Eastern Cape York Sediment and Nutrient Load Report:

Empirical Load Estimates from the Normanby, Annan and Pascoe Rivers

Technical Report for the Cape York Water Quality Improvement Plan

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Cover Photos: top left- Pascoe River in flood at Garraway gauge (Lana Polglase, Feb 2015); top right- Annan River at Little Annan Bridge below Beesbike gauge (Jeff Shellberg, 18th March 2015); Normanby River mouth in flood (Christina Howley, 28th March 2012).

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1 INTRODUCTION

For the management of the Great Barrier Reef (GBR), load estimates are used to compare the amount of sediment or nutrients delivered to the GBR lagoon by different river systems, and to measure change over time in response to management actions or land use changes. A pollutant load may be defined as the mass of a substance (i.e. sediments or nutrients) that passes a particular point of a river (such as a stream gauge) in a specified amount of time (e.g., instantaneous, daily, annually). Mathematically, a load is calculated as the product of water discharge and the concentration of a substance or pollutant in the water. Empirical calculations of loads from field measurements are used to determine how much sediment or nutrients (or other contaminants) are moved from one point in a river to another, or from a river to the coastal environment.

Water Discharge (Q) = the volume of water that passes a cross-section of a river in a specific amount of time.

Pollutant Concentration (C) = is the mass of a pollutant in a given volume of water.

Load (L) = the mass or weight of a substance that passes a cross-section of a river in a specific amount of time. Load is calculated as the product of water discharge times the pollutant concentration for a given interval of time. $\boldsymbol{L = C\ x\ Q}$

The challenge for all river monitoring is to accurately measure nutrient and sediment loads over long periods of time (see Shellberg et al. 2016), and to determine what portion of a load is natural, and what portion is accelerated by human land use. Calculating accurate empirical loads for a given point in a river requires detailed and representative water quality data sets and discharge measurements. Samples must be collected frequently across both baseflow and high water discharge to identify the variability in concentrations. Ideally, both continuous discharge and continuous water quality concentrations would be measured; however, this is often not the case due to a lack of resources. In recent years, loads have been estimated using semi-theoretical catchment models such as the Source Catchments (SedNet) model, which uses catchment information (physical and climate characteristics and land use) and a mix of theoretical and empirical equations to estimate the loads produced by a given river. These models have large uncertainties and have been shown to be inaccurate when applied to Cape York river systems such as the Normanby (Brooks et al. 2013; Brooks et al. 2014). The accuracy of these models often also relies on good quality empirical loads calculations from field monitoring programs, which are limited on Cape York.

For this report, we will calculate annual sediment and nutrient loads based on samples collected at current and historic gauge stations on the Annan, Pascoe and Normanby Rivers in eastern Cape York Peninsula (CYP). These are the only eastern CYP rivers for which adequate data is available to calculate loads. The years for which loads were calculated, and methods used, varied for each site due to differences in water quality sampling regimes and the availability of water discharge data. For the Annan and Pascoe Rivers, loads have only been calculated for the 2014-2015 water year (July-June), when sufficient water quality data were available. For Normanby catchment gauges, the years of intensive event sampling varied from 2 for the Battlecamp gauge (2013-2015) to 7 (2006-2015) at the Kalpowar gauge.

These data are presented only as current best estimates of empirical loads, due to the lack of high frequency continuous sampling of pollutant concentrations, lack of width- and depth integrated sampling to determine average cross-section concentrations, and the uncertainties associated with the various methods of loads calculations. For future improvements in empirical load accuracy on Cape York Peninsula, it is recommended that a ‘Super Gauge’ approach is developed at key sites, based on international standards for fluvial measurements of pollutants (isokinetic, width-depth integrated) and utilising continuous water quality measurements (i.e., turbidity) as surrogates for pollutant concentration through correlation with manual measurements (Shellberg et al. 2016).

The Reef 2050 Plan goal is to reduce end-of-river anthropogenic loads of suspended sediment by at least 20% by 2018, dissolved inorganic nitrogen loads by 50%, and particulate nutrient loads by at least 20% in priority areas. The independent Cape York Water Quality Improvement Plan Science Panel has determined that 20% end-of catchment anthropogenic load reductions for sediment and particulate nutrients are appropriate short-term goals for disturbed catchments in Cape York, including the Normanby and Annan catchments. However, in order to achieve this end-of-catchment reduction, a greater reduction is needed at the most disturbed upstream sub-catchments due to downstream reductions in specific sediment yield. In the Normanby catchment, rates of gully erosion in the upper catchment are estimated to have increased by up to 10 times since the introduction of cattle (Brooks et al. 2013). Sediment yields in the Normanby catchment are estimated to have at least doubled (2x) since European settlement. A 50% anthropogenic sediment and particulate nutrient load reduction target (equating to 25% of total loads if the loads have doubled) was determined by the Science Panel to be a reasonable goal for these disturbed sub-catchment gauge sites, to achieve a 20% reduction of anthropogenic loads (10% of total loads) at end-of-river sites.

There is insufficient understanding of the sources of dissolved inorganic nutrients to set loads targets for end-of-river sites in the Normanby or other disturbed Cape York catchments. However, a 50% anthropogenic load reduction (25% of total) for nitrogen oxides and dissolved inorganic phosphorus is recommended at the Laura River gauge to reduce documented impacts from horticulture (Howley 2010).

For less disturbed river catchments on Cape York, such as the Pascoe and Olive, the goal is to maintain current sediment and nutrient loads until anthropogenic impacts have been better quantified for these catchments. For more pristine catchments such as the Jacky-Jacky and Nesbit River, the goal is to maintain current sediment and nutrient loads with no net increases in land use disturbance that might increase loads above current baselines.

2 METHODS

2.1 Water quality and discharge data

Empirical annual sediment and nutrient loads were calculated using grab samples of pollutant concentrations collected at or near QDNRM gauge sites with available water discharge data. The available water quality data for all eastern Cape York gauges was compiled for all years (Moss and Howley 2015). Water quality data during flood periods are very limited across Cape York, except for at a handful of gauges. At the Normanby River gauge at Kalpowar Crossing (105107A), regular event water quality monitoring by the Rinyirru National Park rangers (QPW) has occurred at since WY 2006 as part of the DSITI Great Barrier Reef Loads Estimates Programme. Upstream in the Normanby catchment between WY 2012-2015, event nutrient and sediment grab samples were collected by the Laura Rangers and Griffith University at 3 additional current gauge sites (Normanby River at Battlecamp-105101; Laura River Coalseam-105102A; East Normanby-105105A) plus one historic gauge site (West Normanby-105016A) where continuous stage recorders were installed to help estimate water discharge (Figure 1). At the Annan River Beesbike gauge (107003A), Annan River estuary (Big Bridge), and Pascoe River Garraway gauge (102102A), water quality samples were collected in WY 2015 by South Cape York Catchments, from which load estimates were calculated for WY 2015. Loads were not calculated for other current and historic gauges across eastern Cape York, due to insufficient water quality data for flood periods.

Water quality grab samples were analysed by QDSITI Chemistry Laboratory for total suspended solids (TSS), total nitrogen (TN), particulate nitrogen (PN), dissolved organic nitrogen (DON), oxidised nitrogen (NOx), ammonium nitrogen (NH_3), total phosphorus (TP), particulate phosphorus (PP), dissolved inorganic phosphorus (DIP) and dissolved organic phosphorus (DOP). Additional samples were analysed by Griffith University for isokinetic suspended sediment concentrations (SSC).

Empirical loads were calculated for six active water discharge gauge sites (Table 1) based on the water quality data collected from 2012 to 2015 and QDNRM continuous (15-minute interval) water discharge data. Water discharge at the historic West Normanby gauge was estimated from new stage recorders deployed in the West Normanby between the years of 2012-2015 (15-minute interval) and the old water discharge rating curves from the historic period (1970-1989). The resultant loads using these historic rating curves should be viewed with caution, as rating curve shift has occurred, especially at low discharge. Water discharge in the Annan River estuary (Big Bridge) was roughly estimated as double the Beesbike gauge discharge determined from local discharge measurements and estimated travel times between upstream and downstream stage gauges (Shellberg et al. 2016).

None of these sites are 'end-of river' locations or are representative of the total basin discharge to the GBR (range 1% to 91%; Table 1). However, all sites serve as important long-term monitoring locations to measure actual changes in water quality. The Pascoe and lower Annan River gauges are well situated to capture much of the catchment area. The Normanby at Kalpowar gauge captures 53.1% of the Normanby Basin, but completely misses the western half that drains to the Kennedy River, as well as the Marrett River.

Table 1: Monitoring Locations/ Gauge Site Characteristics

River Basin	Total Basin Size (km²)	River	Gauge No. / Site Name	Monitored Catchment Area (km²)	% of Total Basin Area	Median Annual discharge (ML)	Distance to River Mouth (km)
Olive-Pascoe	2,124	Pascoe	102102A/ Garraway	1,313	61.8	1,123,486	41.2
Normanby	24,399	Normanby	105107A/ Kalpowar	12,934	53.1	2,451,493	71
Normanby	24,399	Normanby	105101A/ Battlecamp	2,302	9.4	778,644	174
Normanby	24,399	Laura River	105102A/ Coal Seam	1316	5.3	396,375	170
Normanby	24,399	East Normanby	105015A/ East Normanby	297	1.2	131,509	245
Normanby	24,399	West Normanby	105106A/ West Normanby	839	3.4	154,713	244
Annan	983	Annan	107003A/ Beesbike	247	25.1	312,372	34
Annan	983	Annan Estuary	New gauge/ Big Bridge	894	91	N/A	5

The number of samples collected at each site and for each water year varied from a minimum of 13 to 114, as did the representativeness of the samples across different flood stages (rising and falling). The times of sample collection were plotted on hydrographs (Figures 2 – 8) to graphically analyse the timing and frequency of sample collection annually and across flood events. Loads were calculated for those sites that had an adequate number of samples collected during major flood events between 2012 and 2015. Annual loads were calculated based on a July-June water year. Loads estimates for the Annan River at Beesbike and the Annan River estuary for WY 2015 were calculated by Shellberg et al. (2016) on an October to September water year. The water year difference should not make a significant load difference compared to a July cut-off as there is insignificant rainfall and low river flow during the July-September “dry season”.

Loads estimates for the Normanby River Kalpowar gauge from 2006–2012 were calculated previously for the DSITI Great Barrier Reef Loads Estimates Programme (i.e. Turner et al. 2012; Turner et al. 2013; Wallace et al. 2014; Wallace et al. 2015).

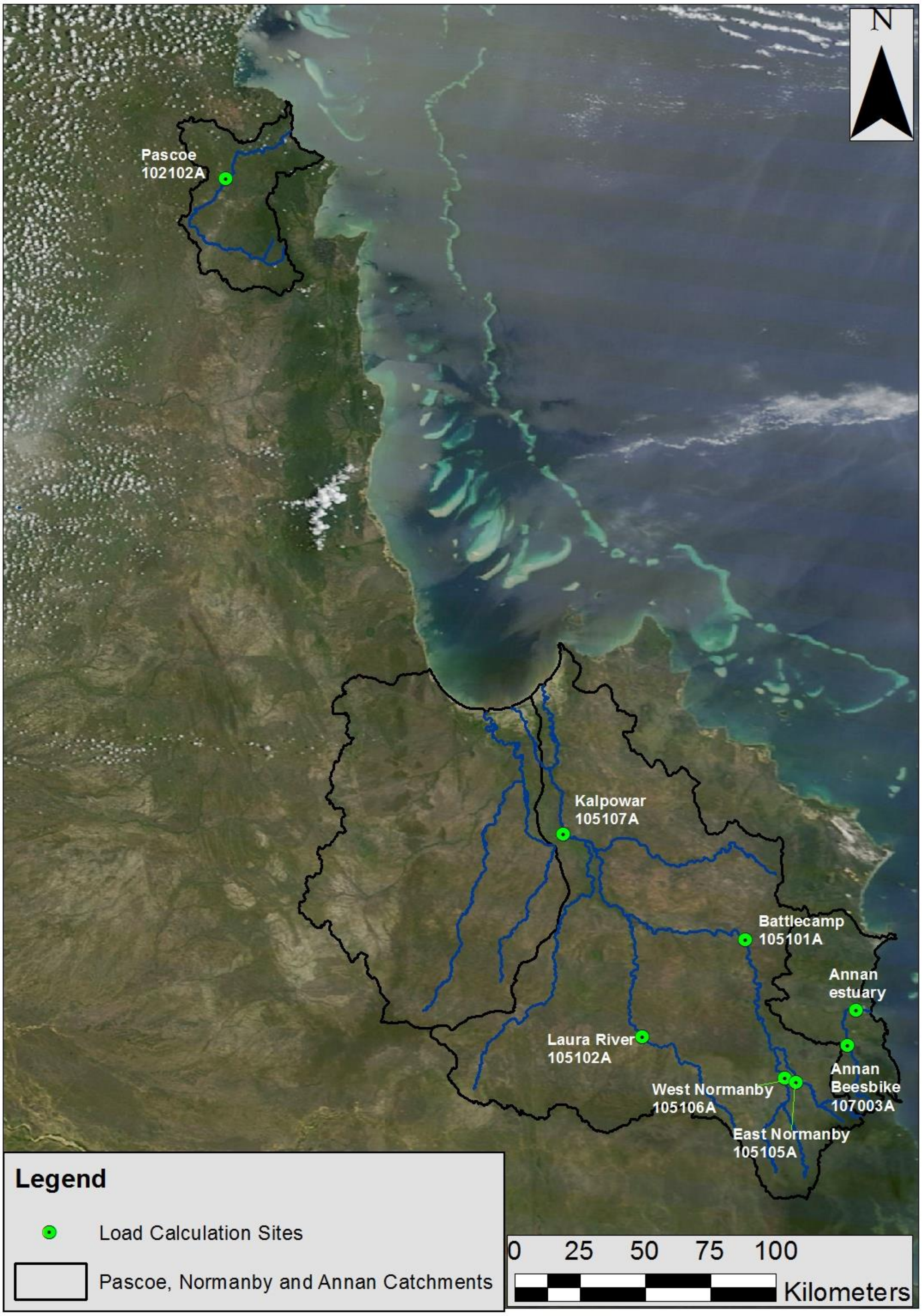

Figure 1: Load calculation sites, including current and historic gauge sites from the Pascoe, Normanby and Annan Rivers and the Annan river estuary.

2.2 Hydrographs for Cape York Gauges: WY 2012-2014

A hydrograph is a plot showing the rate of water discharge (flow) versus time past a specific point in a river. Figures 2 through 8 below show the frequency and timing of samples collected at each gauge / monitoring site from 2012 to 2015.

Ideally, at least seven grab samples of pollutant concentration should be collected across both the rising and falling stage of a flood event, with an absolute minimum annual sample size of 18 (Thomson et al. 2012). For the Cape York sites, sample representativeness (across flood events) was moderate to good at most sites, with the exception of the Normanby River at Battlecamp (Figure 4) which can only be reached by helicopter during major flood events. The April 2014 flood event at Kalpowar Crossing was also poorly sampled (Figure 3).

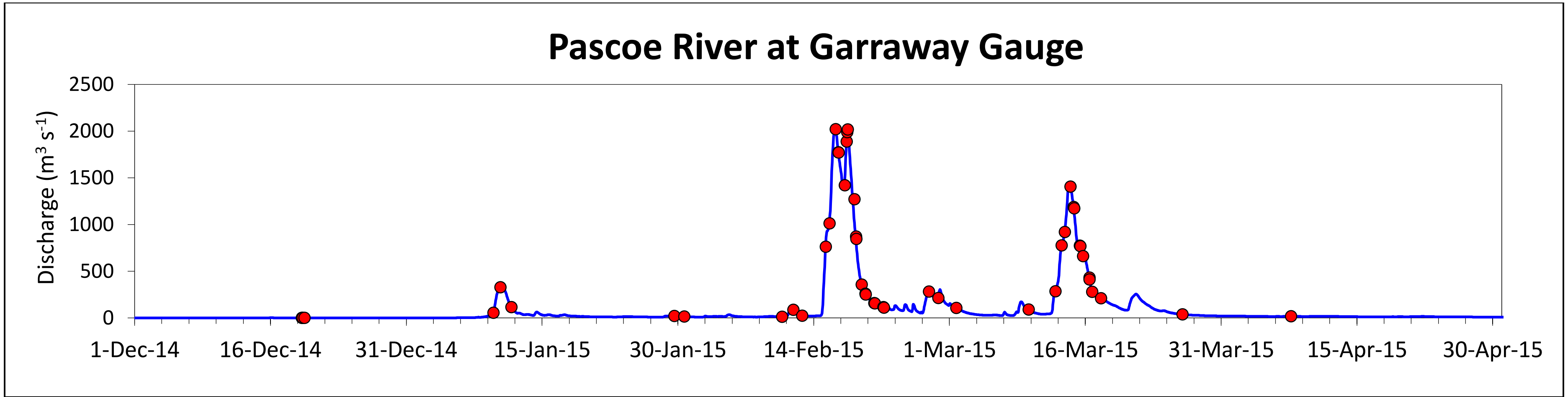

Figure 2: Sample collection time plotted against river discharge at the Pascoe River Garraway gauge site 102102A

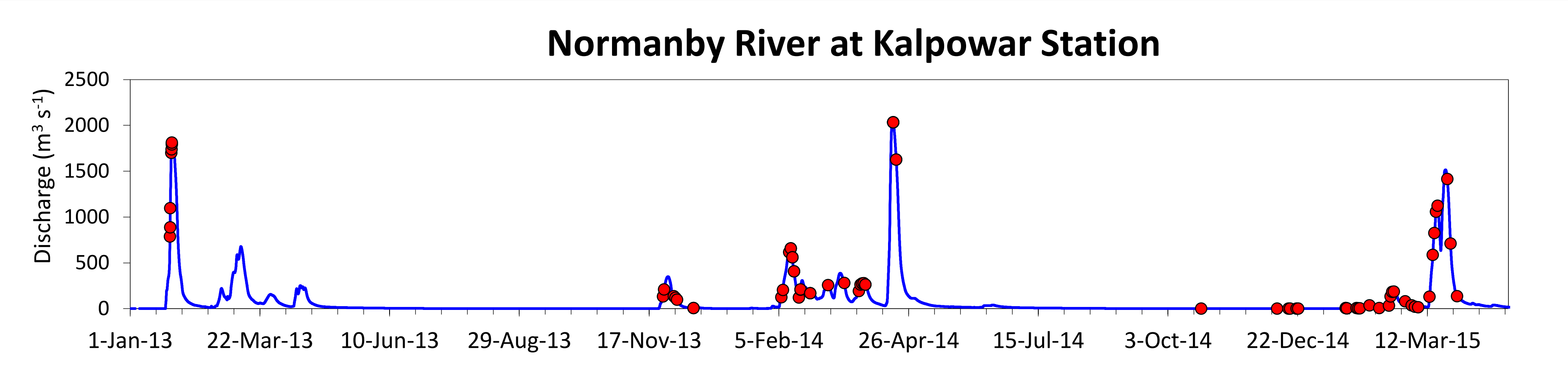

Figure 3: Sample collection time plotted against river discharge at the Normanby River Kalpowar gauge site 105107A

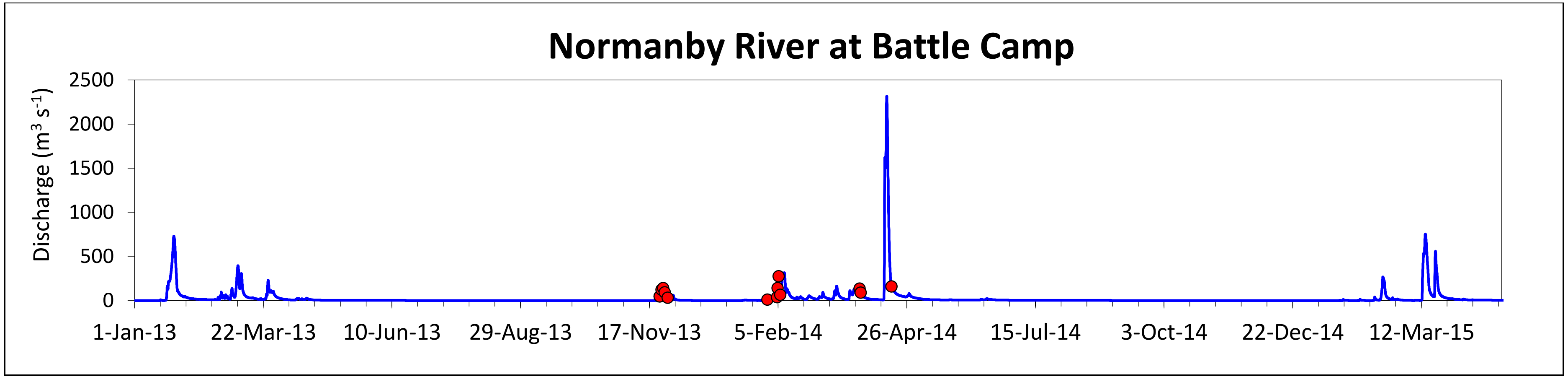

Figure 4: Sample collection time plotted against river discharge at the Normanby River Battlecamp gauge site 105101A

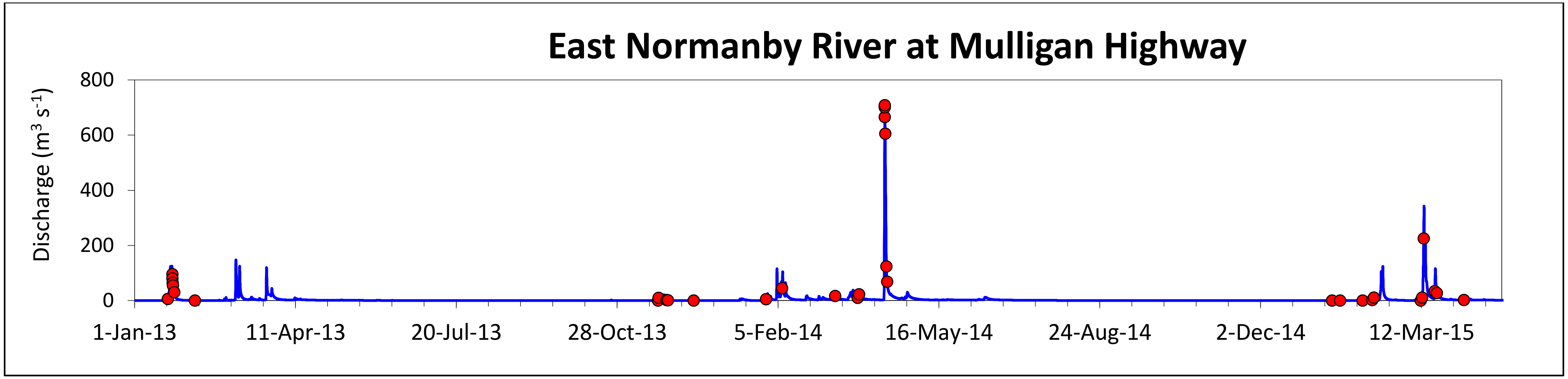

Figure 5: Sample collection time plotted against river discharge at the East Normanby River near gauge site 105105A

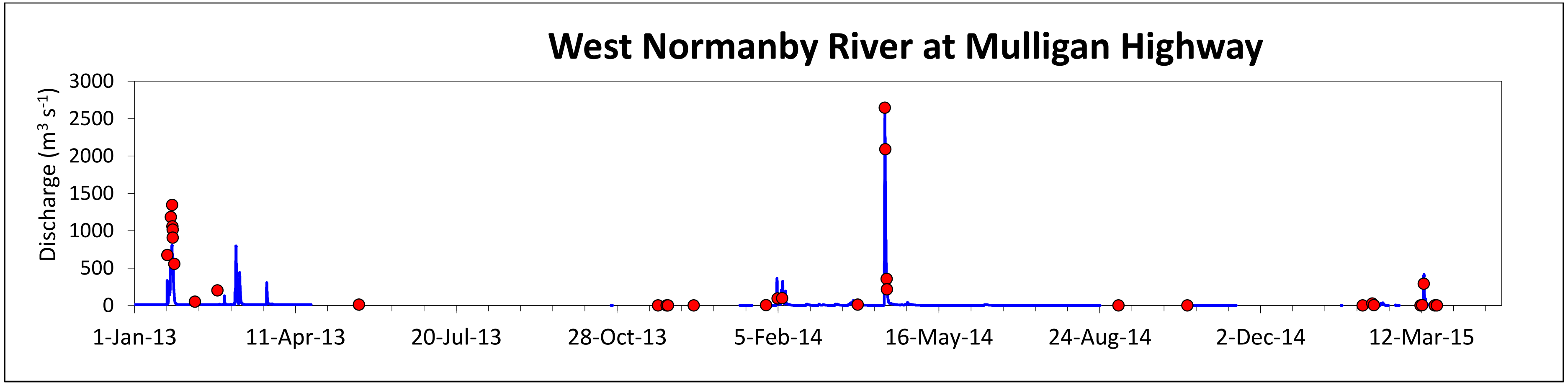

Figure 6: Sample collection time plotted against river discharge at the West Normanby River near historic gauge site 105106A. Discharge at this discontinued DERM gauge site was estimated by Griffith University using stage recorders installed at the site. Gaps represent periods of low or no flow.

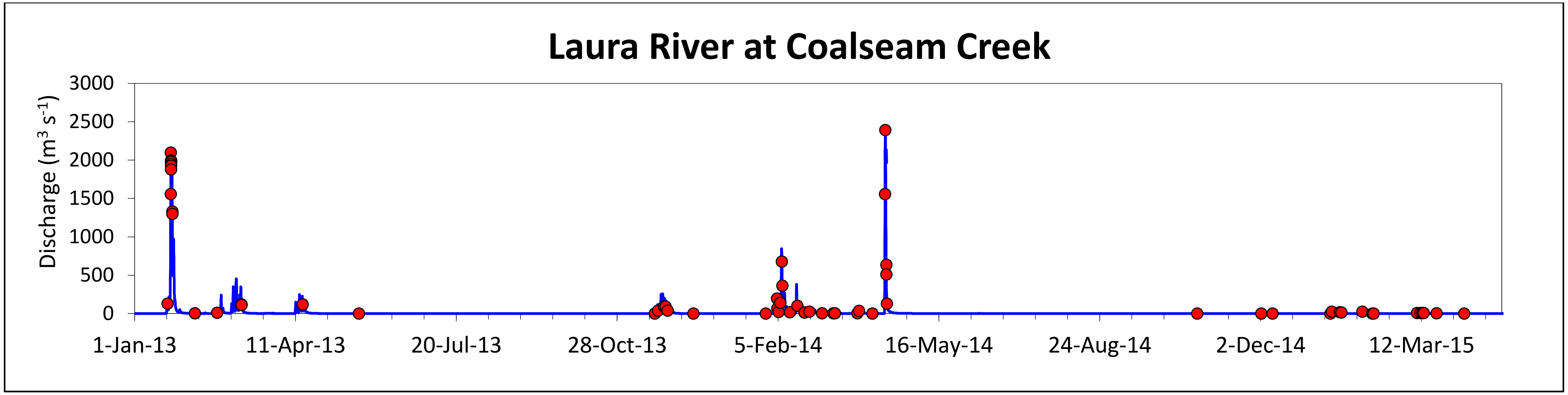

Figure 7: Sample collection time plotted against river discharge at the Laura River near gauge site 105102A

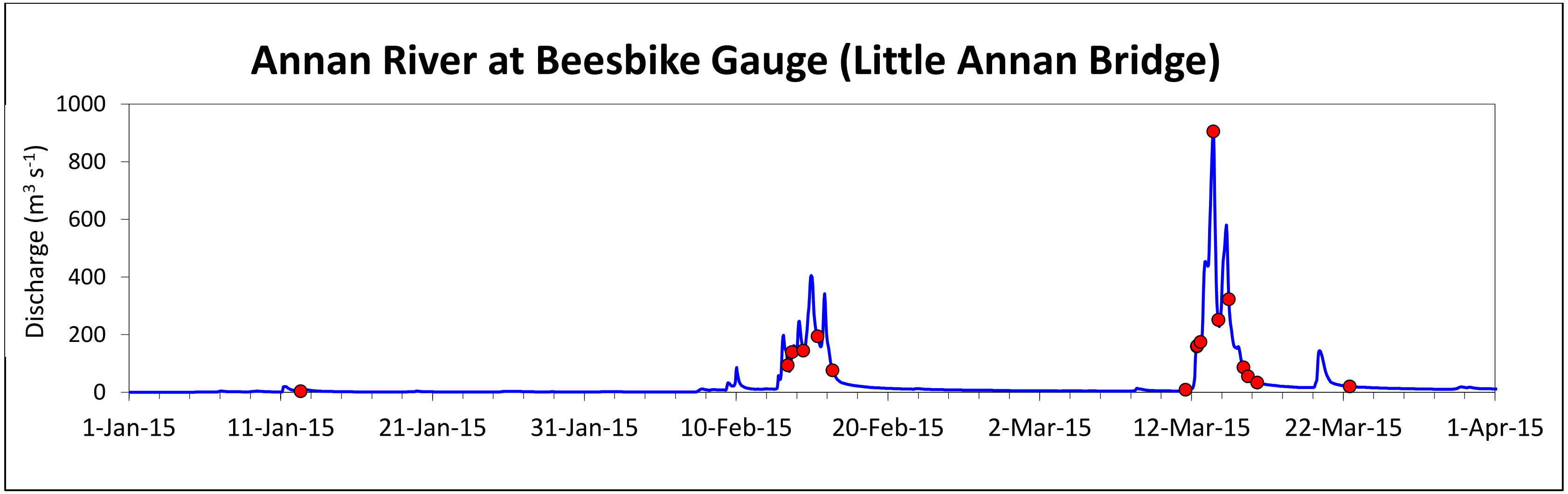

Figure 8: Sample collection time plotted against river discharge at the Annan River Beesbike gauge (107103A)

2.3 Sediment Ratings Curves

Logarithmic-scale graphs of instantaneous water discharge vs. suspended sediment concentration (sediment ratings curves) were produced for gauged monitoring sites to evaluate the different relationships for given years and individual events and assess the ability of water discharge to predict sediment concentration. Sediment ratings curves for all sites are presented in Appendix A (Figures A1- A15). Nutrient rating curves have only been evaluated to date for the West Normanby and Annan Rivers (Figures A13 and A15), with more analysis to come in the future.

Suspended sediment concentrations from well-sampled events were also plotted individually against water discharge on a logarithmic-scale graph to observe consistent static or non-static relationships over given events. Hysteresis loops (non-static) in a sediment rating curve occur when there are changing sediment supply conditions over the course of an event, such as sediment supply exhaustion or the mixing of water from multiple sources with different sediment concentrations. Without continuous concentration data during a flood event, some form of averaging, interpolation or ratio calculation is needed to estimate pollutant concentrations in-between sampling events using the available continuous water discharge data. However, water discharge is often a poor predictor of pollutant concentration where there is non-static hysteresis in rating curves. It is difficult to overcome hysteresis effects without either very frequent sampling (hourly to daily), or the use of continuous surrogate technologies such as continuous turbidity meters or particle analysers (Shellberg et al. 2016).

If reasonable power equation relationships on a log-log graph are indicated by the ratings curve, the resulting power regression equation can be applied over an event, year, or multiple years to calculate loads based on the discharge data. However, this method assumes that the rating curve relationship is consistent over events, seasons and years due to relatively consistent sediment supply and static catchment conditions (i.e., land use and vegetation), and that an average trend-line is a reasonable predictor of concentration over time. For this report, multi-year power regression equations are used to calculate sediment and nutrient loads at the West Normanby and Annan Rivers over the period of WY 2013-2015; the period during which most of the event concentration data was collected. This method could also be used to compare loads at other CYP gauge sites for previous years with limited or no concentration data. This would allow for the comparison of loads at multiple gauges over a consistent period of record using all available data.

2.4 Sediment and Nutrient Load Calculations

In this report, several empirical load calculation methods are compared. The accuracy of the load estimate will depend on the proper application of the most appropriate load estimation method, the sampling regime, and field measurement error of average sediment concentration. Little can be done to compensate for data sets which contain an insufficient number of observations or lack of isokinetic width-depth sampling of average sediment concentrations.

Load estimations were calculated for most sites using the Loads Tool component of the software Water Quality Analyser 2.1.1.4 (eWater 2011). Loads were calculated using multiple methods, including linear interpolation, the Beale ratio and power regression (rating curve) methods. These methods are described in Appendix B. In addition, a simple power regression equation with a logarithmic correction factor (Duan 1983; Ferguson 1986) was also used to calculate loads for the Annan River and West Normanby sites. The results from each method (linear interpolation, Beale ratio and power regression methods) are presented in Appendix C to demonstrate the range of load values estimated for each site. The most appropriate method (Best Estimate) for each site and year was determined based on the number and distribution of samples collected for a given water year (Thomson et al. 2012), the appearance of the rating curve (i.e. the presence of hysteresis), and the goodness of fit (R^2) of the power regression. In general:

- Linear interpolation generally was not selected, as few sites had sufficient daily or sub-daily data across all flood events, except for the Normanby Kalpowar gauge.
- If the majority of major events had multiple samples collected on both the rise and falling stage with the rating curve showing acceptable levels of hysteresis and decent goodness-of-fit, then the concentration power curve (regression) method was selected as the Best Estimate.
- If the majority of events were poorly sampled, or major hysteresis was always present, then the Beale ratio was highlighted as the Best Estimate.

Annual loads were estimated for suspended sediments (TSS/SSC) and nutrients, including total nitrogen (TN), particulate nitrogen (PN), dissolved organic nitrogen (DON), oxidised nitrogen (NOx), ammonium nitrogen (NH_4), total phosphorus (TP), particulate phosphorus (PP), filterable reactive phosphorus (FRP) and dissolved organic phosphorus (DOP).

The best estimates of nutrient and sediment loads for each site are presented in Table 1. Only the manual power regression methods have been applied to the West Normanby and the Annan River estuary sites. Dissolved nutrient loads were not calculated for these two sites because the ratings curves showed very poor (R^2<0.5) relationships between discharge and concentration (with the exception of FRP at the West Normanby). Estimates using the Beale ratio will be calculated in the near future. No nutrient loads have been calculated for the Normanby River Kalpowar gauge in the 2012-13 water year due to insufficient nutrient sample collection during flood events that year.

2.5 Load Uncertainty

The uncertainty of load estimates comes from several sources (Figure 9). Knowledge uncertainly relates to the choice of empirical and statistical model for load estimation (FISP 1963; Helsel and Hirsch 2002; Tennakoon et al. 2011). Stochastic uncertainly relates to the variability and frequency of field sampling (Helsel and Hirsch 2002; Thomson et al. 2012). Measurement uncertainly relates to the accuracy and precision of field and laboratory techniques (APHA 1995; ASTM 2005; Gray et al. 2000; Edwards and Glysson 1998; USGS 2003; Wong et al. 2003).

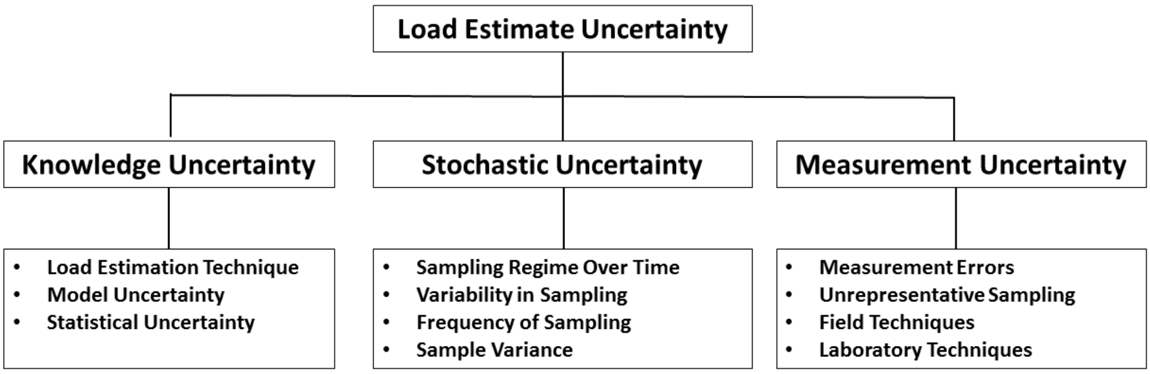

Figure 9: Sources of load estimate uncertainty (after Tennakoon et al. 2011).

The current field data available for Cape York prevent the full assessment of stochastic uncertainly or field measurement uncertainly (Shellberg et al. 2016). For example, the lack of iso-kinetic width-depth sampling prevents the calculation of average cross-section concentrations. Load uncertainty is also influenced by errors in water discharge estimation, especially at the higher end of rating curves (floods), which are poorly measured for water discharge at many Cape York gauges. Improved field data sets are needed in the future following a 'Super Gauge' approach (Shellberg et al. 2016). Knowledge uncertainly in terms of load estimation technique with available data can be assessed using the mean square error (MSE), which calculates the predictive error from a given model to quasi-known values from field sampling including measurement uncertainty. The goodness-of-fit (R^2) of power regression equations can also be used to assess prediction accuracy.

The loads presented in this report represent the current best estimates of sediment and nutrient loads for Cape York rivers and sub-catchment sites. Due to the limitations of the field data sets and load analysis methods, the loads presented in this report are subject to a moderate to high level of uncertainty, with the highest levels of uncertainty applying to the Annan River estuary and West Normanby sites due to discharge calculation uncertainties, and at the Normanby River Battlecamp gauge due to poor flood sampling frequency. Furthermore, the West Normanby 2012-2013 stage-discharge estimates only covered the period from November 2012 to May 2013, so although this captured the major flow events, there may have been additional low flow after May resulting in the loads for this year being underestimated. Many of the loads uncertainties can be reduced through improvements in future field monitoring programs.

3 RESULTS

The "Best Estimates" for suspended sediment and nutrient loads are presented in Table 2. The results of all methods used to compare results at each site, and recent Source Catchments modelled load estimates for end of system sites, are presented in Appendix C.

Table 2: Suspended Sediment and Nutrient Load Estimates for Pascoe, Normanby and Annan River gauge sites

Site Code	Water Year	Discharge	TSS/SSC	TN	PN	DON	NH_3	NOx	TP	PP	DOP	PO_4	Method
		GL/year	ktonnes	tonnes									
Pascoe River 102102A	2014-15	1,315	56	527	142	254	12	69	21	17	13	1	Concentration Power Curve Fitting
Normanby River at Kalpowar 105107A	2006-07	1,766	58	723	170	499	22	36	87	20	49	23	Average Load (linear interpolation of conc.)
	2007-08	3,649	206	1841	595	1143	53	43	167	30	70	78	Average Load (linear interpolation of conc.)
	2008-09	2,350	101	1098	266	753	30	58	98	18	72	25	Beale Ratio
	2009-10	2,927	173	1326	65	1229	46	59	159	30	126	14	Beale Ratio
	2010-11	5,960	268	5605	481	839	68	74	318	31	159	141	Beale Ratio
	2011-12	1,162	46	494	139	338	9	13	87	3	65	28	Average Load (linear interpolation of conc.)
	2012-13	1,828	142										Beale Ratio
	2013-14	2,663	150	2069	623	1200	64	53	258	182	52	11	Concentration Power Curve Fitting
	2014-15	1,556											
Battlecamp 105101A	2013-14	953	584	1589	1256	273	9	55	530	503	13	15	Beale Ratio
	2014-15												
Laura River 105102A	2013-14	396	90	316	173	89	4	20	48	34	4	3	Concentration Power Curve Fitting
	2014-15	22	1	12	4	5	0	0	1	1	0	0	Concentration Power Curve Fitting
East Normanby 105105A	2013-14	166	38	135	71	32	1	26	16	14	2	1	Concentration Power Curve Fitting
	2014-15	94	19	83	40	21	1	11	10	8	1	0	Concentration Power Curve Fitting
West Normanby 105106A	2012-13	332	100	338	230				68	50		6	Power Regression (Rating Curve)
	2013-14	300	138	360	279				79	64		6	Power Regression (Rating Curve)
	2014-15	34	8	31	20				6	4		1	Power Regression (Rating Curve)
Annan River Beesbike 107003A	2014-15	303	24	142	67	44	2	37	21	19	3	1	Concentration Power Curve Fitting / Power Regression (Rating Curve)
Annan River estuary*	2014-15	600	71	271	132				38	32			Power Regression (Rating Curve)

*Shellberg et al. (2016) Calculated based on Water Year from October to September

4 Loads Targets and Future Monitoring

4.1 Load Reduction Targets

There are no empirical river gauge data for Cape York rivers from which to estimate the anthropogenic increase in pollutant loads, but rough estimates of loads increases have been made for some rivers based on the current knowledge of catchment disturbances and water quality impacts. Sedimentary records analysed by OSL dating has shown that there has been a ten-fold (10x) increase in the rates of gully erosion in some upper catchment tributaries of the Normanby (Brooks et al. 2013). From this and other downstream data on sediment deposition and reductions in specific sediment yield, it has been roughly estimated that there has been a doubling of sediment loads at the end-of-river of the Normanby catchment. Particulate nutrient loads are likely to have a similar increase associated with the increase of sediment loads. The relationship between increased sediment loads and dissolved nutrients is less certain. Monitoring in the Laura River indicates that dissolved inorganic nutrient concentrations have increased by approximately 10 times in the upper Laura as a result of horticultural land use (Howley 2010). Erosion and load changes in the Annan and other catchments has not been empirically quantified. However, in the Annan catchment, the mining history, widespread grazing and fire frequencies indicates that loads have at least doubled and were likely much higher during the peak of tin mining in the late 1800's (Shellberg et al. 2016).

Based on this existing knowledge of water quality impacts from moderate land use development on Cape York, but without accurate knowledge of what pre-European loads would have been, long-term loads reduction targets have been set by the consensus of the Cape York WQIP Science Advisory Panel. In accordance with the Reef 2050 Plan goals, the short term target is to reduce end-of-river anthropogenic loads by 20% (10% of total loads) for suspended sediment (SS), particulate nitrogen (PN) and particulate phosphorus (PP) in the Normanby, Annan and other more disturbed catchments. However, to achieve a 20% anthropogenic load reduction at the river mouth, a greater reduction will be needed at upstream sub-catchments sites where anthropogenic impacts are most concentrated (e.g. Laura River and West Normanby River). Thus, a 50% anthropogenic load reduction (25% of total) for suspended sediment and particulate nutrient loads has been set as a target for disturbed upper sub-catchment gauge sites (Table 3).

Insufficient data exists to set dissolved inorganic nutrient reduction targets for the Normanby, Annan, or other disturbed end-of-catchment sites. However, a 50% anthropogenic load reduction (25% of total) for nitrogen oxides and dissolved inorganic phosphorus is recommended for the Laura sub-catchment to reduce fertiliser impacts (Table 3).

For less disturbed river catchments on Cape York, such as the Pascoe and Olive, the goal is to maintain current loads as a maximum until anthropogenic impacts can be better quantified for these catchments. For more pristine catchments such as the Jacky-Jacky and Nesbit River, the goal is to maintain current sediment and nutrient loads with no net increases in human disturbance that might increase loads about current baselines.

Table 3: Total Load Reduction Targets

River	Monitored Site	SS	DIN	FRP	PN	PP
Pascoe River	102102A/ Garraway	MCL	MCL	MCL	MCL	MCL
Normanby River	105107A/ Kalpowar	10%	ID	ID	10%	10%
Upper Normanby	105101A / Battlecamp	25%	ID	ID	25%	25%
Laura River	105102A / Coal Seam	25%	25%	25%	25%	25%
East Normanby	105015A/ East Normanby	25%	ID	ID	25%	25%
West Normanby	105106A/ West Normanby[1]	25%	ID	ID	25%	25%
Upper Annan River	107003A / Beesbike	25%	ID	ID	25%	25%
Annan River Estuary	New gauge/ Big Annan Bridge	10%	ID	ID	10%	10%

MCL Maintain current load
ID Insufficient data

Applying reduction targets directly to annual loads values is problematic since these values are not static. Nutrient and sediment loads at all sites vary considerably depending on the annual water discharge, and other factors such as the timing and location of rainfall and catchment condition at the time of the first flood event. As a result, a percentage load reduction target is best applied to individual flood events based on an accurate measurement of both load and discharge, which can be used to evaluate ratings curves and to calculate event-mean-concentration (EMC). EMC is calculated as the integrated load for an event divided by the integrated water discharge for that event. EMC should be both time and discharge weighted. The accuracy of calculating an EMC is highly dependent on the sampling regimes within events and between different events. Opportunistic grab sampling and small sample sizes can lead to inaccurate estimates of EMC. Thus the EMC method is problematic without both continuous concentration and discharge data.

4.2 Future Monitoring of Loads and Reduction Targets

Future Cape York water quality monitoring programs plan to introduce improved gauging methods based on the ‘Super Gauge’ approach described by Shellberg et al. (2016) in order to set baseline conditions and more accurately monitor changes in loads over time. To reduce stochastic uncertainty in future loads calculations at existing and new priority gauge sites, continuous concentration data for sediment and nutrients will be collected using continuous surrogate measurements (e.g., turbidity), automatic pump sampling of water for concentration analysis triggered by turbidity, and additional iso-kinetic width-depth integrated monitoring. It has been shown that continuous turbidity recording may avoid the significant uncertainty introduced to sediment loads estimates by interpolation and extrapolation of low frequency measurements (Grayson et al., 1996; Lewis, 1996). Suspended sediment concentrations (SSC) will be correlated to and estimated from continuous turbidity (NTU). Event scale rating curves of SSC-vs-NTU will be developed, along with corrections for average width-depth concentrations, to improve calculations of event-scale load. These accurate event loads from continuous data will be used along with event water discharge to calculate the time and discharge weighted event mean concentrations (EMC). Over time and within several years, event-scale loads can be plotted against event-scale water discharge (ML). From these plots, any reduction in actual loads will become evident in a downward shift in these load rating curves over time, and thus reduction in EMC for a given event size, proving or disproving any claims in actual load reduction toward 10 to 25% total load reduction targets.

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6 APPENDIX A: RATING CURVES

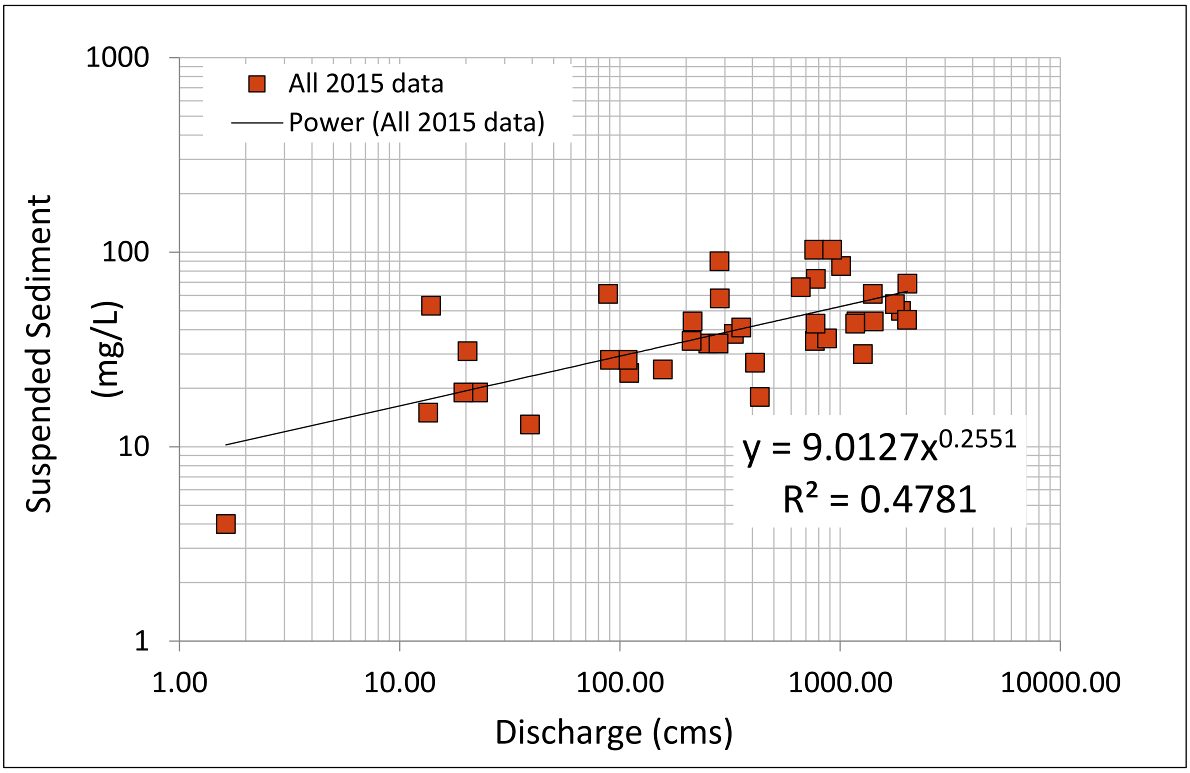

Figure A1: Pascoe River (102102A) Rating Curve for all data from 2015

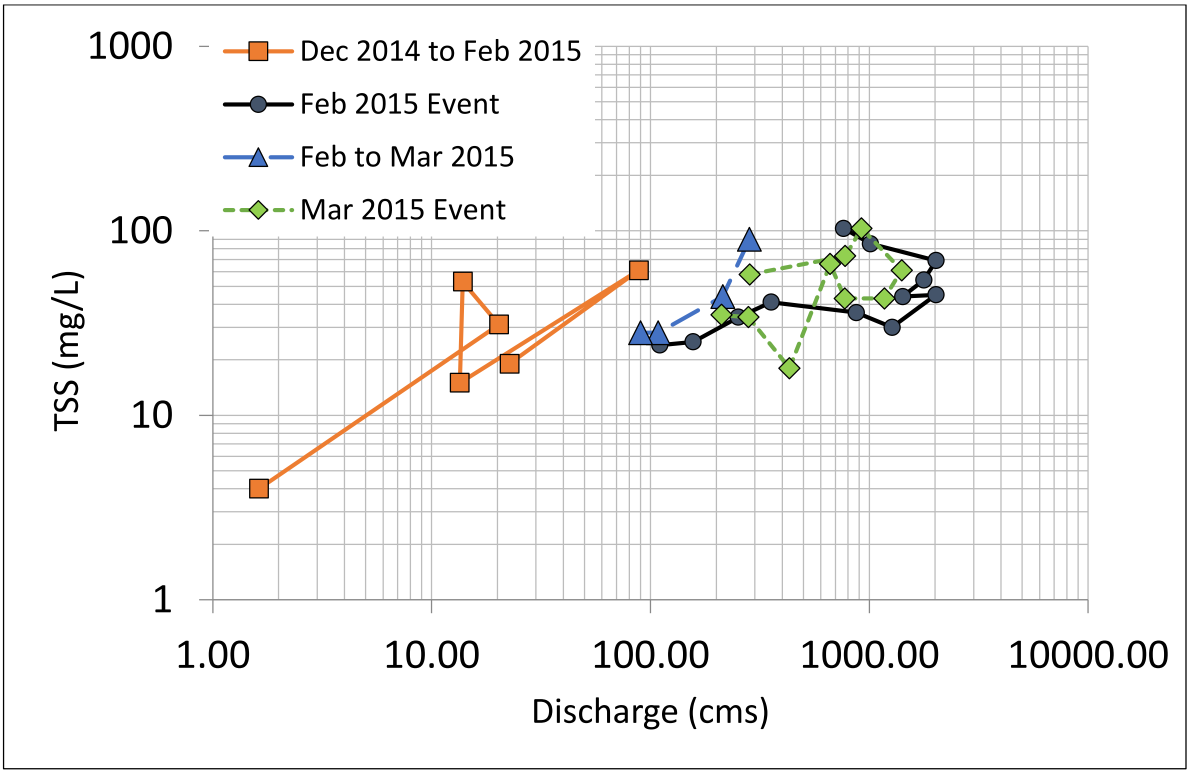

Figure A2: Pascoe River (102102A) Rating Curve showing individual events and hysteresis

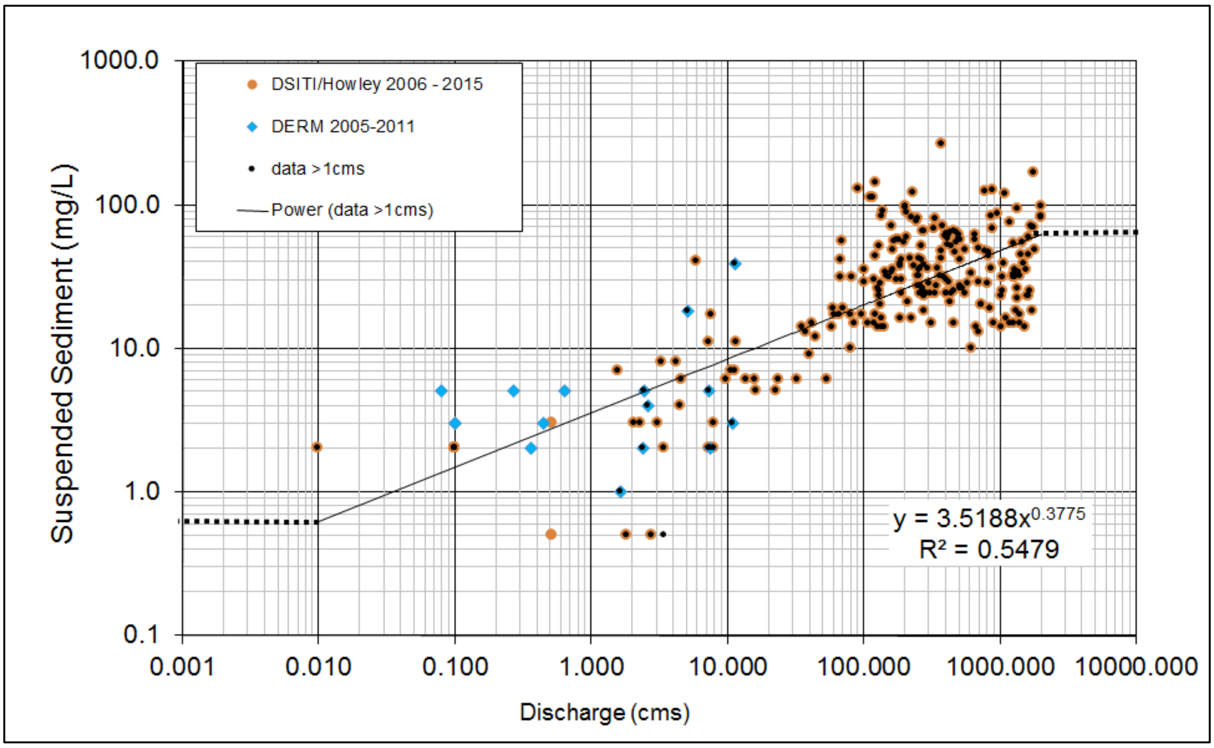

Figure A3: Normanby River Kalpowar (105107A) Rating Curve for all data 2005 - 2015

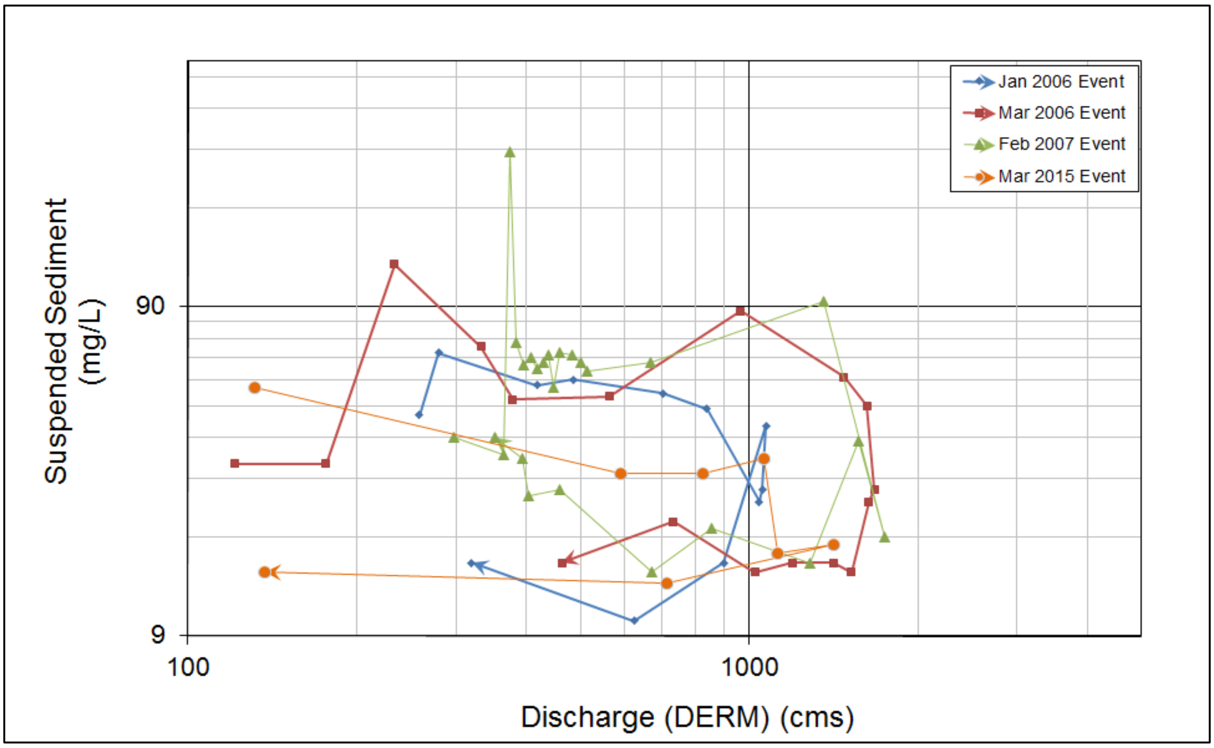

Figure A4: Normanby River Kalpowar (105107A) Rating Curve showing individual events and hysteresis (arrows indicate direction of time)

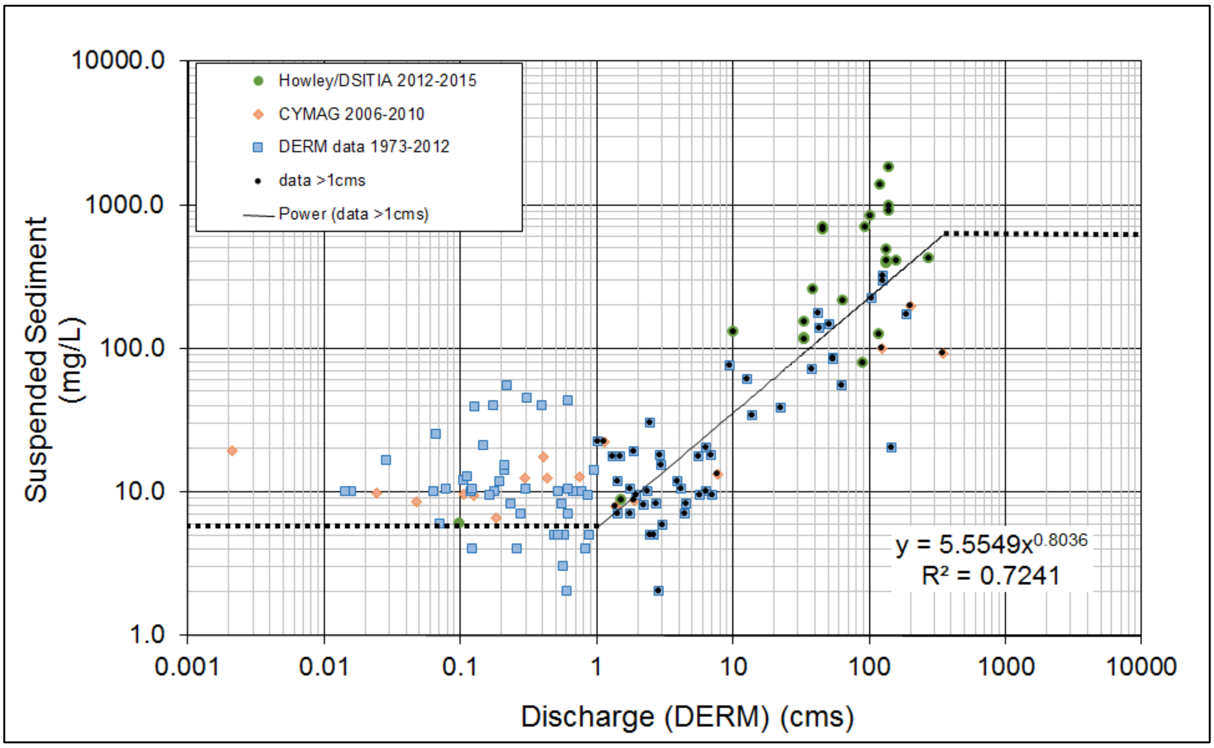

Figure A5: Normanby River Battlecamp (105101A) Rating Curve for all data 1973 - 2015

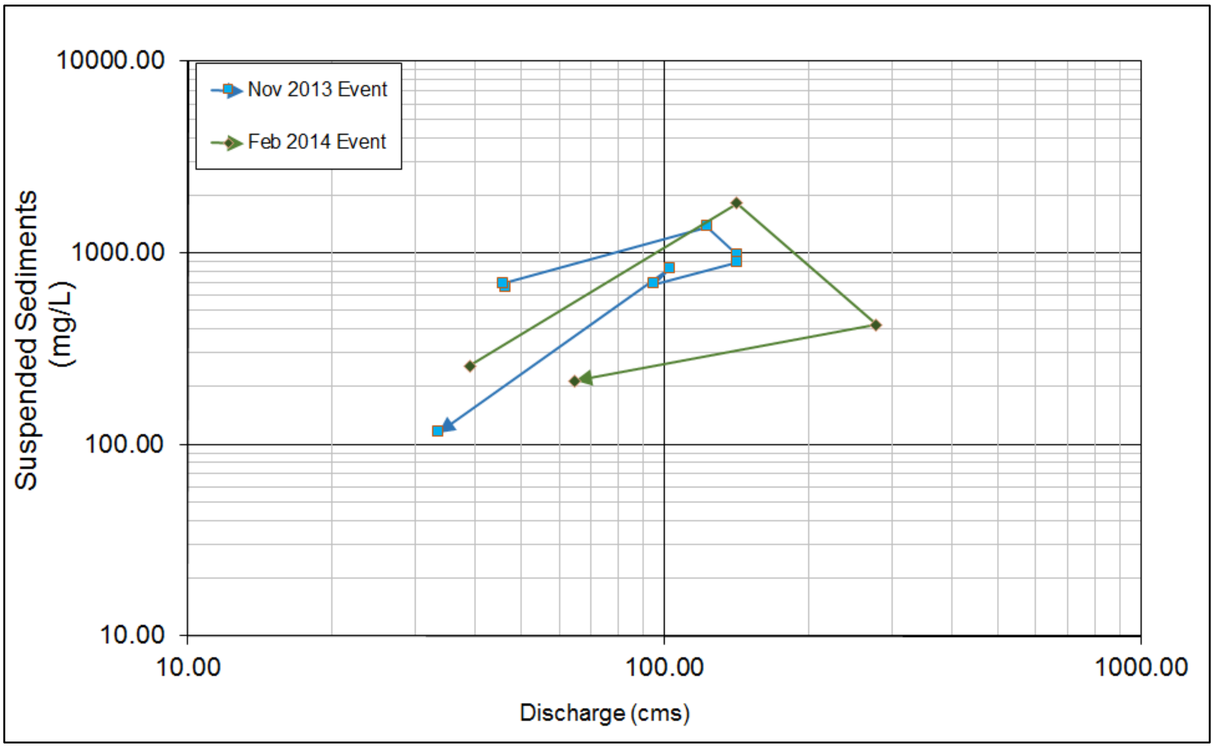

Figure A6: Normanby River Battlecamp (105101A) Rating Curve showing individual flood events and hysteresis (arrows indicate direction of time)

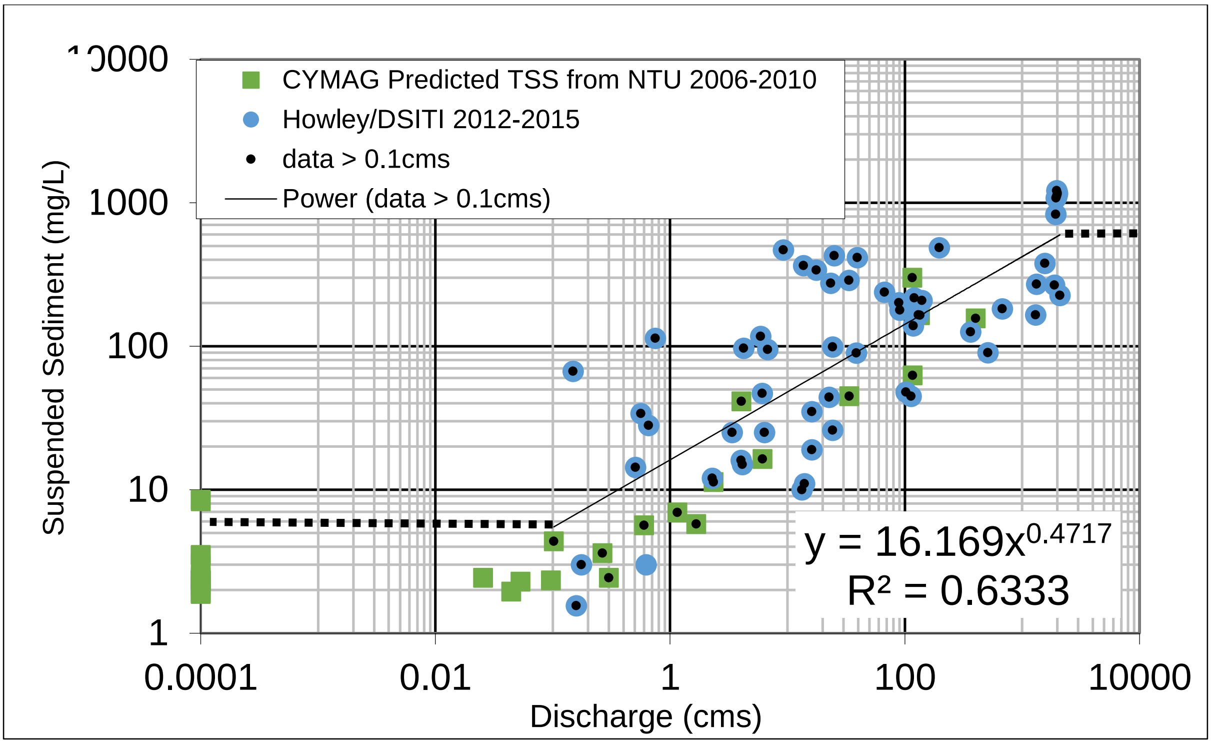

Figure A7: Laura River (105102A) Rating Curve for CYMAG and Howley/DSITIA data 2006 – 2015

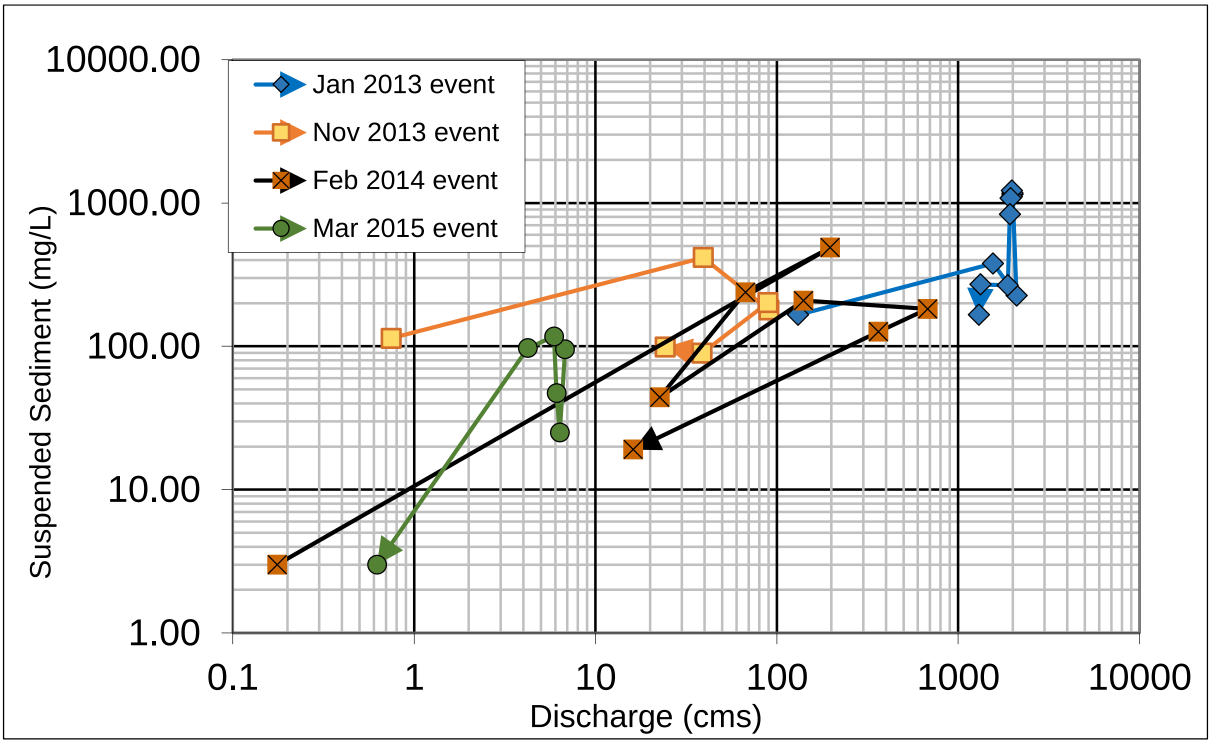

Figure A8: Laura River (105102A) Rating Curve showing individual flood events and hysteresis (arrows indicate direction of time)

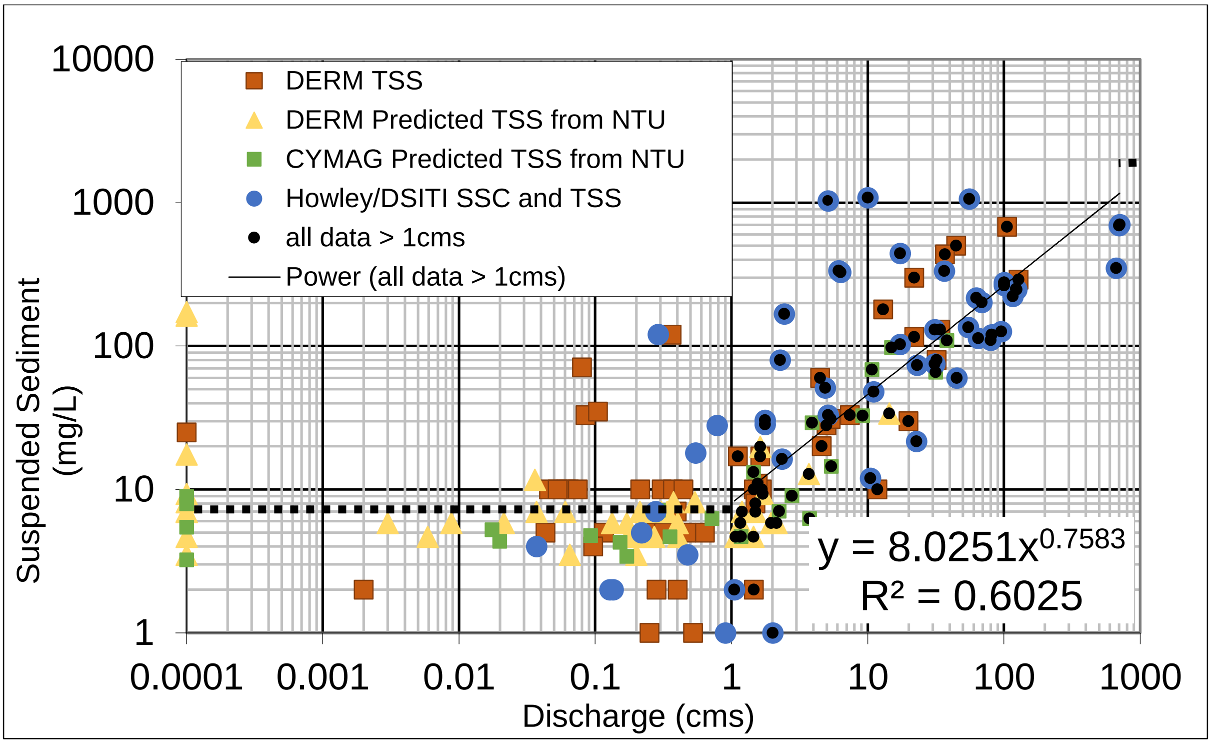

Figure A9: East Normanby River (105105A) Rating Curve for all suspended sediment data (1973 – 2015)

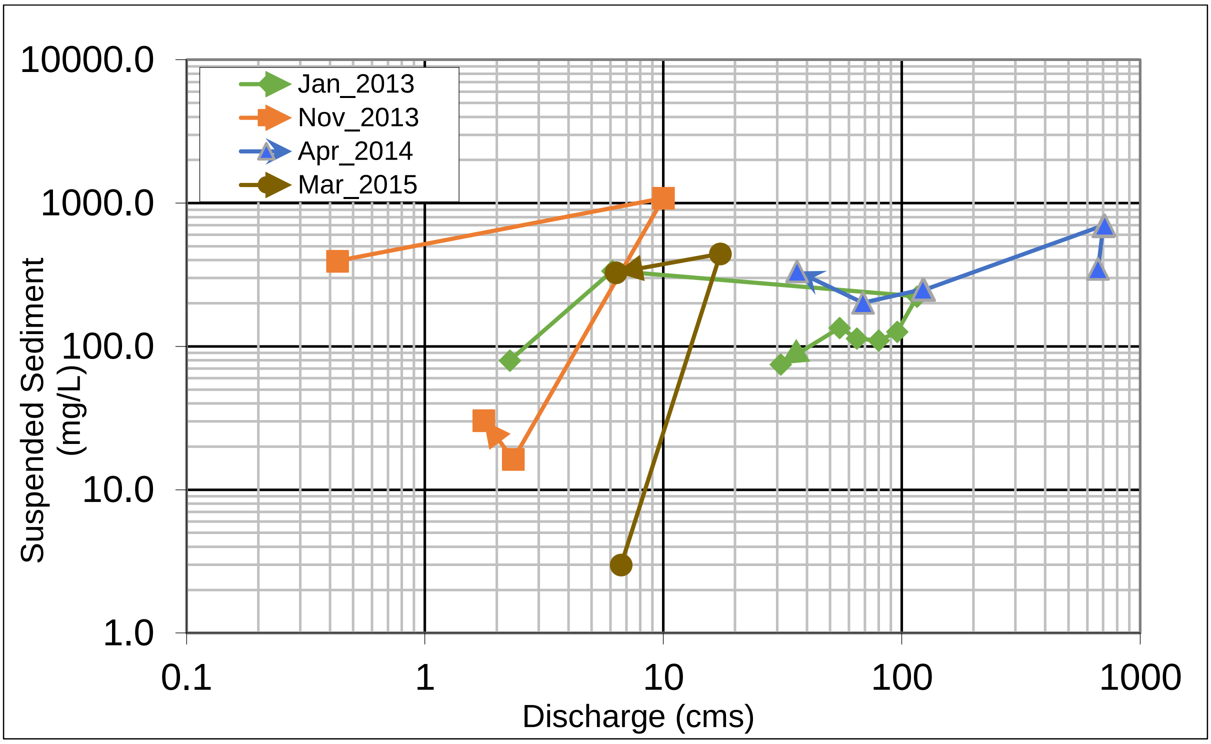

Figure A10: East Normanby River (105105A) Rating Curve showing individual flood events and hysteresis (arrows indicate direction of time)

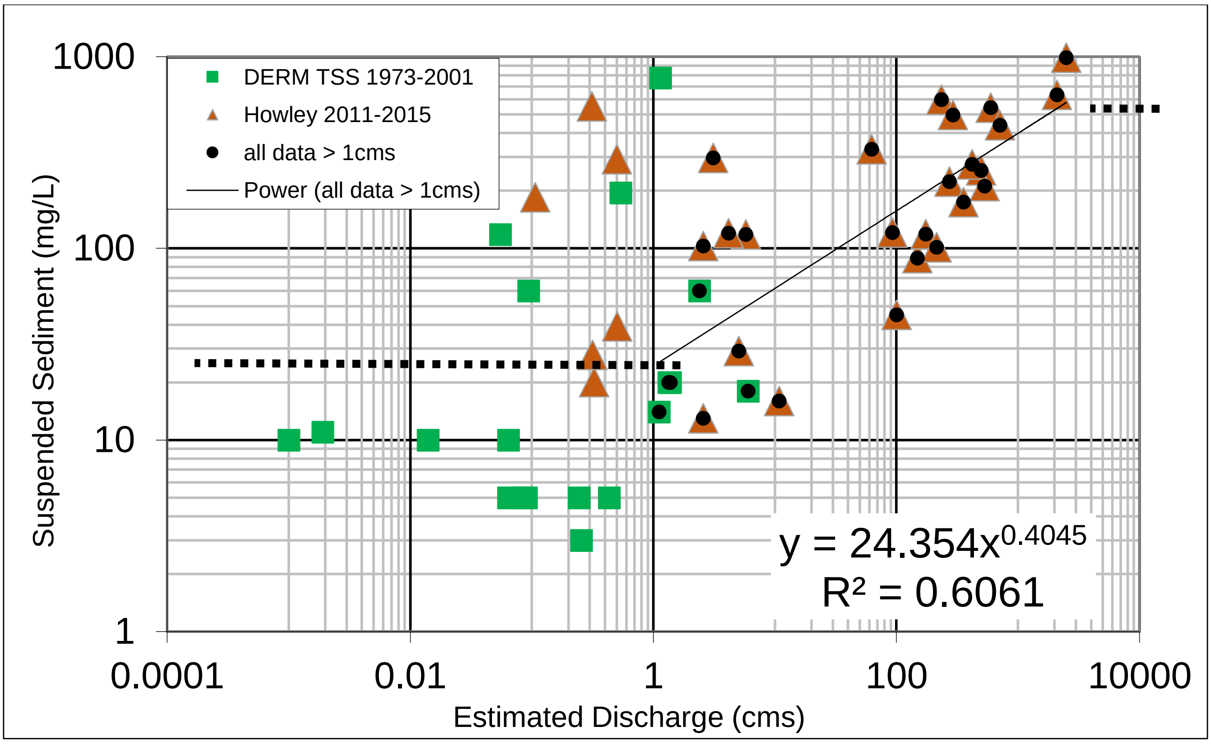

Figure A11: West Normanby River (historic gauge 105106A) Rating Curve for all recent and historic data. Discharge calculated from Griffith University stage recorder (Shellberg unpublished data).

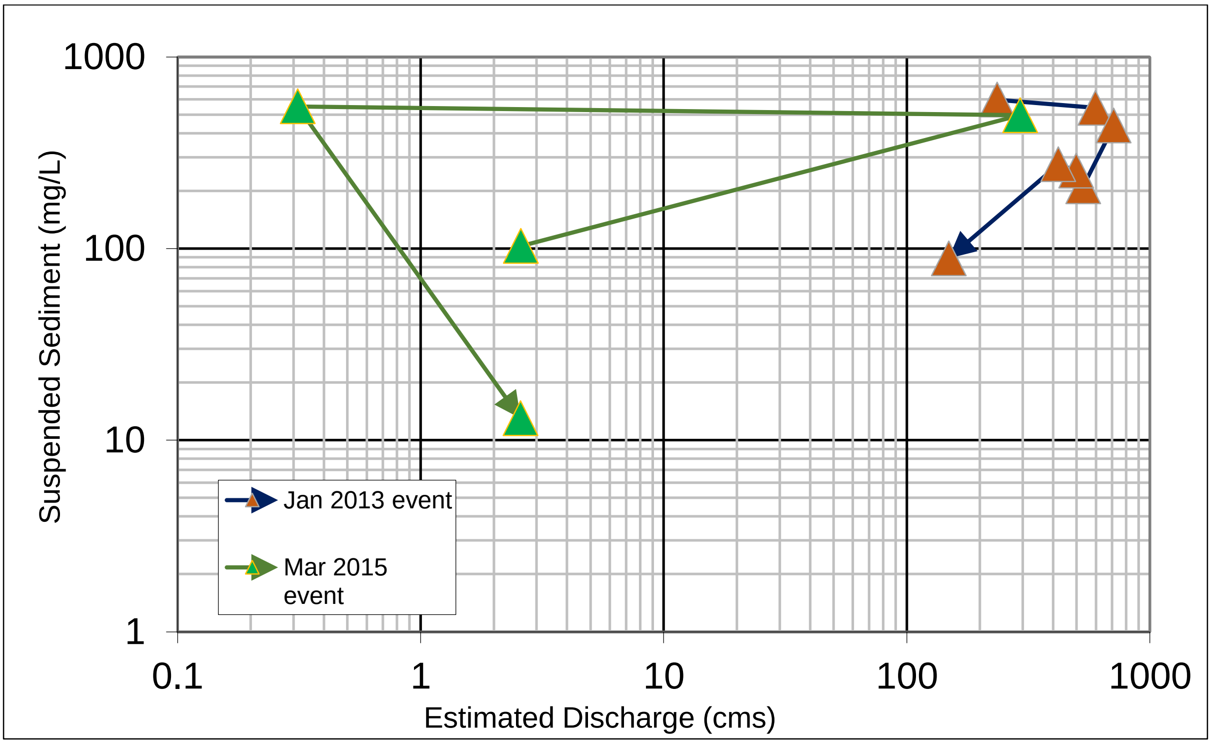

Figure A12: West Normanby River (historic gauge 105106A) Rating Curve showing individual flood events and hysteresis (arrows indicate direction of time).

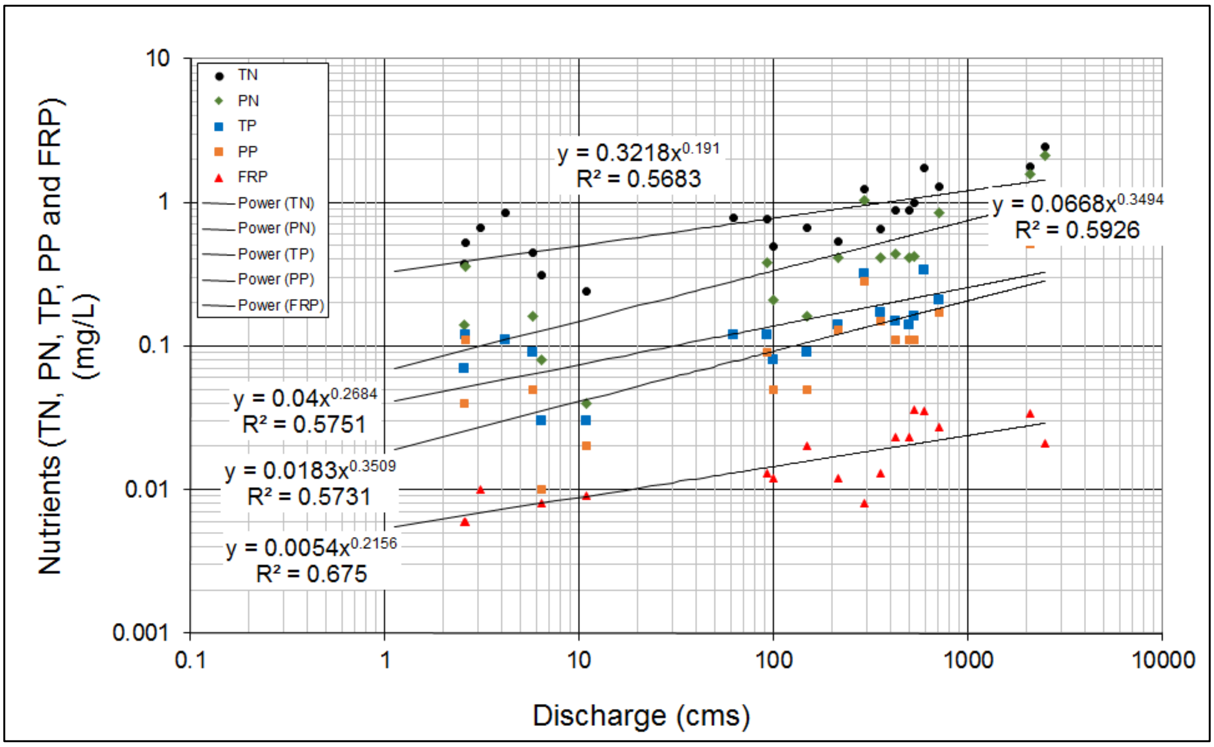

Figure A13: West Normanby River (historic gauge 105106A) Nutrient Rating Curves for all recent and historic data at discharge >1 cms. Recent discharge estimated from Griffith University stage recorders (Shellberg unpublished data).

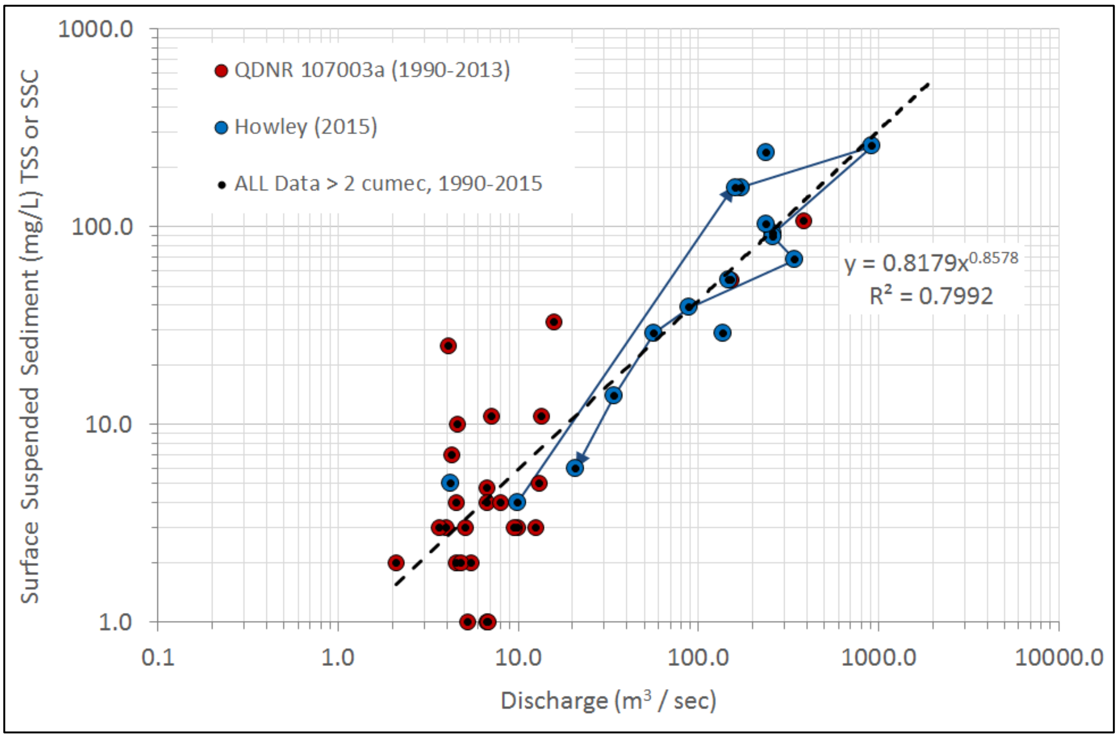

Figure A14: Suspended sediment rating curve from concentration data of suspended sediment and water discharge at the Annan River at Beesbike (107003a) for samples collected > 2 m³/sec in 2015 and some miscellaneous data from 1991-2015. Hysteresis path during the March 2015 (cyclone Nathan) event shown by blue line. (Graph from Shellberg et al. 2016)

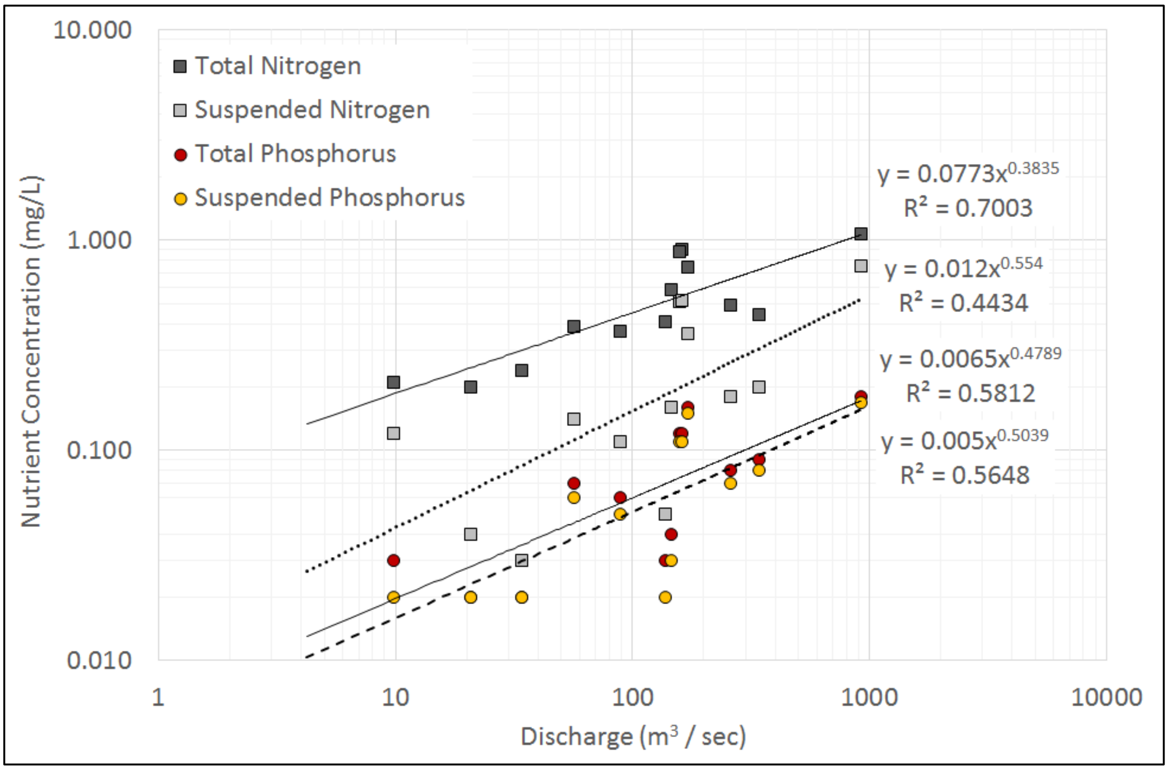

Figure A15: Nutrient rating curves for WY 2015 flood event data at the Beesbike gauge (107003a) (Shellberg et al. 2016)

7 APPENDIX A : LOADS CALCULATION METHODS

Annual loads were calculated by a range of different methods for comparison. The average load (linear interpolation of concentration), Beale ratio and concentration power curve methods were selected to calculate loads using the software Water Quality Analyser 2.1.1.4 (eWater 2011). These methods were applied using the following equations:

Average Load (Linear interpolation of concentration):

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

Where c is the j^{th} sample concentration, and q_j is the inter-sample mean flow (eWater 2011).

Beale ratio:

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

where Q is the total discharge for the period, l is the average load for a sample, L is the observed load, 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 2011; Joo et al. 2012).

Concentration Power Curve (Regression):

This method uses a simple power function to develop the relationship between water discharge (flow rate) and concentration using the samples collected for that water year.

$C = aQ^b$

where **C** is concentration, **a** is coefficient, **Q** is water discharge and **b** is coefficient.

Once the regression relationship is established, it can be used to estimate concentrations for time periods in which a samples were not taken. The total load is calculated as the sum of the loads obtained by multiplying the measured or estimated concentrations by the water discharge.

Power Regression (Multiple Year Rating Curve with correction factor):

Additional loads estimates were calculated manually (not using the WQA software) using power regression equations produced from sediment or nutrient concentration and discharge rating curves (Figures A1 to A15) with a logarithmic correction factor as per Duan (1983) and Ferguson (1986). The corrected regression equations were applied to the 15-minute interval discharge measurements from the West Normanby (2012-2015) and Annan River Beesbike (2015) sites. The total load was calculated as the sum of the 15-minute loads obtained by multiplying the estimated concentrations by the water discharge.

$$\mathbf{C = cf\ (aQ^{b})}$$

Where **C** is concentration, **a** is coefficient, **Q** is flow, **b** is coefficient and **cf** is the correction factor derived from the following equation:

$$\mathbf{c_f = \sum (10\text{^}(LOG10(mc))\text{-}(LOG10(pc)))/n}$$

mc = measured concentration, pc = predicted concentration (from power regression equation), n = number of measured samples.

8 APPENDIX C: COMPARISON OF LOADS CALCULATIONS BY VARIOUS METHODS

Site Code	Water Year	Discharge	TSS/SSC	TN	PN	DON	NH3	NOx	TP	PP	DOP	PO4	Method
		ML/yr	tonnes										
Pascoe River 102102A	2014-2015	1,314,878	60996	548	209	258	13	72	32	25	13	1	Average Load (linear interpolation of conc.)
			68551	614	215	297	16	74	32	24	13	2	Beale Ratio
			56324	**527**	**142**	**254**	**12**	**69**	**21**	**17**	**13**	**1**	**Concentration Power Curve Fitting**
Pascoe End-of-River			18,520		64		55			20		9	Source Catchments model
Normanby River Kalpowar 105107A	2006-07	1,765,705	58518	723	170	499	22	36	87	20	49	23	Average Load (linear interpolation of conc.)
	2007-08	3,649,220	206429	1841	595	1143	53	43	167	30	70	78	Average Load (linear interpolation of conc.)
	2008-09	2,349,685	100584	1098	266	753	30	58	98	18	72	25	Beale Ratio
	2009-10	2,927,302	173214	1326	65	1229	46	59	159	30	126	14	Beale Ratio
	2010-11	5,960,435	268468	5605	481	839	68	74	318	31	159	141	Beale Ratio
	2011-12	1,162,420	46207	494	139	338	9	13	87	3	65	28	Average Load (linear interpolation of conc.)
	2012-13	1,827,697	142316										Beale Ratio
	2013-2014	2,635,687	241491	2030	652	1289	48	39	297	238	53	26	Average Load (linear interpolation of conc.)
			245728	2089	698	1309	50	35	310	247	53	29	Beale Ratio
			150199	**2069**	**623**	**1200**	**64**	**53**	**258**	**182**	**52**	**11**	**Concentration Power Curve Fitting**
	2014-2015	1,556,339											
Normanby End-of-River			180723		**326**		**52**			**96**		**11**	Source Catchments model
													Griffith University model?

Site Code	Water Year	Discharge ML/yr	TSS/SSC	TN	PN	DON	NH3	NOx	TP	PP	DOP	PO4	Method
			tonnes										
Normanby River Battlecamp 105101A	2013-2014	952,875	320475	770	520	203	6	39	222	206	10	9	Average Load (linear interpolation of conc.)
			584097	**1589**	**1256**	**273**	**9**	**55**	**530**	**503**	**13**	**15**	**Beale Ratio**
			868838	1980	1683	363	11	102	692	726	12	24	Concentration Power Curve Fitting
Laura River 105102A	2013-2014	396,364	73020	302	196	77	6	18	72	63	5	7	Average Load (linear interpolation of conc.)
			97971	361	273	67	7	10	105	93	5	9	Beale Ratio
			89748	**316**	**173**	**89**	**4**	**20**	**48**	**34**	**4**	**3**	**Concentration Power Curve Fitting**
	2014-2015	22,559	3632	16	5	6	0	0	2	1	0	0	Average Load (linear interpolation of conc.)
			4435	18	7	6	0	0	3	2	0	0	Beale Ratio
			1087	**12**	**4**	**5**	**0**	**0**	**1**	**1**	**0**	**0**	**Concentration Power Curve Fitting**
East Normanby 105105A	2013-2014	166,448	39168	187	147	31	1	8	25	24	2	1	Average Load (linear interpolation of conc.)
		166,448	50837	365	313	25	1	11	61	59	2	1	Beale Ratio
		166,448	**38485**	**135**	**71**	**32**	**1**	**26**	**16**	**14**	**2**	**1**	**Concentration Power Curve Fitting**
	2014-2015	93,764	30770	120	85	22	1	10	20	18	1	1	Average Load (linear interpolation of conc.)
		93,764	37425	152	109	25	1	18	25	23	1	1	Beale Ratio
		93,764	**19365**	**83**	**40**	**21**	**1**	**11**	**10**	**8**	**1**	**0**	**Concentration Power Curve Fitting**
West Normanby 105106A	2012-2013	331,755	**99599**	**338**	**230**				**68**	**50**		**6**	**Power Regression (Rating Curve)**
	2013-2014	300,330	**138462**	**360**	**279**				**79**	**64**		**6**	**Power Regression (Rating Curve)**
	2014-2015	33,753	**8229**	**31**	**20**				**6**	**4**		**1**	**Power Regression (Rating Curve)**

Site Code	Water Year	Discharge	TSS/SSC	TN	PN	DON	NH3	NOx	TP	PP	DOP	PO4	Method
		ML/yr	tonnes										
Annan River Beesbike 107003A	2014-2015	303,439	19123	141	59	43	2	32	19	16	3	1	Average Load (linear interpolation of conc.)
		303,439	44389	225	127	56	3	37	36	33	3	1	Beale Ratio
		303,439	22395	139	54	**44**	**2**	**37**	18	16	**3**	**1**	**Concentration Power Curve Fitting**
	2014-2015*	283,726	**24011**	**142**	**67**				**21**	**19**			**Power Regression (Rating Curve)**
Annan Estuary 107010	2014-2015*	516,303	**71,500**	**271**	**132**				**38**	**32**			**Power Regression (Rating Curve)**
Annan-Endeavour Basin			20,938		**157**		**41**			**32**		**8**	Source Catchments model (includes Annan and Endeavour River loads)

*Shellberg et al (2016) loads calculated based on water year October – September.