pesticide analyses were analysed at the Queensland Health Scientific Services (QHSS) laboratory, Brisbane.

3.3.1 Electrical conductivity and salinity

Electrical conductivity values were analysed directly using an ATI Orion 130 specific conductivity meter (Analytical Technology, Incorporated, USA), after calibration with reference potassium chloride standards similar to the sample range.

A total of 97 samples were analysed for electrical conductivity in the 2007/08 wet season. Three duplicate field samples were collected to investigate analytical precision. These duplicate samples were within 5%.

3.3.2 Total suspended solids

Samples that were collected for TSS analysis were filtered through pre-weighed GF/C filter membranes (nominally 1.2µm pore size) and oven dried at 103-105ºC for 24 hours before being re-weighed to determine the dry TSS weight. A total of 97 samples were collected and analysed for TSS throughout the 2007/08 wet season. 10% of all TSS samples were duplicated to assess the repeatability of the analysis. Duplicate determinations were, on average, within 10% of each other. In addition, three duplicate field samples were collected to examine analytical precision. These samples were within 10%.

3.3.3 Nutrients

Samples were analysed for total nitrogen (TN) and phosphorus (TP), total filterable nitrogen (TFN) and phosphorus (TFP), ammonia, NO_x (nitrate and nitrite) and filterable reactive phosphorus (FRP). Samples for TN and TP, and TFN and TFP were digested in an autoclave using an alkaline persulfate technique (modified from Hosomi and Sudo 1987) and the resulting solution simultaneously analysed for NO_x and FRP by segmented flow auto-analysis using an ALPKEM Flow Solution II (Alpkem Corporation, Wilsonville, Oregon, USA). The analyses of NO_x, ammonia and FRP were also conducted using standard segmented flow auto-analysis techniques following standard methods (APHA, AWWA and WEF 2005). Particulate nutrient concentrations were calculated by subtracting the total filterable nutrient concentrations from the total nutrient concentrations. Similarly, filterable organic nitrogen or phosphorus (referred to in this report as DON or DOP) was calculated by subtracting of NO_x plus ammonia (for nitrogen) or FRP (for phosphorus) from the TFN or TFP concentration.

A total of 78 samples were collected for nutrient analysis in the 2007/08 wet season. Three duplicate field samples were collected in the wet season to investigate analytical precision. In general, the samples analysed for ammonia, PN, PP, DON, TN and TP were within 10% of each other while the precision of NO_x, DOP and FRP were more variable with some samples outside the 10% range.

3.3.4 Pesticides

The pesticide samples were extracted from water with dichloromethane. The dichloromethane extract was concentrated prior to instrumentation quantification by GCMS analysis at the QHSS laboratory in Brisbane (Laboratory Reference No. 16315). A total of 5 samples were collected for pesticide analysis from the Alligator Creek (downstream) site in the 2007/08 wet season.

3.4 Load Calculations

The continuous time series flow data from the hydrographic gauging stations, and point source water quality data, were entered into the NRW "Brolga database", and loads were calculated using linear interpolation. Loads were normalised to average annual discharge (as specified by the SedNet/ANNEX model) to directly compare to the latest modelled outputs (SedNet model: Kinsey-Henderson et al., 2007; ANNEX model: Post et al., 2006). It should be noted that no gauged flow data are available for the Ross River (Aplins Weir) site, although flow has been calculated using height data provided by the Bureau of Metrology and measurements from the weir (calculations made by Dr Eric Wolanski). We therefore note that the loads estimated for this site would probably incur larger errors compared to the other sites because of the limited flow data.

3.5 Event Mean Concentration Calculations

For the major catchments of the Black Ross WQIP Region (Alligator C., Bluewater C., Ross R., Black R. and Bohle R.), the event mean concentration (EMC) was calculated by dividing the calculated load by the total discharge. We consider this process to be the most reliable at estimating the EMC. However, for the smaller ungauged catchment sites, EMC were estimated by calculating separate means for each of the rising, peak and falling stages of the hydrograph, and then by calculating the average of these three stages to produce the EMC. This process assumes that roughly equal discharge occurs on each of the three hydrograph stages. In some cases, it was difficult to estimate the location on the flow hydrograph of some samples due to the flashy nature of the small waterways in the Black Ross WQIP Region. However, we believe that this process would provide the best possible estimation of the EMC given the lack of flow data and note that one of the more reliable load estimation techniques available uses a stratified flow approach (e.g Letcher et al., 1999; Fox et al., 2005). We have compared this technique using the major catchments where EMC was calculated using the flow data. Overall, there are reasonable comparisons between the two methods with the means of the rise/peak/fall data generally lower than the EMC calculated using the load and flow data (typically within 30%). We have also presented the mean and median concentrations of all the samples collected at each site in the Black Ross WQIP Region for comparison. The final EMC calculated for the various land uses was the average for all the sites within the land use category. For sites where two years of data were available, the values were averaged before taking the mean of all the sites within the land use category to ensure that one site did not bias the final EMC calculation.

Note that some changes have been made when assigning the dominant land uses for the sampling sites compared to that reported in the 2006/07 wet season. In particular, we have changed the 'natural' land use to 'conservation' where the Alligator Creek upstream site is the most representative site in this classification. The Bluewater

Creek upstream and Campus Creek sites have now been included in the 'minimal use' category as the Bluewater Creek upstream site is lightly grazed by cattle and the Campus Creek site is classed as defence lands. Captains Creek has now been classed as an established urban site while the urban land use has been divided into established urban, developing urban on the coastal plain and developing urban on hillslopes. The three major catchment sites (Ross River, Black River and Bohle River) have been removed from classification into land uses and are considered separately. We note that the Stuart Creek downstream site has been retained in the urban/industrial land use although a large proportion of the upstream catchment area is dominated by grazing lands. The water quality of this site exhibits mixed land use signals.

4. RESULTS

4.1 Electrical Conductivity (EC)

The electrical conductivity (EC) of the vast majority of samples collected in the 2007/08 were below 200 µS/cm (Fig. 7). This result indicates that these samples are from a freshwater source and derived from the upstream catchment area. However, EC values exceeded 200 µS/cm in some samples from four tidally influenced monitoring sites comprising Gordon Creek, Woolcock St Drain, Bohle River and Hills St Drain. This result suggests a possible influence from seawater intrusion but could also be attributable to runoff from supratidal estuarine soils. Samples with EC values >1,000 µS/cm were collected before the large events in the 2007/08 wet season.

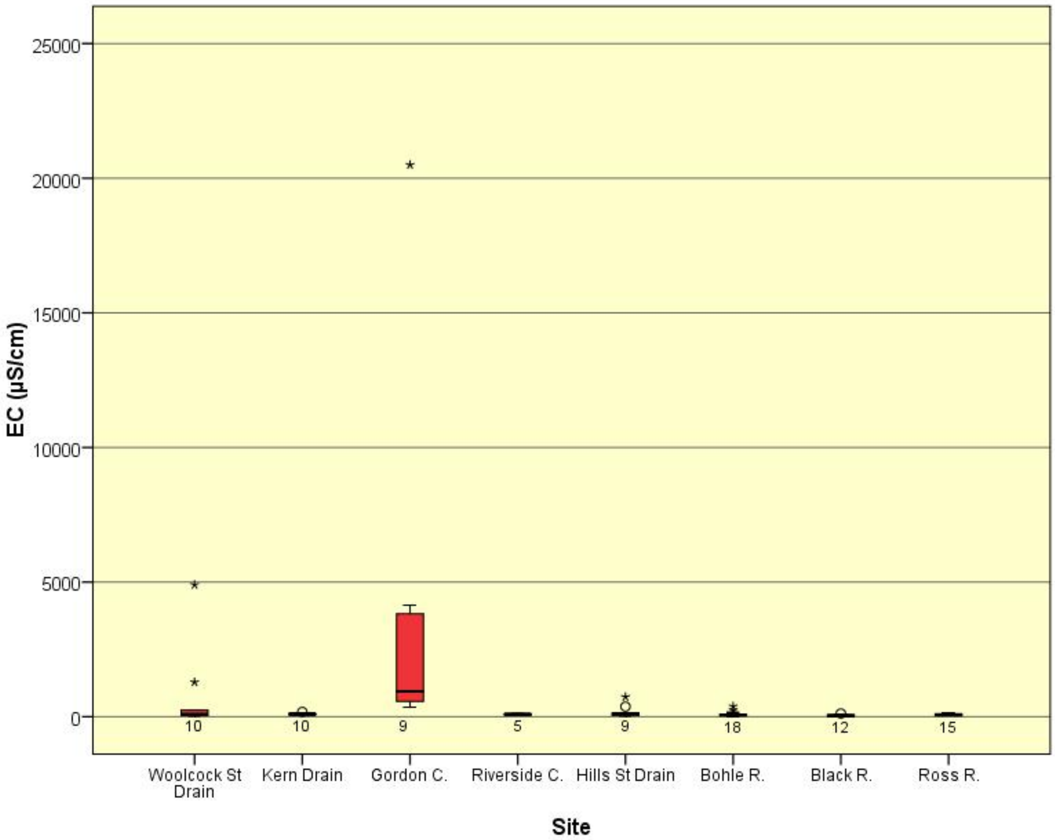


Figure 7. A boxplot summarising electrical conductivity of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

4.2 Total Suspended Solids (TSS)

Similarly to the previous 2006/07 wet season, waterways draining the developing urban sites contained elevated total suspended solid (TSS) concentrations with particularly high contents at the developing urban hillslope site which had a peak TSS concentration of 20,000 mg/L (Fig. 8a). This result is comparable to the peak concentration (34,000 mg/L) measured at this site in the previous wet season. Other opportunistic samples were collected at the same time from undeveloped sites adjacent to this developing urban hillslope site for comparison. These samples were all consistently below 100 mg/L (with most samples below 50 mg/L) and were at least 40-50 fold (and up to ~130 fold) below the concentrations measured at similar hillslope sites draining the developing urban lands. The developing urban sites on the coastal plain (Kern Drain and Gordon Creek) also had considerably higher TSS concentrations compared to the established urban site (Woolcock St Drain) in the 2007/08 wet season (Fig. 8b), a result consistent with the previous year (Liessmann et al., 2007).

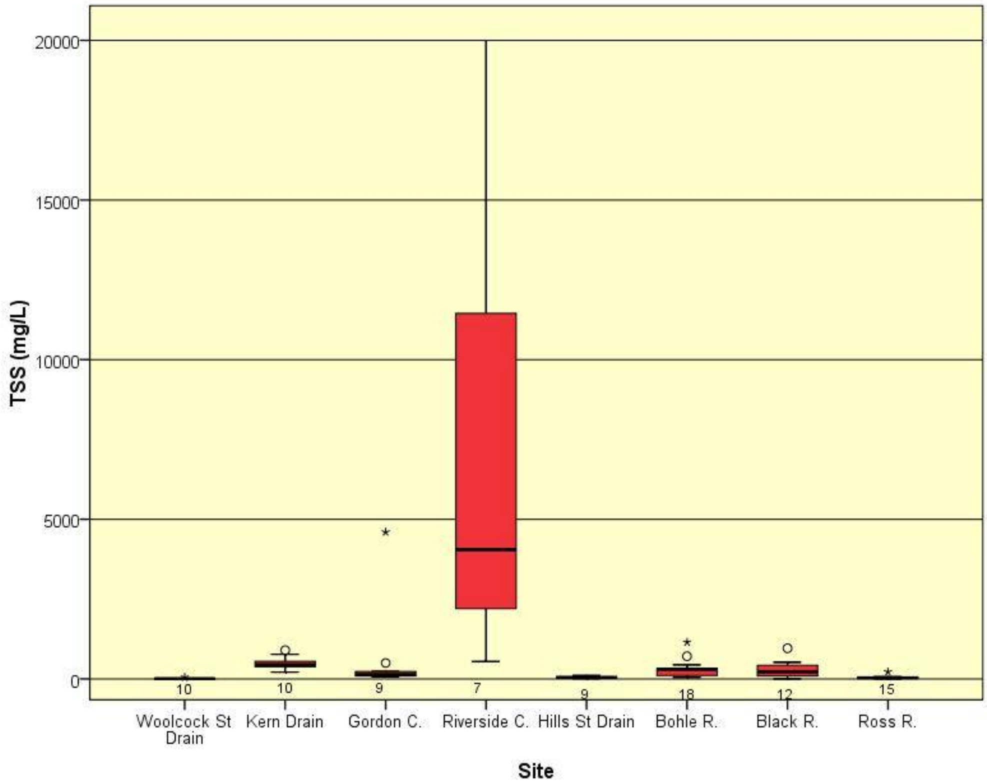


Figure 8a. A boxplot summarising the total suspended solid concentrations (mg/L) of samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

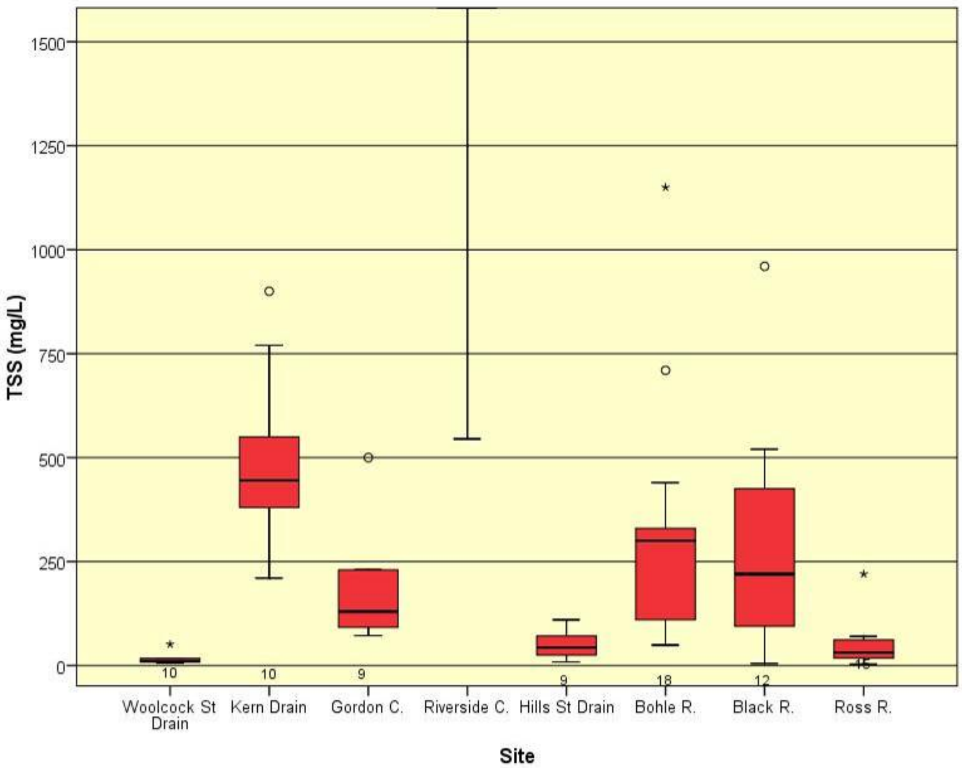


Figure 8b. Re-scaled boxplot of total suspended solid concentrations (mg/L) of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

The summary of the TSS concentrations over the 2006/07 and 2007/08 wet seasons show strong land use signals (Table 2). Interestingly, the TSS EMC calculated for the established urban sites (20 mg/L) is similar to the conservation land use (19 mg/L). The minimal, rural residential, urban industrial (only Stuart C. d/s site) and the light industrial sites had slightly elevated TSS EMC while the developing urban sites all had considerably higher TSS EMC concentrations. The large difference between the TSS EMC for the two urban industrial sites (Stuart C. d/s and Louisa C.) reflects the difference in catchment area and land use. The Stuart Creek d/s site has large upstream catchment area which is largely grazing lands while the Louisa Creek site drains a much smaller catchment area dominated by urban lands.

Table 2. Summary of TSS concentrations (mg/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Dominant Land use	Site	Year	mean (all data)	median (all data)	rise (mean)	peak (mean)	fall (mean)	Mean rise, peak & fall	Mean EMC (mg/L)
Established Urban	Woolcock St Drain	2006/07	22	24	20	29	22	24	**20**
		2007/08	15	10	51	17	8.8	26	
	Captain C.	2006/07	15	15	25	12	7.4	15	
Developing Urban (coastal plain)	Kern Drain	2006/07	339	278	612	284	185	360	**795**
		2007/08	502	445	637	770	389	599	
	Gordon C.	2006/07	409	351	783	444	184	470	
		2007/08	662	130	4600	500	123	1741	
Developing Urban (Hillslope)	Riverview C.	2006-08	11142	4975					**11140***
Light Industrial	Hill St Drain	2007/08	49	43	100	46	26	57	**57**
Urban/ industrial	Stuart C. (d/s)	2006/07	237	200	257	305	169	244	**130**
	Louisa C.	2006/07	14	12	21	15	7.8	15	
Rural residential	Sachs C.	2006/07	29	7.1	139	21	5.6	55	**35**
	Bluewater C. (d/s)	2006/07	27	8.3	40	45	4.4	30	
	Alligator C. (d/s)	2006/07	20	19	20	14	24	19	
Minimal use	Stuart C. (u/s)	2006/07	96	63	41	224	49	105	**56**
	HenCamp C.	2006/07	27	9.3	46	47	14	36	
	Campus C.	2006/07	14	3.5	10	49	1.9	20	
	Bluewater C. (u/s)	2006/07	55	18	130	48	9	62	
Conservation	Alligator C. (u/s)	2006/07	12	7	34	19	4.6	19	**19**

*This land use was not fully sampled over the hydrograph and most samples were collected over the rise and peak stages. Therefore this mean is probably overestimated.

Suspended sediment loads calculated for the major catchments over the monitoring period show mixed comparisons with the latest SedNet model run (Kinsey-Henderson et al., 2007). The flow adjusted sediment loads calculated for the three largest catchments in the Townsville Region (Ross River, Black River and Bohle River) compared reasonably well with the SedNet model (Table 3), although the comparisons for the smaller catchments (Alligator Creek and Bluewater Creek) were poor. This result is expected as the SedNet model is not specifically designed for small, flat coastal catchments of which there would be little/no input data available for the model from these areas. Interestingly, the loads for the Ross River showed high variability over the two wet seasons with the EMC in the 2007/08 wet season (50 mg/L) half that of the previous wet season (100 mg/L). The extension to the Ross River Dam spillway which was completed prior to the 2007/08 wet season may explain the lower suspended sediment EMC as more trapping of sediments may have occurred. Sampling in the 2008/09 wet season may help to investigate this assertion. In contrast, the EMC for the Bohle River was higher in the 2007/08 wet season compared to 2006/07 (Table 3). The EMC for the Black River was consistent over the successive wet seasons. We suggest that the average flow data used by the SedNet/ANNEX model may be underestimated for the Ross River and overestimated for the Bohle River. While the flow events of 2006/07 and 2007/08 have been relatively high in the region for both the Bohle and Ross Rivers, the SedNet models predicts average flows of 204,400 ML and 29,200 ML, respectively. This estimate is 50,000 ML higher than the 2006/07 and 2007/08 flows in the Bohle River which were among the highest flows recorded for this system in the 22 year gauged record (see section 2). In contrast the predicted flow for the Ross River is only around 10% of the discharge recorded in 2006/07 and 2007/08. Therefore the estimate of annual loads of sediments and nutrients by the SedNet/ANNEX model would also be compromised due to these discrepancies in annual flow.

Table 3. Suspended sediment loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

	2006/07			**2007/08**			**Comparison to model**	
Catchment	**Sediment load 2007 (tonnes)**	**Total flow volume (ML)**	**EMC (mg/L)**	**Sediment load 2008 (tonnes)**	**Total flow volume (ML)**	**EMC (mg/L)**	**Load adjusted to mean annual flow* (tonnes)**	**SedNet model** (tonnes)**
Alligator Creek	600	41,500	15				**530**	**8,500**
Black River	33,000	135,000	240	41,000	180,400	230	**17,000**	**20,200**
Bluewater Creek	2,700	63,500	40				**1,600**	**12,500**
Bohle River	22,000	147,000	150	35,100	154,200	230	**39,000**	**59,000**
Ross River	26,500	261,000	100	14,500	290,000	50	**2,500**	**1,400**

*As specified by the SedNet model.
**Kinsey-Henderson et al. (2007).

4.3 Nutrients

4.3.1 Particulate nitrogen and phosphorus

Particulate nitrogen (PN) concentrations displayed similar variability across sites in the 2007/08 wet season with the Ross River site generally having the lowest concentrations (Fig. 9). The summary EMC for PN (Table 4) show there is little variability in PN across the different land uses of the Black Ross WQIP Region. The established urban sites had higher PN EMC compared to the developing urban sites; this result indicates the runoff of more fertile soils in the established urban lands. Interestingly, the PN loads for Ross River across the 2006/07 and 2007/08 wet seasons display the opposite trend to the TSS loads where the PN EMC was higher in the 2007/08 wet season (Table 5). In addition, the PN load for the Black River was considerably higher in the 2007/08 wet season compared to the previous 2006/07 year. The measured flow-normalised PN loads were consistently much lower than the loads predicted by the ANNEX model (Post et al., 2006).

Particulate phosphorus (PP) concentrations followed similar trends to TSS in the 2007/08 wet season (Fig. 10) with elevated PP in the developing urban land use (Kern Drain). The summary EMC (Table 6) for PP also typically follow the TSS EMC with the highest concentrations in the developing urban land use. However, the EMC of PP for the light industrial and urban industrial sites appears to be more elevated relative to TSS. PP loads for the gauged catchments are shown in Table 7. Loads and EMC of PP were similar for the three large catchments over the successive wet seasons and did not conform to the TSS trend. Similarly to the PN, the measured flow-normalised PP loads were considerably much lower than the ANNEX model prediction.

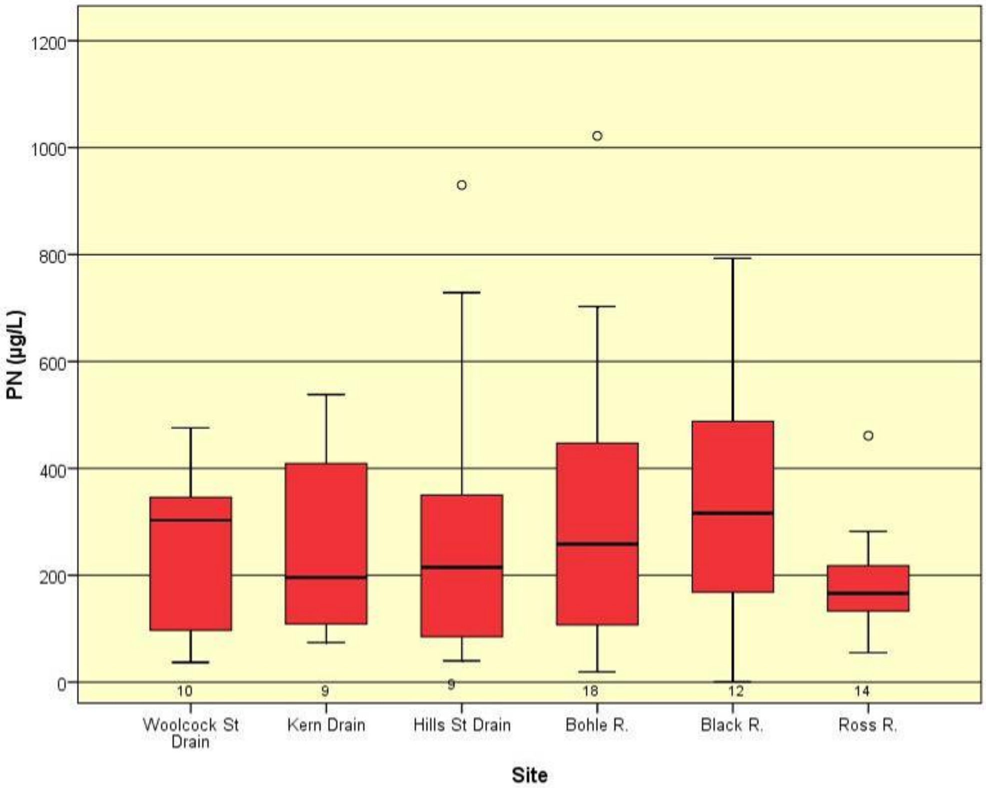


Figure 9. Boxplot of particulate nitrogen concentrations (µg N/L) of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

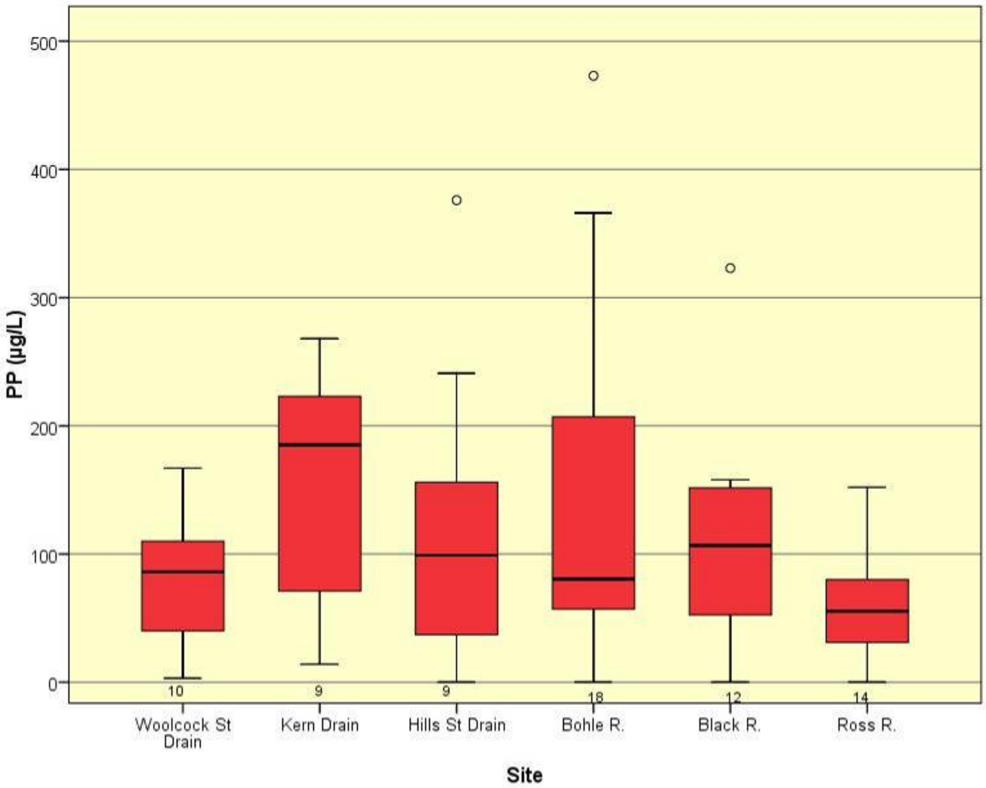


Figure 10. Boxplot of particulate phosphorus concentrations (µg P/L) of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

Table 4. Summary of PN concentrations (µg N/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Dominant Land use	Site	Year	mean (all data)	median (all data)	rise (mean)	peak (mean)	fall (mean)	Mean rise, peak & fall	Average EMC (µg N/L)
Established Urban	Woolcock St Drain	2006/07	144	61	89	419	34	181	**220**
		2007/08	256	303	392	261	234	296	
	Captain C.	2006/07	204	169	150	97	366	204	
Developing Urban (coastal plain)	Kern Drain	2006/07	175	135	132	79	240	150	**190**
		2007/08	264	196	244	483	234	320	
	Gordon C.	2006/07	154	140	209	79	145	144	
Light Industrial	Hill St C.	2007/08	324	215	259	319	360	313	**310**
Urban/ industrial	Stuart C. (d/s)	2006/07	309	265	382	304	260	315	**210**
	Louisa C.	2006/07	108	95	75	100	136	104	
Rural residential	Sachs C.	2006/07	121	69	303	123	81	169	**120**
	Bluewater C. (d/s)	2006/07	64	40	68	84	47	66	
	Alligator C. (d/s)	2006/07	110	113	123	107	93	108	
Minimal use	Stuart C. (u/s)	2006/07	175	138	124	270	136	177	**150**
	HenCamp C.	2006/07	93	63	124	50	100	91	
	Campus C.	2006/07	92	91	149	92	7.8	83	
	Bluewater C. (u/s)	2006/07	211	152	409	95	156	220	
Conservation	Alligator C. (u/s)	2006/07	128	58	500	50	54	201	**200**

Table 5. Particulate nitrogen loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Catchment	2006/07			2007/08			Comparison to model	
	PN load 2007 (kilograms)	Total flow volume (ML)	EMC (ug N/L)	PN load 2008 (kilograms)	Total flow volume (ML)	EMC (µg N/L)	Load adjusted to mean annual flow* (kilograms)	ANNEX model** (kilograms)
Alligator Creek	2,200	41,500	53				**2,000**	**37,200**
Black River	3,000	135,000	22	41,000	180,400	230	**9,200**	**124,400**
Bluewater Creek	2,600	63,500	40				**1,500**	**77,800**
Bohle River	20,000	147,000	130	36,000	154,200	240	**39,000**	**288,300**
Ross River	36,000	261,000	140	58,000	290,000	200	**4,900**	**17,300**

*As specified by the ANNEX model.
**Post et al. (2006).

Table 6. Summary of PP concentrations (µg P/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Dominant Land use	Site	Year	mean (all data)	median (all data)	rise (mean)	peak (mean)	fall (mean)	Mean rise, peak & fall	Average EMC (µg P/L)
Established Urban	Woolcock St Drain	2006/07	53	58	52	71	43	55	**69**
		2007/08	79	86	135	91	68	98	
	Captain C.	2006/07	61	46	93	23	67	61	
Developing Urban (coastal plain)	Kern Drain	2006/07	123	117	161	141	94	132	**130**
		2007/08	158	185	188	257	131	192	
	Gordon C.	2006/07	93	84	124	80	79	94	
Light Industrial	Hill St C.	2007/08	124	99	137	93	140	123	**120**
Urban/ industrial	Stuart C. (d/s)	2006/07	181	122	196	214	147	186	**110**
	Louisa C.	2006/07	42	36	29	27	54	37	
Rural residential	Sachs C.	2006/07	22	19	33	21	19	24	**20**
	Bluewater C. (d/s)	2006/07	12	11	14	21	5.4	13	
	Alligator C. (d/s)	2006/07	27	22	39	13	15	22	
Minimal use	Stuart C. (u/s)	2006/07	70	69	53	100	60	71	**47**
	HenCamp C.	2006/07	13	13	12	8	15	12	
	Campus C.	2006/07	31	23	29	60	19	36	
	Bluewater C. (u/s)	2006/07	68	38	87	67	57	70	
Conservation	Alligator C. (u/s)	2006/07	11	10	12	23	7.6	14	**14**

Table 7. Particulate phosphorus loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Catchment	2006/07			2007/08			Comparison to model	
	PP load 2007 (kilograms)	Total flow volume (ML)	EMC (ug P/L)	PP load 2008 (kilograms)	Total flow volume (ML)	EMC (ug P/L)	Load adjusted to mean annual flow* (kilograms)	ANNEX model** (kilograms)
Alligator Creek	410	41,500	10				**360**	**10,600**
Black River	9,200	135,000	68	13,000	180,400	73	**5,200**	**19,900**
Bluewater Creek	800	63,500	13				**460**	**16,900**
Bohle River	12,600	147,000	86	13,500	154,200	88	**18,000**	**46,200**
Ross River	15,000	261,000	57	17,000	290,000	59	**1,700**	**3,100**

*As specified by the ANNEX model.

**Post et al. (2006).

4.3.2 Dissolved organic nitrogen and phosphorus

The waterways draining the urban and light industrial lands contained elevated concentrations of both DON and DOP in the 2007/08 wet season (Figs. 11 and 12). The summarised DON EMC across the different land uses in the Black Ross Region also shows elevated concentrations in the urban and light industrial land uses, although all sites displayed a higher EMC than the conservation land use (Table 8). EMC of DON for the three major catchments were similar over successive wet seasons (Table 9). The flow-adjusted loads of DON for the major gauged catchments in the Black Ross WQIP Region show reasonable agreement with the ANNEX model (Table 9).

Similarly to DON, the EMC for DOP in the different land uses were all higher than the conservation land use (Table 10). In particular, the urban and light industrial sites had highly elevated DOP EMC with the highest EMC recorded at the light industrial site (130 µg P/L). This EMC was twice that of any other land use in the Black Ross WQIP Region (Table 10). EMC of DOP for the three major catchments were similar over successive wet seasons (Table 11). The flow adjusted loads of DOP were in reasonable agreement with the latest ANNEX model of Post et al. (2006).

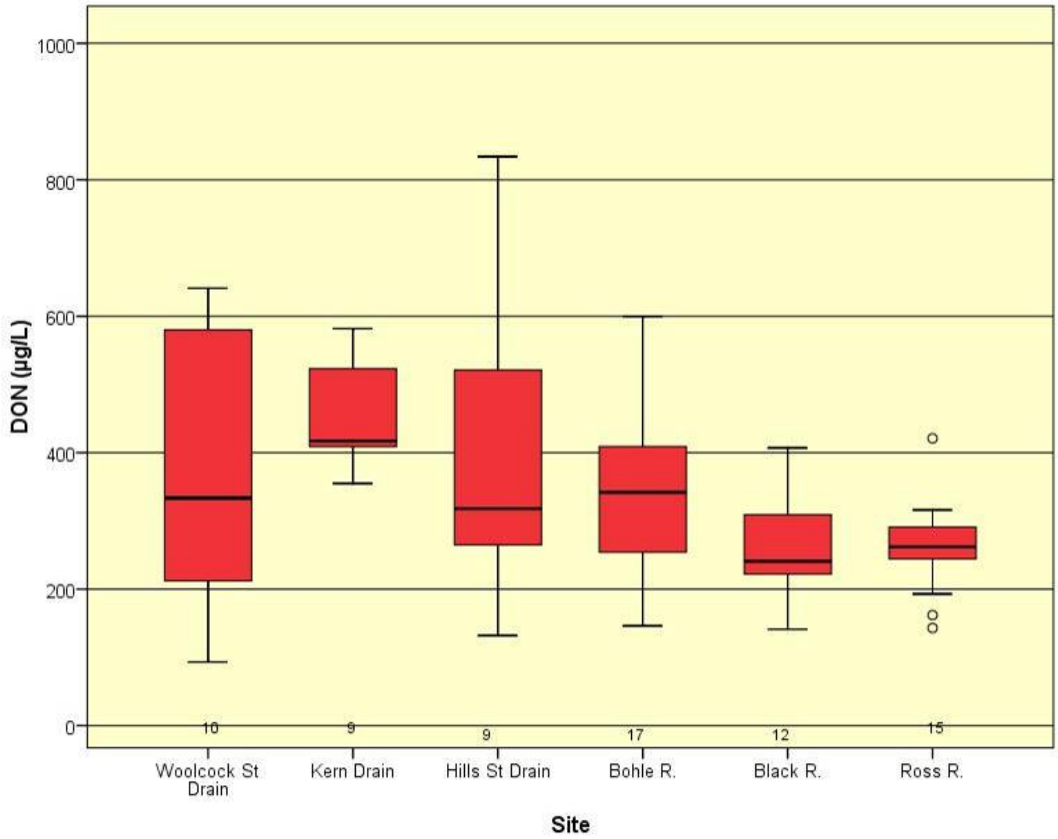


Figure 11. Boxplot of dissolved organic nitrogen concentrations (µg N/L) of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

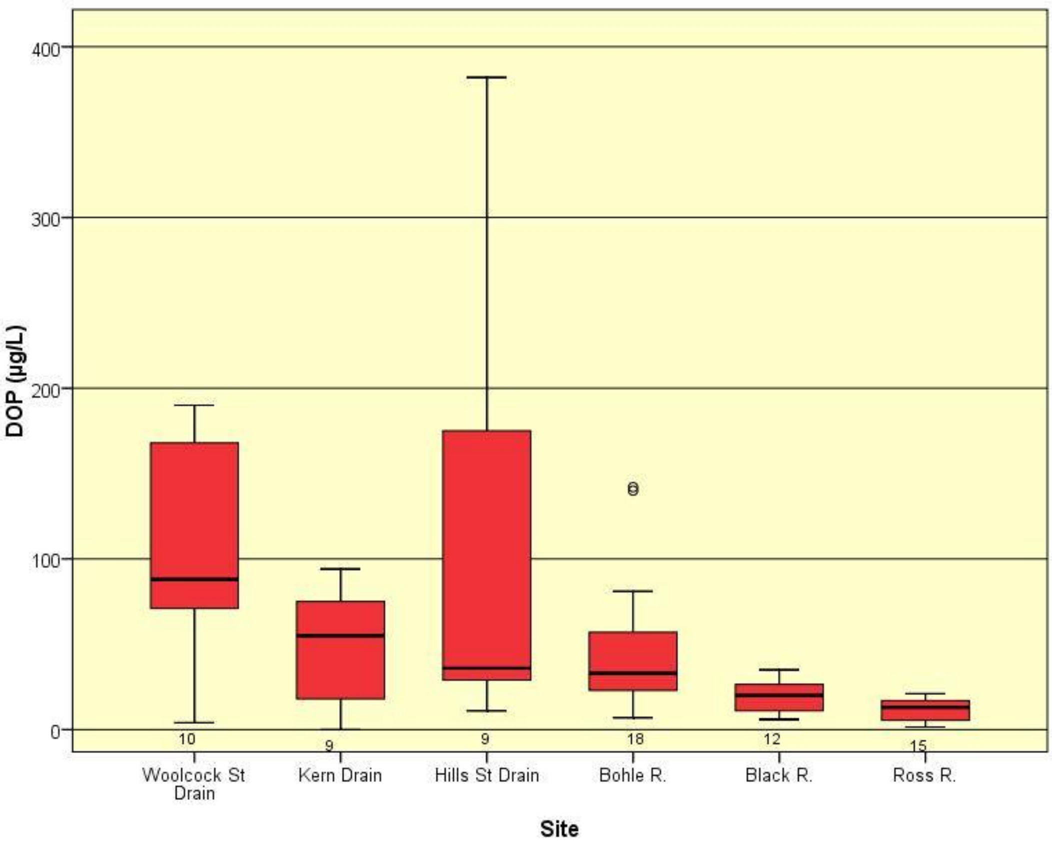


Figure 12. Boxplot of dissolved organic phosphorus concentrations (µg P/L) of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

Table 8. Summary of DON concentrations (µg N/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Dominant Land use	Site	Year	mean (all data)	median (all data)	rise (mean)	peak (mean)	fall (mean)	Mean rise, peak & fall	Average EMC (µg N/L)
Established Urban	Woolcock St Drain	2006/07	419	426	437	208	537	394	**365**
		2007/08	369	334	229	252	422	301	
	Captain C.	2006/07	380	359	403	369	369	380	
Developing Urban (coastal plain)	Kern Drain	2006/07	449	399	448	391	475	438	**400**
		2007/08	457	417	357	412	498	422	
	Gordon C.	2006/07	382	402	404	294	395	364	
Light Industrial	Hill St C.	2007/08	415	318	301	386	495	394	**395**
Urban/ industrial	Stuart C. (d/s)	2006/07	281	226	309	308	242	286	**315**
	Louisa C.	2006/07	362	343	362	273	381	339	
Rural residential	Sachs C.	2006/07	257	248	286	320	237	281	**230**
	Bluewater C. (d/s)	2006/07	183	170	225	199	141	188	
	Alligator C. (d/s)	2006/07	203	224	192	269	187	216	
Minimal use	Stuart C. (u/s)	2006/07	270	284	255	298	259	271	**225**
	HenCamp C.	2006/07	240	211	198	145	269	204	
	Campus C.	2006/07	245	200	271	199	229	233	
	Bluewater C. (u/s)	2006/07	210	206	147	169	278	198	
Conservation	Alligator C. (u/s)	2006/07	171	174	164	184	169	172	**170**

Table 9. Dissolved organic nitrogen loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Catchment	2006/07			2007/08			Comparison to model	
	DON load 2007 (kilograms)	Total flow volume (ML)	EMC (µg N/L)	DON load 2008 (kilograms)	Total flow volume (ML)	EMC (µg N/L)	Load adjusted to mean annual flow* (kilograms)	ANNEX model** (kilograms)
Alligator Creek	4,900	41,500	120				**4,300**	**5,400**
Black River	40,900	135,000	300	38,000	180,400	210	**19,000**	**14,500**
Bluewater Creek	7,700	63,500	120				**4,500**	**6,700**
Bohle River	39,000	147,000	270	37,000	154,200	240	**51,400**	**37,700**
Ross River	85,000	261,000	330	74,000	290,000	260	**8,500**	**6,700**

*As specified by the ANNEX model.
**Post et al. (2006).

Table 10. Summary of DOP concentrations (µg P/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Dominant Land use	Site	Year	mean (all data)	median (all data)	rise (mean)	peak (mean)	fall (mean)	Mean rise, peak & fall	Average EMC (µg P/L)
Established Urban	Woolcock St Drain	2006/07	35	25	15	48	52	38	**60**
		2007/08	105	88	86	158	93	112	
	Captain C.	2006/07	46	18	55	73	8.2	45	
Developing Urban (coastal plain)	Kern Drain	2006/07	27	18	42	28	19	30	**19**
		2007/08	50	55	85	44	39	56	
	Gordon C.	2006/07	18	9	10	10	26	15	
Light Industrial	Hill St C.	2007/08	122	36	173	97	116	129	**130**
Urban/ industrial	Stuart C. (d/s)	2006/07	14	14	13	16	12	14	**15**
	Louisa C.	2006/07	20	17	28	3.0	18	16	
Rural residential	Sachs C.	2006/07	9.4	3.9	28	8.6	5.6	14	**10**
	Bluewater C. (d/s)	2006/07	4.9	4.4	8.4	2.9	3.7	5.0	
	Alligator C. (d/s)	2006/07	11	8.6	11	7	14	11	
Minimal use	Stuart C. (u/s)	2006/07	19	11	9	16	22	16	**9.3**
	HenCamp C.	2006/07	5.2	5.5	3.3	4.7	5.5	4.5	
	Campus C.	2006/07	12	12	14	9.3	11	11	
	Bluewater C. (u/s)	2006/07	5.3	4.9	6.0	8.0	3.1	5.7	
Conservation	Alligator C. (u/s)	2006/07	3.2	3.5	6.4	0.0	3.2	3.2	**3.2**

Table 11. Dissolved organic phosphorus loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Catchment	2006/07			2007/08			Comparison to model	
	DOP load 2007 (kilograms)	Total flow volume (ML)	EMC (µg P/L)	DOP load 2008 (kilograms)	Total flow volume (ML)	EMC (µg P/L)	Load adjusted to mean annual flow* (kilograms)	ANNEX model** (kilograms)
Alligator Creek	360	41,500	9				**320**	**300**
Black River	1,800	135,000	13	2,600	180,400	14	**1,000**	**700**
Bluewater Creek	140	63,500	2				**81**	**300**
Bohle River	2,100	147,000	14	4,500	154,200	29	**4,400**	**1,800**
Ross River	1,600	261,000	6	2,200	290,000	8	**200**	**300**

*As specified by the ANNEX model.
**Post et al. (2006).

4.3.3 Dissolved inorganic nitrogen and phosphorus

On average, ammonia concentrations were relatively higher at Woolcock St Drain, although values exceeding 20 µg N/L were also measured at all sites monitored in the 2007/08 wet season (Fig. 13). The EMC for ammonia show that all land uses contain elevated concentrations compared to the conservation land use, with higher concentrations in the established and developing urban sites (Table 12). Ammonia loads were generally low across the major gauged catchments with the exception of the Ross River load in the 2006/07 wet season (27,200 kg) (Table 13). No loads have been predicted for ammonia in the ANNEX model and so no comparisons can be drawn with the flow-adjusted loads.

Oxidised nitrogen (NO_x: nitrite and nitrate) concentrations were relatively consistent across the sites monitored in the 2007/08, with the lowest concentrations in the Ross River (Fig. 14). Similarly to ammonia, the NO_x EMC was higher in all land uses compared to the conservation land use, with particularly elevated EMC for the established urban, developing urban and rural residential sites (Table 14). Lower NO_x loads were calculated in the 2007/08 wet season for the Bohle and Ross Rivers compared to the previous 2006/07 water year (Table 15). NO_x loads could not be compared with the ANNEX model, although the model performance can be compared to the loads of dissolved inorganic nitrogen (DIN= NO_x + ammonia). The flow-adjusted DIN loads for all of the major gauged catchments were all lower than the loads predicted by the ANNEX model (Table 16). In particular, the ANNEX loads for the Bohle and Black Rivers were much higher than the monitoring data. This result suggests there is an error in the ANNEX model where the land uses in these catchment areas may have been incorrectly assigned. However, the loads of nitrogen discharged from the sewage treatment plants, which discharge below the catchment monitoring sites for both the Bohle and Black Rivers, may account for some of these discrepancies (see section 4.4).

Filterable reactive phosphorus concentrations were elevated at the Woolcock St Drain, Kern Drain, Hills St Drain and the Bohle River sites compared to the Black and Ross Rivers in the 2007/08 wet season (Fig. 15). Waterways draining the urban and industrial lands had considerably elevated FRP EMC, with the highest EMC found at the light industrial site (Table 17). Loads for FRP over the 2006/07 and 2007/08 wet seasons for the major gauged catchments are presented in Table 17. The loads show little variation in the FRP EMC over the two monitored wet seasons at the Bohle and Ross Rivers. Flow-adjusted loads for FRP were lower than those predicted by the ANNEX model (Table 18), although the influence of the sewage treatment plants have not been considered in the flow adjusted loads (see section 4.4).

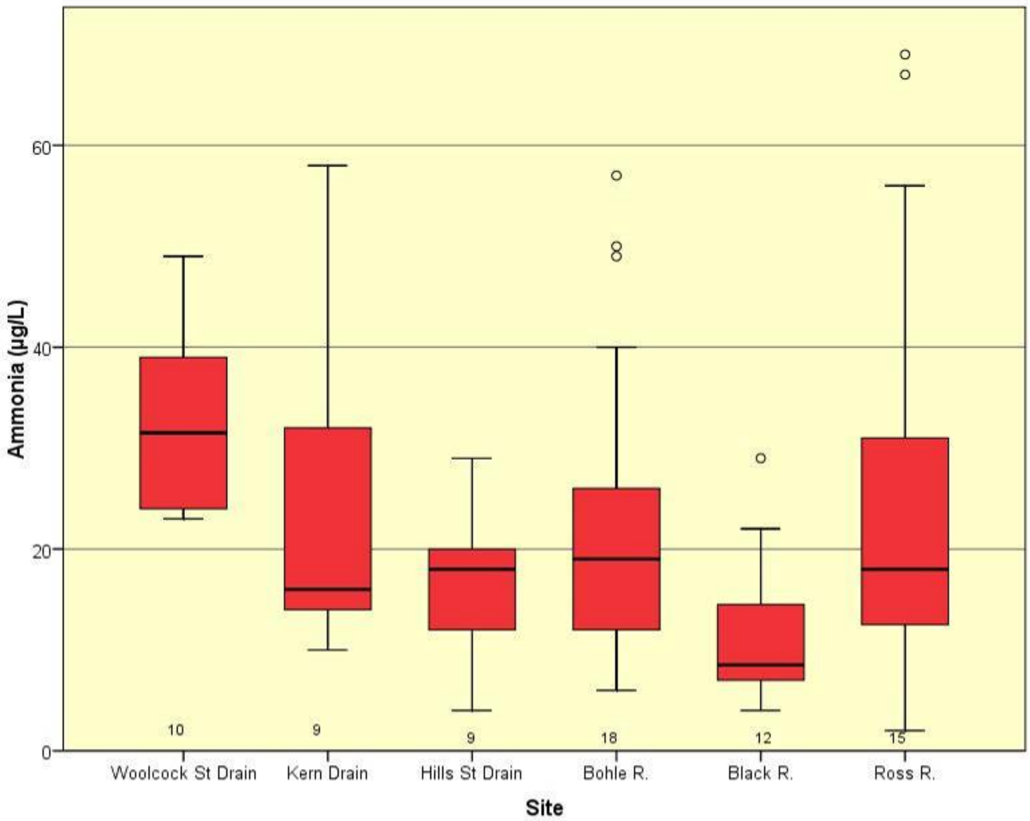


Figure 13. Boxplot of ammonia-N concentrations (µg N/L) of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

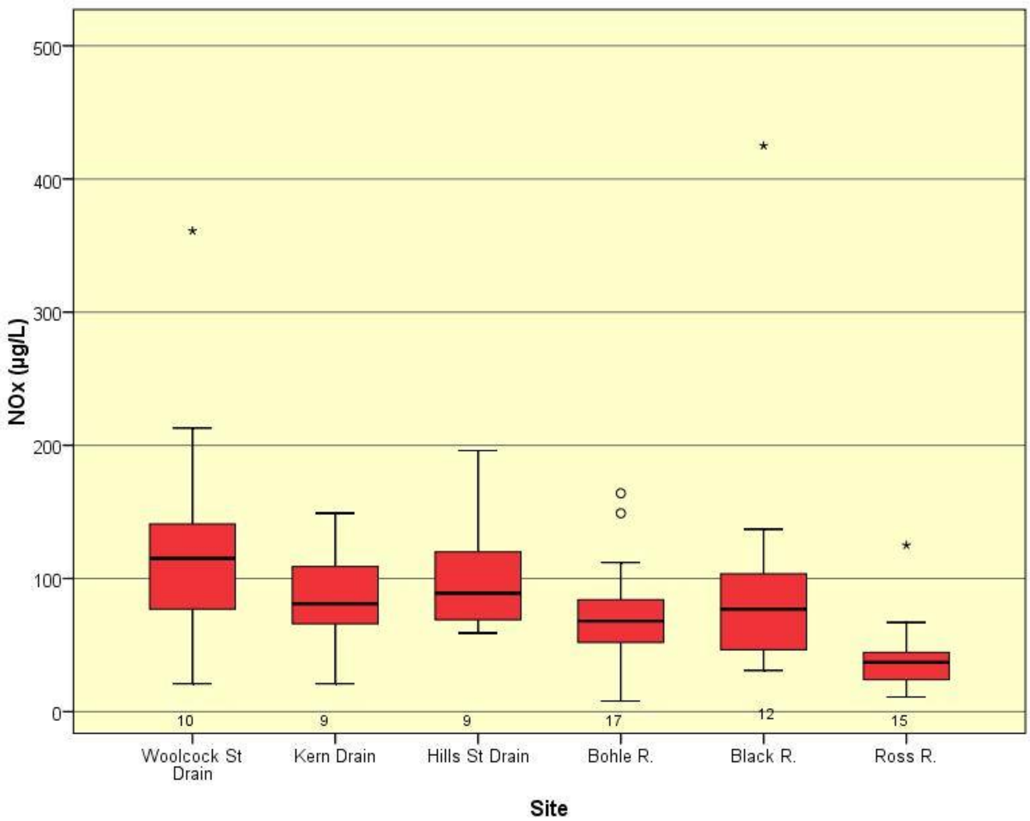


Figure 14. Boxplot of oxidised nitrogen-N concentrations (µg N/L) of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

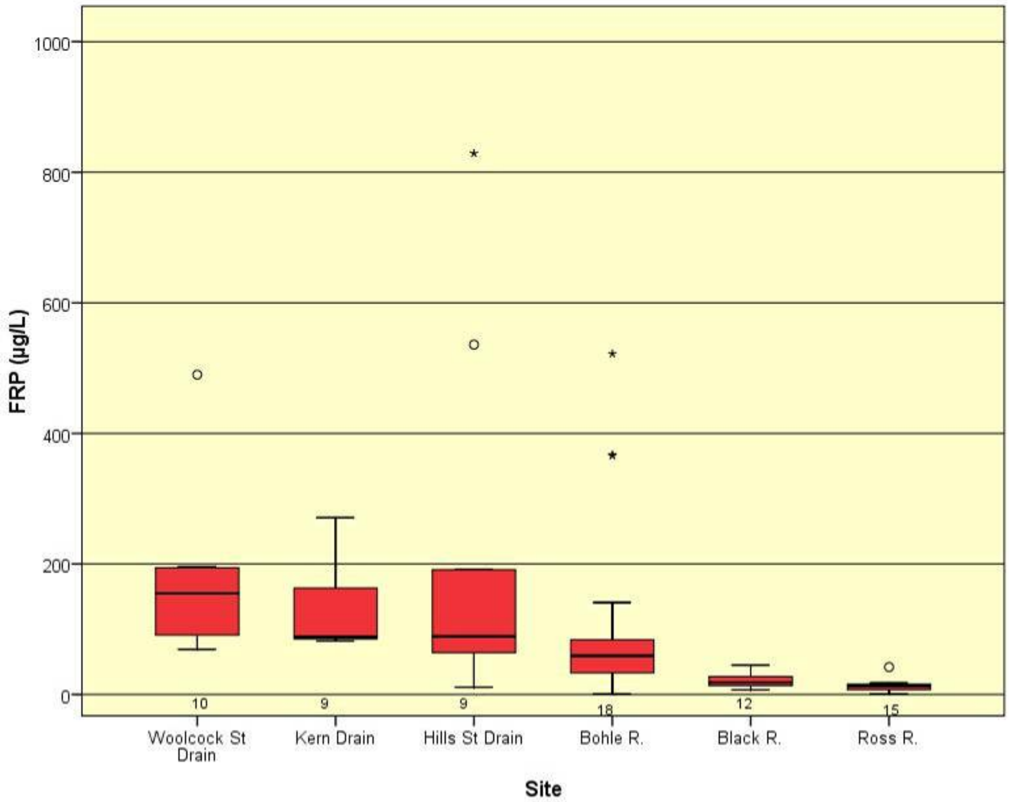


Figure 15. Boxplot of filterable reactive phosphorus concentrations (µg P/L) of the samples collected from the Black Ross WQIP Region over the 2007/08 wet season.

Table 12. Summary of Ammonia-N concentrations (µg N/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Dominant Land use	Site	Year	mean (all data)	median (all data)	rise (mean)	peak (mean)	fall (mean)	Mean rise, peak & fall	Average EMC (µg N/L)
Established Urban	Woolcock St Drain	2006/07	39	24	21	15	81	39	**29**
		2007/08	33	32	39	26	34	33	
	Captain C.	2006/07	22	16	17	7.0	43	22	
Developing Urban (coastal plain)	Kern Drain	2006/07	40	36	37	54	35	42	**38**
		2007/08	25	16	34	11	24	23	
	Gordon C.	2006/07	49	42	32	35	62	43	
Light Industrial	Hill St C.	2007/08	17	18	25	9.0	18	17	**17**
Urban/ industrial	Stuart C. (d/s)	2006/07	3.4	<0.2	2.0	8.4	0.7	3.7	**6.9**
	Louisa C.	2006/07	12	5.5	9.3	7.0	14	10	
Rural residential	Sachs C.	2006/07	2.4	2.0	8.0	2.5	1.1	3.9	**9.6**
	Bluewater C. (d/s)	2006/07	4.4	1.7	9.0	4.8	0.8	4.9	
	Alligator C. (d/s)	2006/07	27	7.0	47	7.0	6.0	20	
Minimal use	Stuart C. (u/s)	2006/07	22	5.0	44	25	17	29	**13**
	HenCamp C.	2006/07	9.7	3.0	42	1.5	7.8	17	
	Campus C.	2006/07	3.3	2.0	5.3	2.0	1.0	2.8	
	Bluewater C. (u/s)	2006/07	3.9	2.0	9.0	1.0	2.3	4.1	
Conservation	Alligator C. (u/s)	2006/07	4.0	1.0	2.0	6.0	4.0	4.0	**4.0**

Table 13. Ammonia-N loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

	2006/07			2007/08			Comparison to model	
Catchment	**Ammonia load 2007 (kilograms)**	**Total flow volume (ML)**	**EMC (µg N/L)**	**Ammonia load 2008 (kilograms)**	**Total flow volume (ML)**	**EMC (µg N/L)**	**Load adjusted to mean annual flow* (kilograms)**	**ANNEX model** (kilograms)**
Alligator Creek	140	41,500	3				**120**	**N/A**
Black River	1,800	135,000	13	1,500	180,400	8	**800**	**N/A**
Bluewater Creek	330	63,500	5				**190**	**N/A**
Bohle River	1,200	147,000	8	2,800	154,200	18	**2,700**	**N/A**
Ross River	27,000	261,000	100	8,000	290,000	28	**1,900**	**N/A**

*As specified by the ANNEX model.
**Post et al. (2006).

Table 14. Summary of NO_x-N concentrations (µg N/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Dominant Land use	Site	Year	mean (all data)	median (all data)	rise (mean)	peak (mean)	fall (mean)	Mean rise, peak & fall	Average EMC (µg N/L)
Established Urban	Woolcock St Drain	2006/07	114	114	106	82	146	111	130
		2007/08	135	115	110	145	135	130	
	Captain C.	2006/07	134	72	62	97	242	134	
Developing Urban (coastal plain)	Kern Drain	2006/07	103	87	78	101	119	99	120
		2007/08	84	81	109	81	76	89	
	Gordon C.	2006/07	161	140	113	147	192	151	
Light Industrial	Hill St C.	2007/08	102	89	99	107	100	102	100
Urban/ industrial	Stuart C. (d/s)	2006/07	81	95	79	78	84	80	94
	Louisa C.	2006/07	90	92	96	146	80	107	
Rural residential	Sachs C.	2006/07	188	181	204	41	218	154	150
	Bluewater C. (d/s)	2006/07	152	142	196	148	122	155	
	Alligator C. (d/s)	2006/07	92	55	30	297	82	136	
Minimal use	Stuart C. (u/s)	2006/07	165	131	75	136	191	134	94
	HenCamp C.	2006/07	57	52	38	22	67	42	
	Campus C.	2006/07	107	54	127	12	125	88	
	Bluewater C. (u/s)	2006/07	104	87	107	164	61	111	
Conservation	Alligator C. (u/s)	2006/07	28	28	33	30	26	30	30

Table 15. Oxidised nitrogen-N loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Catchment	2006/07			2007/08			Comparison to model	
	NOx-N load 2007 (kilograms)	Total flow volume (ML)	EMC (µg N/L)	NOx load 2008 (kilograms)	Total flow volume (ML)	EMC (µg N/L)	Load adjusted to mean annual flow* (kilograms)	ANNEX model** (kilograms)
Alligator Creek	2,200	41,500	52				**1,900**	**N/A**
Black River	14,000	135,000	100	11,000	180,400	59	**6,000**	**N/A**
Bluewater Creek	7,000	63,500	110				**4,050**	**N/A**
Bohle River	11,000	147,000	73	7,600	154,200	49	**12,500**	**N/A**
Ross River	25,000	261,000	97	9,700	290,000	33	**1,900**	**N/A**

*As specified by the ANNEX model.
**Post et al. (2006).

Table 16. Dissolved inorganic nitrogen loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Catchment	2006/07 DIN load 2007 (kilograms)	2006/07 Total flow volume (ML)	2006/07 EMC (µg N/L)	2007/08 DIN load 2008 (kilograms)	2007/08 Total flow volume (ML)	2007/08 EMC (µg N/L)	Comparison to model: Load adjusted to mean annual flow* (kilograms)	Comparison to model: ANNEX model** (kilograms)
Alligator Creek	2,300	41,500	55				**2,050**	**4,100**
Black River	15,800	135,000	120	12,500	180,400	69	**6,850**	**1,070,700**
Bluewater Creek	7,300	63,500	115				**4,200**	**5,200**
Bohle River	12,200	147,000	83	10,400	154,200	67	**15,400**	**149,700**
Ross River	52,000	261,000	200	17,700	290,000	61	**3,800**	**4,800**

*As specified by the ANNEX model.
**Post et al. (2006).

Table 17. Summary of FRP concentrations (µg P/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Dominant Land use	Site	Year	mean (all data)	median (all data)	rise (mean)	peak (mean)	fall (mean)	Mean rise, peak & fall	Average EMC (µg P/L)
Established Urban	Woolcock St Drain	2006/07	226	214	241	149	258	216	**150**
		2007/08	173	155	91	116	202	136	
	Captain C.	2006/07	129	138	131	134	121	129	
Developing Urban (coastal plain)	Kern Drain	2006/07	203	186	191	217	204	204	**130**
		2007/08	130	88	90	85	151	109	
	Gordon C.	2006/07	102	124	96	117	100	104	
Light Industrial	Hill St C.	2007/08	219	89	50	265	270	195	**195**
Urban/ industrial	Stuart C. (d/s)	2006/07	87	83	79	85	93	86	**104**
	Louisa C.	2006/07	117	134	106	142	121	123	
Rural residential	Sachs C.	2006/07	34	29	72	39	25	45	**26**
	Bluewater C. (d/s)	2006/07	6.4	6.1	6.2	6.7	6.4	6.4	
	Alligator C. (d/s)	2006/07	28	20	31	14	31	25	
Minimal use	Stuart C. (u/s)	2006/07	53	55	55	74	44	58	**31**
	HenCamp C.	2006/07	7.3	5.1	4.9	9.9	7.0	7.3	
	Campus C.	2006/07	59.0	54.0	74.0	25.0	54.0	51.0	
	Bluewater C. (u/s)	2006/07	6.3	5.1	8.2	2.8	7.3	6.1	
Conservation	Alligator C. (u/s)	2006/07	17	15	3.0	31	18	17	**17**

Table 18. Filterable reactive phosphorus loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons.

Catchment	2006/07			2007/08			Comparison to model	
	FRP load 2007 (kilograms)	Total flow volume (ML)	EMC (µg P/L)	FRP load 2008 (kilograms)	Total flow volume (ML)	EMC (µg P/L)	Load adjusted to mean annual flow* (kilograms)	ANNEX model** (kilograms)
Alligator Creek	770	41,500	19				**680**	**1,300**
Black River	4,200	135,000	31	2,300	180,400	13	**1,600**	**2,900**
Bluewater Creek	300	63,500	5				**170**	**900**
Bohle River	8,300	147,000	56	6,300	154,200	41	**9,900**	**34,900**
Ross River	4,200	261,000	16	3,100	290,000	11	**390**	**3,300**

*As specified by the ANNEX model.
**Post et al. (2006).

4.4 Sewage treatment plant contributions

Water quality data (total nitrogen and total phosphorus) from the outflows of the three sewage treatment plants (STP) which discharge into the Bohle River (Condon, Deeragun and Mt St John STP) were obtained from the Townsville City Council. We note that the Deeragun STP discharges into a tributary of the Bohle River, Saunders Creek, while the Mt St John STP discharges into a drain before entering the lower reaches of the Bohle River. The discharge from these two STP enters the Bohle River below the water quality monitoring site; the Condon STP discharges upstream of the monitoring site.

Annual loads of total nitrogen (TN) and total phosphorus (TP) for these three STP have been estimated by GHD (2007). Loads for the Condon and Deeragun STP were recalculated using the data obtained from the Townsville City Council and by assuming constant outflows of 1 ML/day and 0.6 ML/day, respectively as specified in the GHD (2007) report. Our calculations suggest that the previous load estimates may be too high (Table 19). However, the accuracy of the load estimates for both studies may be compromised due to the high variability and the sparseness of the water quality data for these relatively small STP (samples typically collected fortnightly). Loads for the Mt St John STP were calculated using both flow and concentration (ammonia-N, nitrate-N, TN, phosphate-P and TP) data obtained by the Townsville City Council. We consider these loads to be more accurate than for the Condon and Deeragun STP due to the higher resolution dataset and the greater consistency in the concentration data over time. Our loads for the Mt St John STP were higher than the GHD (2007) estimate (Table 20) which is probably due to the underestimation of the flow discharge by GHD (2007). GHD (2007) estimated a flow discharge of 5.5 ML per day; however, flow data obtained from the Townsville City Council which was used in this study had an average of 10.5 ML/day (estimated outflow to the Bohle River). The Mt St John STP data show that high proportions of the TN and TP load consist of the dissolved inorganic fractions including DIN (~85% of TN) and phosphate (~75% of TP) (Table 20).

The TN and TP loads for the Bohle River (at the monitoring site) in the 2006/07 wet season were 70,600 and 23,000 kilograms, respectively, compared to the loads of 1,700 and 2,300 kilograms of TN and TP, respectively, calculated for the Condon STP. Therefore we estimate that the Condon STP contributed about 2% of the annual

2006/07 Bohle River TN load and approximately 10% of the total TP load at the monitoring site. The TN and TP loads calculated for the Bohle River monitoring site in 2007/08 were 83,400 and 24,300 kilograms, respectively. Therefore, the Condon STP would have contributed a similar proportion to the TN and TP load in 2007/08. The Deeragun and Mt St John STPs combined have the potential to contribute another 130,000 and 21,000 kilograms of TN and TP respectively to the annual load of the Bohle River. Therefore these two STPs may collectively contribute up to ~60% of TN and ~45% of TP to the total end of catchment load of the Bohle River. Because a higher proportion of the TN and TP discharged from the STP are made up of the more bioavailable forms including DIN and phosphate, respectively (see Table 20), we estimate that the Deeragun and Mt St John STP may contribute up to 90% of the total DIN load and 60% of the total phosphate load from the Bohle River. In addition, the discrepancies in the dissolved nitrogen and phosphorus loads between the calculated loads and the ANNEX model for the Bohle River may be explained by the STP. When the STPs are factored into the calculated DIN (120,000 kg) and FRP (25,700 kg) loads for the Bohle River, they closely match those predicted by the ANNEX model (149,700 kg and 34,900 kg, respectively).

The Mt Low STP discharges into the lower reaches of the Black River below the monitoring site and also contributes a considerable proportion of TN and TP to the end-of-catchment discharge. Similarly to the Bohle River, a close comparison between the FRP load from the Black River predicted by the ANNEX model (2,900 kg) and the calculated flow-adjusted load (2,600 kg) is achieved when the contribution of the STP is considered. However, the model prediction of the annual DIN load for the Black River is considerably overestimated even with the STP contribution.

The Cleveland Bay STP discharges into the lower reaches of Sandfly Creek and would contribute considerable amounts of bioavailable nitrogen and phosphorus to the catchment load (Table 20). This STP is probably factored into the ANNEX model for the Ross River discharge and so may explain the discrepancies for DIN and FRP between the flow adjusted load (sampling site is upstream of the STP) and the model. A marked reduction in the loads of nitrogen and phosphorus discharged from the Cleveland Bay STP occurs in 2007/08. During the time, the plant was upgraded incorporating a biological component to remove DIN and phosphate from the effluent. This result shows that the upgrade of STP can considerably reduce end-of-catchment loads particularly for DIN and phosphate. However, we note that the constant discharge of STPs throughout the year during low flow conditions is a different water quality issue than water quality associated with event flow conditions (see discussion).

Table 19. Estimated loads (kilograms) for the Condon, Deeragun and Mt Low STP and the comparison with the GHD (2007) estimate.

Water year	Condon STP		Deeragun STP		Mt Low STP	
	TN	TP	TN	TP	TN	TP
1998/99	2,110	1,920	1,300	1,490	1,160	1,000
1999/00	1,980	1,740	1,560	1,350	2,290	1,460
2000/01	1,320	2,090	1,400	1,460	2,770	1,270
2001/02	2,150	2,640	1,550	1,710	1,800	1,640
2002/03	2,480	2,620	1,890	1,920	1,850	1,410
2003/04	1,190	2,470	2,250	2,050	1,620	1,590
2004/05	1,760	2,590	2,590	1,700	1,430	1,600
2005/06	950	2,310	3,250	1,680	2,400	1,090
2006/07	1,550	2,710	1,370	1,560	1,520	1,020
Average	**1,721**	**2,343**	**1,907**	**1,658**	**1,871**	**1,342**
GHD (2007) estimate	**4,380**	**2,920**	**2,847**	**1,971**	**N/A**	**N/A**

Table 20. Estimated loads (kilograms) for the Cleveland Bay and Mt St John STP and the comparison with the GHD (2007) estimate.

Water year	Ammonia-N (kg)	Nitrate-N (kg)	TN (kg)	Phosphate-P (kg)	TP (kg)
Cleveland Bay STP					
2004/05	69,600	33,500	125,000	2,900	41,000
2005/06	73,500	26,900	126,000	2,600	39,200
2007/08	620	16,700	27,300	460	5,900
Average (2004-2006)	**71,550**	**30,200**	**125,500**	**2,750**	**40,100**
Mt St John STP					
2004/05	36,000	58,800	107,000	16,000	22,800
2005/06	55,000	68,000	136,000	18,000	21,900
2006/07	66,000	55,300	136,000	13,000	18,200
2007/08	51,000	69,800	139,000	10,000	14,200
Average	**52,000**	**62,975**	**129,500**	**14,250**	**19,275**
GHD (2007) estimate			**68,255**		**12,045**

4.5 Pesticide residues in Alligator Creek

Five samples were collected at the Alligator Creek downstream site (Bruce Hwy) for pesticide analysis in the 2007/08 wet season to determine if the endosulfan residues detected in the previous 2006/07 wet season were persistent across the two monitored years. Endosulfan residues (or any other pesticide residues analysed by the GCMS method) were not detected in any of the samples collected in 2007/08.

5. DISCUSSION

The monitoring results from the 2007/08 wet season show similar trends to the previous 2006/07 water year and support the strong water quality signals observed in Liessmann et al. (2007). The developing urban monitoring sites had the highest suspended sediment concentrations, with particularly high sediment concentrations recorded at the developing urban site on a hillslope. Improved management strategies (e.g. timing of development in dry season, develop/clear land in smaller areas at a time, placement of silt curtains) in developing urban lands will help reduce sediment runoff from these sites. These strategies should also reduce the runoff of the associated particulate nutrient phases, although while the established urban sites had considerably lower suspended sediment EMC than the developing urban sites, the established sites had higher particulate nitrogen EMC. This result indicates that the soils of the established urban lands are more fertile. The average and range of suspended sediment concentrations across the three major catchments of the Black Ross WQIP Region (Black, Bohle and Ross Rivers) were comparable to other coastal catchments adjacent to the region (e.g. Haughton River; see Bainbridge et al., 2007b).

The EMC at the major catchment sites for particulate nitrogen were variable across wet seasons and did not conform to the trends observed in the TSS. In comparison, the EMC for particulate phosphorus displayed uniformity over the two successive wet seasons at the large catchment sites but did not conform to the TSS trends for the Ross and Bohle Rivers. These findings are perplexing and may be related to the erosion of different catchment areas which have different proportions of nitrogen and phosphorus. The comparisons between the flow-adjusted loads and the ANNEX model for PN and PP were poor; this model does not account for the nutrient-poor soils in these dry tropical coastal catchments (see Bainbridge et al., 2007a). Another possibility is that the proportions of erosion mechanisms (hillslope, gully and streambank) assigned to these catchments are incorrect.

Waterways draining the urban land uses (both developing and established) contained slightly elevated dissolved organic nitrogen (DON) concentrations and are probably linked to runoff from urban gardens. DON is generally not highly bio-available and hence of lesser ecological importance than DIN which is 100% bio-available (Brodie and Mitchell, 2005). Dissolved organic phosphorus (DOP) concentrations were elevated in the urban sites and may be sourced to cleaning products, animal excreta and phosphorus-based fertilisers. The light industrial site produced the highest DOP EMC and is probably sourced to cleaning products such as detergents. The potential environmental impacts of elevated DOP runoff are unknown at this stage.

Ammonia concentrations were elevated in the waterways draining urban lands and may be linked to sewage effluent, animal excreta and fertiliser runoff. Water courses draining rural residential, urban and light industry land uses had elevated concentrations of oxidised nitrogen compared to the conservation sites; this result may reflect some use of fertilisers as well more fertile soils in these areas (e.g. from top dressings).

Watercourses draining urban and light industrial lands had highly elevated filterable reactive phosphorus (FRP) concentrations. These high concentrations are probably sourced to phosphorus-based fertilisers (e.g. blood and bone), cleaning products (e.g.

detergents), wastewater, industrial effluent and animal excreta (e.g. dogs). We consider the runoff of FRP to be of high concern in the Black Ross WQIP region. The particularly high concentrations of FRP at the light industrial site indicates that industrial effluent and detergent-based products probably provide the main source of inorganic phosphorus in this land use. In addition, a brown sludge was observed at this site consistently through the 2007/08 wet season and it is recommended that sampling should continue in the upcoming wet season to identify the source of this material (which may also be linked to the high FRP concentrations).

Similarly to the previous 2006/07 wet season, the comparisons of the loads from the major catchment sites to the current SedNet and ANNEX model runs were generally poor. This result highlights the need for a more detailed modelling approach (i.e. tailored to the urbanised landscape) in the Black Ross WQIP Region before models can be used as a tool for management decision making, such as the setting of end of catchment pollutant targets.

Most of the nutrient load associated with rainfall runoff would be expected to pass through the river estuary quite quickly. Some of the coarser sediment may be deposited within the tidal wetland systems but virtually all of the fine and highly bio-available dissolved contaminants will probably be discharged from the river mouth in a matter of hours during large storm events. The hydrographs for this year suggest that high concentrations of stormwater contaminants would have been resident in the estuary for no more than about 20 days during this wet season. Moreover, due to the combined effects of elevated turbidity (which limits photosynthesis to the very surface of the water column), elevated flows (which wash away plankton biomass) and low salinity (which imposes osmoregulatory stresses on estuarine organisms) it is highly unlikely that there would be much biological uptake of nutrients within the estuary during this time.

Some of the fine sediment would be expected to flocculate and settle outside the river mouth once the river plume has dispersed sufficiently to reach salinities greater than about 10 psu or so. This sediment will be remobilised by tidal currents and some could eventually be carried back into the river where it would be incorporated into estuary muds, potentially contributing to the systems productivity. The sediments would also gradually be carried up the coast and deposited in other estuaries to the north.

The results from the sewage treatment plant water quality data show that they collectively contribute a high proportion of total nitrogen and phosphorus to the annual load from the major rivers in the Black Ross WQIP Region (Black, Bohle and Ross Rivers). The available data suggest that planned upgrades to these plants have the potential to significantly reduce N and P loads and may help to improve ambient water quality conditions in the estuaries of these rivers. Indeed, the Bohle River estuary and lower catchment area contains consistently high NO_x, ammonia and filterable reactive phosphorus concentrations throughout the dry season making it one of the more polluted rivers in Queensland (Cox et al., 2005). These high nutrient concentrations have been linked to sewage effluent, although nutrient levels have declined over a 10 year period due to improvements in sewage treatment (Cox et al., 2005).

The nutrients contained in sewage effluent probably enter the system constantly over the whole year. Moreover, floodtides would be expected to carry a lot of the effluent back upstream into the upper estuary and associated inter-tidal wetland systems, where tidal flushing can be quite inefficient and water residence times can be quite high. This maximises opportunities for uptake by biota and virtually ensures that the ecosystem detains a significant proportion of the nutrients for a long time. It is likely that little of these nutrients are transported very far into the marine environment during the dry season. The residence and cycling times of the nutrient-rich effluent discharge requires further research to evaluate the ecological risk to instream, estuarine and marine ecosystems.

A lot of the nutrients that do reach the marine environments outside of the river mouth will have already been incorporated into the food web and will arrive there in the form of living organisms. Theoretically the planktonic portion of this living nutrient pool is captured in water samples and is therefore concomitantly taken into account in ambient water quality data (although since plankton are not always homogenously distributed through the water column, major sampling errors can occur). However, the nektonic and benthic portions of this nutrient export (i.e. fish and crustacea, etc) are seldom factored into load calculations, even though they are potentially a significant pathway by which the nutrients contained in STP effluents actually reach the GBR lagoon.

The potential ecological implications of this kind of nutrient export have not been studied and are extremely difficult to gauge. Given how significant the STP loads are, a detailed investigation of potential impacts on the estuary, and especially the initial receiving environments is warranted.

Endosulfan residues (or any other pesticide residues) were not detected in the 2007/08 wet season at the Alligator Creek site. This result may reflect a number of different possibilities and it should be noted that this was only a preliminary study, and the widespread presence of agricultural and urban activities across the Townsville Region (e.g. mango plantations, cane and pineapple) suggests pesticides may be present in the landscape. Currently there is little known about the products and quantities of pesticides applied, and therefore the potential for off-site transport of these pesticides into local waterways during either low flow or flood event conditions is also poorly constrained.

6. CONCLUSIONS AND RECOMMENDATIONS

The results from the 2007/08 water quality monitoring program further support the conclusions drawn from the 2006/07 results and strengthen the water quality dataset available for urban and industrial land uses in dry tropical environments. Moreover, this dataset that contains event mean concentrations (EMC) for the major land uses of the region and provides the basis for detailed modelling activities to be undertaken for target setting and other catchment management exercises. The data gathered from these two wet seasons provide a valuable resource to help develop catchment models and provide a baseline to compare with future monitoring efforts. The latest data from 2007/08 show two of the key water quality concerns identified in the previous 2006/07, namely suspended sediment in the developing urban sites and FRP in the urban and industrial land uses, are consistent over the two monitored wet seasons. The addition of the light industrial site in the 2007/08 monitoring program showed very high levels of FRP and DOP from this land use and helped to highlight the possible main sources of dissolved phosphorus in the Black Ross WQIP Region. Loads from the sewerage treatment plants show that they may contribute a high proportion of bioavailable nitrogen and phosphorus exported from the Black Ross Region. However, plant upgrades have the potential to considerably reduce the loads of N and P. Endosulfan residues were not detected in Alligator Creek in the 2007/08 wet season.

We recommend that monitoring continue into the 2008/09 wet season with a particular focus on the main catchment sites where sediment and nutrient loads can be calculated. These sites include: Black River, Bohle River, Ross River, Alligator Creek and Bluewater Creek. The variability in the loads especially in the Bohle and Ross Rivers over the two successive wet seasons shows that additional data are required to better constrain the EMC for the major waterways of the Black Ross WQIP Region. In addition, we also recommend that the light industrial site be monitored in the 2008/09 wet season for sediments and nutrients. This site contained highly elevated concentrations of phosphorus species and a brown sludge was observed at this site throughout the monitoring program. We recommend that the Hills Street Drain site be monitored into the 2008/09 wet season to determine the constituents of this brown sludge. The monitoring of this site into 2008/09 will also provide two wet seasons of data for the light industrial land use. Finally we recommend a scoping study to review the operations of the local STPs (and previous works), determine the residence times of sewage effluent (cycling of nutrients) in the Bohle River estuary and to assess the ecological risk of STP discharge.

7. REFERENCES

APHA, AWWA and WEF 2005. *Standard methods for the examination of water and wastewater*. 20th edition, eds LS Clesceri, AE Greenberg & AD Eaton, American Public Health Association, American Water Work Association, Water Environment Federation, Washington DC.

Bainbridge, Z.T. Lewis, S.E. Brodie, J. E. 2007a. Sediment and nutrient exports for the Burdekin River catchment, north Queensland: A comparison of monitoring and modelling data. In Oxley, L. and Kulasiri, D. (eds) *MODSIM 2007 International Congress on Modelling and Simulation.* Modelling and Simulation Society of Australia and New Zealand, December 2007, pp. 874-880. ISBN: 978-0-9758400-4-7. http:/www.mssanz.au/modsim07/Papers/DegreeofSite_s37_Bainbridge_.pdf

Bainbridge, Z. Lewis, S. Brodie, J. 2007b. *Event-based community water quality monitoring in the Burdekin Dry Tropics Region: 2006-2007* (2 volumes). ACTFR Report No. 07/22 for the Burdekin Dry Tropics NRM. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Brodie, J.E. Mitchell, A.W. 2005. Nutrients in Australian tropical rivers: changes with agricultural development and implications for receiving environments. *Marine and Freshwater Research*, **56**: 279-302.

Cox, M.E. Moss, A. Smyth, G.K. 2005. Water quality condition and trend in north Queensland waterways. *Marine Pollution Bulletin*, **51**: 89-98.

Fox, D.R. Etchells, T. Tan, K.S. (2005), *Protocols for the optimal measurement of nutrient loads,* A report to West Gippsland Catchment Management Authority, Australian Centre for Environmetrics, July 2005.

GHD. 2007. Thuringowa water: report for Condon WPP upgrade, preliminary sustainability assessment, June 2007.

Hosomi, M. Sudo, R. 1987. Simultaneous determination of total nitrogen and total phosphorus in freshwater samples using persulfate digestion. *International Journal of Environmental Studies,* **27**: 267-275.

Kinsey-Henderson, A. Sherman, B. Bartley, R. 2007. *Improved SedNet modelling of grazing lands in the Burdekin catchment*. CSIRO Land and Water Science Report **63/07** for the Burdekin Dry Tropics NRM, September 2007.

Letcher, R.A. Jakeman, A.J. Merritt, W.S. McKee, L.J. Eyre, B.D. Baginska, B. (1999), *Review of techniques to estimate catchment exports*, Environmental Protection Authority Technical Report, EPA, Sydney. ISBN: 0731327098.

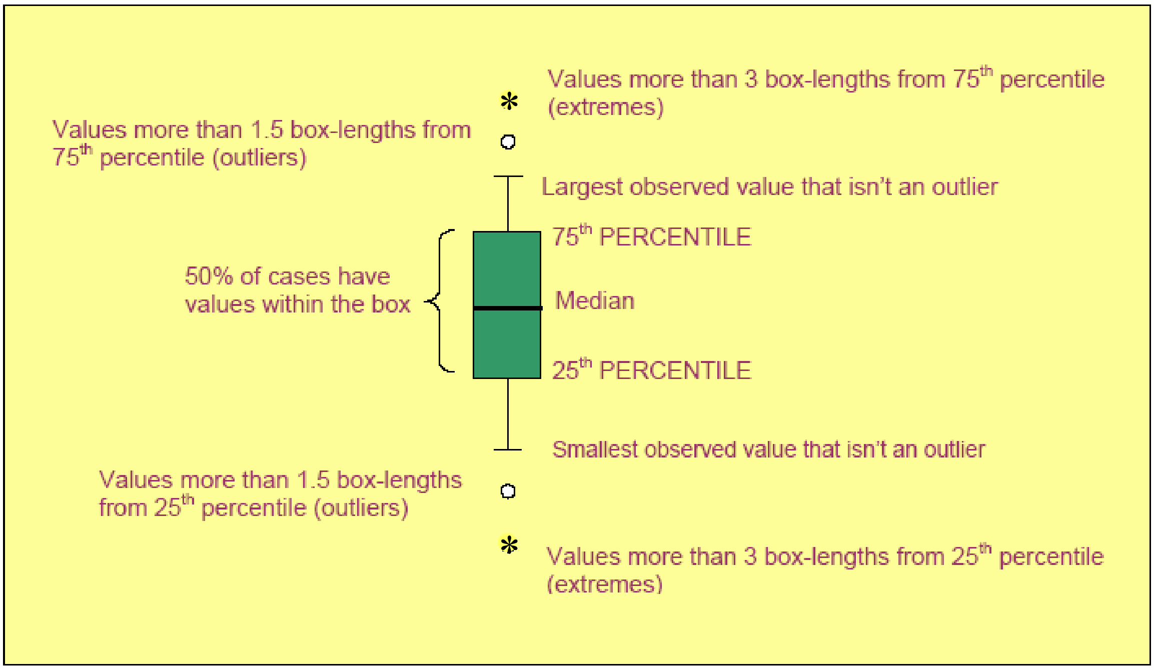
Liessmann, L. Lewis, S. Bainbridge, Z. Brodie, J. Faithful, J. Maughan. M. 2007. *Event-based water quality monitoring of the Ross and Black River Basins during the 2006/07 wet season*. ACTFR Report No. **07/09** for the Creek to Coral Black Ross WQIP.

Post, D., Bartley, R., Corfield, J., Nelson, B., Kinsey-Henderson, A., Hawdon, A., Gordon, I., Abbott, B., Berthelsen, S., Hodgen, M., Keen, R., Kemei, J., Vleeshouwer, J., MacLeod, N. and Webb, M. 2006. *Sustainable grazing for a healthy Burdekin catchment.* CSIRO Land and Water Science Report 62/06. 220pp.

APPENDIX A

Box Plot Diagram

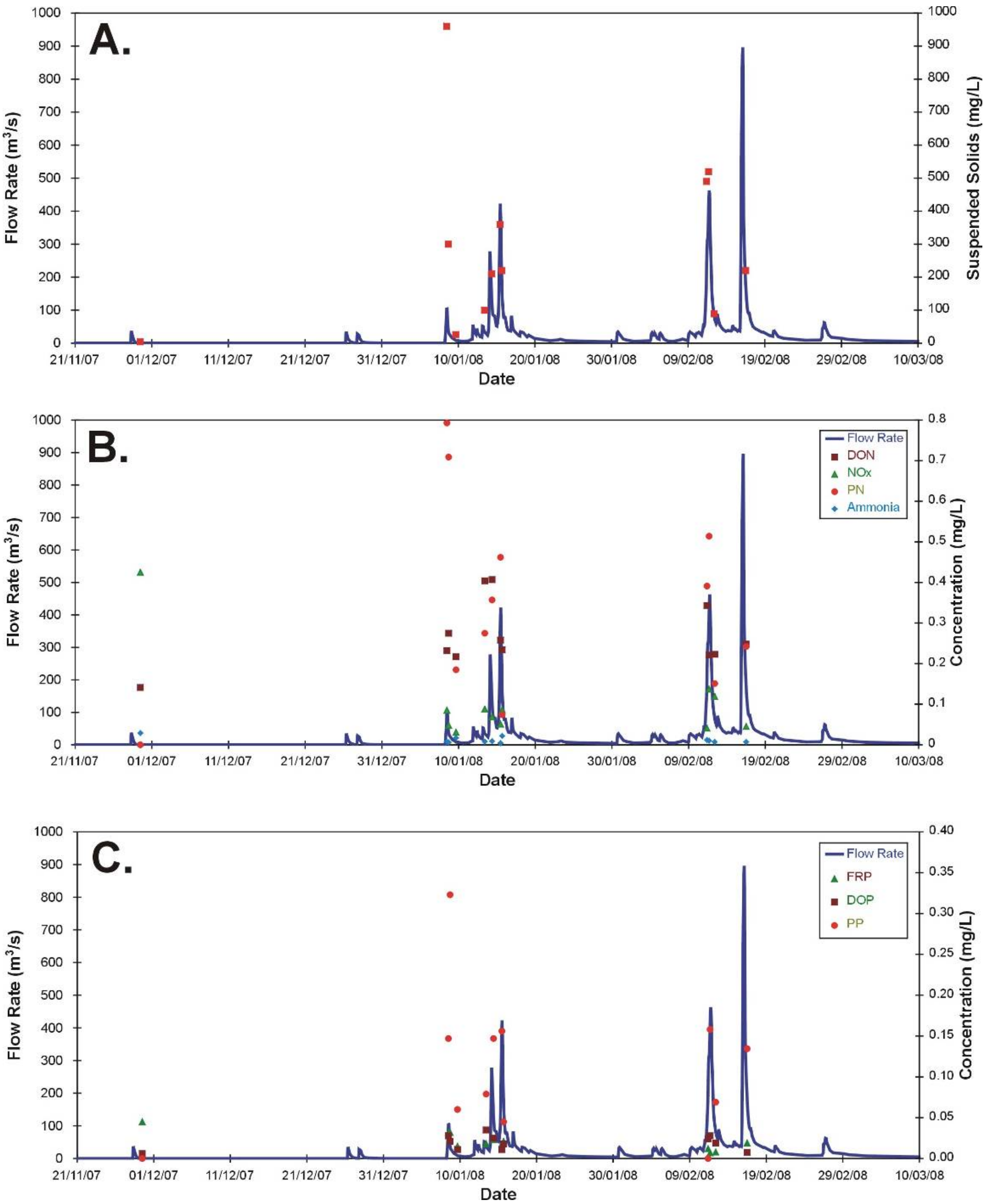
Appendix A: **Box plot diagram showing major features of the plot**



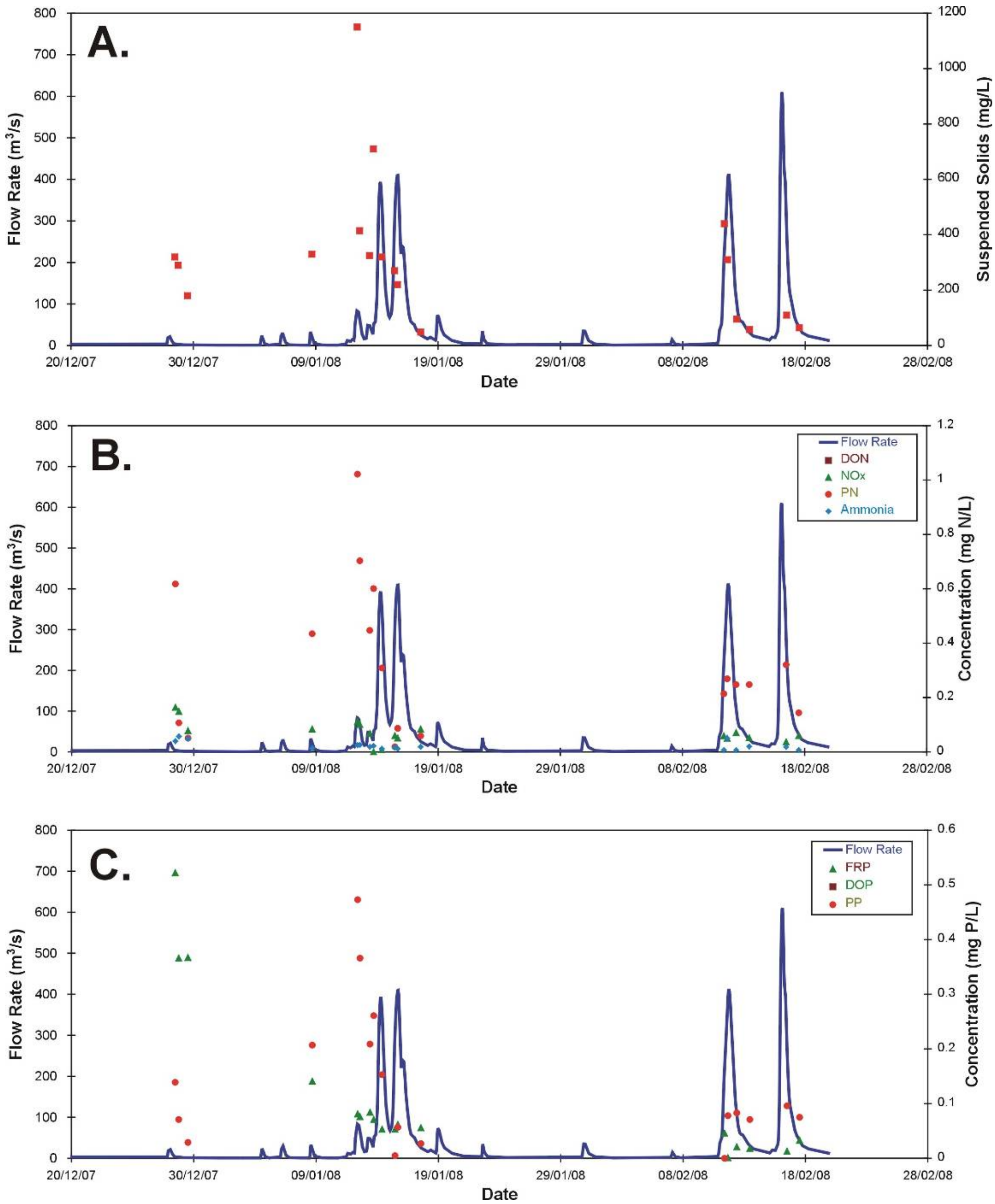
Box Plots: Summary plot based on the median, quartiles, and extreme values. The box represents the inter-quartile range which contains the 50% of values. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers. A line across the box indicates the median.

APPENDIX B

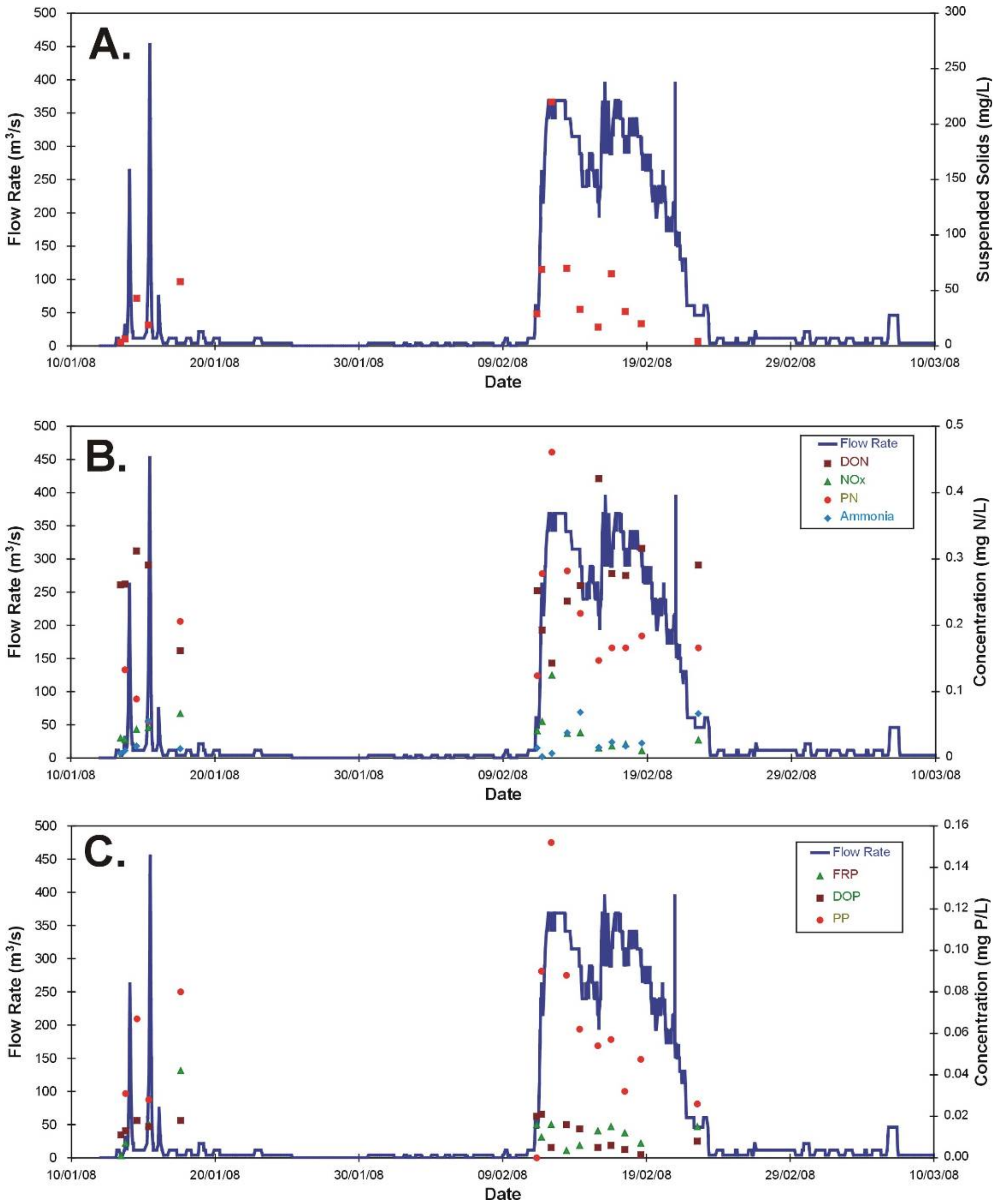
Hydrographs of the major watercourses in the Black Ross WQIP Region



Summary of the water quality data over the hydrograph for the Black River site including total suspended sediment concentrations (A), nitrogen (B) and phosphorus (C) species.



Summary of the water quality data over the hydrograph for the Bohle River site including total suspended sediment concentrations (A), nitrogen (B) and phosphorus (C) species.



Summary of the water quality data over the hydrograph for the Ross River site including total suspended sediment concentrations (A), nitrogen (B) and phosphorus (C) species.

APPENDIX C

Water quality data

Site Name	Land use	Date collected	Time collected	Cond-uctivity (µS/cm)	Total Suspended Solids (mg/L)	Total Nitrogen (µg N/L)	Ammonia (µg N/L)	NO_X (µg N/L)	DON (µg N/L)	Particulate N (µg N/L)
Woolcock St Drain	Established urban	28/12/07	12:00	4900	12	820	49	72	375	324
Woolcock St Drain	Established urban	28/12/07	17:10	1283	8.4	949	44	115	580	210
Woolcock St Drain	Established urban	26/12/07	15:35	84.8	9.4	893	35	120	641	97
Woolcock St Drain	Established urban	12/1/08	10:10	95.9	7.9	617	23	115	197	282
Woolcock St Drain	Established urban	9/1/08	15:00	242	7.2	832	32	361	93	346
Woolcock St Drain	Established urban	14/1/08	12:30	88.9	6	729	31	21	640	37
Woolcock St Drain	Established urban	13/1/08	14:55	63.3	11	937	24	141	427	345
Woolcock St Drain	Established urban	15/1/08	9:35	49.7	17	868	23	77	292	476
Woolcock St Drain	Established urban	13/1/08	9:00	32.2	17	499	28	213	212	46
Woolcock St Drain	Established urban	13/1/08	16:35	34.9	51	770	39	110	229	392
Kern Drain	Developing urban (Plain)	28/12/07	9:00	107	520	798	19	122	582	75
Kern Drain	Developing urban (Plain)	26/12/07	16:35	100.7	430	827	16	109	506	196
Kern Drain	Developing urban (Plain)	14/1/08	13:00	110.7	430	635	16	93	417	109
Kern Drain	Developing urban (Plain)	13/1/08	14:30	104.2	365	916	32	66	409	409
Kern Drain	Developing urban (Plain)	12/1/08	13:45	87.4	380	1121	14	46	523	538
Kern Drain	Developing urban (Plain)	28/12/07	17:55	175.8	210	692	47	21	550	74
Kern Drain	Developing urban (Plain)	12/1/08	9:10	77.3	770	987	11	81	412	483
Kern Drain	Developing urban (Plain)	26/12/07	10:00	63.5	900					
Kern Drain	Developing urban (Plain)	13/1/08	9:20	76.5	550	681	10	149	355	167
Kern Drain	Developing urban (Plain)	13/1/08	17:40	61.4	460	806	58	68	359	321
Gordon Creek	Developing urban (Plain)	26/12/07	15:20	20500	230					
Gordon Creek	Developing urban (Plain)	28/12/07	13:00	3690	92					
Gordon Creek	Developing urban (Plain)	13/1/08	15:10	940	140					
Gordon Creek	Developing urban (Plain)	13/1/08	8:15	392	130					
Gordon Creek	Developing urban (Plain)	28/12/07	17:00	4140	76					
Gordon Creek	Developing urban (Plain)	12/1/08	10:30	3820	72					
Gordon Creek	Developing urban (Plain)	14/1/08	12:15	573	120					
Gordon Creek	Developing urban (Plain)	15/1/08	9:25	354	500					

Site Name	Land use	Date collected	Time collected	Cond-uctivity (µS/cm)	Total Suspended Solids (mg/L)	Total Nitrogen (µg N/L)	Ammonia (µg N/L)	NO_X (µg N/L)	DON (µg N/L)	Particulate N (µg N/L)
Gordon Creek	Developing urban (Plain)	13/1/08	16:25	921	4600					
Riverside Creek	Developing urban (Slope)	27/12/07	19:45	89.1	3200					
Riverside Creek	Developing urban (Slope)	27/12/07	19:45	110.5	20000					
Riverside Creek	Developing urban (Slope)	5/1/08	1:00		1200					
Riverside Creek	Developing urban (Slope)	5/1/08	1:00		17000					
Riverside Creek	Developing urban (Slope)	13/1/08	17:00	72.3	4050					
Riverside Creek	Developing urban (Slope)	13/1/08	17:00	57.7	5900					
Riverside Creek	Developing urban (Slope)	13/1/08	18:10	97.5	545					
Freshwater Dr Ck	Comparison site (Slope)	13/1/08	18:00	73.6	25					
Campus Creek	Comparison site (Slope)	13/1/08	17:40	52.9	82					
Campus Creek 2	Comparison site (Slope)	13/1/08	17:50	52.5	46					
Hill St Drain	Light industrial	28/12/07	17:40	134.4	8.5	479	20	69	305	85
Hill St Drain	Light industrial	9/1/08	14:45	376	43	975	18	86	521	350
Hill St Drain	Light industrial	14/1/08	12:45	131.7	36	527	13	123	318	73
Hill St Drain	Light industrial	13/1/08	14:40	738	18	1906	22	120	834	930
Hill St Drain	Light industrial	13/1/08	8:40	124	25	1574	11	66	768	729
Hill St Drain	Light industrial	15/1/08	10:35	37.8	43	243	12	59	132	40
Hill St Drain	Light industrial	11/2/08	9:05	76.9	71	648	4	196	259	189
Hill St Drain	Light industrial	13/1/08	17:00	31.2	110	776	29	108	336	303
Hill St Drain	Light industrial	11/2/08	15:20	52.6	89	589	20	89	265	215
Ross River	Major catchment	11/2/08	8:45	114.1	29	432	15	41	252	124
Ross River	Major catchment	13/2/08	10:35	66.4	69	606	40	29	247	290
Ross River	Major catchment	13/2/08	10:35	63.8	71	581	36	45	226	274
Ross River	Major catchment	14/2/08	8:30	72.1	33	585	69	38	260	218
Ross River	Major catchment	15/2/08	15:00	45.8	17	599	16	15	421	147
Ross River	Major catchment	18/2/08	14:45	45.4	20	524	22	9	311	182
Ross River	Major catchment	18/2/08	14:45	45.5	20	543	23	13	321	186
Ross River	Major catchment	22/2/08	13:05	59.5	4.1	551	67	27	291	166

Site Name	Land use	Date collected	Time collected	Cond-uctivity (µS/cm)	Total Suspended Solids (mg/L)	Total Nitrogen (µg N/L)	Ammonia (µg N/L)	NO_X (µg N/L)	DON (µg N/L)	Particulate N (µg N/L)
Ross River	Major catchment	16/2/08	13:00	44.2	65	486	24	18	278	166
Ross River	Major catchment	17/2/08	12:00	45	31	480	18	21	275	166
Ross River	Major catchment	12/2/08	9:00	45.9	220	736	7	125	143	461
Ross River	Major catchment	11/2/08	16:45	75.8	69	528	2	55	193	278
Ross River	Major catchment	17/1/08	14:20	63.7	58	449	14	67	162	206
Ross River	Major catchment	14/1/08	13:25	101.3	43	462	18	43	312	89
Ross River	Major catchment	15/1/08	9:00	123.3	19	448	56	46	291	55
Ross River	Major catchment	13/1/08	18:10	132.1	6.3	434	11	28	262	133
Ross River	Major catchment	13/1/08	10:40	142.8	3.2	TBC	7	30	261	
Black River	Major catchment	29/11/07	12:05	120.9	4.6	595	29	425	141	0
Black River	Major catchment	8/1/08	16:50	29.8	300	1038	6	48	275	709
Black River	Major catchment	15/1/08	16:35	40.3	220	416	22	86	234	74
Black River	Major catchment	15/1/08	11:15	30.9	360	775	4	51	258	462
Black River	Major catchment	13/1/08	10:05	65.3	100	775	8	88	404	275
Black River	Major catchment	8/1/08	11:30	27	960	1118	8	85	232	793
Black River	Major catchment	14/1/08	9:00	38.8	210	842	9	69	407	357
Black River	Major catchment	9/1/08	16:00	98.9	26	450	17	31	217	185
Black River	Major catchment	11/2/08	9:35	38.6	490	787	12	41	343	391
Black River	Major catchment	16/2/08	12:10	35.2	210	516	4	31	277	204
Black River	Major catchment	16/2/08	12:10	36.7	230	568	10	59	219	280
Black River	Major catchment	11/2/08	16:05	31.7	520	882	10	137	221	514
Black River	Major catchment	12/2/08	9:40	62.5	89	500	7	119	223	151
Bohle River	Major catchment	28/12/07	18:30	248	290	864	57	149	551	107
Bohle River	Major catchment	29/12/07	12:30	387	180	778	49	78	600	51
Bohle River	Major catchment	28/12/07	11:40	163.8	320	1404	40	164	582	618
Bohle River	Major catchment	17/1/08	13:40	101.8	49	489	19	84	327	59
Bohle River	Major catchment	8/1/08	16:30	90.3	330	875	14	84	342	435
Bohle River	Major catchment	15/1/08	10:50	40.3	270	350	17	60	254	19

Site Name	Land use	Date collected	Time collected	Cond-uctivity (µS/cm)	Total Suspended Solids (mg/L)	Total Nitrogen (µg N/L)	Ammonia (µg N/L)	NO_X (µg N/L)	DON (µg N/L)	Particulate N (µg N/L)
Bohle River	Major catchment	15/1/08	16:20	38.3	220	337	12	51	187	87
Bohle River	Major catchment	12/1/08	9:30	62.3	1150	1568	25	112	409	1022
Bohle River	Major catchment	14/1/08	9:20	33.2	320	645	12	8	316	309
Bohle River	Major catchment	13/1/08	17:05	70.9	710	1318	22			601
Bohle River	Major catchment	12/1/08	14:10	63.8	415	1181	26	101	351	703
Bohle River	Major catchment	13/1/08	9:40	78.5	325	957	19	68	423	447
Bohle River	Major catchment	11/2/08	9:20	44.8	440	652	7	59	372	214
Bohle River	Major catchment	13/2/08	11:00	87.1	58	674	20	52	354	248
Bohle River	Major catchment	16/2/08	11:45	20.1	110	522	18	37	146	321
Bohle River	Major catchment	17/2/08	12:30	56.4	64	519	7	60	308	144
Bohle River	Major catchment	11/2/08	15:50	35.6	310	569	50	50	200	269
Bohle River	Major catchment	12/2/08	9:25	43.9	95	530	6	71	205	248

Site Name	Land use	Date collected	Time collected	Total Phosphorus (µg P/L)	Filterable Reactive P (µg P/L)	DOP (µg P/L)	Particulate P (µg P/L)
Woolcock St Drain	Established urban	28/12/07	12:00	300	186	4	110
Woolcock St Drain	Established urban	28/12/07	17:10	347	194	90	63
Woolcock St Drain	Established urban	26/12/07	15:35	579	490	49	40
Woolcock St Drain	Established urban	12/1/08	10:10	246	89	71	86
Woolcock St Drain	Established urban	9/1/08	15:00	227	69	72	86
Woolcock St Drain	Established urban	14/1/08	12:30	366	188	175	3
Woolcock St Drain	Established urban	13/1/08	14:55	473	196	190	87
Woolcock St Drain	Established urban	15/1/08	9:35	438	124	147	167
Woolcock St Drain	Established urban	13/1/08	9:00	290	107	168	15
Woolcock St Drain	Established urban	13/1/08	16:35	312	91	86	135
Kern Drain	Developing urban (Plain)	28/12/07	9:00	287	214	18	55
Kern Drain	Developing urban (Plain)	26/12/07	16:35	353	271	11	71
Kern Drain	Developing urban (Plain)	14/1/08	13:00	316	88	73	155
Kern Drain	Developing urban (Plain)	13/1/08	14:30	387	87	77	223
Kern Drain	Developing urban (Plain)	12/1/08	13:45	405	82	55	268
Kern Drain	Developing urban (Plain)	28/12/07	17:55	177	163	0	14
Kern Drain	Developing urban (Plain)	12/1/08	9:10	386	85	44	257
Kern Drain	Developing urban (Plain)	26/12/07	10:00				
Kern Drain	Developing urban (Plain)	13/1/08	9:20	362	83	94	185
Kern Drain	Developing urban (Plain)	13/1/08	17:40	363	97	75	191
Gordon Creek	Developing urban (Plain)	26/12/07	15:20				
Gordon Creek	Developing urban (Plain)	28/12/07	13:00				
Gordon Creek	Developing urban (Plain)	13/1/08	15:10				
Gordon Creek	Developing urban (Plain)	13/1/08	8:15				
Gordon Creek	Developing urban (Plain)	28/12/07	17:00				
Gordon Creek	Developing urban (Plain)	12/1/08	10:30				
Gordon Creek	Developing urban (Plain)	14/1/08	12:15				
Gordon Creek	Developing urban (Plain)	15/1/08	9:25				

Site Name	Land use	Date collected	Time collected	Total Phosphorus (µg P/L)	Filterable Reactive P (µg P/L)	DOP (µg P/L)	Particulate P (µg P/L)
Gordon Creek	Developing urban (Plain)	13/1/08	16:25				
Riverside Creek	Developing urban (Slope)	27/12/07	19:45				
Riverside Creek	Developing urban (Slope)	27/12/07	19:45				
Riverside Creek	Developing urban (Slope)	5/1/08	1:00				
Riverside Creek	Developing urban (Slope)	5/1/08	1:00				
Riverside Creek	Developing urban (Slope)	13/1/08	17:00				
Riverside Creek	Developing urban (Slope)	13/1/08	17:00				
Riverside Creek	Developing urban (Slope)	13/1/08	18:10				
Freshwater Dr Ck	Comparison site (Slope)	13/1/08	18:00				
Campus Creek	Comparison site (Slope)	13/1/08	17:40				
Campus Creek 2	Comparison site (Slope)	13/1/08	17:50				
Hill St Drain	Light industrial	28/12/07	17:40	182	146	11	25
Hill St Drain	Light industrial	9/1/08	14:45	199	64	36	99
Hill St Drain	Light industrial	14/1/08	12:45	138	41	36	61
Hill St Drain	Light industrial	13/1/08	14:40	1587	829	382	376
Hill St Drain	Light industrial	13/1/08	8:40	1021	536	244	241
Hill St Drain	Light industrial	15/1/08	10:35	134	68	29	37
Hill St Drain	Light industrial	11/2/08	9:05	209	191	18	0
Hill St Drain	Light industrial	13/1/08	17:00	420	89	175	156
Hill St Drain	Light industrial	11/2/08	15:20	299	11	170	118
Ross River	Major catchment	11/2/08	8:45	36	16	20	0
Ross River	Major catchment	13/2/08	10:35	112	4	16	92
Ross River	Major catchment	13/2/08	10:35	103	3	16	84
Ross River	Major catchment	14/2/08	8:30	82	6	14	62
Ross River	Major catchment	15/2/08	15:00	72	13	5	54
Ross River	Major catchment	18/2/08	14:45	58	9	2	47
Ross River	Major catchment	18/2/08	14:45	54	5	1	48
Ross River	Major catchment	22/2/08	13:05	49	15	8	26

Site Name	Land use	Date collected	Time collected	Total Phosphorus (µg P/L)	Filterable Reactive P (µg P/L)	DOP (µg P/L)	Particulate P (µg P/L)
Ross River	Major catchment	16/2/08	13:00	78	15	6	57
Ross River	Major catchment	17/2/08	12:00	48	12	4	32
Ross River	Major catchment	12/2/08	9:00	173	16	5	152
Ross River	Major catchment	11/2/08	16:45	121	10	21	90
Ross River	Major catchment	17/1/08	14:20	140	42	18	80
Ross River	Major catchment	14/1/08	13:25	103	18	18	67
Ross River	Major catchment	15/1/08	9:00	59	16	15	28
Ross River	Major catchment	13/1/08	18:10	51	7	13	31
Ross River	Major catchment	13/1/08	10:40	TBC	1	11	
Black River	Major catchment	29/11/07	12:05	51	45	6	0
Black River	Major catchment	8/1/08	16:50	376	32	21	323
Black River	Major catchment	15/1/08	16:35	84	21	18	45
Black River	Major catchment	15/1/08	11:15	185	18	11	156
Black River	Major catchment	13/1/08	10:05	132	18	35	79
Black River	Major catchment	8/1/08	11:30	207	32	28	147
Black River	Major catchment	14/1/08	9:00	195	23	25	147
Black River	Major catchment	9/1/08	16:00	86	15	11	60
Black River	Major catchment	11/2/08	9:35	36	12	24	0
Black River	Major catchment	16/2/08	12:10	151	14	9	128
Black River	Major catchment	16/2/08	12:10	171	24	6	141
Black River	Major catchment	11/2/08	16:05	193	7	28	158
Black River	Major catchment	12/2/08	9:40	96	8	19	69
Bohle River	Major catchment	28/12/07	18:30	518	366	81	71
Bohle River	Major catchment	29/12/07	12:30	538	367	142	29
Bohle River	Major catchment	28/12/07	11:40	690	522	29	139
Bohle River	Major catchment	17/1/08	13:40	114	56	31	27
Bohle River	Major catchment	8/1/08	16:30	488	141	140	207
Bohle River	Major catchment	15/1/08	10:50	71	53	13	5

Site Name	Land use	Date collected	Time collected	Total Phosphorus (µg P/L)	Filterable Reactive P (µg P/L)	DOP (µg P/L)	Particulate P (µg P/L)
Bohle River	Major catchment	15/1/08	16:20	142	62	23	57
Bohle River	Major catchment	12/1/08	9:30	594	81	40	473
Bohle River	Major catchment	14/1/08	9:20	252	53	46	153
Bohle River	Major catchment	13/1/08	17:05	407	71	75	261
Bohle River	Major catchment	12/1/08	14:10	477	76	35	366
Bohle River	Major catchment	13/1/08	9:40	350	84	57	209
Bohle River	Major catchment	11/2/08	9:20	67	46	21	0
Bohle River	Major catchment	13/2/08	11:00	116	18	27	71
Bohle River	Major catchment	16/2/08	11:45	116	13	7	96
Bohle River	Major catchment	17/2/08	12:30	116	33	8	75
Bohle River	Major catchment	11/2/08	15:50	128	1	49	78
Bohle River	Major catchment	12/2/08	9:25	128	21	24	83