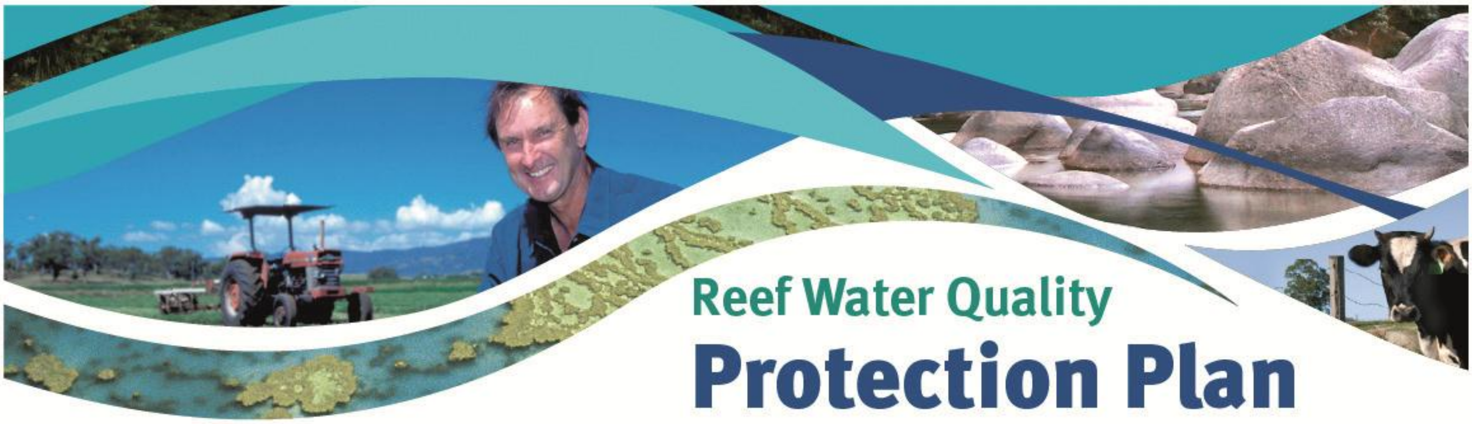

Sediment, Nutrient and Pesticide Loads

Great Barrier Reef Catchment Loads Monitoring 2009-2010

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Executive summary

Diffuse pollutant loads discharged from Queensland's east-coast rivers have caused a decline in water quality in the Great Barrier Reef lagoon. This decline in water quality is known to directly impact the health of the Great Barrier Reef and its ecosystems.

The Reef Water Quality Protection Plan 2009 (Reef Plan) aims to halt and reverse the decline in water quality and enhance the resilience of the Reef to threatening processes (e.g. coral bleaching, ocean acidification, disease, climate change and overfishing) by improving land management practices.

Reef Plan is underpinned by pollutant reduction targets that include a 20 per cent reduction in anthropogenic load of total suspended solids by 2020; a 50 per cent reduction in anthropogenic load of nutrients (nitrogen and phosphorus) by 2013; and a 50 per cent decrease in photosystem II inhibitor herbicides[1] by 2013.

Progress towards Reef Plan targets is measured through the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef Program) which is jointly funded by the Australian and Queensland governments. The Paddock to Reef Program includes catchment scale water quality monitoring of pollutant loads entering the Great Barrier Reef lagoon which is implemented through the Great Barrier Reef Catchment Loads Monitoring Program.

To meet Action 10 under Reef Plan, pollutant loads were estimated by the Great Barrier Reef Catchment Loads Monitoring Program in the following natural resource management regions and priority catchments:

- Cape York region – Normanby catchment
- Wet Tropics region – Barron, Johnstone, Tully and Herbert catchments
- Burdekin region – Burdekin and Haughton catchments
- Mackay-Whitsundays region – Plane and Pioneer catchments
- Fitzroy region – Fitzroy catchment
- Burnett-Mary region – Burnett catchment

This report presents pollutant load estimates based on monitoring data from the 2009-2010 monitoring year. The monitoring data generated by this program provides the point of truth to validate loads predicted by source catchment models. These modelled loads are used to report annually on progress towards the Reef Plan targets.

Weather patterns in Queensland during 2009-2010 were influenced by a rapid transition from dry conditions of an El Niño in the late winter and spring through to the intense rainfall depressions and cyclones associated with a La Niña, which developed in the late wet season. Isolated intense rainfall resulted in major flow events in the Pioneer, Plane and Fitzroy river catchments with significant exceedance of mean annual discharge recorded at the end-of-system gauges for each of these catchments.

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[1] Photosystem II inhibitor herbicides are those herbicides that exert toxicity to plants by inhibiting the photosystem II component of photosynthesis. The priority herbicides for this program are ametryn, atrazine, diuron, hexazinone and tebuthiuron.

Ten end-of-system sites and 11 sub-catchment sites were monitored for total suspended solids and nutrients in 2009-2010 and seven end-of-system and four sub-catchment sites were monitored for photosystem II inhibitor herbicides. During 2009-2010 the monitored catchments generated approximately 6.95 million tonnes of total suspended solids, 30,000 tonnes of nitrogen, and 9300 tonnes of phosphorus. The Fitzroy and Burdekin rivers, representing 82 per cent of the monitored area, exported the highest loads of all pollutants with 79 per cent of the total suspended solids (5.5 million tonnes), 65 per cent of the total nitrogen (19,400 tonnes) and 81 per cent of the total phosphorus (7500 tonnes) load. The low relative contribution of the Burdekin River to the pollutant load compared to previous monitoring years may be the result of below average rainfall received in the Burdekin River catchment and significant exceedance of the mean annual discharge in the Fitzroy River during the 2009-10 monitoring year.

At least one photosystem II inhibitor herbicide was detected at each monitored site, with the most frequently detected being atrazine. Only pesticide loads for individual events were calculated. The largest event load of atrazine was recorded in the Fitzroy River (approximately 1200 kilograms).

Yields (the load divided by the monitored surface area of the catchment) were calculated to compare the rate of pollutant delivery between catchments. The total suspended solid and nutrient yields from the Pioneer, Plane and Johnstone catchments were the largest (with total suspended solids yields greater than 116 tonnes per square kilometre and nutrient yields greater than 250 kilograms per square kilometre), whilst the smallest yield occurred in the Burnett catchment (with total suspended solids yields less than 4 tonnes per square kilometre and nutrient yields less than 38 kilograms per square kilometre). The largest yield of atrazine was from the Plane catchment (0.2 kilograms per square kilometre), and the Burnett catchment had the smallest yield of atrazine (0.0004 kilograms per square kilometre).

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1 Introduction

The Great Barrier Reef World Heritage Area is located off the north-east coast of Australia and is recognised as the largest coral reef ecosystem in the world (Furnas 2003; Rayment 2003). It is widely acknowledged that the Great Barrier Reef is at significant risk from degraded water quality caused by pollutants exported from catchments adjacent to the Great Barrier Reef (Wachenfeld et al. 1998; State of Queensland and Commonwealth of Australia, 2003; Brodie et al. 2008; Hunter and Walton 2008; Brodie et al. 2009; DPC 2009; Packett et al. 2009; Brodie et al. 2010). In order to improve water quality entering from these catchments, the Queensland and Australian Governments cooperatively initiated the Reef Water Quality Protection Plan 2009 (Reef Plan) with the short-term goal to halt and reverse the decline in water quality entering the Great Barrier Reef lagoon by 2013 (DPC 2009).

The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef program) measures progress towards Reef Plan goals and targets. The Paddock to Reef program is a joint collaboration involving the Australian and Queensland Governments, industry, regional natural resource management bodies and research organisations (DPC 2011). It is a world-leading approach to integrate data and information on management practices, catchment indicators, water quality loads and the health of the Great Barrier Reef.

To assist in evaluating the progression towards the water quality targets of Reef Plan, the Great Barrier Reef Catchment Loads Monitoring Program was implemented to monitor and report on loads of total suspended solids, nutrients and pesticides in 11 priority catchments under the Paddock to Reef program.

Evidence of elevated anthropogenic loads of total suspended solids, nutrients and pesticides exported to the Great Barrier Reef lagoon since European settlement have been reported extensively over recent years (e.g., Nicholls 1988; Wachenfeld et al. 1998; Eyre 1998; Fabricius et al. 2005; Hunter and Walton 2008; Packett et al. 2009; Brodie et al. 2010; Kroon et al. 2011). Kroon et al. (2011) estimated that since European settlement the mean annual load of total suspended solids exported to the Great Barrier Reef lagoon has increased by 5.5 times, total nitrogen has increased by 5.7 times and total phosphorus has increased by 8.9 times. Photosystem II inhibitor herbicides were not present before European settlement. The majority of pollutant loads are generated during the wet season as runoff during flood events from catchments adjacent to the Great Barrier Reef (Nicholls 1988; Eyre 1998).

Thirty-five catchments flow into the Great Barrier Reef lagoon, and cover an area of approximately 424,000 square kilometres. These catchments extend from the tropics to the subtropics over 1500 kilometres of the Queensland coastline (DPC 2011). Across the study area, there are substantial climatic differences within and between catchments, with highly variable rainfall patterns, variable hydrology and differences in geology. These factors contribute to the high variability in estimated total suspended solids, nutrient and pesticide loads between catchments and years (Furnas et al. 1997; Devlin and Brodie 2005; Joo et al. 2012).

Of these 35 catchments, 11 catchments were monitored by the Great Barrier Reef Catchment Loads Monitoring Program. The 11 catchments were selected based on inputs from the regional National Action Plan for Salinity and Water Quality Program officers, the Great Barrier Reef Marine Park Authority and the Australian Centre for Tropical Freshwater Research (DERM 2011a). The 11 priority monitored catchments and the natural resource management regions in which they occur (Figure 2.1) are listed below:

- Cape York region – Normanby catchment
- Wet Tropics region – Barron, Johnstone, Tully and Herbert catchments
- Burdekin region – Burdekin and Haughton catchments
- Mackay-Whitsundays region – Plane and Pioneer catchments
- Fitzroy region – Fitzroy catchment
- Burnett-Mary region – Burnett catchment

Grazing is the largest single land use within the Great Barrier Reef catchments (DPC 2011), with other significant land uses being conservation, forestry, sugarcane, horticulture and other cropping. In the Cape York region, the Normanby catchment is dominated by grazing, with a large amount of land set aside for conservation in State protected areas. In the Wet Tropics the main land uses are grazing in the west, sugarcane on the coastal flood plains and small areas of horticulture. Large areas of the Wet Tropic region are also set aside for conservation purposes in the Wet Tropics World Heritage Area. Land use in the Burdekin region is dominated by grazing with irrigated sugarcane, horticulture and cropping located in the lower Burdekin catchment. Within the Mackay-Whitsunday region the Pioneer and Plane catchments are dominated by grazing, conservation and forestry. This region also contains relatively large areas of sugarcane cultivation along the coastline. Grazing, dry land cropping (including cotton) and mining are the dominant land uses within the Fitzroy region. Land use within the Burnett-Mary region is a mixture of grazing, dairy, horticulture, sugarcane and other cropping (DPC 2011).

This report presents pollutant load estimates for the 2009-2010 monitoring year. These data are presented as annual loads for all monitored sites for total suspended solids, nutrients and as event loads for pesticides. The yields (the load per square kilometre) of pollutants from the 11 catchments are also presented to provide added context to the rate of pollutant delivery between catchments (including dominant land uses).

The scope of this report is confined to the estimation and reporting of loads exported from the monitored area of each catchment and as such these pollutant loads do not represent the total load discharged to the Great Barrier Reef lagoon[2]. This report does not link land uses or regions to loads of total suspended solids, nutrients or pesticides. The reported loads are estimated from monitoring data, which provides the point of truth to validate the modelled catchment loads. These modelled loads are used to report annually on progress towards water quality targets in the Reef Plan Report Card (DPC 2011).

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[2] Not all catchments that drain to the Great Barrier Reef lagoon were monitored. In addition, the end-of-system monitoring sites are not located at the mouth of the river or creek (refer to Section 2.1) and this unmonitored portion of the catchment or sub-catchment may contribute, remove or degrade total suspended solids, nutrients and pesticides.

2 Methods

2.1 Monitoring sites

Eleven priority catchments were identified for monitoring under the Paddock to Reef Program. Monitoring sites were established at existing Queensland Government stream gauging stations (Table 2.1) where possible. Sites are classified as either end-of-system or sub-catchment sites. End-of-system sites are defined as the lowest point in a river or creek, which does not have tidal influence and the volume of water, can be accurately gauged. Sub-catchment sites are located on rivers that have different drainage basins to the major river for those catchments. Sub-catchment sites were selected to provide specific water quality details on various land uses or on a geographical region for enhanced model validation.

Between 1 July 2009 and 30 June 2010 monitoring was undertaken at 24 sites located in the 11 priority catchments (Figure 2.1 and Table 2.1). Monitoring at three sites (Bowen River at Myuna, Isaac River at Yatton and Theresa Creek at Gregory Highway) was limited in 2009-2010 due to logistical reasons; therefore no data for these sites will be presented in this report.

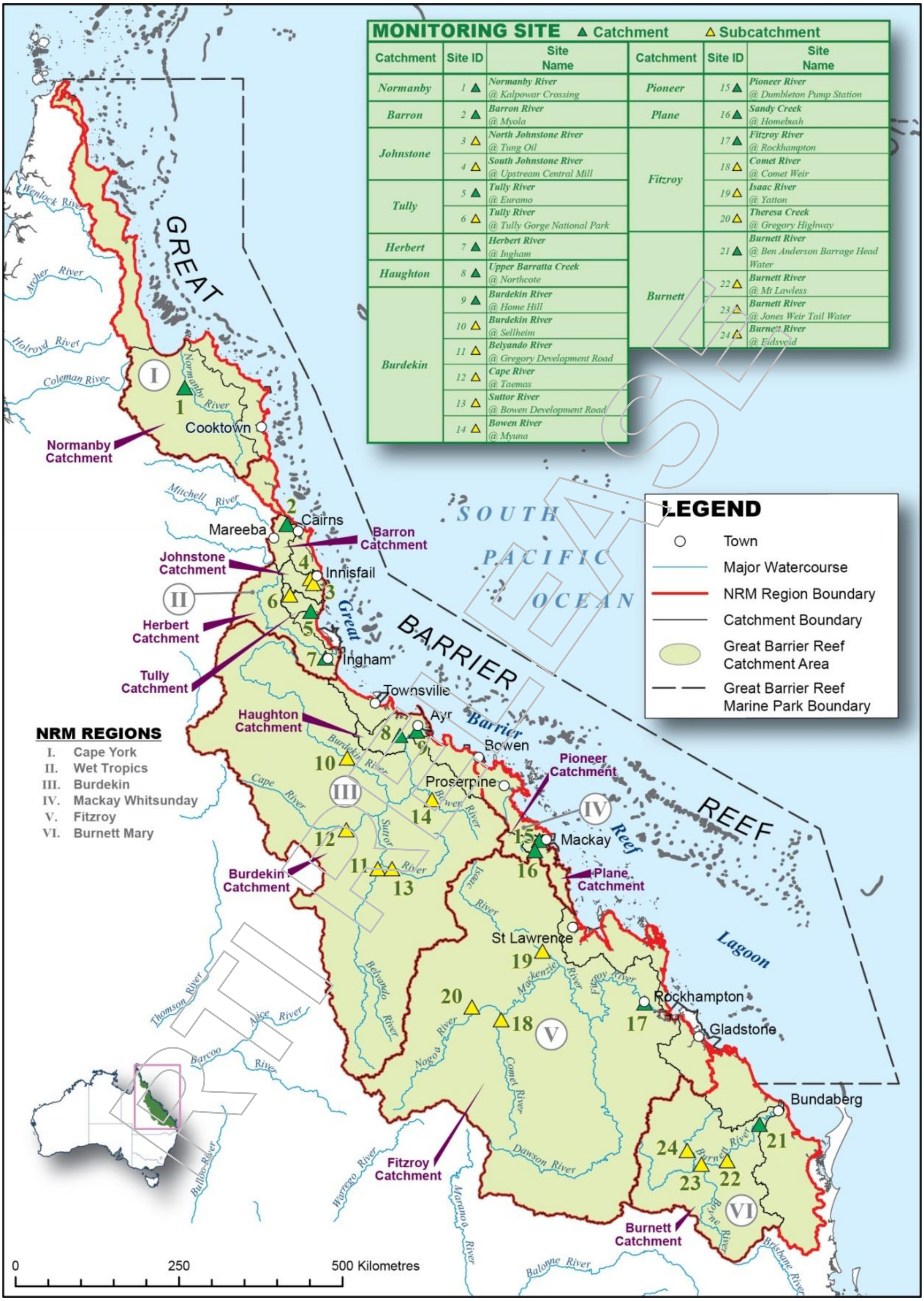
Ten end-of-system sites and 14 sub-catchment sites were selected to monitor total suspended solids and nutrients (Table 2.1) in 2009-2010 while seven end-of-systems and four sub-catchment sites were selected to monitor photosystem II inhibitor herbicides (Table 2.1). The monitored catchment area for all sites is provided in Table 7.1, Appendix C.

2.2 Rainfall

Rainfall data were obtained from the Commonwealth of Australia, Bureau of Meteorology National Climate Centre data archive (www.bom.gov.au). These data were synthesised using the Bureau of Meteorology's web-based mapping tools (Bureau of Meteorology 2012) to create isotopic maps of Queensland to display total annual rainfall and annual rainfall deciles during the 2009-2010 monitoring year.

2.3 Water quality sampling

Water samples were collected according to methods outlined in the Environmental Protection (Water) Policy Monitoring and Sampling Manual (DERM 2009). Water quality samples were collected between 1 July 2009 and 30 June 2010. Four different sampling methods were used to collect water samples, depending on equipment availability and suitability for use at each site. The four methods used were: manual grab sampling; automatic grab sampling; Van Dorn sampling and passive sampling. The methods employed at each site are shown in Table 2.1.



Catchment	Site ID	Site Name
Normanby	1 ▲	Normanby River @ Kalpowar Crossing
Barron	2 ▲	Barron River @ Myola
Johnstone	3 △	North Johnstone River @ Tung Oil
	4 △	South Johnstone River @ Upstream Central Mill
Tully	5 ▲	Tully River @ Euramo
	6 △	Tully River @ Tully Gorge National Park
Herbert	7 ▲	Herbert River @ Ingham
Haughton	8 ▲	Upper Barratta Creek @ Northcote
Burdekin	9 ▲	Burdekin River @ Home Hill
	10 △	Burdekin River @ Sellheim
	11 △	Belyando River @ Gregory Development Road
	12 △	Cape River @ Taemas
	13 △	Suttor River @ Bowen Development Road
	14 △	Bowen River @ Myuna
Pioneer	15 ▲	Pioneer River @ Dumbleton Pump Station
Plane	16 ▲	Sandy Creek @ Homebush
Fitzroy	17 ▲	Fitzroy River @ Rockhampton
	18 △	Comet River @ Comet Weir
	19 △	Isaac River @ Yatton
	20 △	Theresa Creek @ Gregory Highway
Burnett	21 ▲	Burnett River @ Ben Anderson Barrage Head Water
	22 △	Burnett River @ Mt Lawless
	23 △	Burnett River @ Jones Weir Tail Water
	24 △	Burnett River @ Eidsvold

Figure 2.1 Map indicating the natural resource management regions and catchments where the Great Barrier Reef Catchment Loads Monitoring Program monitored in 2009-2010.

Table 2.1 Summary information on sites monitored as part of the Great Barrier Reef Catchment Loads Monitoring Program between 1 July 2009 and 30 June 2010.

NRM Region	Catchment	Gauging station	River and site name	Type of site	Analytes monitored	Sample collection method	Latitude (decimal degrees)	Longitude (decimal degrees)
Cape York	**Normanby**	105107A	Normanby River at Kalpowar Crossing	EoS	TSS, N	Manual	-14.91850	144.21000
Wet Tropics	**Barron**	110001D	Barron River at Myola	EoS	TSS, N	Manual, automatic	-16.79983	145.61211
	Johnstone	112004A	North Johnstone River at Tung Oil	S-C	TSS, N	Manual	-17.54694	145.93167
		112101B	South Johnstone River at Upstream Central Mill	S-C	TSS, N, PSII	Manual, passive	-17.61056	145.97889
	Tully	113006A	Tully River at Euramo	EoS	TSS, N, PSII	Manual, automatic, passive	-17.99361	145.94111
		113015A	Tully River at Tully Gorge National Park	S-C	TSS, N	Manual, automatic	-17.77265	145.65065
	Herbert	116001F	Herbert River at Ingham	EoS	TSS, N	Manual, Van Dorn	-18.63611	146.14194
Burdekin	**Haughton**	119101A	Barratta Creek at Northcote	EoS	TSS, N, PSII	Manual, passive	-19.70000	147.16667
	Burdekin	120001A	Burdekin River at Home Hill	EoS	TSS, N, PSII	Manual, passive	-19.64167	147.39583
		120002C	Burdekin River at Sellheim	S-C	TSS, N	Manual	-20.00778	146.43694
		120301B	Belyando River at Gregory Development Road	S-C	TSS, N, PSII	Manual, automatic, passive	-21.53528	146.85889
		120302B	Cape River at Taemas	S-C	TSS, N	Manual, automatic	-20.99944	146.42722
		120310A	Suttor River at Bowen Development Road	S-C	TSS, N, PSII	Manual, automatic, passive	-21.53171	147.05226
		120205A	Bowen River at Myuna	S-C	TSS, N	Manual, automatic	-20.58333	147.60000
Mackay-Whitsundays	**Pioneer**	125013A	Pioneer River at Dumbleton Pump Station	EoS	TSS, N, PSII	Manual, automatic, passive	-21.14407	149.07528
	Plane	126001A	Sandy Creek at Homebush	EoS	TSS, N, PSII	Manual, passive	-21.28333	149.01666
Fitzroy	**Fitzroy**	1300000	Fitzroy River at Rockhampton	EoS	TSS, N, PSII	Manual, passive	-23.38111	150.51691
		130504B	Comet River at Comet Weir	S-C	TSS, N, PSII	Manual, passive	-23.61247	148.55139
		130401A	Isaac River at Yatton	S-C	TSS, N	Manual	-22.66583	149.11695
		130206A	Theresa Creek at Gregory Highway	S-C	TSS, N	Manual	-23.43333	148.15000
Burnett-Mary	**Burnett**	136014A	Burnett River at Ben Anderson Barrage Head Water	EoS	TSS, N, PSII	Manual, passive	-25.04928	152.09854
		136002D	Burnett River at Mt Lawless	S-C	TSS, N	Manual, automatic	-25.54598	151.65426
		136094A	Burnett River at Jones Weir Tail Water	S-C	TSS, N	Manual, automatic	-25.59642	151.29627
		136106A	Burnett River at Eidsvold	S-C	TSS, N	Manual, automatic	-25.40380	151.10220

(EoS = end-of-system site, S-C = sub-catchment site, TSS = total suspended solids, N = nutrients, PSII = photosystem II inhibitor herbicides).

Intensive sampling (daily or every few hours) occurred during high flow events and reduced sampling (monthly) was undertaken during ambient (low or base-flow) conditions. Where possible, total suspended solids, nutrients and pesticide samples were collected concurrently. Approximately 50 per cent of the total suspended solids and nutrient samples were collected by manual grab sampling and 50 per cent were collected using ISCO refrigerated automatic pump samplers. Samples were stored and transported in accordance with the Environmental Protection (Water) Policy Monitoring and Sampling Manual (DERM 2009).

Both passive samplers and manual grab sampling were used for monitoring pesticides. Passive samplers were deployed as the primary sampling method for pesticides over the 2009-2010 monitoring year as per the original experimental design (subsequently published in DERM 2011b). A comparison was made between the loads estimated from the two methods, which revealed discrepancies that warranted further investigation (see Appendix F). A decision was made to use grab sampling data as the primary method for estimating the event-based pesticide loads for this report, as this was the more recognised method to estimate loads. As manual grab sampling was intended as the secondary method for pesticide monitoring (based on the original experimental design), sampling was targeted towards event-based monitoring and was limited to only a few events over the wet-season. The collection of grab samples for pesticide analysis was in accordance with the Environmental Protection (Water) Policy Monitoring and Sampling Manual (DERM 2009).

2.4 Quality control

Quality control procedures were implemented in the Great Barrier Reef Catchment Loads Monitoring Program for the 2009-2010 monitoring year. These included:

- a pilot training program to standardise sample collection methods (that would lead to a state-wide training program)
- an emphasis on adherence to accepted sample storage conditions and holding times
- implementing quality checking of sample metadata and chain-of-custody documentation
- initiating the collection of quality-based samples for: field blanks, trip blanks and spiked samples in order to check for any sample contamination or laboratory analytical problems
- initiating the collection of replicates in order to quantify variability associated with sampling; and
- reviewing inter-laboratory result verification and investigation into inter-laboratory blind analysis.

2.5 Water quality sample analysis

Total suspended solids and nutrient analyses were undertaken by the Environment and Resource Sciences Chemistry Centre (Indooroopilly, Queensland) according to Standard Methods 2540 D, 4500-NO_3 I, 4500-NH_3 H, 4500-N_{org} D and 4500-P G (APHA-AWWA-WPCF 2005). Total suspended solids samples were analysed by a gravimetric methodology and nutrient samples were analysed via Flow Injection Analysis (colourimetric techniques).

Queensland Health Forensic and Scientific Services (Coopers Plains, Queensland) undertook the analysis of water samples and passive samplers for pesticides. All pesticide grab samples were extracted via liquid-liquid extraction and analysed using liquid chromatography-mass spectrometry (LC-MS) to quantify the five priority photosystem II inhibitor herbicides (ametryn, atrazine (including its breakdown products, desethyl atrazine and desisopropyl atrazine), diuron, hexazinone and tebuthiuron). Other pesticides detected using liquid chromatography-mass spectrometry were also reported; however, loads and yields were only calculated for the five priority photosystem II inhibitor herbicides. Up to 50 per cent of samples at some sites were also analysed for more hydrophobic pesticides (e.g. organochlorines, organophosphates, synthetic pyrethroids and phenoxyacid herbicides) using gas chromatography-mass spectrometry (Smith et al. 2012). Loads and yields were not calculated using these data.

Environment and Resource Sciences Chemistry Centre (Indooroopilly, Queensland) and Queensland Health Forensic and Scientific Services (Coopers Plains, Queensland) laboratories are accredited by the National Association of Testing Authorities (NATA, Australia) for the analyses conducted. Table 2.2 provides a summary of all analysed parameters and the practical quantitation limits.

2.6 River discharge

River discharge data (hourly-interpolated flow, m^{3}s^{-1}) were extracted from the Department of Environment Resource Management, Surface Water Database using the Hydstra pre-programmed script (http://watermonitoring.derm.qld.gov.au/host.htm). Only data with a quality code of 10 to 30, based on the Department of Environment and Resource Management hydrographic methodology for quality rating flow data (DERM 2011c), were exported. The method used to calculate discharge by the Surface Water Database is presented in Appendix A. If such data were not available due to a gauging station error, flows with a quality code of 60 were used. If samples were collected at sites without a Department of Environment and Resource Management gauging station (due to logistic or workplace health and safety reasons) a ‘flow factor’ was calculated. ’Flow factors’ were based on flow data from the nearest upstream gauging station/s. Flow factors were applied at the following five monitoring sites: Burdekin River at Home Hill; Fitzroy River at Rockhampton; Pioneer River at Dumbleton Head Water; Burnett River at Ben Anderson Barrage Head Water and the Burnett River at Mt Lawless. In general, the flow factors adjust the timing of the flow for the delay in time it takes water to flow from the gauging station to the monitoring site. The flow factors used to calculate discharge at these monitoring locations are provided in Table 3.1.

Table 2.2 Summary information for each parameter analysed including the practical quantitation limit

Monitored pollutants	Abbreviation	Analysed parameter	Practical quantitation limit
Sediments			
Total suspended solids	TSS	Total suspended solids	1 mg L^{-1}
Nutrients			
Total nitrogen	TN	Total nitrogen as N	0.03 mg L^{-1}
Particulate nitrogen	PN	Total nitrogen (suspended) as N	0.03 mg L^{-1}
Dissolved organic nitrogen	DON	Organic nitrogen (dissolved) as N	0.03 mg L^{-1}
Dissolved inorganic nitrogen	DIN	Ammonium nitrogen as N	0.002 mg L^{-1}
		Oxidised nitrogen as N	0.001 mg L^{-1}
Total phosphorus	TP	Total Kjeldahl phosphorus as P	0.01 mg L^{-1}
Particulate phosphorus	PP	Total phosphorus (suspended) as P	0.01 mg L^{-1}
Dissolved organic phosphorus	DOP	Organic phosphorus (dissolved) as P	0.01 mg L^{-1}
Dissolved inorganic phosphorus	DIP	Phosphate phosphorus as P	0.001 mg L^{-1}
Pesticides – Grab samples			
Diuron	Pesticide (PSII)	Diuron	0.01 µg L^{-1}
Ametryn		Ametryn	0.01 µg L^{-1}
Atrazine		Atrazine + desethyl atrazine + desisopropyl atrazine	0.01 µg L^{-1}
Tebuthiuron		Tebuthiuron	0.01 µg L^{-1}
Hexazinone		Hexazinone	0.01 µg L^{-1}
Pesticides – Passive samplers			
Diuron	Pesticide (PSII)	Diuron	1.0 ng sampler^{-1}
Ametryn		Ametryn	1.0 ng sampler^{-1}
Atrazine		Atrazine + total atrazine metabolites	1.0 ng sampler^{-1}
Tebuthiuron		Tebuthiuron	1.0 ng sampler^{-1}

2.7 Data analysis

2.7.1 Rating of sampling representivity

The suitability of the total suspended solids and nutrients data at each site between July 2009 and June 2010 to estimate loads was assessed by determining the representivity of the data using an approach based on Kroon et al. (2010) and Joo et al. (2012). The suitability of pesticide data was not assessed, as only event-based loads were calculated. The total suspended solids and nutrient data were assessed against two criteria:

1. the number of samples collected in the top five per cent of flow; and
2. the ratio between the highest flow rate sampled and the maximum flow rate recorded (both measured in $m^3 s^{-1}$).

The representivity was determined by assigning a score using the system presented in Table 2.3.

Table 2.3 Scores assigned to total suspended solids and nutrients data to rate their representivity

No. of samples in top 5% of flow	Score	Ratio of highest flow sampled to maximum flow recorded	Score
0 - 9	1	0.0 - 0.19	1
10 - 19	2	0.2 - 0.39	2
20 - 29	3	0.4 - 0.59	3
30 - 39	4	0.6 - 0.79	4
>40	5	0.8 - 1.0	5

The rating of sample representivity for each monitoring site was the sum of the scores for the two criteria. Sample representivity was rated as “excellent” when the total score was greater than or equal to eight, “good” when the total score was six or seven, “moderate” for total scores of four or five or “indicative” when the score was less than four. Furthermore, hydrographs were used to verify the scores. Nutrient and total suspended solids data were used only to estimate loads if they scored four or higher.

2.7.2 Loads estimation

Load estimations were calculated using the Loads Tool component of the Water Quality Analyser (WQA) 2.1.1.0 (Water Quality Analyser v2 2011). Annual and daily loads were estimated for total suspended solids and nutrients, including total nitrogen, particulate nitrogen, dissolved organic nitrogen, oxidised nitrogen, ammonium nitrogen, total phosphorus, particulate phosphorus, dissolved inorganic phosphorus, and dissolved organic phosphorus. However, only annual loads are presented in this report. Based on the sampling design (section 2.3 and DERM 2011c) pesticide loads were only estimated for events and only for ametryn, atrazine (including its metabolites), diuron, hexazinone and tebuthiuron.

The total suspended solids and nutrient loads were calculated using concentrations reported in milligrams per litre (mg L^{-1}) and loads for pesticides were calculated using concentration data in micrograms per litre (µg L^{-1}). The Tully River monitoring site at Tully Gorge National Park, was only established in December 2009, therefore annual loads could not be calculated for the 2009-2010 season at this site and event loads only were estimated.

Two methods were used to derive load estimates at each site: linear interpolation and the Beale ratio. The linear interpolation and Beale ratio methods were applied using the following equations.

Linear interpolation:

$$Load = \sum_{j=1}^{n} \frac{c_j + c_{j+1}}{2} \times q_j \qquad \textbf{Equation 1}$$

where c_j is j^{th} sample concentration, and q_j is inter-sample mean flow (Tennakoon 2008).

Beale ratio:

$$Load = Q\left(\frac{\bar{l}}{\bar{q}}\right)\left\{\frac{1 + \frac{1}{N}\frac{\rho\sigma L\sigma Q}{\bar{l}\bar{q}}}{1 + \frac{1}{N}\frac{\sigma^2 Q}{\bar{q}^2}}\right\} \qquad \textbf{Equation 2}$$

where Q is the total discharge for the period, $\bar{l}$ is the average load for sample, L is the observed load, $\bar{q}$ is the average of N discharge measurements, σ is the standard error of L and ρ is the correlation coefficient for L and Q (eWater Cooperative Research Centre. 2011; Joo et al. 2012).

2.7.2.1 Total suspended solids and nutrient loads

The most appropriate method (linear interpolation or Beale ratio) to estimate annual total suspended solids and nutrients loads was determined using the following criteria:

- if the majority of major events were sampled with sampling points on both the rise and fall, then the linear interpolation method was applied (e.g. Figure 7.15 , Appendix B)
- if the majority of the events were not adequately sampled but the representivity rating was “good” or better, the Beale ratio was applied (e.g. Figure 7.7, Appendix B)
- if the majority of the events were not adequately sampled and the representivitiy rating was “indicative”, then annual loads were not estimated (e.g. Figure 7.17 , Appendix B).

Once the appropriate loads estimation method was determined, the annual loads were calculated using the following procedure:

- water quality concentration data with a date and time stamp were imported into Water Quality Analyser (WQA) 2.1.1.0 for each parameter
- flow data (m^3s^{-1}) were imported into WQA on an hourly-interpolated time stamp

- the flow data were then aligned to the water quality concentration data
- if the water quality concentration data were below the practical quantitation limit specified by the Environment and Resource Science Chemistry Centre, the results were adjusted to a value of 50 per cent of the practical quantitation limit
- the hydrograph and water quality concentration data were checked for relevance and suitability (i.e. trends in relation to hysteresis, visual relationship of water quality concentrations to flow and representativeness)
- using the Loads Tool component of WQA, an annual load based on the period 1 July to 30 June was derived using the appropriate loads estimation method (outlined above).

At some sites, linear interpolation was determined to be the most appropriate estimation method, but inadequate ambient sampling points were available to calculate annual loads using Water Quality Analyser 2.1.1.0. In these cases, calculated data points that were 50 per cent of the concentration of the first and last samples collected over the year were inserted into the dataset at 1 July 2009 and 30 June 2010 respectively, to provide tie-down concentrations for calculations (Tennakoon 2008).

2.7.2.2 Pesticide loads calculated from grab samples data

The most appropriate method (linear interpolation or Beale ratio) to calculate event pesticide loads was determined using the following process:

- if the event captured the peak flow and samples were collected on both the rise and fall, then linear interpolation method was applied (e.g. the first major event in Figure 7.5).
- if sampling for the event did not capture the peak flow and sampling was not distributed evenly over the rise and fall, then Beale ratio was used to calculate the load
- if sampling did not meet the above criteria, then event loads were not calculated.

Once the appropriate loads estimation method was determined, the pesticide event loads were calculated using the following procedure:

- water quality concentration data with a date and time stamp were imported into Water Quality Analyser (WQA) 2.1.1.0 for each parameter
- flow data (m^3s^{-1}) were imported into WQA on an hourly-interpolated time stamp
- the flow data were then aligned to the water quality concentration data
- the beginning of an event was identified by a sudden increase in the slope of the hydrograph, whilst a considerably flattened slope identified the end of an event
- if a sample was not collected at the beginning or the end of an event, then tie-down concentration values were taken to be 50 per cent of the minimum concentration measured during the event (eWater 2011)
- the hydrograph and water quality concentration data were checked for relevance and suitability (i.e. trends in relation to hysteresis, visual relationship of water quality concentrations to flow and representativeness)

- the data were then processed by the Loads Tool component of WQA to calculate event loads.

When pesticide concentrations in grab samples were below the practical quantitation limit (i.e. less than 0.01 µg L^{-1}), the results from the passive sampler deployments were checked for detections. Where a pesticide concentration was less than practical quantitation limit in grab samples but was detected in a passive sampler deployed at the same time, half the practical quantitation limit (0.005 µg L^{-1}) was used as an estimate of the concentration in the grab sample. In cases where the concentration in the grab sample was less than the practical quantitation limit and was not detected in the passive sampler, the concentration was assumed to be 0 µg L^{-1}. If concentrations in all grab samples and passive samplers were less than practical quantitation limit over a whole event, no load could be calculated for that event and the result was reported as ‘below detection’.

2.7.3 Yields

Yields are the load of pollutants (e.g. tonnes) from a monitored area of land (e.g. km^2) within a catchment (i.e. t km^{-2}). Yields provide a useful means of rapidly comparing the rate of pollutant delivery between monitored catchment areas. Yields also allow differences in the rate of pollutant loads derived from dominant land use types in each catchment or sub-catchment area (e.g. areas proportionally dominated by cane cropping *vs*. dry land grazing) to be rapidly identified. For the 2009-2010 monitoring year, yields were calculated by dividing each estimated annual pollutant load by the total monitored catchment area. Yields were calculated for each pollutant at all sub-catchment and end-of-system sites.

3 Results and discussion

Due to logistical reasons, monitoring at three sites (Bowen River at Myuna, Isaac River at Yatton and Theresa Creek at Gregory Highway) was not sufficient in 2009-2010 to estimate loads. As a result no data for these sites are presented in this report.

3.1 Rainfall and river discharge

The weather in Queensland during the 2009-2010 monitoring year was influenced by a rapid transition from dry conditions of an El Niño in the late-winter and spring through to the intense rainfall depressions and cyclones associated with the La Niña which developed mid-way during the monitoring period (Bureau of Meteorology 2010a).

Figure 3.1 displays the total annual rainfall for the monitored period and Figure 3.2 illustrates a decile rainfall map, which displays whether the rainfall is above average, average or below average from the historical annual rainfall records. Isolated intense rainfall resulted in major flow events in the Pioneer, Plane and Fitzroy catchments (Bureau of Meteorology 2010b) with significant exceedance of mean annual discharge recorded at the end-of-system gauges for each of these catchments (Table 3.1 and Figure 3.3). Discharge in the Barron, Burdekin and Burnett catchments over this period was between 68-81 per cent of the mean annual discharge, reflecting reduced potential for the transport of pollutants from these catchments to the near-shore receiving environments of the Great Barrier Reef lagoon.

3.2 Sampling representivity

Analysis of sampling representivity for the 2009-2010 monitoring year have shown that “good” and “excellent” sampling ratings were achieved at all 21 monitoring sites except Barratta Creek where a “moderate” representivity rating was achieved and Tully River at Tully Gorge National Park where the representivity could not be determined (Table 7.1, Appendix C). These representivity ratings support the adequacy of the water quality data for the purpose of pollutant loads estimation.

3.3 Total suspended solids and nutrient load estimates and yields

The 2009-2010 estimated annual loads and yields of total suspended solids and nutrients for the 11 monitored catchments were determined using measured discharge and water quality data. These estimates are the loads transported past the monitoring site and do not necessarily represent the load discharged to the Great Barrier Reef lagoon – loads discharged to the Great Barrier Reef are determined through catchment modelling and are reported elsewhere by the Paddock to Reef Program. The estimated annual loads and yields are presented in Table 3.2 to Table 3.5 and the percentage contribution of each monitored catchment to the total annual load for each parameter is presented in Figures 7.22 to 7.30 and Appendix E. Load estimates for the upper Tully River monitoring site (measured at Tully Gorge National Park) could only be calculated for events (see Section 2.7.2) and are therefore presented in Appendix D.

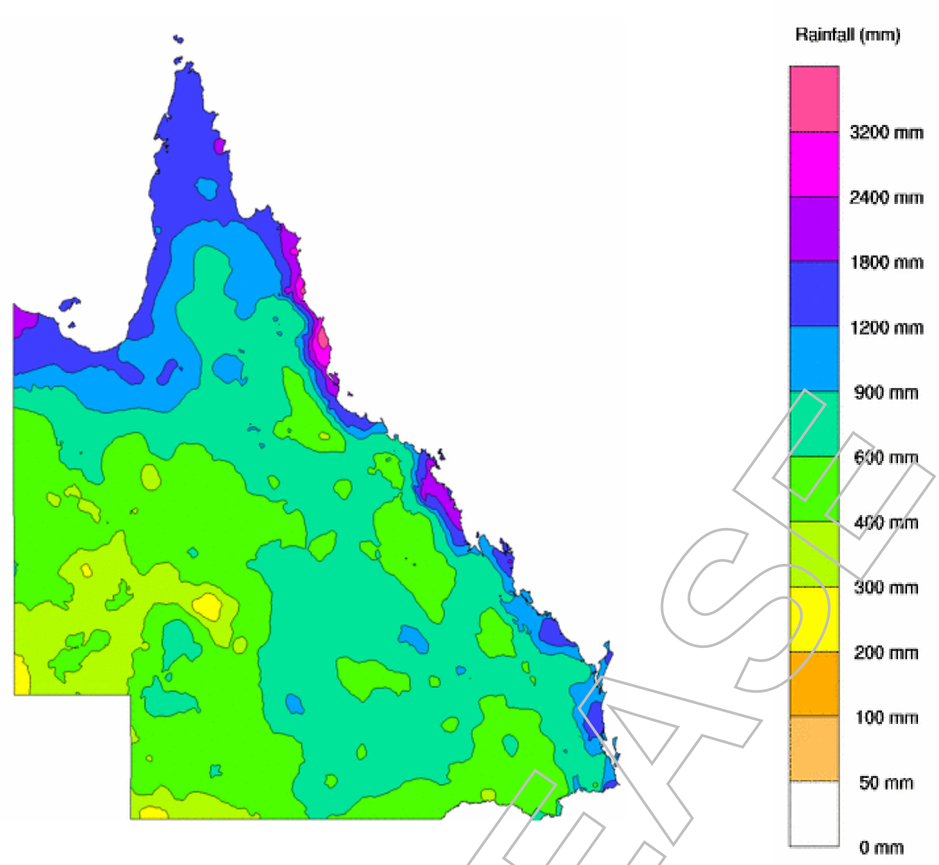


Figure 3.1 Queensland rainfall totals for 1 July 2009 to 30 June 2010 (© Copyright Commonwealth of Australia 2012, Bureau of Meteorology 2012).

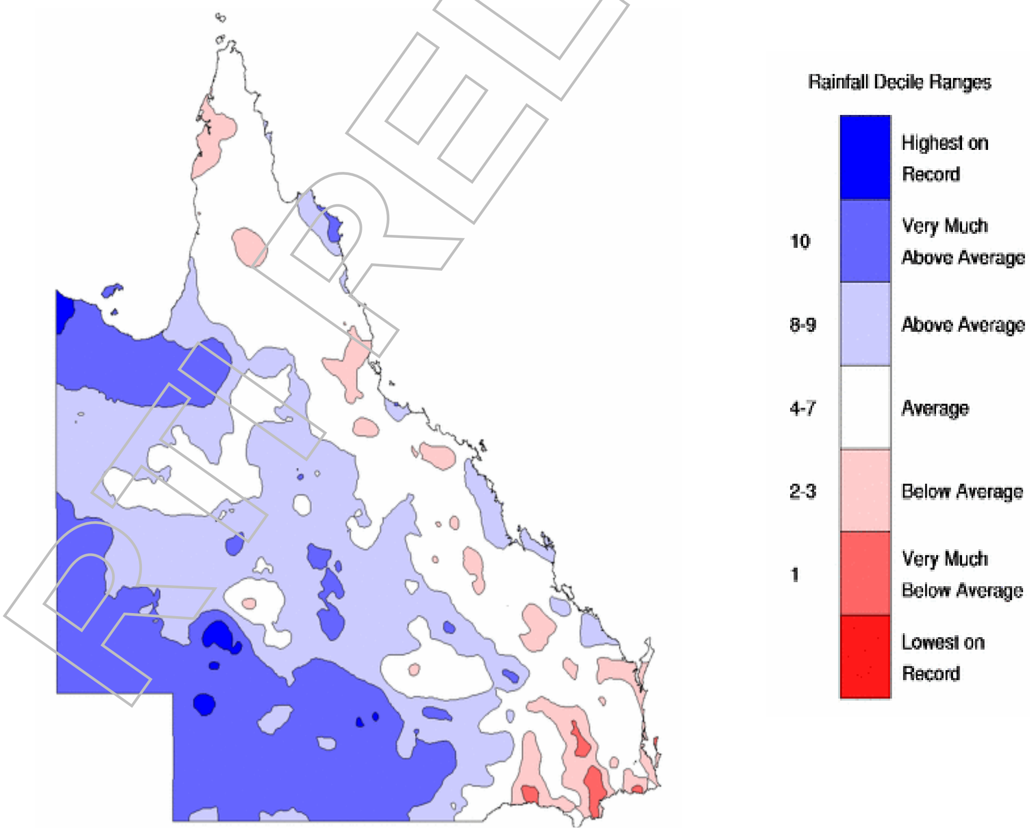


Figure 3.2 Queensland rainfall deciles for 1 July 2009 to 30 June 2010 (© Copyright Commonwealth of Australia 2012, Bureau of Meteorology 2012). Note: Each decile represents a 10th percentile of historical annual rainfall records.

Figure 3.3 Discharge for the end-of-system sites (including the North Johnstone and South Johnstone rivers) between 1 July 2009 and 30 June 2010 compared to the long-term mean annual discharge (Table 3.1).

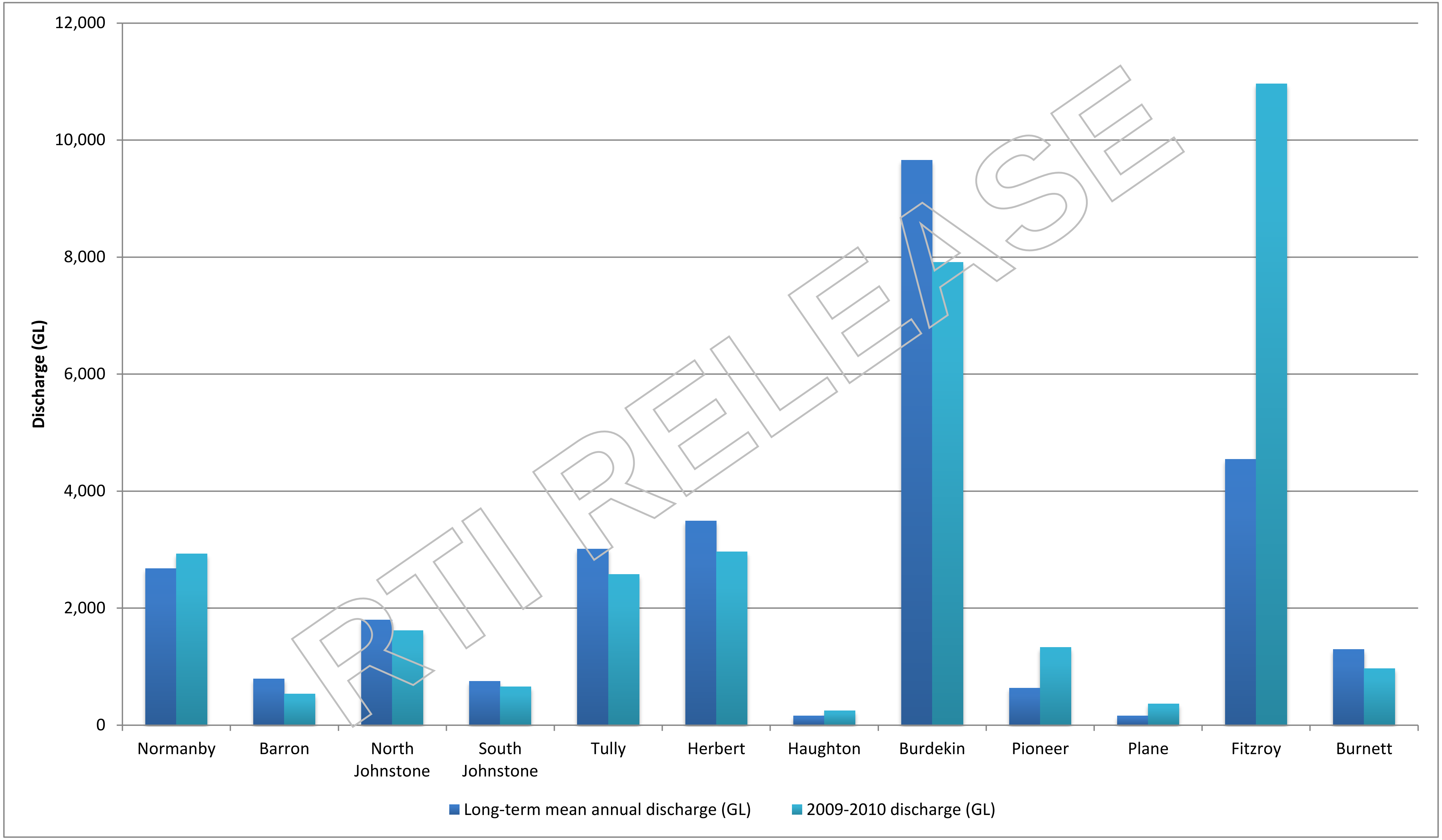


Table 3.1 Summary flow characteristics for the 2009-2010 monitoring year (including flow factors for Burdekin River at Home Hill; Fitzroy River at Rockhampton; Pioneer River at Dumbleton Pump Station; Burnett River at Ben Anderson Barrage Head Water and the Burnett River at Mt Lawless). Sites in bold are end-of-system sites.

Catchment	Gauging station	River and gauging site	Start year of flow records	Long term mean annual discharge	Discharge during 2009-2010	Discharge as a percentage of the long term mean annual discharge	Historical maximum recorded flow	Maximum recorded flow 2009-2010	Percentage of maximum recorded flow observed in 2009-2010
				(GL)	(GL)	(%)	($m^3 s^{-1}$)	($m^3 s^{-1}$)	(%)
Normanby	105107A	**Normanby River at Kalpowar Crossing**	2005	2673	2927	109	1878	958	51
Barron	110001D	**Barron River at Myola**	1957	788	533	68	4556	714	16
Johnstone	112004A	North Johnstone River at Tung Oil	1966	1795	1615	90	4517	814	18
	112101B	South Johnstone River at Upstream Central Mill	1974	746	653	88	1848	202	11
Tully	113006A	**Tully River at Euramo**	1972	3010	2573	85	1055	513	49
	113015A	Tully River at Tully Gorge National Park	12/2009	523	523	100	191	191	100
Herbert	116001F	**Herbert River at Ingham**	1915	3488	2962	85	11,919	1041	9
Haughton	119101A	**Barratta Creek at Northcote**	1974	155	245	158	1107	432	39
Burdekin	120001A$^{\#}$	**Burdekin River at Home Hill**	1973	9655	7907	81	25,483	6271	25
	120002C	Burdekin River at Sellheim	1968	4563	2612	57	23,960	3051	13
	120301B	Belyando River at Gregory Development Road	1976	597	906	152	4274	657	15
	120302B	Cape River at Taemas	1968	688	774	113	3000	1196	40
	120310A	Suttor River at Bowen Development Road	2006	585	391	67	2386	482	20
Pioneer	125013A$^{\$}$	**Pioneer River at Dumbleton Pump Station**	1977	633	1326	209	6348	3018	48
Plane	126001A	**Sandy Creek at Homebush**	1966	158	365	231	1314	720	55
Fitzroy	1300000$^{€}$	**Fitzroy River at Rockhampton**	1964	4544	10,961	238	14,549	3429	24
	130206A	Comet River at Comet Weir	1956	231	281	122	4153	455	11
Burnett	136014A^{+}	**Burnett River at Ben Anderson Barrage Head Water**	1910	1291^	967^{+}	75	14,357	1625^{+}	9
	136002D$^{¥}$	Burnett River at Mt Lawless	1909	953	820	86	17,055	1554	9
	136094A	Burnett River at Jones Weir Tail Water	1981	268	762	284	2471	1951	79
	136106A	Burnett River at Eidsvold	1960	150	163	109	2652	198	7

# discharge data from Clare GS 120006B
$ estimated from historical discharge data including Mirani Weir GS 125007A
€ discharge data from The Gap GS 130005A ($Time_{Rockhampton} = Time_{Gap} + 14.5$ hours)
+ estimated from discharge data for Fig Tree GS 136007A, Degilbo GS 136011A and Perry GS 136019A
^ estimated from historical discharge data including Walla GS 136001A and B
¥ estimated from historical discharge data including Yenda GS 136002A

3.3.1 Total suspended solids

3.3.1.1 Total suspended solid load

The entire monitored total suspended solids load from all catchments (end-of-system) in 2009-2010 was 6.95 megatonnes (Mt). The majority (89 per cent) of the total suspended solids load originated from the Fitzroy (51 per cent; 3.56 Mt), Burdekin (28 per cent; 1.94 Mt), Pioneer (5 per cent; 0.37 Mt) and Herbert (5 per cent; 0.34Mt) catchments (Figure 7.22, Appendix E). The remaining catchments contributed 11 per cent (0.74 Mt) of the total suspended solids load, with the Barron catchment contributing the highest of the remaining load with three per cent (0.17 Mt). The Fitzroy and Burdekin catchments have previously been shown to be the largest exporters of total suspended solids (Joo et al. 2012). The low relative contribution of the Burdekin River during the 2009-2010 monitoring year may be the result of below average rainfall in the Burdekin catchment (81 per cent of the annual average discharge) and the higher than average rainfall in the Fitzroy catchment (nearly 2.5 times the annual average discharge) (Table 3.1 and Figure 3.3).

The spatial variation in the total suspended solids loads between sub-catchments is evident in load estimates for the Burdekin sub-catchments. A large proportion of the catchment total suspended solids load is derived from the upper Burdekin River (monitored at Sellheim), with substantially lower loads derived from the Belyando, Cape and Suttor rivers (Table 3.2). The end-of-system load in the Burdekin River (monitored at Home Hill) was approximately 53 per cent of the upper Burdekin River sub-catchment load, indicating a significant reduction in total suspended solids load between the sub-catchment and end-of-system monitoring sites. The reduced total suspended solids load is likely the result of reduced flow velocity as these rivers enter the Burdekin Falls Dam and resultant deposition of suspended solids. A similar trend is also evident for the Burnett River with results indicating the Paradise Dam trapped a high proportion (approximately 73 per cent) of the total suspended solids load (Table 3.2).

3.3.1.2 Total suspended solid yields

The yield of total suspended solids (Table 3.3) was highest in the smaller coastal catchments that received high annual rainfall (Figure 3.1), and contain a larger proportion of intensive land use, including horticulture and sugarcane. The highest total suspended solids yields were in the Pioneer (252 t km^{-2}), Johnstone (North Johnstone River 71 t km^{-2} and South Johnstone River 121 t km^{-2}) and Plane (116 t km^{-2}) catchments. These results are in marked contrast to the comparatively low total suspended solids yields in the large dry catchments of the Fitzroy (26 t km^{-2}), Burdekin (15 t km^{-2}), Normanby (13 t km^{-2}) and Burnett (4 t km^{-2}) catchments.

In Burdekin River sub-catchments, the yield of total suspended solids was low in the Belyando, Suttor and Cape Rivers (5-12 t km^{-2}) compared to the relatively high yield in the upper Burdekin River (100 t km^{-2}) sub-catchment.

3.3.2 Nitrogen

3.3.2.1 Nitrogen load

The entire monitored total nitrogen load from all catchments during in 2009-2010 was 30 kilotonnes (kt). The majority (78 per cent) of the total nitrogen load originated from the Fitzroy (43 per cent; 12.99 kt), Burdekin (21 per cent; 6.41 kt), Herbert (7 per cent; 2.18 kt) and Pioneer (7 per cent; 1.93 kt) catchments (Table 3.2 and Figure 7.23, Appendix E). The remaining catchments combined contributed 22 per cent (6.49 kt) of the total nitrogen load, with the Normanby catchment contributing the most of the remaining load, with five per cent or 1.32 kt.

The cumulative total load of particulate nitrogen for all monitored catchments was approximately one third of the combined total nitrogen load, being 11.7 kt. The proportions of the particulate nitrogen load exported by each catchment (end-of-system) were similar to that of total nitrogen load. The majority (77 per cent) of the particulate nitrogen load originated from the Fitzroy (40 per cent; 4.29 kt), Burdekin (20 per cent; 3.08 kt), Pioneer (9 per cent; 0.96 kt) and Herbert (8 per cent; 0.92 kt) catchments (Table 3.2 and Figure 7.24, Appendix E). The remaining catchments combined contributed 23 per cent (2.46 kt) of the particulate nitrogen load. The Normanby was the fifth largest producer of total nitrogen (5 per cent) but was the second lowest producer of particulate nitrogen (1 per cent; 0.06 kt); in this instance the Barron catchment contributed the most to the remaining load, with five per cent or 0.59 kt.

A cumulative total load of 5.52 kt of dissolved inorganic nitrogen was observed from monitored catchments during 2009-2010. The majority (78 per cent) of the dissolved inorganic nitrogen load originated from the Fitzroy (37 per cent, 2.06 kt), Burdekin (24 per cent, 1.30 kt), Pioneer (9 per cent 0.48 kt) and Tully (8 per cent; 0.45 kt) catchments (Table 3.2 and Figure 7.25, Appendix E). The remaining catchments combined contributed 22 per cent (1.23 kt) of the dissolved inorganic nitrogen load, with the Herbert catchment contributing the most to the remaining load, with six per cent or 0.34 kt.

Oxidised nitrogen as N accounted for 90 per cent or 4.98 kt of the dissolved inorganic nitrogen load across all monitored catchments, with ammonium nitrogen as N comprising the remaining ten per cent (0.54 kt) (Table 3.2). In the majority of catchments, the relative proportion of oxidised nitrogen (as N) to ammonium nitrogen (as N) was high, ranging from 5:1 to 20:1. In contrast, in the Burnett and Normanby catchments the relative proportions are essentially 1:1 (Table 3.2). This could indicate the influence of groundwater input during low flow periods for these two catchments.

The summed dissolved organic nitrogen load from all monitored catchments in 2009-2010 was 13.14 kt. The majority (83 per cent) of this load originated from the Fitzroy (51 per cent; 6.65 kt), Burdekin (16 per cent; 2.13 kt), Normanby (9 per cent; 1.23 kt) and Herbert (7 per cent; 0.94 kt) catchments (Table 3.2 and Figure 7.26, Appendix E). The remaining catchments combined contributed 17 per cent (2.19 kt) of the dissolved organic nitrogen load, with the Burnett catchment contributing the most to the remaining load, with four per cent or 0.58 kt. The large proportion of dissolved organic nitrogen load exported by the Normanby was most likely due to naturally occurring dissolved organic nitrogen.

In the Burdekin catchment approximately half of the reported end-of-system total nitrogen load (6.41 kt) was delivered from the upper Burdekin River sub-catchment (3.19 kt) monitored at Selheim, with less total nitrogen exported from the Belyando (0.74 kt), Cape (0.52 kt) and Suttor (0.33 kt) sub-catchments (Table 3.2).

3.3.2.2 Nitrogen yield

The largest yields of total nitrogen and particulate nitrogen were derived from the Pioneer, Plane and South Johnstone catchments (Table 3.3), which contain a high proportion of irrigated cropping land-use (DPC 2011). Conversely, the large dry grazing catchments of the Burnett, Burdekin and Fitzroy catchments had comparatively low total nitrogen and particulate nitrogen yields (Table 3.3). The yields of dissolved inorganic nitrogen and dissolved organic nitrogen were similar for the high rainfall coastal catchments of the Pioneer, Plane, North Johnstone, South Johnstone and Tully catchments which ranged between 245 to 321 kg km^{-2} for dissolved inorganic nitrogen and 210 to 402 kg km^{-2} for dissolved organic nitrogen (Table 3.3). The yield from all other catchments was considerably lower.

3.3.3 Phosphorus

3.3.3.1 Phosphorus load

The combined total phosphorus load from all monitored catchments (end-of-system) in 2009-2010 was 9.33 kt. The vast majority (81 per cent) of the total phosphorus load originated from only two catchments, the Fitzroy (57 per cent; 5.32 kt) and Burdekin (24 per cent; 2.21 kt) (Table 3.2, Figure 7.27, Appendix E). The remaining catchments combined contributed only 19 per cent (1.79 kt) of the total phosphorus load, with the Pioneer catchment contributing the most to the remaining load, with five per cent or 0.34 kt.

The magnitude of the particulate phosphorus load exported by each catchment (end-of-system) was similar to that of total phosphorus load, with the cumulative total load for all monitored catchments being 7.08 kt. The majority (80 per cent) of the particulate phosphorus load originated from only the Fitzroy (61 per cent; 3.86 kt) and Burdekin (19 per cent; 1.92 kt) catchments (Table 3.2 and Figure 7.28, Appendix E). The remaining catchments combined contributed only 20 per cent (1.30 kt) to the particulate phosphorus load, with the Pioneer catchment contributing most to the remaining load, with four per cent, or 0.27 kt.

A cumulative total dissolved inorganic phosphorus load of 1.65 kt of was observed from monitored catchments during 2009-2010. The majority (84 per cent) of the dissolved inorganic phosphorus load originated from the Fitzroy (69 per cent, 1.14 kt) and Burdekin (15 per cent, 0.24 kt), catchments (Table 3.2 and Figure 7.29, Appendix E). The remaining catchments combined contributed 16 per cent (0.26 kt) of the dissolved inorganic phosphorus load, with the Pioneer catchment contributing most to the remaining load, with five per cent or 0.08 kt.

The dissolved organic phosphorus load from all monitored catchments in 2009-2010 was 0.76 kt. The majority (87 per cent) of the dissolved organic phosphorus load originated from the Fitzroy (54 per cent; 0.41 kt), Burdekin (13 per cent; 0.10 kt), Herbert (12 per cent; 0.09 kt) and Tully (7 per cent; 0.06 kt) catchments (Table 3.2 and Figure 7.30, Appendix E). The remaining catchments combined contributed 13 per cent (0.10 kt) of the dissolved organic phosphorus load, with the North Johnstone catchment contributing most to the remaining load, with three per cent or 0.03 kt.

The loads of total phosphorus and particulate phosphorus derived from the upper Burdekin River sub-catchment (measured at Sellheim) were 5.6 and 7.0 times greater respectively than the cumulative loads derived from the remaining Burdekin sub-catchments; Cape, Belyando and Suttor rivers (Table 3.2). For dissolved inorganic phosphorus loads in the Burdekin catchment the highest were from the upper Burdekin sub-catchment measured at Sellheim (62 t) and Belyando (41 t) River, with comparatively low loads derived from the Suttor (11 t) and Cape (6 t) rivers. A similar trend was also observed for the dissolved organic phosphorus load amongst catchments in the Burdekin with the highest loads occurring in the upper Burdekin River measured at Sellheim (Table 3.4).

3.3.3.2 Phosphorus load yield

The Pioneer, Plane and South Johnstone catchments produced the highest yields of total phosphorus, particulate phosphorus and dissolved inorganic phosphorus, with all total phosphorus yields being greater than 253 kg km^{-2}. The yield of dissolved inorganic phosphorus from Sandy Creek (113 kg km^{-2}) was exceptionally high compared to all other catchments, with twice the yield of dissolved inorganic phosphorus from the Pioneer River (57 kg km^{-2}) and six times the yield from the South Johnstone River (20 kg km^{-2}). Notably, the yield of dissolved organic phosphorus was highest in the South Johnstone (43 kg km^{-2}), North Johnstone (28 kg km^{-2}) and Tully (42 kg km^{-2}) rivers, with only moderate to low yields derived from the Plane (15 kg km^{-2}), Herbert (11 kg km^{-2}) and Pioneer (11 kg km^{-2}) catchments (Table 3.4).

Table 3.2 Estimated total suspended solids and nutrient loads for 2009-2010. Sites in bold are end-of-system sites.

Catchment	Gauging station	Site name	n	TSS (t)	TN (t)	PN (t)	NO_x-N (t)	NH_4-N (t)	DIN (t)	DON (t)	TP (t)	DIP (t)	PP (t)	DOP (t)
Normanby	105107A[B]	**Normanby River at Kalpowar Crossing**	8	173,214	1326	65	59	46	105	1229	159	30	126	14
Barron	110001D[B]	**Barron River at Myola**	45	174,425	827	594	43	7	50	187	147	10	135	5
Johnstone	112004A[B]	North Johnstone River at Tung Oil	50	66,040	827	382	232	9	241	225	143	14	116	26
	112101B[B]	South Johnstone River at Upstream Central Mill	55	48,298	423	248	92	6	98	84	101	8	81	17
Tully	113006A[L]	**Tully River at Euramo**	220	69,506	1165	396	426	24	450	502	111	11	88	61
Herbert	116001F[B]	**Herbert River at Ingham**	61	336,382	2175	916	287	49	336	941	337	32	223	92
Haughton	119101A[B]	**Barratta Creek at Northcote**	28	21,360	267	52	98	5	103	114	30	11	15	5
Burdekin	120001A[L]	**Burdekin River at Home Hill**	45	1,937,798	6411	3080	1195	108	1303	2129	2213	241	1915	99
	120002C[B]	Burdekin River at Sellheim	8	3,620,561	3185	2415	139	33	172	598	1828	62	1720	51
	120301B[L]	Belyando River at Gregory Development Road	93	190,728	738	297	8	18	26	420	167	41	118	14
	120302B[L]	Cape River at Taemas	115	185,522	519	288	3	6	9	236	94	6	79	14
	120310A[B]	Suttor River at Bowen Development Road	57	58,456	334	127	9	6	15	192	69	11	50	7
Pioneer	125013A[B]	**Pioneer River at Dumbleton Pump Station**	26	373,818	1929	962	420	57	477	372	488	84	267	10
Plane	126001A[B]	**Sandy Creek at Homebush**	33	37,814	397	179	81	5	86	131	97	37	66	5
Fitzroy	1300000[L]	**Fitzroy River at Rockhampton**	66	3,563,583	12,989	4291	1945	115	2060	6646	5321	1143	3863	411
	130504B[L]	Comet River at Comet Weir	19	1,455,773	2709	1561	159	47	206	943	1791	471	1223	94
Burnett	136014A[L]	**Burnett River at Ben Anderson Barrage Head Water**	47	146,732	1262	542	101	114	215	578	181	25	185	18
	136002D[L]	Burnett River at Mt Lawless	60	547,924	1479	1077	68	25	93	505	330	34	325	23
	136094A[L]	Burnett River at Jones Weir Tail Water	65	398,154	1408	828	70	47	117	423	341	27	294	21
	136106A[L]	Burnett River at Eidsvold	76	14,765	311	93	48	13	61	166	48	15	30	8

[L] = linear interpolation method used to calculate loads; [B] = Beale ratio method used to calculate loads; n = number of water samples collected during 2009-2012 and used for load calculations

TSS = total suspended solids; TN = total nitrogen; PN = particulate nitrogen; NOx-N = oxidised nitrogen as N; NH_4-N = ammonium nitrogen as N; DIN = dissolved inorganic nitrogen (DIN = (NOx-N) + (NH_4-N)); DON = dissolved organic nitrogen;

TP = total phosphorus; DIP = dissolved inorganic phosphorus; PP = particulate phosphorus; DOP = dissolved organic phosphorus.

Table 3.3 Total suspended solids and nitrogen yields calculated for 2009-2010 along with monitored area and per cent of catchment monitored. Sites in bold are end-of-system sites.

Catchment	Gauging station	Site name	Monitored area	Monitored area of catchment	TSS	TN	PN	NO_x-N	NH_4-N	DIN	DON
			(km^2)	(%)	($t\ km^{-2}$)	($kg\ km^{-2}$)	($kg\ km^{-2}$)	($kg\ km^{-2}$)	($kg\ km^{-2}$)	($kg\ km^{-2}$)	($kg\ km^{-2}$)
Normanby	105107A^{B}	**Normanby River at Kalpowar Crossing**	12,934	53	13	103	5	5	4	8	95
Barron	110001D^{B}	**Barron River at Myola**	1945	89	90	425	305	22	4	26	96
Johnstone	112004A^{B}	North Johnstone River at Tung Oil	925	40	71	894	413	251	10	261	243
	112101B^{B}	South Johnstone River at Upstream Central Mill	400	17	121	1058	620	230	16	245	210
Tully	113006A^{L}	**Tully River at Euramo**	1450	86	48	803	273	294	17	310	346
Herbert	116001F^{B}	**Herbert River at Ingham**	8581	87	39	253	107	33	6	39	110
Haughton	119101A^{B}	**Barratta Creek at Northcote**	753	19	28	355	69	130	7	137	151
Burdekin	120001A^{L}	**Burdekin River at Home Hill**	129,939	99	15	49	24	9	1	10	16
	120002C^{B}	Burdekin River at Sellheim	36,290	28	100	88	67	4	1	5	16
	120301B^{L}	Belyando River at Gregory Development Road	35,411	27	5	21	8	0.2	1	1	12
	120302B^{L}	Cape River at Taemas	16,074	12	12	32	18	0.2	0.4	1	15
	120310A^{B}	Suttor River at Bowen Development Road	10,758	8	5	31	12	1	1	1	18
Pioneer	125013A^{B}	**Pioneer River at Dumbleton Pump Station**	1485	94	252	1299	648	283	38	321	251
Plane	126001A^{B}	**Sandy Creek at Homebush**	326	13	116	1218	549	248	15	264	402
Fitzroy	1300000^{L}	**Fitzroy River at Rockhampton**	139,159	98	26	93	31	14	1	15	48
	130504B^{L}	Comet River at Comet Weir	16,457	12	88	165	95	10	3	13	57
Burnett	136014A^{L}	**Burnett River at Ben Anderson Barrage Head Water**	32,891	99	4	38	16	3	3	7	18
	136002D^{L}	Burnett River at Mt Lawless	29,355	88	19	50	37	2	1	3	17
	136094A^{L}	Burnett River at Jones Weir Tail Water	21,700	65	18	65	38	3	2	5	19
	136106A^{L}	Burnett River at Eidsvold	7117	21	2	44	13	7	2	9	23

^{L} = linear interpolation method used to calculate loads; ^{B} = Beale ratio method used to calculate loads; TSS = total suspended solids; TN = total nitrogen; PN = particulate nitrogen; NOx-N = oxidised nitrogen as N; NH_4-N = ammonium nitrogen as N; DIN = dissolved inorganic nitrogen (DIN = (NOx-N) + (NH_4-N)); DON = dissolved organic nitrogen.

Table 3.4 Phosphorus yields calculated for 2009-2010 along with monitored area and per cent of catchment monitored. Sites in bold are end-of-system sites.

Catchment	Gauging station	Site name	Monitored area	Monitored area of catchment	TP	DIP	PP	DOP
			(km^2)	(%)	(kg km^{-2})	(kg km^{-2})	(kg km^{-2})	(kg km^{-2})
Normanby	105107A^{B}	**Normanby River at Kalpowar Crossing**	12,934	53	12	2	10	1
Barron	110001D^{B}	**Barron River at Myola**	1945	89	76	5	69	3
Johnstone	112004A^{B}	North Johnstone River at Tung Oil	925	40	155	15	125	28
	112101B^{B}	South Johnstone River at Upstream Central Mill	400	17	253	20	203	43
Tully	113006A^{L}	**Tully River at Euramo**	1450	86	77	8	61	42
Herbert	116001F^{B}	**Herbert River at Ingham**	8581	87	39	4	26	11
Haughton	119101A^{B}	**Barratta Creek at Northcote**	753	19	40	15	20	7
Burdekin	120001A^{L}	**Burdekin River at Home Hill**	129,939	99	17	2	15	1
	120002C^{B}	Burdekin River at Sellheim	36,290	28	50	2	47	1
	120301B^{L}	Belyando River at Gregory Development Road	35,411	27	5	1	3	0.4
	120302B^{L}	Cape River at Taemas	16,074	12	6	0.4	5	1
	120310A^{B}	Suttor River at Bowen Development Road	10,758	8	6	1	5	1
Pioneer	125013A^{B}	**Pioneer River at Dumbleton Pump Station**	1485	94	329	57	180	7
Plane	126001A^{B}	**Sandy Creek at Homebush**	326	13	298	113	202	15
Fitzroy	1300000^{L}	**Fitzroy River at Rockhampton**	139,159	98	38	8	28	3
	130504B^{L}	Comet River at Comet Weir	16,457	12	109	29	74	6
Burnett	136014A^{L}	**Burnett River at Ben Anderson Barrage Head Water**	32,891	99	6	1	6	1
	136002D^{L}	Burnett River at Mt Lawless	29,355	88	11	1	11	1
	136094A^{L}	Burnett River at Jones Weir Tail Water	21,700	65	16	1	14	1
	136106A^{L}	Burnett River at Eidsvold	7117	21	7	2	4	1

^{L} = linear interpolation method used to calculate loads; ^{B} = Beale ratio method used to calculate loads; TP = total phosphorus; DIP = dissolved inorganic phosphorus; PP = particulate phosphorus; DOP = dissolved organic phosphorus;.

3.4 Priority photosystem II inhibitor herbicide event-based loads

Initially it was anticipated that annual pesticide loads would be calculated for the 2009-2010 wet season using the event-mean concentration data obtained from passive samplers. A comparison of event-based loads estimated from the passive sampler data and event-based loads estimated from grab sample data indicated significant inconsistencies between the estimated loads (Appendix F). It was therefore decided to use the grab sample data to estimate event-based loads as grab sampling is a standard method of collecting data for loads calculations. A study is currently being undertaken to investigate these differences. The initial sampling design for the program was to cover a minimum of two events using grab sampling over the wet season (DERM 2011b), and therefore there was an insufficient coverage of grab samples to calculate annual pesticide loads. Due to sufficient sampling frequency and distribution over the hydrograph, most fluctuations in concentration levels were adequately captured and so the majority of load estimations were calculated using the linear method. The estimated event-based loads (Table 3.5) were used to validate models.

Loads were calculated for up to six events at each site, depending on the sampling coverage and the number of events over the 2009-2010 wet season for each site. For instance, there were only four major events in the Fitzroy River over the wet season and each of these had sufficient sample coverage to estimate the event load of photosystem II inhibitor herbicides. Conversely, there were seven events in the Tully River over the wet season; however, only three of these events were sufficiently sampled for pesticides to estimate loads. The events that were sampled sufficiently for load estimations varied in their duration and total discharge. For example, events at Sandy Creek lasted 3-7 days with a total maximum discharge of 63 GL, whereas an event at the Burnett River lasted 33 days with a discharge of 855 GL.

Trends in the loads were evident between events; the first or second event sampled always contained the highest loads of the photosystem II inhibitor herbicides and for the events that followed there was generally a negative relationship between pesticide load and event number (Table 3.5). Making solid comparisons between catchments using event loads is somewhat confounded due to the exhaustion of the pesticide loads over successive events, i.e. inconsistencies between catchments in which events were sampled (and loads calculated), may mean for some catchments, the maximum event-based load may not have been recorded. Sites in which the first-flush was monitored are indicated in Table 3.5. Due to this trend in load exhaustion over sequential events, only the events that contained the maximum recorded load of pesticides (and thus the maximum load per yield) were used for comparisons between catchments (values in bold in Table 3.5). The largest load of the five priority photosystem II inhibitor herbicides in an event was tebuthiuron in the Fitzroy River (1354 kg) and the highest yield in any event in 2009-2010 was diuron from the Plane catchment (0.4 kg km^{-2}).

When comparing between catchments, the maximum event loads of ametryn ranged from 0.6 kg in the Haughton catchment (Table 3.5) to 7 kg in the Fitzroy River (Table 3.5). On a yield basis, however, the load of ametryn from the Fitzroy catchment was the smallest (0.00006 kg km^{-2}), and the highest was from the Plane catchment (0.02 kg km^{-2}). It should be noted that for the Fitzroy catchment, ametryn was detected only by passive samplers. Thus, a concentration of half the practical quantitation limit (0.005 μg L^{-1}) was used to estimate the ametryn load for that event, and therefore the maximum load reported for the Fitzroy is due principally to the large discharge volume rather than high ametryn concentrations.

The largest load of atrazine was recorded in the Fitzroy River (1187 kg), and the smallest load was recorded in the South Johnstone River (2.3 kg) (Table 3.5). The highest yield of atrazine was from the Plane catchment (0.2 kg km^{-2}), and the Burnett catchment showed the smallest yield (0.0004 kg km^{-2}) out of all the catchments.

Recorded loads of diuron ranged from 5.5 kg in the South Johnstone River to 208.5 kg in the Pioneer River. The largest yield of diuron was from the Plane catchment (0.4 kg km^{-2}), and the smallest yield was from the Fitzroy catchment (0.0002 kg km^{-2}).

Similar to atrazine, the largest loads of hexazinone and tebuthiuron were recorded at the Fitzroy River (53.4 kg and 1354 kg, respectively) and the smallest loads were in the South Johnstone River (0.6 kg and 0.4 kg, respectively). For tebuthiuron, the Fitzroy catchment also had the highest yield (0.01 kg km^{-2}); however, along with the Burnett catchment, the Fitzroy had the smallest hexazinone yield (0.0004 kg km^{-2}). The Burnett catchment also recorded the smallest yield of tebuthiuron (0.0005 kg km^{-2}). Lastly, the highest yield of hexazinone (0.1 kg km^{-2}) was recorded at the Plane catchment.

Similar to the annual loads of nutrients, the greatest loads of the priority photosystem II inhibitor herbicides, except diuron, were recorded in the Fitzroy River. This result is likely to be a factor of the large catchment size and discharge volume. The Fitzroy catchment also had the smallest or equal smallest yield of photosystem II inhibitor herbicides except for the second event for tebuthiuron where the yield was the highest of any catchment with a value of 0.01 kg km^{-2} (Table 3.5). Conversely, Sandy Creek in the Plane catchment, with the smallest monitored area, recorded the highest yields for the majority of the photosystem II inhibitor herbicides.

Table 3.5 Information describing each monitored event, event-based loads and yield (in parenthesis), calculated for the five priority photosystem II inhibitor herbicides: ametryn, atrazine, diuron, hexazinone and tebuthiuron. Maximum load and yields for each catchment are presented in bold.

Catchment	Gauging station (monitored area-km^2)	Event number	n	Event period (date time 24hr)	Event duration	Discharge (GL)	Ametryn (kg)	Atrazine (kg)	Diuron (kg)	Hexazinone (kg)	Tebuthiuron (kg)
South Johnstone	112101B (400)	1	9	22/01/10 2:00 – 16/02/10 5:00	25 d 3 h	89	BD	1.8 (0.005)	2.2 (0.006)	0.4* (0.001)	**0.4*** **(0.001)**
		2	6	22/03/10 0:00 – 14/04/2010 2:00	22 d 14 h	137	BD	**2.3** **(0.006)**	**5.5** **(0.01)**	**0.6*** **(0.002)**	BD
Tully	113006A (1450)	1	12	21/01/10 1:00 – 9/02/10 21:00	19 d 20 h	243	BD	**37.4** **(0.03)**	**32.9** **(0.02)**	**17.4** **(0.01)**	BD
		2	10	9/03/10 17:00 – 22/03/10 23:00	13 d 6 h	215	BD	12.3 (0.008)	17.3 (0.01)	12.4 (0.009)	BD
		3	8	22/03/10 21:00 – 15/04/10 21:00	24 d	541	BD	8.8* (0.006)	5.8 (0.004)	10.9 (0.008)	BD
Haughton	119101A (753)	1^F	4	28/12/09 19:00 – 13/01/10 16:00	15 d 22 h	5	0.3 (0.0004)	42.1 (0.06)	20.3 (0.03)	0.3 (0.0004)	0.1 (0.0001)
		2	8	24/01/10 10:00 – 6/02/10 3:00	12 d 18 h	32	**0.6** **(0.0008)**	**82.1** **(0.1)**	**44.5** **(0.06)**	**0.9** **(0.001)**	**0.5** **(0.0007)**
		3	5	11/02/10 1:00 – 27/02/10 3:00	16 d 3 h	55	0.3* (0.0004)	6.5 (0.009)	2.4 (0.003)	0.3 (0.0004)	0.3* (0.0004)
		4	6	21/03/10 15:00 – 8/04/10 0:00	17 d 10 h	30	0.2* (0.0003)	3.8 (0.005)	0.8 (0.001)	0.2 (0.0003)	0.2* (0.0003)
Burdekin	120001A (129,939)	1	15	3/02/10 4:00 – 21/03/10 23:00	46 d 19 h	4756	BD	**89.1** **(0.0007)**	**23.7** **(0.0002)**	**23.7** **(0.0002)**	23.7 (0.0002)
	120301B (35,411)	1^F	4	30/01/10 12:00 – 18/02/10 1:00	18 d 13 h	92	BD	1.8 (0.00005)	BD	BD	8.9 (0.0003)
		2	6	18/02/10 1:00 – 21/03/10 9:00	31 d 8 h	654	BD	11.4 (0.0003)	BD	3.3 (0.00009)	**73.7** **(0.002)**
	120310A (10,758)	1	5	15/02/10 3:00 – 19/03/10 10:00	32 d 7 h	200	BD	17.1 (0.0005)	BD	BD	58 (0.002)
Pioneer	125013A (1485)	1^F	6	22/01/10 22:00 – 30/01/10 17:00	7 d 19 h	74	**3.1** **(0.002)**	**139.2** **(0.09)**	**208.5** **(0.1)**	**49.9** **(0.03)**	BD
		2	3	30/01/10 15:00 – 4/02/10 14:00	4 d 23 h	196	1.8 (0.001)	51.4 (0.03)	101.8 (0.07)	24.1 (0.02)	BD
		3	3	20/03/10 20:00 – 3/04/10 13:00	13 d 17 h	332	1.6* (0.001)	9.9 (0.007)	6.4 (0.004)	5 (0.003)	BD

n = the number of grab samples used to estimate loads; BD = concentration of all samples below detection limit; bolded values indicate the maximum load and yield for the catchment; * = loads calculated based on grab sample concentrations of half the detection limit as detections were only made with passive samplers for these events.

Table 3.5 continued

Catchment	Gauging station (monitored area-km^2)	Event number	n	Event period (date time 24hr)	Event duration	Discharge (GL)	Ametryn (kg)	Atrazine (kg)	Diuron (kg)	Hexazinone (kg)	Tebuthiuron (kg)
Plane	126001A (326 km^2)	1^F	6	24/01/10 19:00 – 30/01/10 17:00	5 d 23 h	44	**5.5 (0.02)**	**53.1 (0.2)**	**136.2 (0.4)**	**47.2 (0.1)**	BD
		2	3	30/01/10 16:00 – 4/02/10 0:00	4 d 21 h	60	1.2 (0.004)	18.6 (0.06)	62.6 (0.2)	16.5 (0.05)	BD
		3	5	9/02/10 9:00 – 13/02/10 19:00	4 d 11 h	30	0.4 (0.001)	5.4 (0.02)	15.7 (0.05)	8 (0.02)	BD
		4	3	17/02/10 15:00 – 21/02/10 2:00	3 d 13 h	33	0.3 (0.0009)	4.4 (0.01)	11 (0.03)	5.5 (0.02)	BD
		5	3	21/02/10 3:00 – 25/02/10 1:00	4 d	30	0.2 (0.0006)	3 (0.009)	7.8 (0.02)	4.1 (0.01)	BD
		6	3	20/03/10 21:00 – 27/03/10 23:00	7 d 3 h	63	BD	2.8 (0.009)	4.1 (0.01)	2.8 (0.009)	BD
Fitzroy	1300000 (139,159 km^2)	1	11	31/01/10 20:30 – 11/02/10 17:30	10 d 21 h	1419	**7* (0.00006)**	193.9 (0.001)	9.3 (0.00007)	7.9 (0.00006)	228.8 (0.002)
		2	17	11/02/10 15:30 – 7/03/10 0:30	23 d 9 h	4408	BD	**1187.1 (0.009)**	**25.7 (0.0002)**	**53.4 (0.0004)**	**1353.9 (0.01)**
		3	9	7/03/10 0:30 – 21/03/10 14:30	14 d 14 h	3072	BD	623 (0.004)	14.8* (0.0001)	21.6 (0.0002)	588.8 (0.004)
		4	10	21/03/10 0:30 – 15/04/10 3:30	24 d 15 h	1815	BD	221.5 (0.002)	9* (0.00007)	10.1 (0.00008)	189.8 (0.001)
	130504B (16,457 km^2)	1^F	7	31/01/10 4:00 – 17/02/10 3:00	16 d 23 h	432	BD	223.1 (0.01)	BD	16.4 (0.001)	130 (0.008)
		2	4	17/02/10 3:00 – 2/03/10 20:00	13 d 17 h	908	BD	239.3 (0.01)	BD	19.8 (0.001)	172.2 (0.01)
		3	6	2/03/10 20:00 – 31/03/10 22:00	29 d 2 h	904	4.4 (0.0003)	401.3 (0.02)	BD	19 (0.001)	147.4 (0.009)
Burnett	136014A (32,891 km^2)	1^F	27	28/02/10 10:00 – 2/04/10 11:00	33 d 2 h	855	BD	**13.6 (0.0004)**	**15 (0.0005)**	**14.2 (0.0004)**	**15.4 (0.0005)**

n = the number of grab samples used to estimate loads; BD = concentration of all samples below detection limit; F = first flush event; * = loads calculated based on grab sample concentrations of half the detection limit as detections were only made with passive samplers for these events.

4 Conclusions

Loads for total suspended solids and nutrients were determined for 11 catchments and the loads of five priority PSII pesticides were determined for eight catchments during the 2009-2010 monitoring year. During this period:

- the monitored catchments generated approximately 6.95 million tonnes of total suspended solids, 30,000 tonnes of nitrogen, and 9,300 tonnes of phosphorus
- the Fitzroy and Burdekin rivers, representing 82 per cent of the monitored area, generated the highest loads of all non-pesticide pollutants with 79 per cent of the total suspended solids, 65 per cent of the total nitrogen and 81 per cent of total phosphorus loads
- photosystem II inhibitor herbicides were detected at all monitored sites
- the most frequently detected photosystem II inhibitor herbicide was atrazine
- the largest event load of atrazine was recorded in the Fitzroy River (1187 kg), and the smallest load occurred in the South Johnstone River (2.3 kg)
- atrazine and hexazinone were present in all catchments, and diuron, tebuthiuron and ametryn were detected less frequently in fewer catchments
- total suspended solid and nutrient yields in the Pioneer, Plane, Johnstone and Tully catchments were the largest, whilst the smallest yields occurred in the Burdekin and Fitzroy catchments
- the largest yield of atrazine was from the Plane catchment (0.2 kg km^{-2}), and the Burnett catchment had the smallest (0.0004 kg km^{-2}).

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7 Appendices

Appendix A Calculation of discharge

Discharge as contained in the Queensland Government surface water database is calculated following the equation:

$$q = va$$

where, q = the discharge (m^3/s), a = the cross-sectional area of the river, and v = average velocity of the flow in the cross-sectional area.

Discharge is calculated for sub-sectional areas of the river channel and summed to determine the discharge across the whole cross-sectional area. Sub-sectional areas were calculated from a known width multiplied by the river gauge height at time *t*. River gauge height was recorded by gauging stations using a float or a pressure sensor at intervals of approximately fifteen minutes. Flow velocity was determined for each cross-sectional area at time *t* using a current meter. Flow records were extracted for each end-of-system from the Queensland Government electronic data management system (Hydstra).

Appendix B Hydrograph plots of discharge and sample collection points

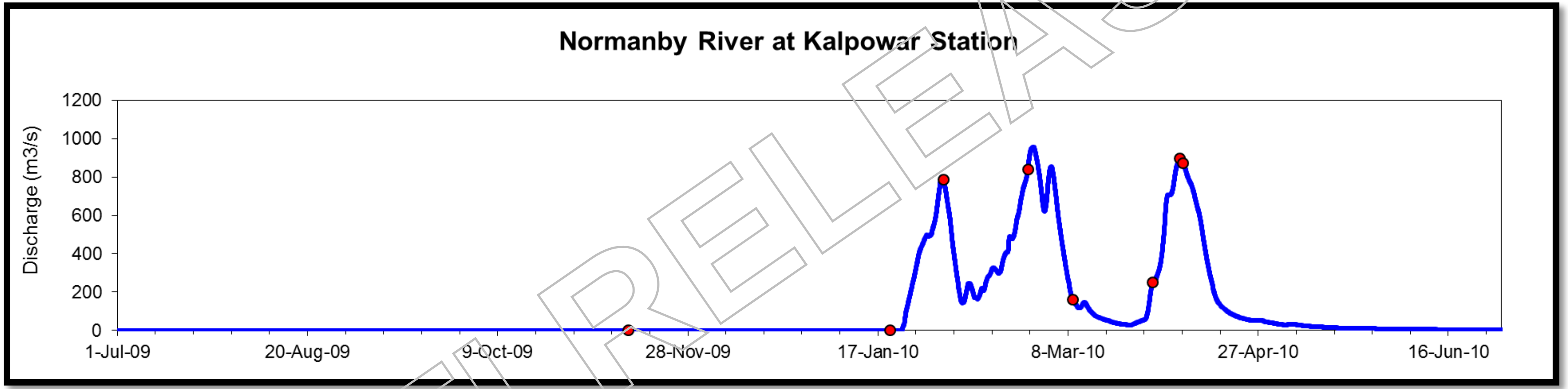

Figure 7.1 Hydrograph showing changes in discharge and sample coverage for Normanby River at Kalpowar Station between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

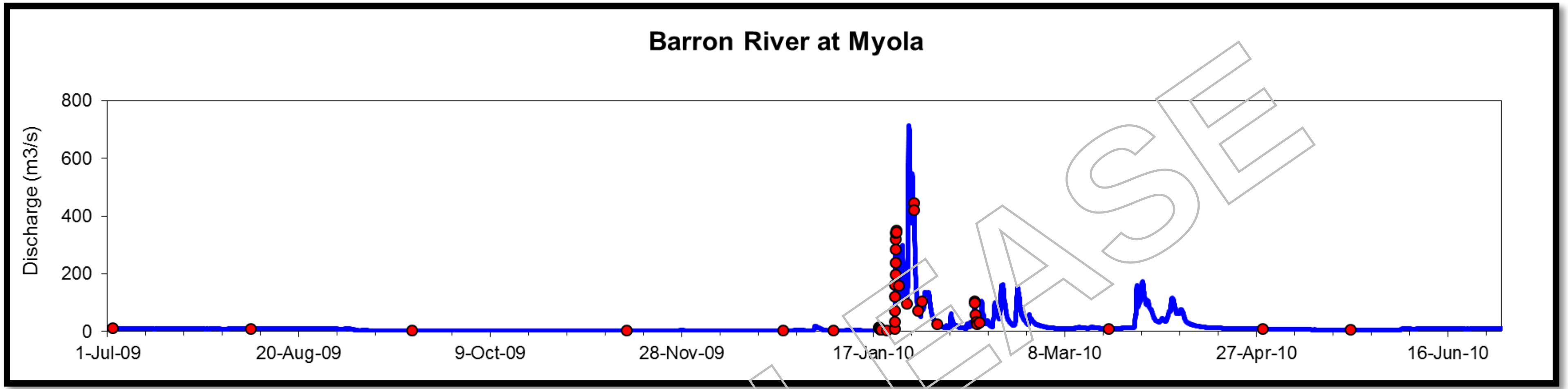

Figure 7.2 Hydrograph showing changes in discharge and sample coverage for Barron River at Myola between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

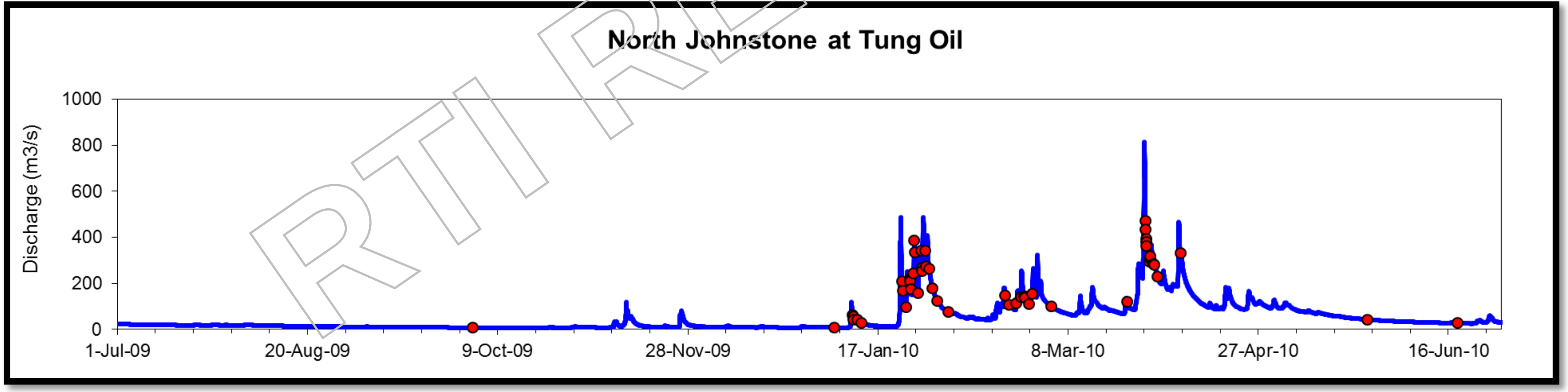

Figure 7.3 Hydrograph showing changes in discharge and sample coverage for North Johnstone River at Tung Oil between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

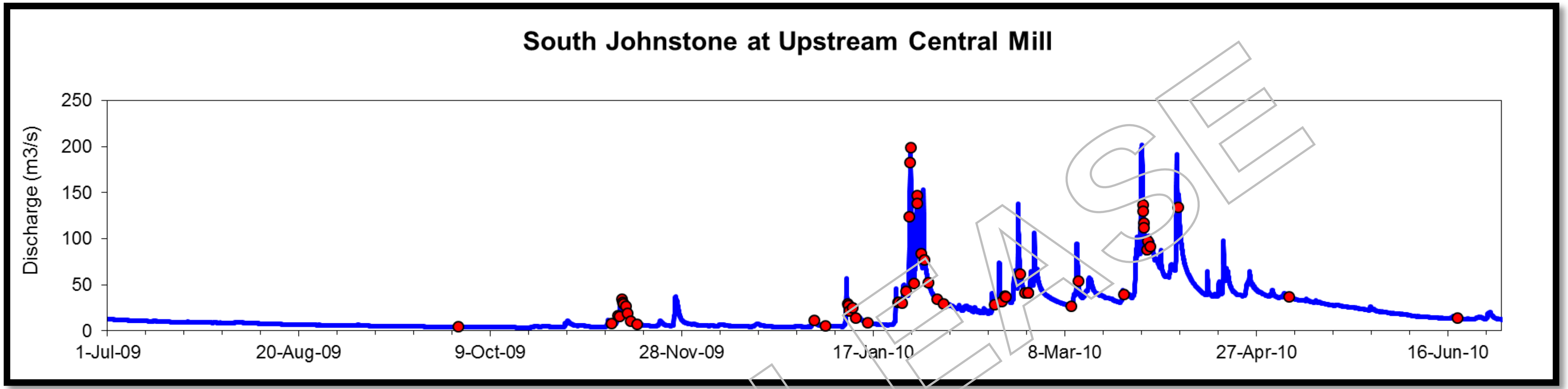

Figure 7.4 Hydrograph showing changes in discharge and sample coverage for South Johnstone River at Upstream Central Mill between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

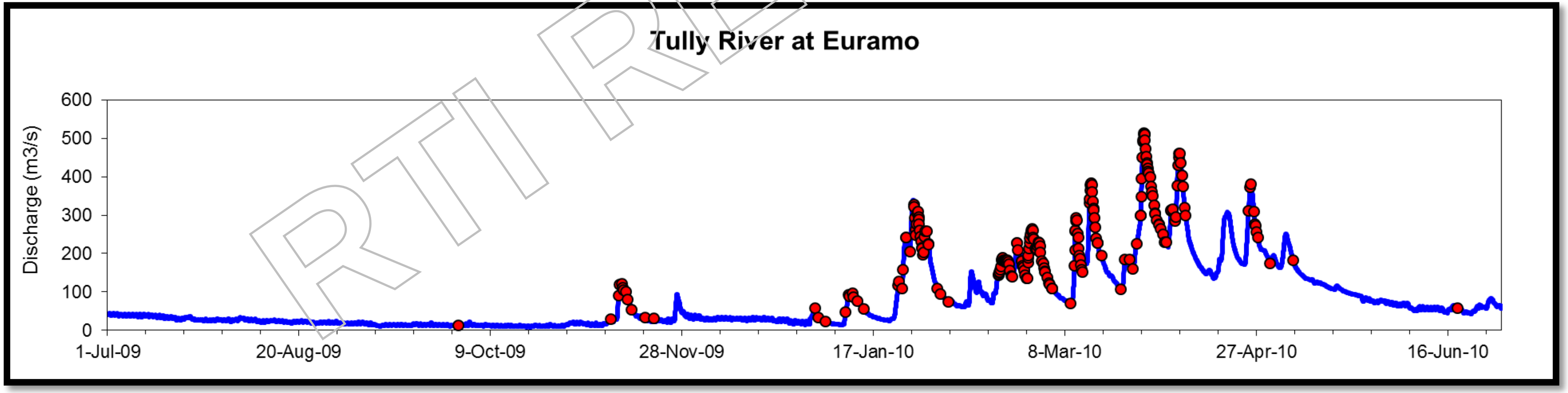

Figure 7.5 Hydrograph showing changes in discharge and sample coverage for Tully River at Euramo between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

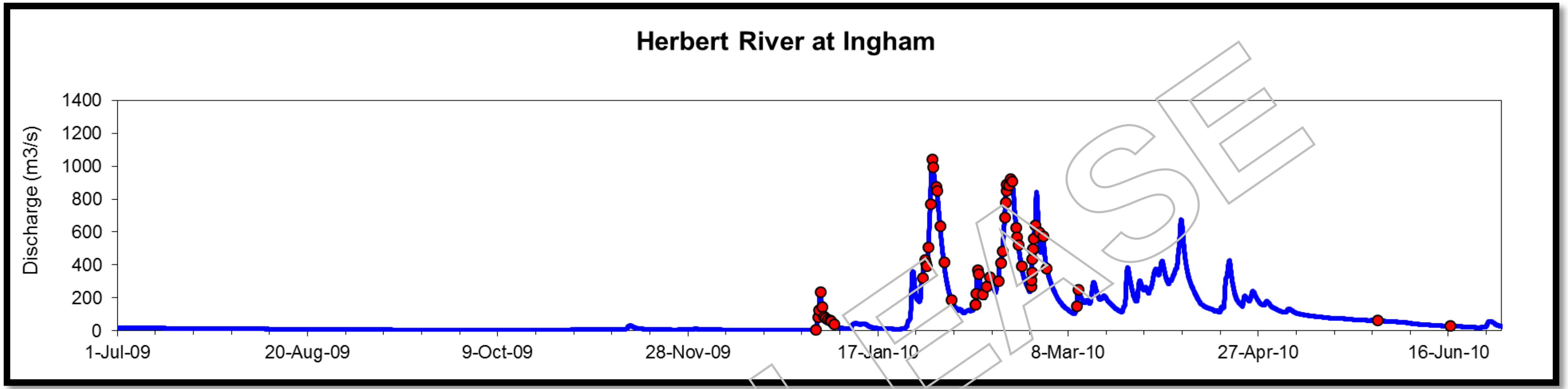

Figure 7.6 Hydrograph showing changes in discharge and sample coverage for Herbert River at Ingham between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

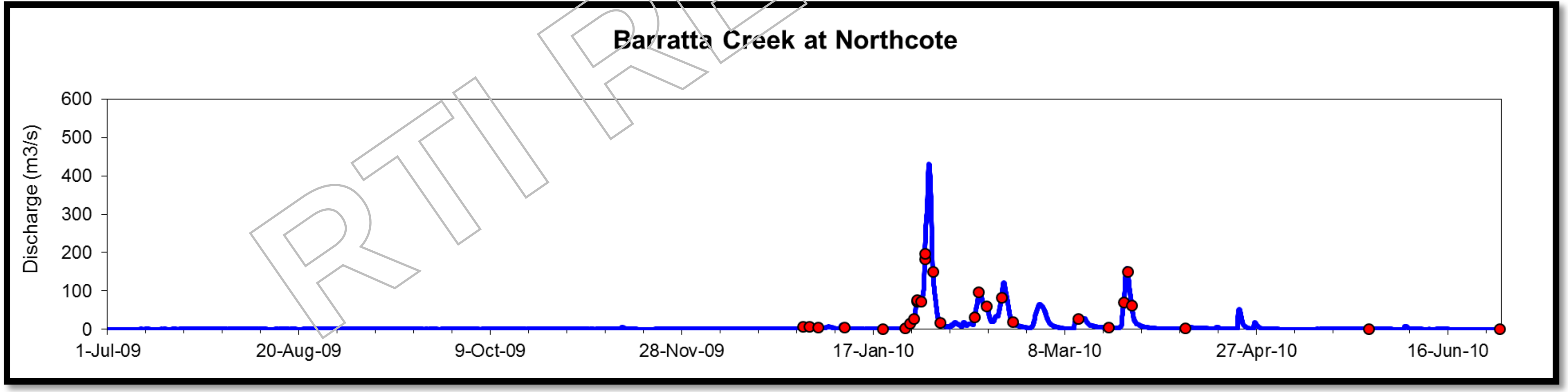

Figure 7.7 Hydrograph showing changes in discharge and sample coverage for Barratta Creek at Northcote between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

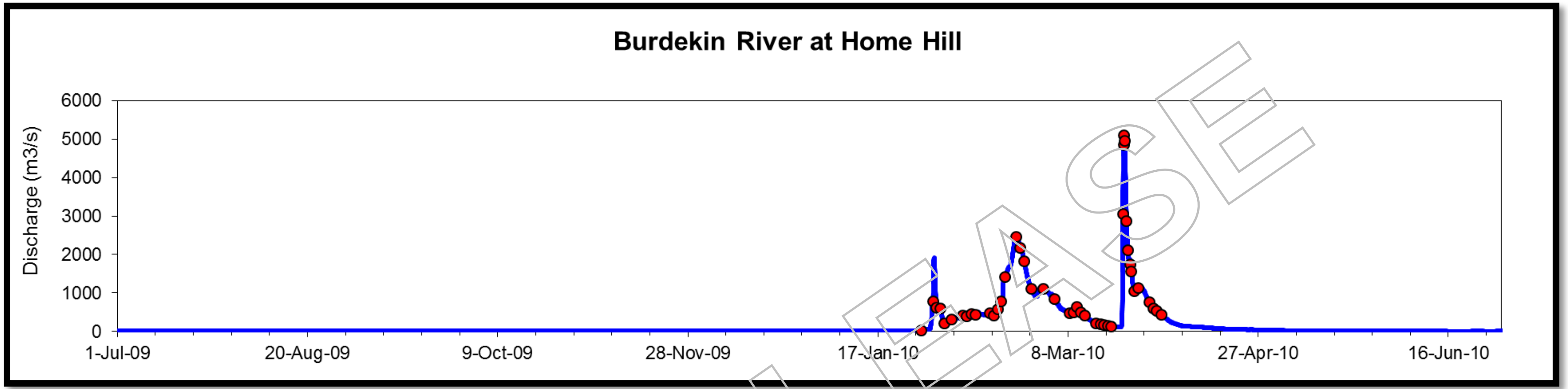

Figure 7.8 Hydrograph showing changes in discharge and sample coverage for Burdekin River at Home Hill between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

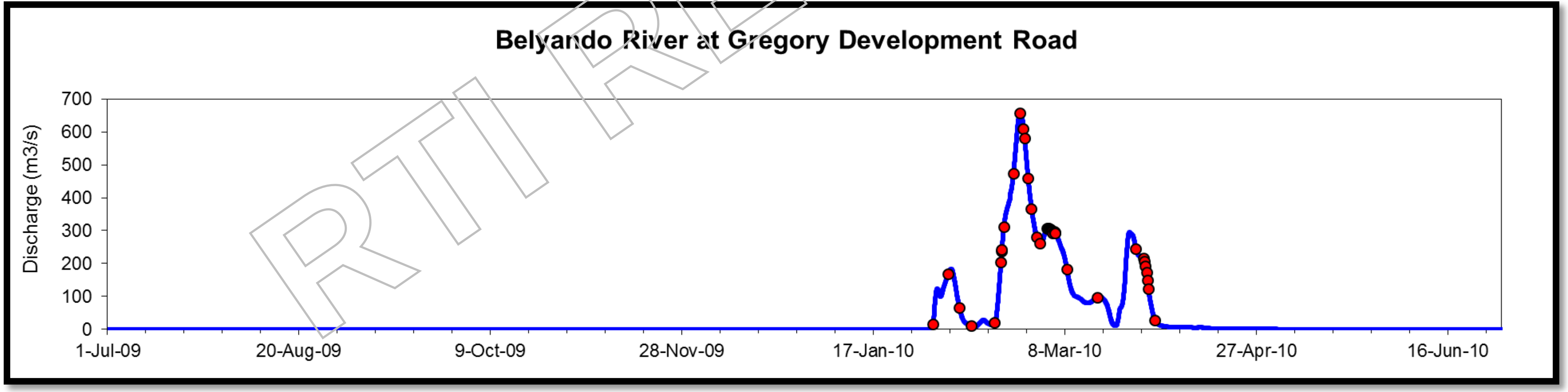

Figure 7.9 Hydrograph showing changes in discharge and sample coverage for Belyando River at Gregory Development Road between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

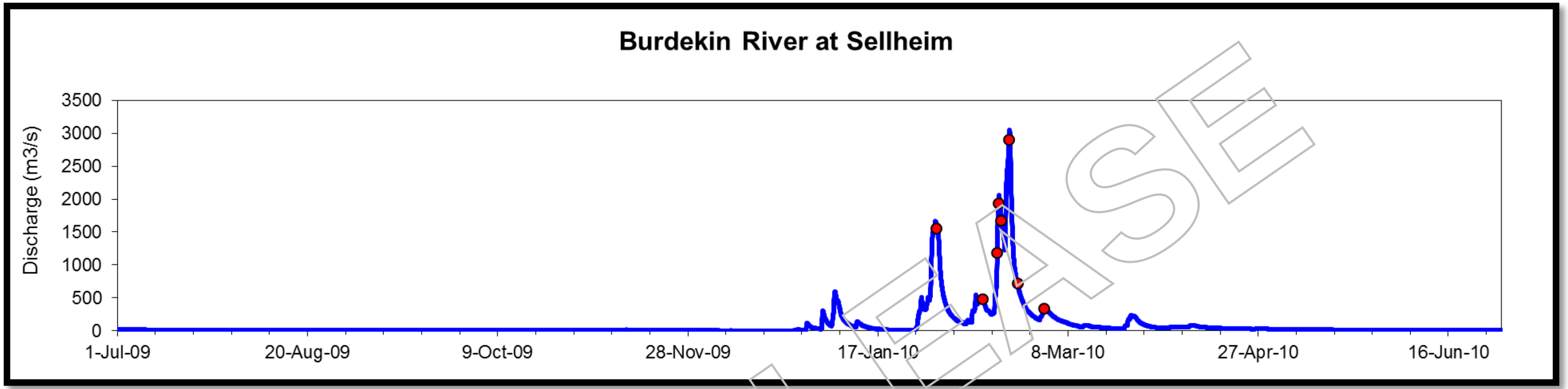

Figure 7.10 Hydrograph showing changes in discharge and sample coverage for Burdekin River at Sellheim between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

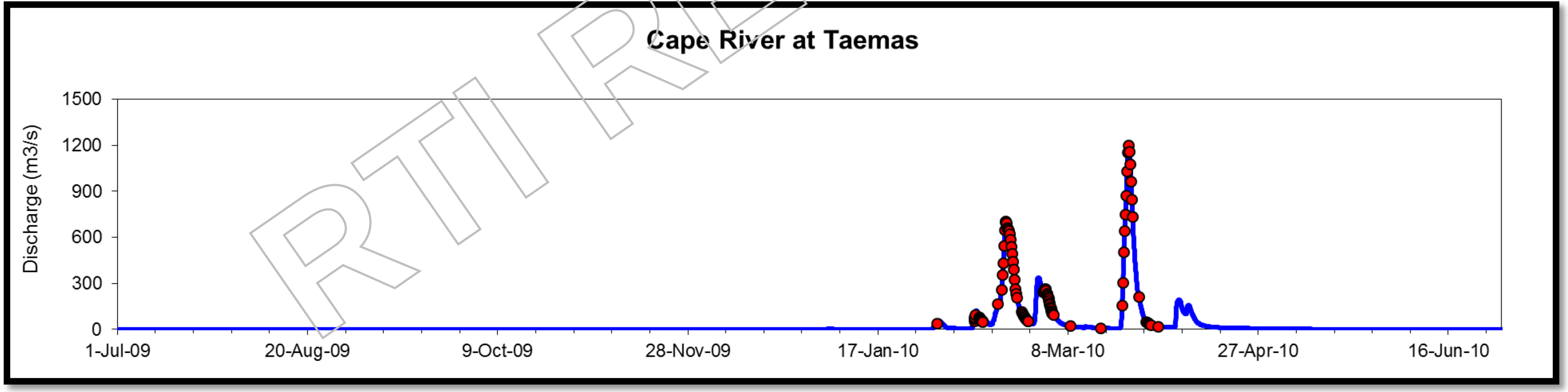

Figure 7.11 Hydrograph showing changes in discharge and sample coverage for Cape River at Taemas between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

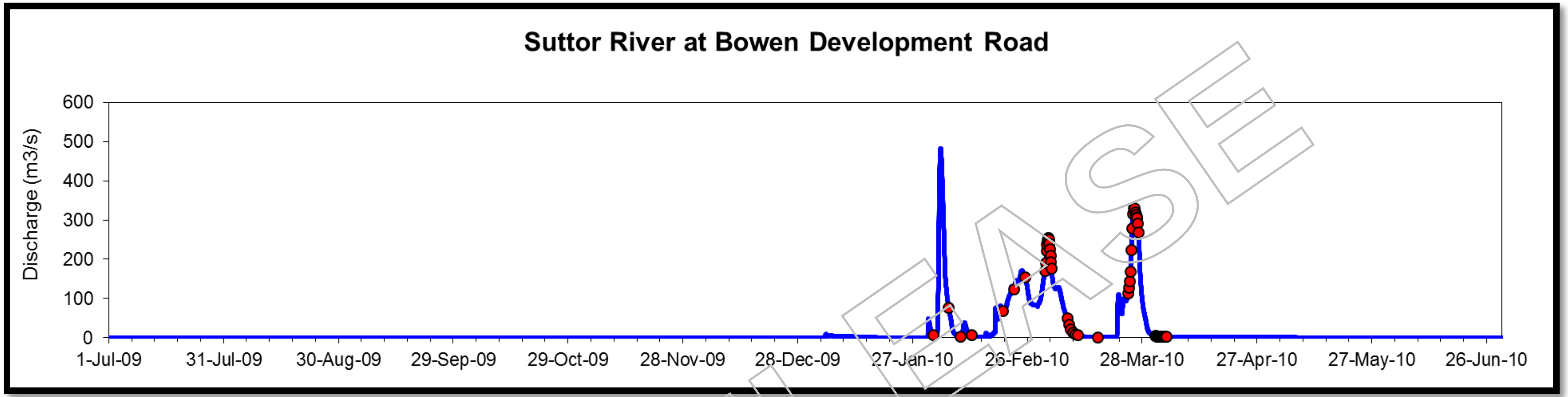

Figure 7.12 Hydrograph showing changes in discharge and sample coverage for Suttor River at Bowen Development Road between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

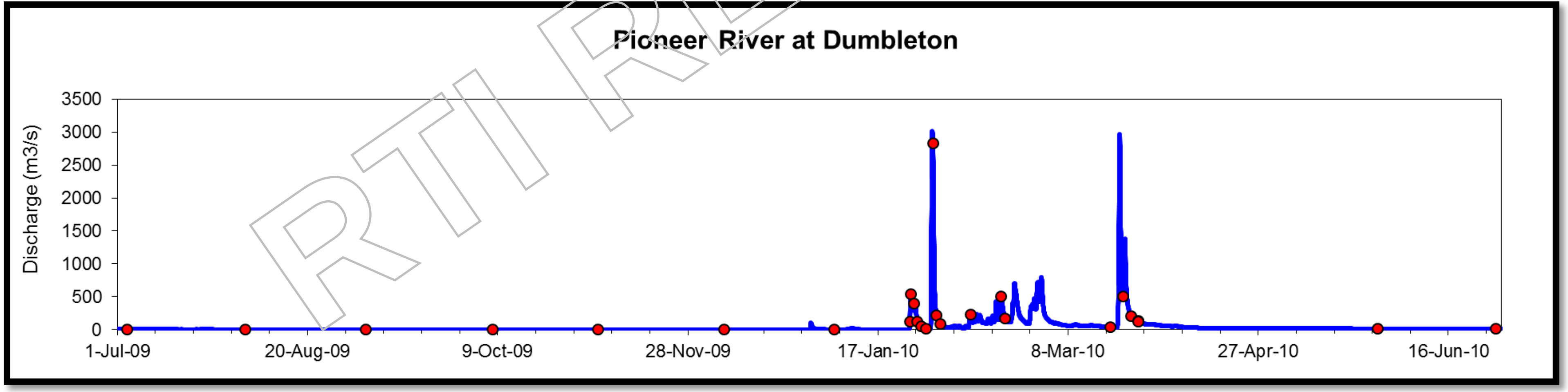

Figure 7.13 Hydrograph showing changes in discharge and sample coverage for Pioneer River at Dumbleton Pump Station between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

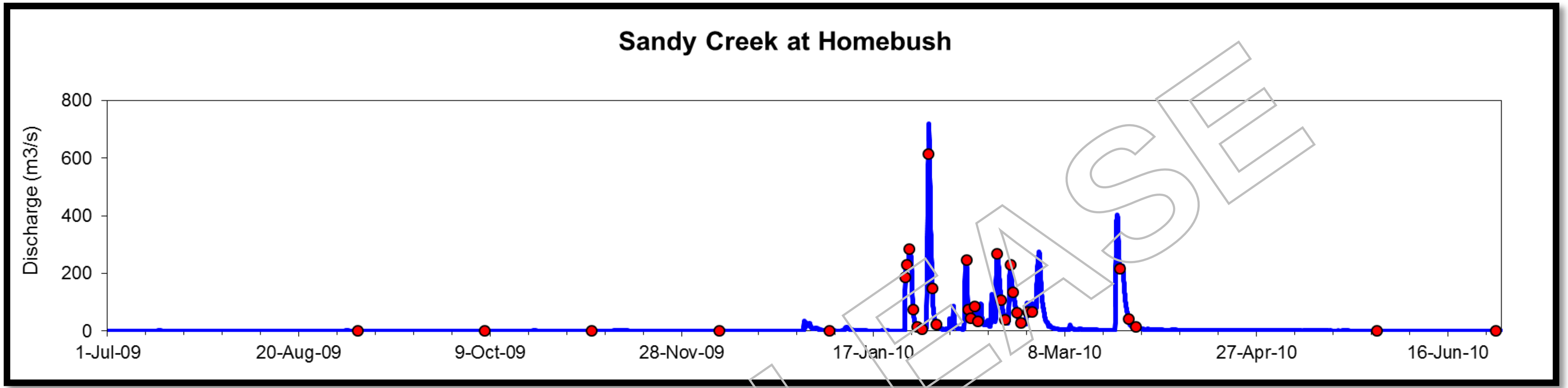

Figure 7.14 Hydrograph showing changes in discharge and sample coverage for Sandy Creek at Homebush between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

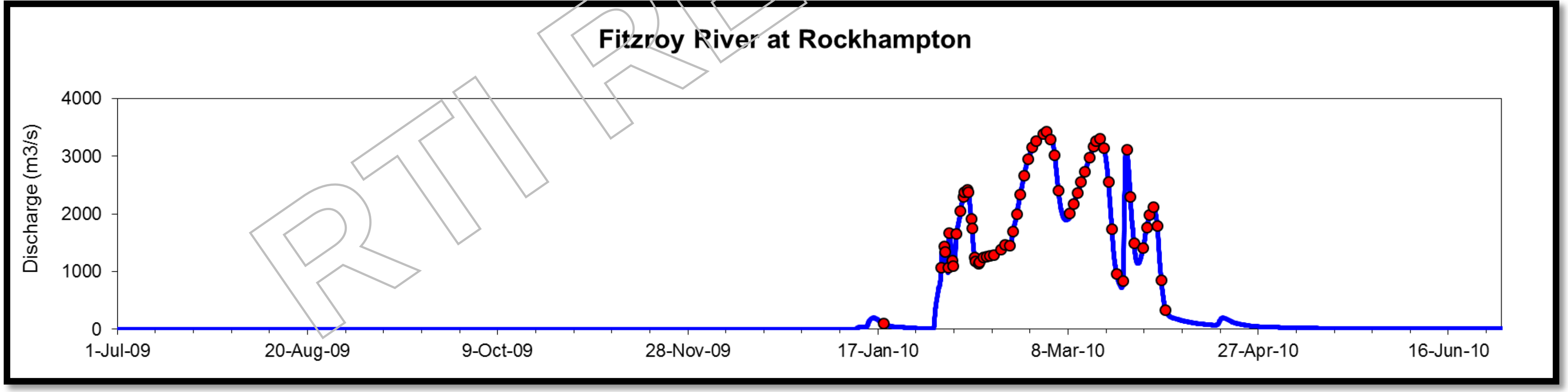

Figure 7.15 Hydrograph showing changes in discharge and sample coverage for Fitzroy River at Rockhampton between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

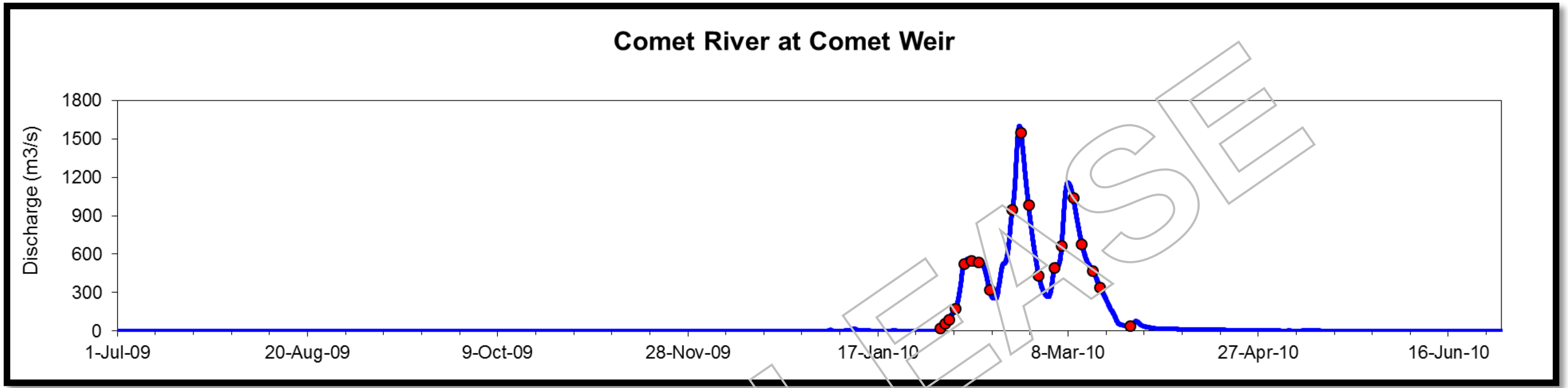

Figure 7.16 Hydrograph showing changes in discharge and sample coverage for Comet River at Comet Weir between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

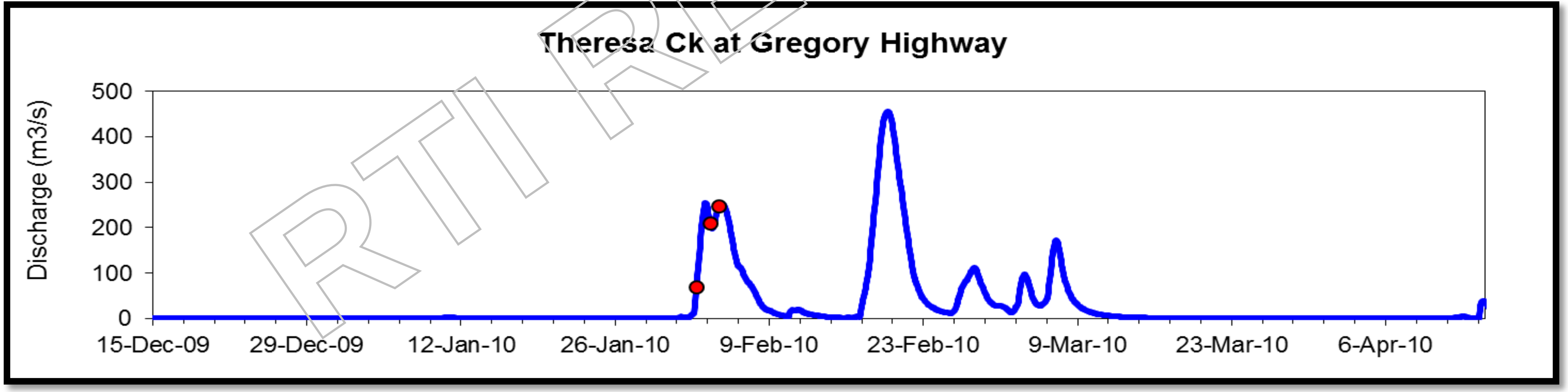

Figure 7.17 Hydrograph showing changes in discharge and sample coverage for Theresa Creek at Gregory Highway between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points. Note: loads were not calculated at this site due to the lack of samples.

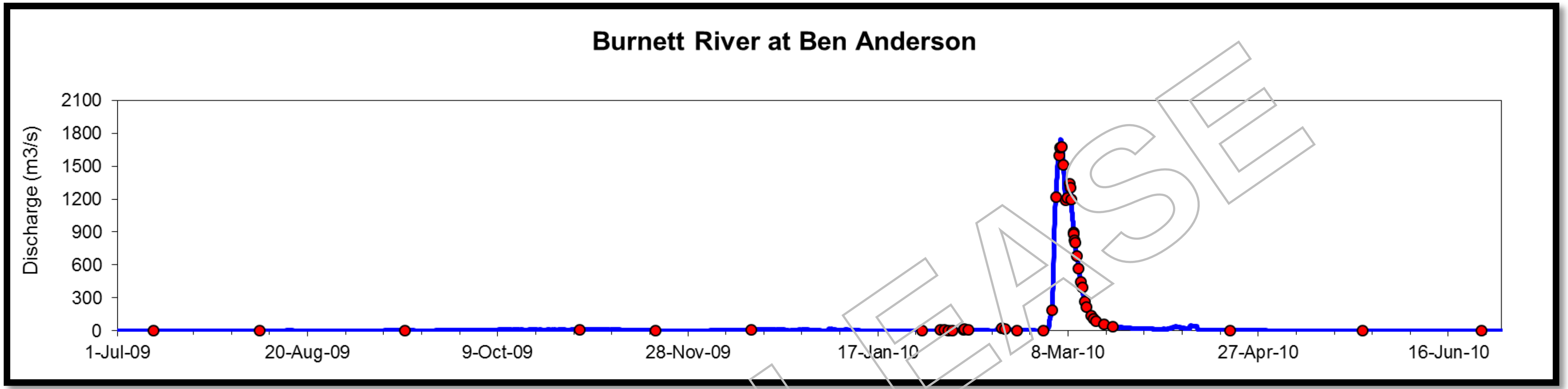

Figure 7.18 Hydrograph showing changes in discharge and sample coverage for Burnett River at Ben Anderson Barrage Head Water between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

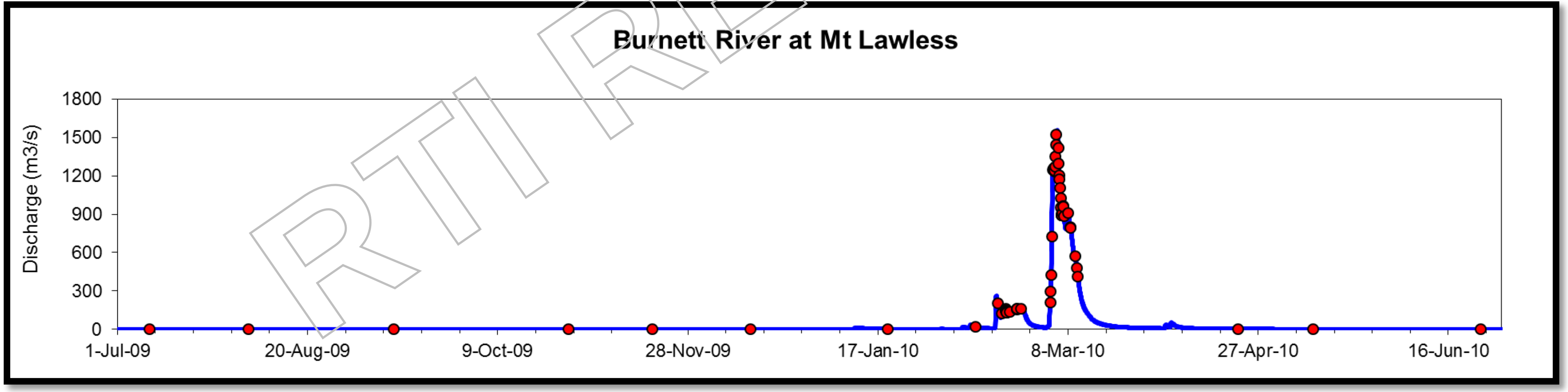

Figure 7.19 Hydrograph showing changes in discharge and sample coverage for Burnett River at Mt Lawless between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

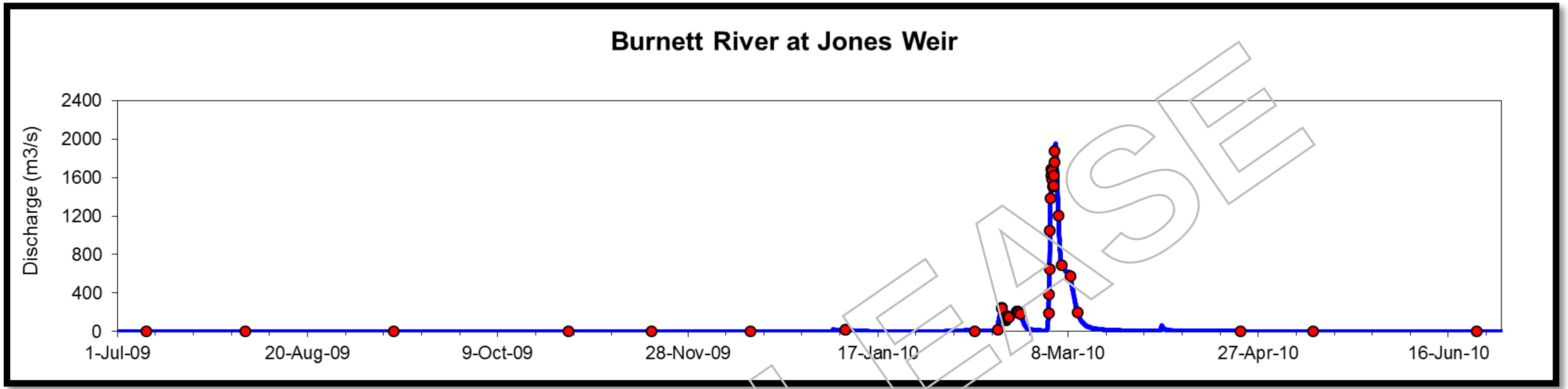

Figure 7.20 Hydrograph showing changes in discharge and sample coverage for Burnett River at Jones Weir Tail Water between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

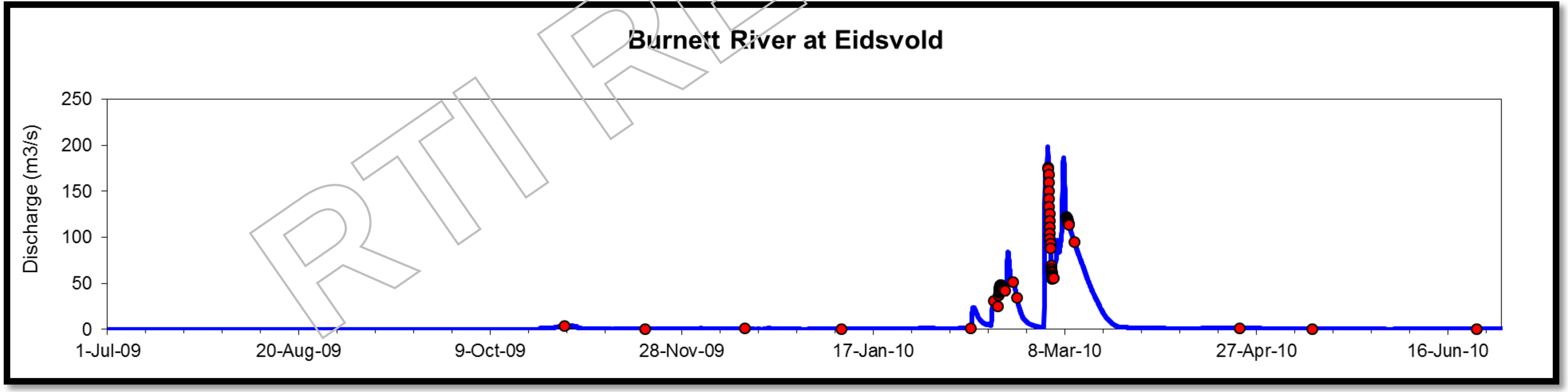

Figure 7.21 Hydrograph showing changes in discharge and sample coverage for Burnett River at Eidsvold between July 2009 and June 2010. Blue solid line indicates discharge and red circles indicate sample collection points.

Appendix C Monitoring and catchment site information

Table 7.1 Total catchment surface area, the area and percentage of the catchments monitored at sites, the number of samples collected, and the representivity rating for 2009-2010. Sites in bold are end-of-system sites.

NRM Region	Catchment	Gauging station	Site name	Total catchment surface area (km^2)	Monitored surface area (km^2)	Monitored surface area of catchment (%)	Number of samples (n)	Representivity rating
Cape York	**Normanby**	105107A	**Normanby River at Kalpowar Crossing**	24,399	12,934	53	8	good
Wet Tropics	**Barron**	110001D	**Barron River at Myola**	2188	1945	89	45	good
	Johnstone	112004A	North Johnstone River at Tung Oil	2325	925	40	50	good
		112101B	South Johnstone River at Upstream Central Mill		400	17	55	good
	Tully	113006A	**Tully River at Euramo**	1683	1450	86	220	excellent
		113015A	Tully River at Tully Gorge National Park		482	29	161	NA*
	Herbert	116001F	**Herbert River at Ingham**	9844	8581	87	61	excellent
Burdekin	**Haughton**	119101A	**Barratta Creek at Northcote**	4051	753	19	28	moderate
	Burdekin	120001A	**Burdekin River at Home Hill**	130,120	129,939	99	45	good
		120002C	Burdekin River at Sellheim		36,290	28	8	good
		120301B	Belyando River at Gregory Development Road		35,411	27	93	excellent
		120302B	Cape River at Taemas		16,074	12	115	excellent
		120310A	Suttor River at Bowen Development Road		10,758	8	57	excellent
Mackay-Whitsundays	**Pioneer**	125013A	**Pioneer River at Dumbleton Head Water**	1572	1485	94	26	good
	Plane	126001A	**Sandy Creek at Homebush**	2539	326	13	33	good
Fitzroy	**Fitzroy**	1300000	**Fitzroy River at Rockhampton**	142,552	139,159	98	66	good
		130504B	Comet River at Comet Weir		16,457	12	19	good
Burnett-Mary	**Burnett**	136014A	**Burnett River at Ben Anderson Barrage Head Water**	33,207	32,891	99	47	excellent
		136002D	Burnett River at Mt Lawless		29,355	88	60	excellent
		136094A	Burnett River at Jones Weir Tail Water		21,700	65	65	excellent
		136106A	Burnett River at Eidsvold		7117	21	76	excellent

***A representivity rating could not be determined as the site was not established for the entire 2009-2010 year.**

Appendix D Event-based loads in Tully River at Tully Gorge National Park

Table 7.2 Estimated event-based loads for total suspended solids and nitrogen in Tully River at Tully Gorge National Park (1 January - 30 July 2010).

Catchment	Gauging station	Event number	n	Event period (date time)	Event duration	Discharge (ML)	TSS (t)	TN (t)	PN (t)	NO_x-N (t)	NH_4-N (t)	DIN (t)
Tully	113015A	1^{B}	54	22/01/10 9:00 – 3/02/10 23:00	12d 14h	51,049	2287	32.5	19.3	5.0	0.5	5.5
		2^{B}	16	17/02/10 22:00 – 22/02/10 0:00	4d 2h	16,291	478	6.6	3.9	0.8	0.2	1.0
		3^{L}	23	12/03/10 13:00 – 18/3/10 11:00	5d 23h	30,377	788	12.4	6.9	1.8	0.6	2.4
		4^{L}	24	25/3/10 21:00 – 1/04/10 8:00	6d 12h	44,280	1023	17.0	9.4	2.2	0.3	2.5
		5^{L}	19	23/04/10 23:00 – 30/4/10 17:00	6d 19h	38,380	990	12.7	7.5	2.0	0.3	2.3

^{L} = linear interpolation method used to calculate loads; ^{B} = Beale ratio method used to calculate loads; n = number of water samples collected during 2009-2010 and used for load calculations

TSS = total suspended solids; TN = total nitrogen; PN = particulate nitrogen; NOx-N = oxidised nitrogen as N; NH_4-N = ammonium nitrogen as N; DIN = dissolved inorganic nitrogen (DIN = (NOx-N) + (NH_4-N)).

Table 7.3 Estimated event-based loads for phosphorus in Tully River at Tully Gorge National Park (1 January - 30 July 2010).

Catchment	Gauging station	Event number	n	Event period (date time)	Event duration	Discharge (ML)	DON (t)	TP (t)	DIP (t)	PP (t)	DOP (t)
Tully	113015A	1^{B}	54	22/01/10 9:00 – 3/02/10 23:00	12d 14h	51,049	6.1	3.1	0.3	2.2	0.4
		2^{B}	16	17/02/10 22:00 – 22/02/10 0:00	4d 2h	16,291	2.2	0.3	0.05	0.1	0.3
		3^{L}	23	12/03/10 13:00 – 18/3/10 11:00	5d 23h	30,377	4.5	1.2	0.1	0.9	0.5
		4^{L}	24	25/3/10 21:00 – 1/04/10 8:00	6d 12h	44,280	7.2	1.5	0.2	1.1	0.4
		5^{L}	19	23/04/10 23:00 – 30/4/10 17:00	6d 19h	38,380	3.0	0.6	0.1	0.4	0.3

^{L} = linear interpolation method used to calculate loads; ^{B} = Beale ratio method used to calculate loads; n = number of water samples collected during 2009-2010 and used for load calculations
DON = dissolved organic nitrogen TP = total phosphorus; DIP = dissolved inorganic phosphorus; PP = particulate phosphorus; DOP = dissolved organic phosphorus.

Appendix E Contribution (as per cent) of each catchment to the total monitored loads during 2009-2010.

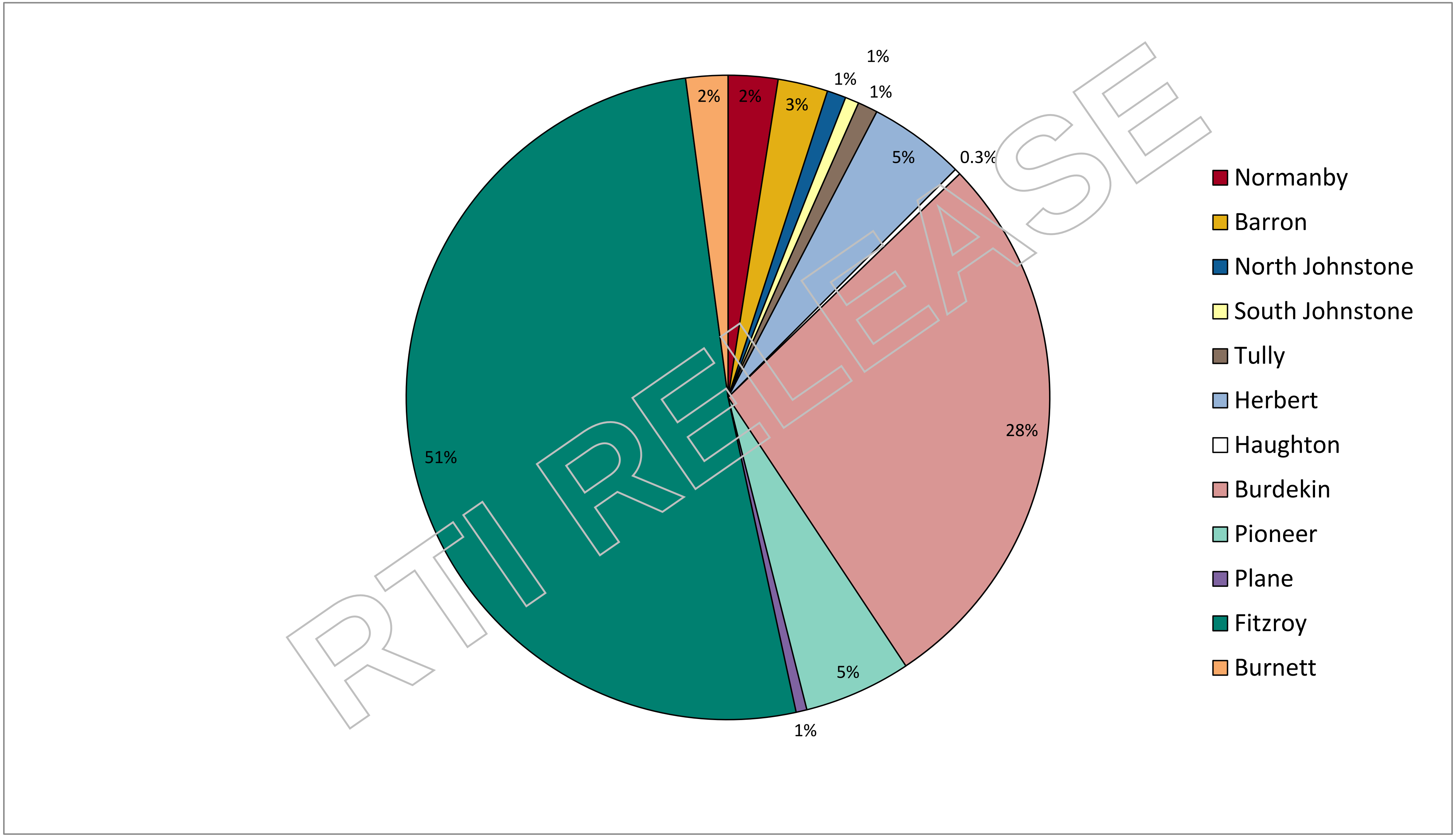

Figure 7.22 Per cent contribution from each catchment to the whole monitored total suspended solid load.

🟥 Normanby 🟨 Barron 🟦 North Johnstone 🟨 South Johnstone 🟫 Tully 🟦 Herbert ⬜ Haughton 🟥 Burdekin 🟩 Pioneer 🟪 Plane 🟩 Fitzroy 🟧 Burnett

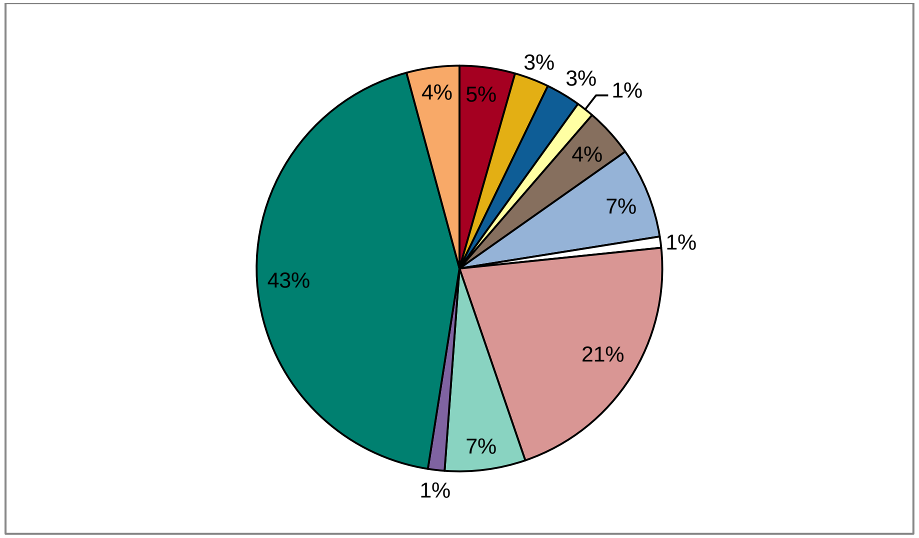

Figure 7.23 Per cent contribution from each catchment to the whole monitored total nitrogen load.

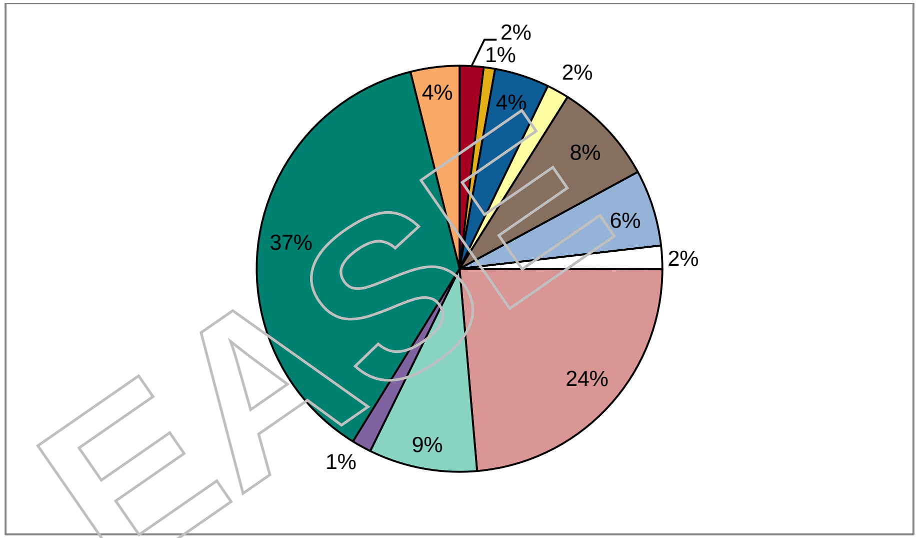

Figure 7.25 Per cent contribution from each catchment to the whole monitored dissolved inorganic nitrogen load.

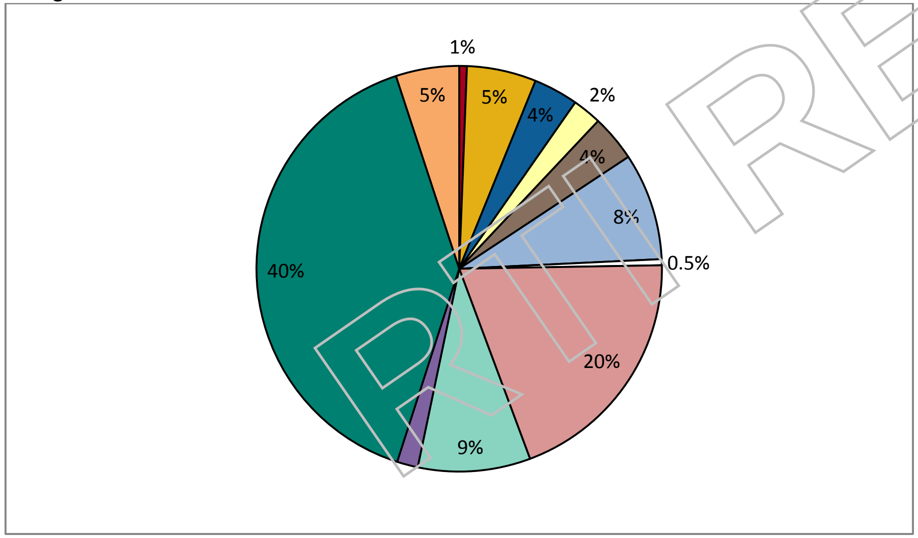

Figure 7.24 Per cent contribution from each catchment to the whole monitored particulate nitrogen load.

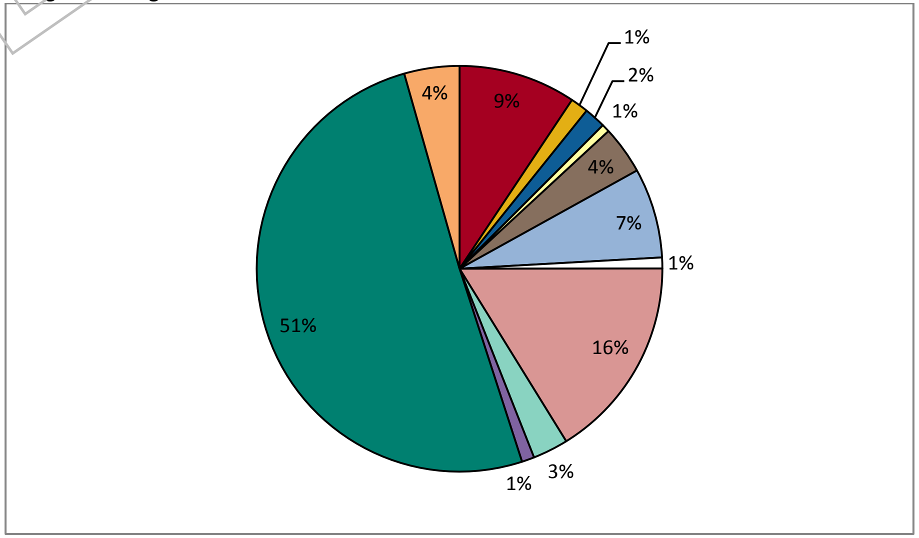

Figure 7.26 Per cent contribution from each catchment to the whole monitored dissolved organic nitrogen load.

🟥 Normanby 🟨 Barron 🟦 North Johnstone ☐ South Johnstone 🟫 Tully 🟦 Herbert ☐ Haughton 🟥 Burdekin 🟩 Pioneer 🟪 Plane 🟩 Fitzroy 🟧 Burnett

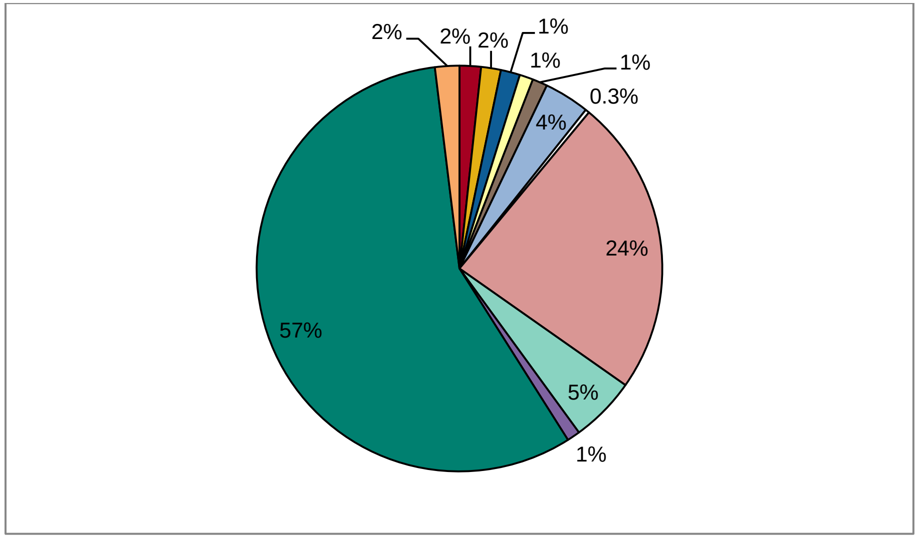

Figure 7.27 Per cent contribution from each catchment to the whole monitored total phosphorus load.

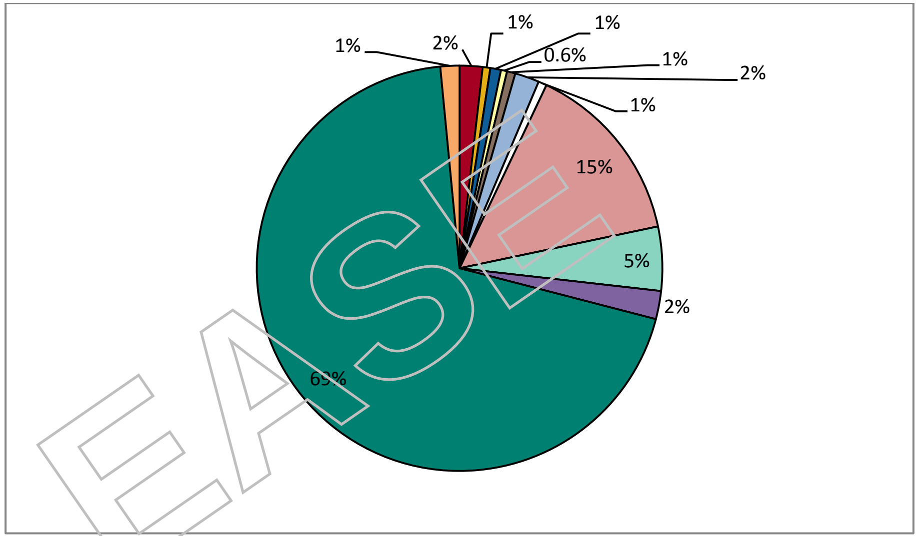

Figure 7.29 Per cent contribution from each catchment to the whole monitored dissolved inorganic phosphorus load.

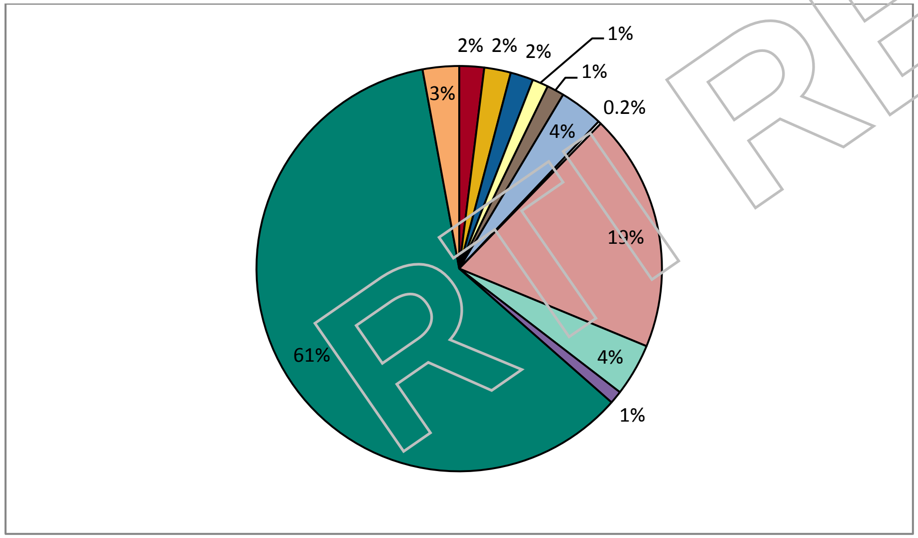

Figure 7.28 Per cent contribution from each catchment to the whole monitored particulate phosphorus load.

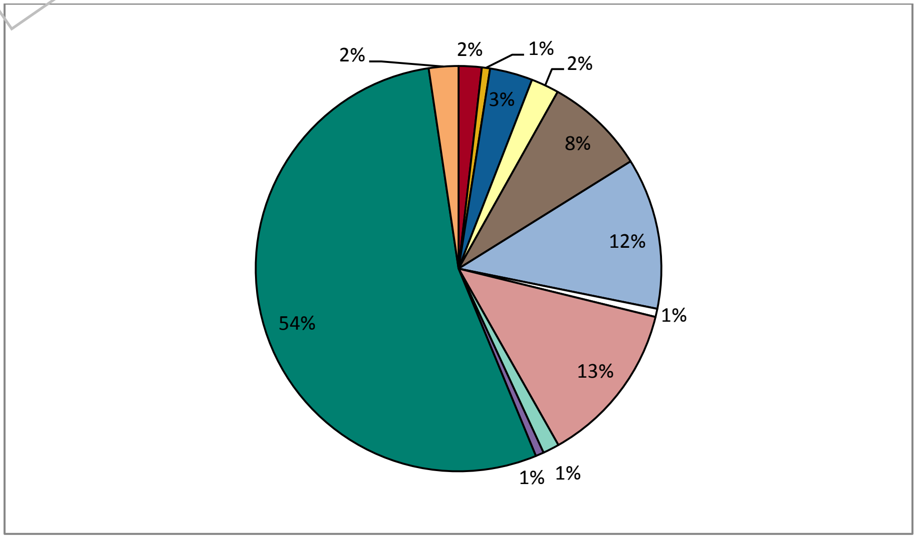

Figure 7.30 Per cent contribution from each catchment to the whole monitored dissolved organic phosphorus load.

Appendix F Comparison of grab sampling and passive sampling

Passive sampler deployment

Each passive sampler unit consisted of three types of passive samplers; two SDB-RPS Empore™ disks (EDs), a semipermeable membrane device (SPMD) and polydimethylsiloxane (PDMS) device. The EDs, SPMDs and PDMSs were prepared by the National Research Centre for Environmental Toxicology (EnTox) using the method by Shaw et al. (2010). Each ED was mounted in a Teflon case which holds the disks in position and allows the membrane to be exposed to passing water, as well as protecting the membranes from passing debris. The SPMD and PDMS were mounted in a stainless steel cage that allowed the surrounding water to move through the cage and come into contact with the membranes, while also protecting the membranes from passing debris. Plaster flow monitors were deployed along with the passive samplers to determine the average flow of water moving over the surface of the EDs (O'Brien et al. 2009), which in turn was used to calculate the event mean concentration of each of the pesticides extracted from the EDs. All of the five priority photosystem II inhibitor herbicides are sampled by the EDs, whereas only a few are sampled by the SPMDs and PDMSs. Therefore, event mean concentrations were estimated only for the priority photosystem II inhibitor herbicides extracted by the EDs.

Passive sampler units were deployed in flowing water at each site for up to one month. However, if a large event occurred during deployment, the sampling unit was collected as soon as possible once flow had returned to near ambient conditions/levels. Upon retrieval, passive samplers were transported to National Centre for Environmental Toxicology (EnTox) for extraction of the accumulated pesticides and analysis using the methods of Shaw et al. (2010). A total of 50 passive samplers were deployed in 2009-2010 at the 11 sites sampled for pesticides with 44 of these analysed for pesticide residues. The other six were lost or damaged during deployment.

Comparison of pesticide detection by grab sampling and passive sampling

From grab samples analysed with LC-MS, other photosystem II inhibitor herbicides were detected (simazine, and bromacil), as well as non-photosystem II inhibitor herbicides (metolachlor and prometryn), and an insecticide (imidacloprid). Eighty grab samples were concurrently analysed using GC-MS, which detected two herbicides, propazine and metribuzin, as well as the mosquito repellent, DEET. Thirteen grab samples from Barratta Creek and Sandy Creek were also analysed for phenoxy acid herbicides, detecting three types of synthetic auxins, 2,4-D, MCPA and fluroxypyr.

In general, passive samplers detected a greater number of pesticides at each site than grab sampling (Table 7.4). In addition to herbicides, grab sampling detected only one type of insecticide, imidacloprid, whereas the passive samplers were also able to detect five organophosphate insecticides (diazinon, chlorpyrifos, chlorfenvinphos, prothiophos and propiconazole), three organochlorine insecticides (dieldrin, endosulfan beta and endosulfan sulphate), as well as a fungicide (tebuconazole). The passive samplers were also valuable in detecting the five priority herbicides during periods when concentrations were below the practical quantitation limit for analysis of grab samples.

Table 7.4 Pesticides detected from grab samples and passive samplers

Grab sample analysis			Passive samplers	
LC-MS	**GC-MS**	**Phenoxyacid**	**Empore disks**	**PDMS & SPMD**
Ametryn (P)	Deet (D)	2,4-D (H)	Ametryn (P)	Diuron breakdown (M)
Atrazine (P)	Propazine (H)	MCPA (H)	Atrazine (P)	Atrazine (P)
Desethyl Atrazine (M)	Metribuzin (H)	Fluroxypyr (H)	Desethyl Atrazine (M)	Diazinone (OP)
Desisopropyl Atrazine			Desisopropyl Atrazine	Metolachlor (H)
Diuron (P)			Diuron (P)	Chlorpyriphos (OP)
Hexazinone (P)			Hexazinone (P)	Prothiophos (OP)
Tebuthiuron (P)			Tebuthiuron (P)	Dieldrin (OC)
Prometryn (H)			Prometryn (H)	Propiconazole (OP)
Simazine (H)			Simazine (H)	Tebuconazole (F)
Bromacil (H)			Bromacil (H)	Trifluralin (H)
Metolachlor (H)			Metolachlor (H)	Ametryn (P)
Imidacloprid (I)			Imidacloprid (I)	Endosulfan beta (OC)
				Endosulfan Sulphate (OC)

Note: D = insect deterrent; F = fungicide; H = herbicide; I = insecticide; M = herbicide metabolite; OC = organochlorine; OP = organophosphate; (P) = Priority photosystem II inhibitor herbicide

Comparison of load calculations by passive sampling and grab sampling

In order to assess the effectiveness of data from passive samplers being used to calculate loads, a comparison was made between loads calculated from passive sampler data and loads calculated from grab sample data. To calculate a load from the passive sampler results, concentrations derived from the passive samplers were considered to be a mean concentration for the whole of the deployment period, i.e. an event mean concentration (EMC). Loads for each deployment period were then calculated from passive samplers using the following equation:

$$\text{Load} = \text{EMC x } Q \qquad \textbf{Equation 3}$$

where, EMC is the event mean concentration and Q is the discharge calculated by WQA (eWater 2011) for the period of the deployment.

Where possible, the photosystem II inhibitor herbicide loads for the period of a passive sampler deployment, based on the results from grab samples and results from passive samplers (Empore disks), were compared. There was sufficient grab sampling coverage during the deployment of three passive samplers to permit valid comparison. These three passive sampler deployments were at three sites, the Tully River at Euramo, the Fitzroy River at Rockhampton and Barratta Creek at Northcote, the details of which are reported in Table 7.5.

Table 7.5 Passive sampler deployment period and corresponding grab sampling coverage for a comparison of loads calculated from passive sampler and grab samples.

Site	Deployment dates	Deployment period (days)	Number of grab samples
Tully River at Euramo	8/01/10 – 6/02/10	29	13
Fitzroy River at Rockhampton	26/03/10 – 12/04/10	17	8
Barratta Creek at Northcote	19/01/10 – 3/02/10	15	8

Figure 7.31 illustrates the loads derived from the first deployment of passive sampler units at the Tully River and Barratta Creek and the third deployment at the Fitzroy River at Rockhampton. The results indicate that there were large and inconsistent differences in the loads calculated by the two sampling methods. At the Fitzroy and Tully rivers, the loads derived from grab samples were greater than the loads derived from passive sampler data by factors ranging from less than one to greater than three times. The reverse was true for loads calculated for pesticides in Barratta Creek, i.e. loads calculated from passive sampler results were greater than loads calculated from grab samples.

The reasons for the inconsistencies between the sampling methods are difficult, at this point, to ascertain. Observations of the passive samplers during deployment indicated that there may have been problems associated with their positioning in the water column at high flow velocities. Flow velocities at sample sites are highly variable, fluctuating over an event from low flow (~10cms^{-1}) to very high flow (>1ms^{-1}). Furthermore, the frequencies of flow velocities over an event commonly have a skewed distribution. The current method for determining the event mean concentration using the PFM is based on stable flow conditions and assumes a normal distribution. Shaw and Mueller (2009) have also found that fluctuations in pesticide concentrations, which were found to occur over an event, can lead to an underestimation of the predicted concentration. Conversely, grab sampling only covered approximately 50 per cent of the deployment period, which could also lead to discrepancies in the loads estimated from the two methods.

Summary

Passive samplers have a wide range of applications and on this occasion have proven their efficacy for measuring low level concentrations of the priority photosystem II inhibitor herbicides and increasing the range of detectable pesticides. However, the large differences in the loads calculated between passive sampling and grab sampling warrants further investigation. From the results and observations reported here, there is not enough information to ascertain which method is providing the most accurate load estimation. Given that there is little reference in the literature to the use of passive samplers for load estimation compared to the extensive work conducted on the use of grab sampling, opting to use the more recognised method is the most viable resolution at this stage. It is highly recommended that a more detailed assessment take place to determine the sources of variation and whether passive samplers can be used in the place of grab sampling in these types of hydrologic systems to estimate the most accurate pesticide load.

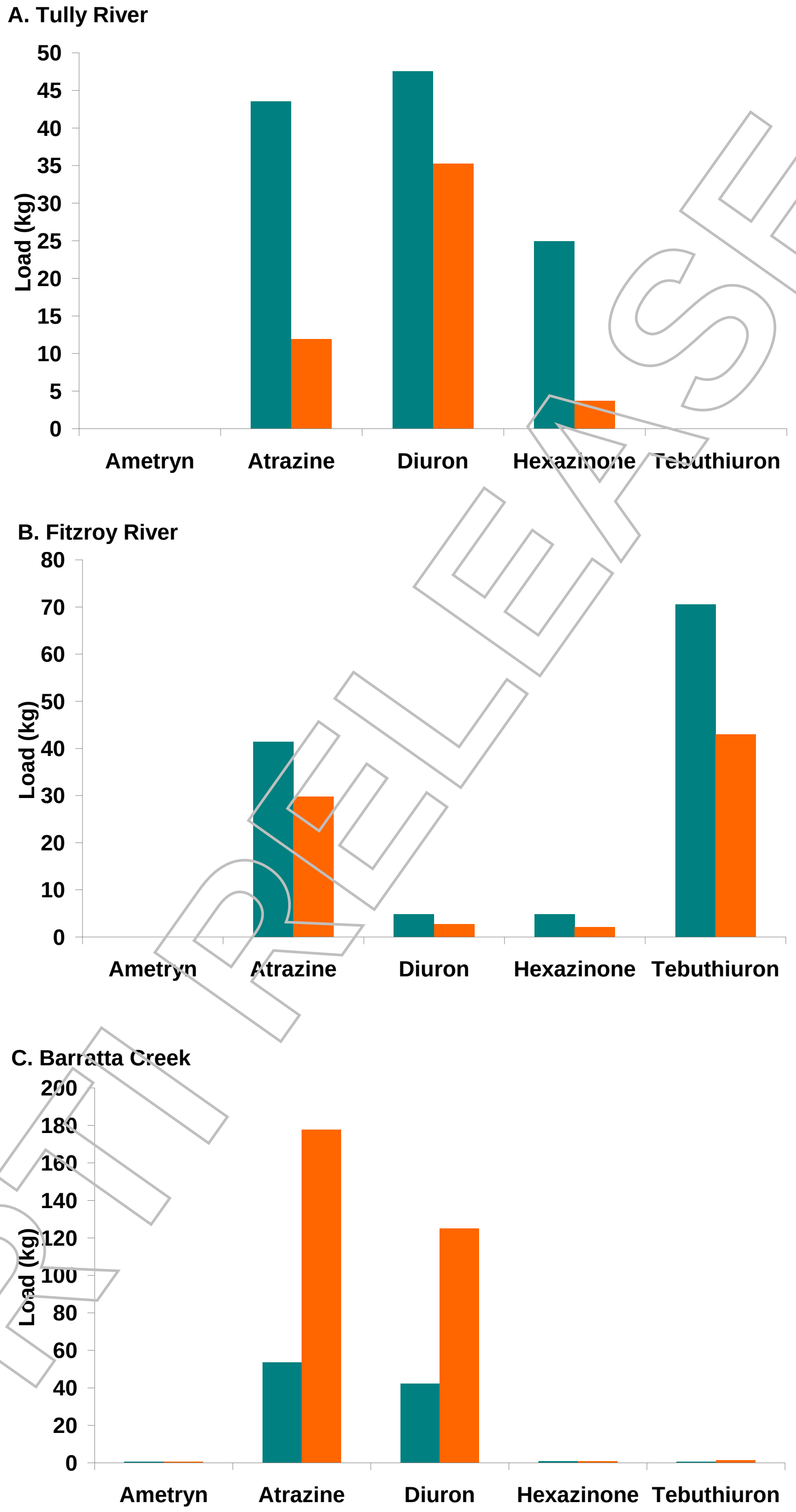

Figure 7.31 Photosystem II inhibitor herbicide loads estimated from herbicide concentrations obtained from grab samples (🟩) and Empore disk passive samplers (🟧) collected during the same period. Loads were estimated for three sites: (A) the Tully River at Euramo, (B) the Fitzroy River at Rockhampton and (C) Barratta Creek at Northcote. Loads from the grab sample results were calculated using the Beale method. Note, the atrazine loads were calculated with atrazine concentrations only and did not include desethyl atrazine or desisopropyl atrazine.