Temporal changes in catchment sediment and nutrient loads and the influence of riparian forests.

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Summary

Event sediment and nutrient loads have been calculated from water quality and hourly discharge data from eight sites across South East Queensland. The catchments range in size from 56 to 2965km^2. In total 5694 water quality samples were collected and analysed. In most cases there is very good coverage of both low flow periods, and event flows, with samples being collected through the hydrographs. Total loads were calculated for 374 events across the eight catchments. The event data were divided into pre and post 1-1-2012 and ANOVA tests were used to determine if there had been any change in TSS, TP and TN yields. Only two sites showed a change in the log load to log discharge relationships between the two periods; sediment loads declined by 2.6 times for Laidley Creek at Warrego Highway, and total phosphorus increased by 1.6 times in Coochin Creek. The lack of any significant change at most sites was not surprising given that an analysis of land use indicates there has been very little change in the eight catchments over these periods. The decrease in sediment yields for Laidley Creek at Warrego Highway is attributed to an improvement in channel condition between the two periods. The increased total phosphorus loads in Coochin Creek are the result of increased TP concentrations, but the cause is yet unknown.

Data from these eight sites for the period 2002 to 2010 had been used previously, in conjunction with data from fourteen now discontinued monitoring sites, to test the hypothesis that sediment and nutrient loads from catchments decrease proportionally with the increasing proportion of the stream length draining areas of remnant vegetation. Here we use the additional event loads data from these sites in combination with the previous data, and recent mapping of the riparian forest cover. This mapping indicates that for most of the catchments the riparian forest cover is far more extensive than previously estimated (by ¼ of the catchment stream length). The previous under-estimate of forest cover resulted in an over-estimate of the effectiveness of riparian vegetation in decreasing sediment and nutrient loads. The sediment yield per unit area from a catchment containing no riparian forest is now predicted to be between 5 and 10 times that of a fully vegetated channel network, with a best estimate of 7 times (previously 100 times). For total phosphorus (TP) this is between 12 and 21 with a best estimate of 16 times (previously 40), and for total nitrogen (TN) between 2.4 and 3.9 with a best estimate of 3.0 times (previously 2.1 – the increase results from the removal of a non-conforming catchment - Coochin Creek).

The analyses and data presented enable testable hypotheses to be proposed. For instance, in the Warrill Creek catchment there are 1955km of channel of which 723km is well vegetated. Currently the annual sediment load is 40,140t/yr. Increasing the riparian forest cover from 37%, by 550km, to 65% is predicted to decrease the annual load by ~50% to 22,500t/yr; increasing to 100% cover would drop this to 11,300t/yr. These statements are all testable by continuing the water quality and stream flow monitoring while revegetating the riparian zone. Once revegetation areas are established measuring between 6 and 10 events would be sufficient to statistically test these statements.

Cover photograph: Mid-Brisbane River at Burtons Bridge taken by Mark Waud one week after the 2022 floods. Rehabilitation works are now underway at this site (2024).

1.0 Introduction

A decline in the ecosystem health of Australia's Moreton Bay, a Ramsar wetland of international significance, has been attributed to sediments and nutrients derived from catchment sources (Bunn et al., 2007; Leigh et al., 2013). The upper catchments of the region's rivers have undergone large-scale clearing of native forests for agricultural production resulting in a 3 to 9 fold increase in sediment accretion in the bay over the last 100 years (Coates-Marnane et al., 2016). Studies into the sources of sediment and associated nutrients have shown a dominance of channel erosion (Wallbrink, 2004; Olley et al., 2013). These studies proposed that conservation works aimed at reducing sediment and associated nutrient loads to the Bay should focus primarily on rehabilitation, through reforestation, of the gully and channel network and decreasing the runoff. To quantify the likely effectiveness of such revegetation strategies Olley et al., (2015) evaluated the relationship between remnant catchment vegetation and sediment and nutrient loads delivered to waterways in the region. They tested the hypothesis that sediment and nutrient loads from catchments decrease proportionally with the increasing proportion of the stream length draining areas of remnant vegetation. Event-load data were measured in 186 flow events between 2002 and 2010 across 22 sub-catchments with different proportions of remnant vegetation. The sediment yield per unit area from a catchment containing no remnant vegetation was predicted to be between 50 and 200 times that of a fully vegetated channel network; total phosphorus between 25 and 60 times; and total nitrogen between 1.6 and 4.1 times. Of the 22 monitoring sites they examined data from, eight are still active, or have been active until recently. Here we examine the additional data from these sites, evaluate if there has been any change in the "at site" discharge-load relationships and re-evaluate the likely effectiveness of riparian revegetation strategies using more up to date mapping of the riparian forest cover (Healy, 2022).

2.0 Methods

2.1 Study area

Moreton Bay is in Southeast Queensland on the eastern coast of Australia (Figure 1). Catchments draining into the Bay have an area of approximately 22,600km^2 with a peak elevation of 1360m in the west along the Great Dividing Range (Abal et al., 2005; Bunn et al., 2007). The region is subtropical with mean maximum monthly temperatures ranging between 21 and 29°C. The total annual rainfall ranges between 900 and 1800mm, with the majority falling during the warm spring and summer months (October to February). Prior to European settlement, in 1823, the region's waterways were extensively covered with woody vegetation (NVIS, 1997; Kemp et al., 2015). European settlement, and associated land clearing, agriculture, and grazing activities has led to significant increases in sediment loads to Moreton Bay (Dennison and Abal, 1999; Saxton, et al., 2012, Coates-Marnane et al., 2016). Approximately two thirds of the native woody vegetation in the region have been cleared since the beginning of European settlement. In addition, the loss of ground cover and increases in impervious surfaces (including compacted soils), has likely enhanced runoff rates, leading to greater volumes and rates of flow in channels (as found to have occurred in the nearby Comet River - Siriwardena et al., 2006), which exacerbates channel erosion. Channel erosion dominates the supply of sediment in the region (Wallbrink, 2004; Olley et al., 2013).

2.2 Data

Stream discharge: Stream discharge data in ML/hr was obtained for all sites from the Surface Water Database, managed by the Queensland Government Department of Regional Development, Manufacturing and Water (https://water-monitoring.information.qld.gov.au/).

Nutrient concentration data: Nutrient concentration data was obtained from the South East Queensland Catchment Loads Monitoring Program (SEQCLMP). The SEQCLMP collects manual grab samples approximately monthly during low flow periods, and at high frequency during high flow events via both manual grab samples and refrigerated autosamplers. The samples are collocated at the river gauge. Water samples were collected at various intervals throughout the and the number of samples collected during a flow event was based on event duration and magnitude, as well as the ability for staff to access and refresh the autosamplers during the event. Automatic samplers were triggered to begin sampling when water levels rose above ~10cm of the base flow level at each site and subsequently samples were taken at various time and height intervals. Samples were collected from the sites and processed into analysis containers within 48 hours of sampling and transported to the laboratory. Water quality samples were analysed for total suspended solids (TSS), total nitrogen (TN), dissolved inorganic nitrogen (DIN – as oxidised nitrogen and ammonium nitrogen), filterable reactive phosphorus (FRP) and total phosphorus (TP) by the Environmental Resource Sciences Chemistry Centre (Indooroopilly then Dutton Park, QLD) using National Association of Testing Authorities (NATA) accredited methods (APHA-AWWA-WPCF 2005). In total 5694 samples were analysed.

Catchment characteristics: Changes in land cover from 2007 to 2020 were assessed using Geoscience Australia detailed landcover database (https://www.dea.ga.gov.au/products/dea-land-cover). Changes in land use could not be assessed as the latest land use mapping product for the region is 2012. Previously, to estimate the extent of riparian forest the proportion of stream draining remnant woody vegetation in each sub-catchment was determined using the Survey and Mapping of Vegetation Communities and Regional Ecosystems of Queensland, Version 6.0b (Queensland Herbarium, 2009). This time mapped riparian forest cover (2019) has been used (Healy, 2022). This provides a more accurate assessment of the riparian forest extent.

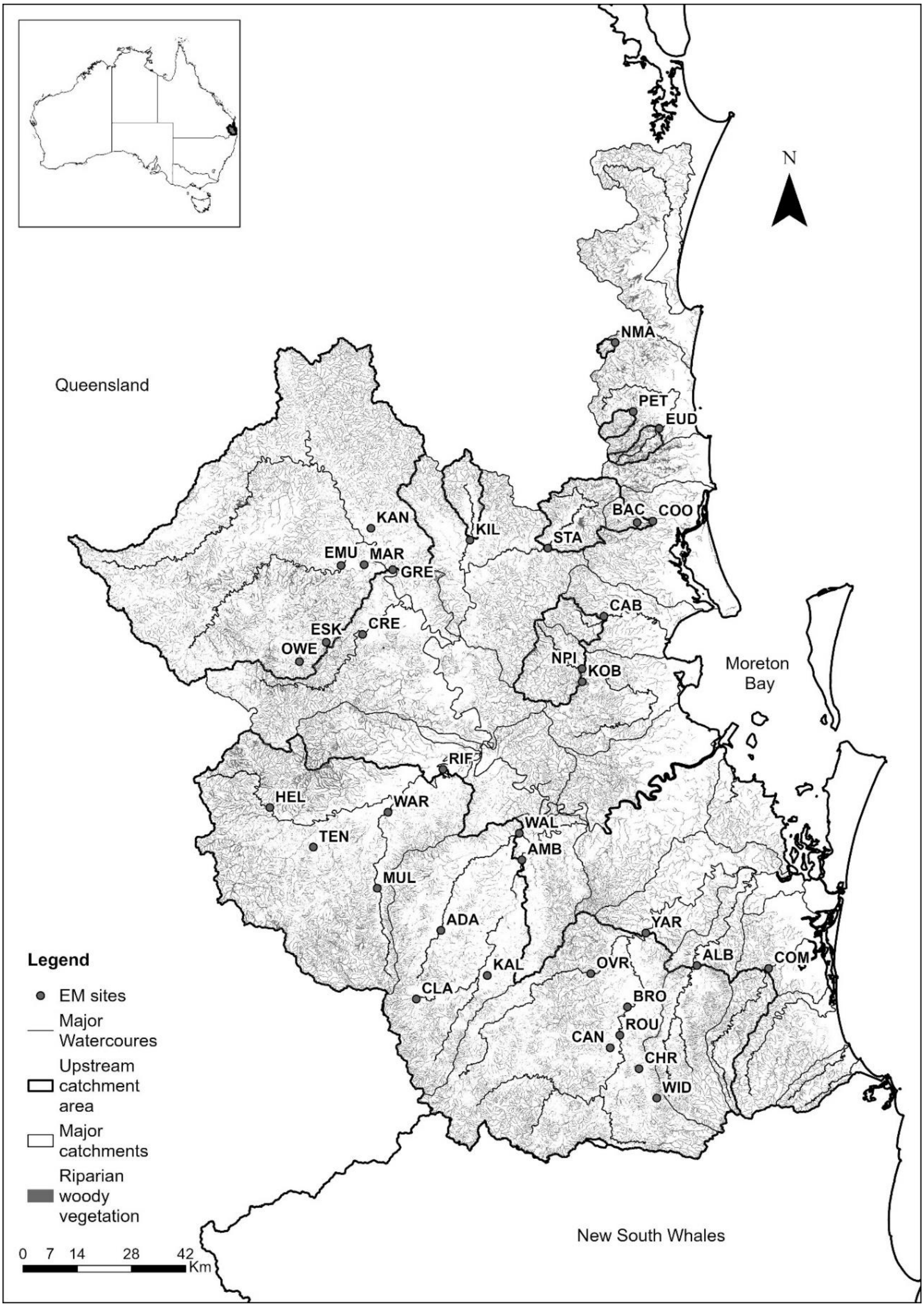
2.3 Data analysis

Load calculations: Concentration values were interpolated between data records by continuing the previously recorded value until a new sample is collected. Loads were calculated by multiplying the hourly discharge from gauges by the measured or interpolated concentrations. Flows were separated into events and base flow. This was done by visual inspection of the stage height data. Events which had samples well distributed through the hydrograph and at least two samples collected on the rising limb were include in the analysis.

Statistical analyses: The software package Statistixl (2023) (https://www.statistixl.com) was used to compare:

i) Firstly, to test for changes in the discharge-load relationships at each of the eight sites pre and post January 2012, the slopes and intercepts of the log Q (discharge) and log (L) loads data were compared (ANOVA).

ii) Secondly, all event loads and discharges were corrected for area and expressed as load per unit area (t/km^2), and discharge per unit area (ML/km^2). The slopes and intercepts of the log (ML/A) (discharge) and log (L/A) loads data were compared (ANOVA) to test whether the relationship between load (dependent variable) and flow (independent variable) was homogeneous. The expectation being that the slopes would be homogeneous but the intercept different. The difference in intercepts being due to changes in catchment attributes. Following Olley et al., (2015) we used multiple linear regression to determine the relationship between loads per unit area, discharge per unit area and proportion of the channel and riparian zone covered by riparian forest. For this analysis we also included the data from now discontinued sites used in Olley et al, (2015) (Figure 1 and Table1).



NovFigure 1 Map of South East Queensland (SEQ) identifying the location of event monitoring sampling stations (EM sites). The three letter code relates map locations to the site data in Table 1. The inset map shows the location of the SEQ region on the Australian continent.

Table 1: Summary information for event monitoring catchments analysed including site name, location, catchment area, total stream length, proportion of riparian forest, number of events captured and the data collection period.

Abbreviation	Site name	Site number	Latitude	Longitude	Catchment area (km^2)	Stream length (km)	Riparian Forest %	Events	Data collection period
WAL	Bremer River at Walloon	143107A	-27.60	152.69	622	1440.6	34%	44	Nov 2007 – Oct 2021
AMB	Warrill Creek at Amberley	143108A	-27.67	152.70	914	1954.6	37%	51	Dec 2007 – Mar 2023
LOC	Lockyer Creek at Rifle Range Road	143210B	-27.42	152.59	2965	6059.2	55%	10	Dec 2011 – Mar 2023
MUL	Laidley Creek at Mulgowie	143209B	-27.73	152.36	167	394.3	72%	30	Nov 2007 – Sept 2011, Dec 2015 – April 2023
WAR	Laidley Creek at Warrego Highway	143229A	-27.55	152.39	450	965.2	48%	26	
YAR	Logan River at Yarrahappini	145014A	-27.83	152.99	2416	5285.1	47%	56	Sep 2007 – Mar 2023
CAB	Caboolture River at Upper Caboolture	142001A	-27.10	152.89	94	204.9	72%	82	Jul 2007 – Mar 2023
COO	Coochin Creek at Mawsons Road	141010A	-26.88	153.00	56	133.0	76%	75	Jul 2007 – Mar 2023
Addition sites used in the analysis from Olley et al., (2015). Riparian forest percentages estimated from Healy, (2022).									
ALB	Albert River at Bromfleet	145102B	-27.91	153.11	544	1188.0	58%	7	Jun 2007 – Jun 2010
BRO	Logan River at Bromelton Weir	145025A	-28.01	152.95	1364	2978.4	51%	8	Jun 2007 – Jun 2010
EMU	Emu Creek at Boat Mt	31301	-26.98	152.28	915	1934.4	45%	5	Feb 2003 – Jun 2010
EUD	Eudlo Creek at Kiels Mountain	141008A	-26.66	153.02	62	144.9	80%	6	Jun 2007 – Jun 2010
GRE	Brisbane River at Gregor's	30101	-26.99	152.40	3866	8035.6	45%	13	Dec 2002 – Jun 2010
HEL	Lockyer Creek at Helidon Number 3	143203C	-27.54	152.12	357	771.9	80%	4	Jun 2007 – Jun 2010
KIL	Kilcoy Creek at Kilcoy	143312A	-26.92	152.58	131	292.9	57%	13	Jun 2007 – Jun 2010
KOB	Kobble Creek at Mt Samson Rd	10201	-27.25	152.84	47	83.0	89%	8	Feb 2003 – Jun 2010
NPR	North Pine River at Dayboro STP	10101	-27.22	152.84	189	416.4	65%	19	Feb 2003 – Jun 2010
OVR	Teviot Brook at The Overflow	145012A	-27.93	152.86	503	1121.0	36%	8	Jun 2007 – Jun 2010
PET	Petrie Creek at Warana Bridge	141003C	-26.63	152.95	38	91.1	80%	3	Jun 2007 – Jun 2010
ROU	Logan River at Round Mountain	145008A	-28.07	152.93	1262	2760.5	52%	8	Jun 2007 – Jun 2010
STA	Stanley River at Woodford	20101	-26.94	152.76	249	557.4	75%	30	Feb 2003 – Jun 2010

3.0 Catchment characteristics

Summary information for event monitoring catchments analysed included site name, location, catchment area, total stream length, proportion of riparian forest, number of events captured and the data collection period are given in Table 1. Also included are the discontinued sites used in Olley et al. (2015) with updated riparian forest cover data.

3.1 Land cover change

Using Geoscience Australia detailed landcover database (https://www.dea.ga.gov.au/products/dea-land-cover) we have assessed changes in land-cover in the catchments by comparing the 2020 cover data with that of 2007 for the eight studied catchments. All of the catchments, apart from the Laidley upstream of Mulgowie, had an increase in artificial surfaces (roads, buildings etc) with this cover class increasing between 2.1 and 3.6 times (Table 2). However, only a small proportion of the catchment areas were affected (<0.7%). Changes in cropping area (horticulture and cropping) ranged from a decline of 20% in Coochin Creek to a growth of 300% in the Logan catchment. This growth in the Logan catchment has been associated with a 5% decline in the areas covered by Natural vegetation (grazing and woodland).

Table 2: Changes in area 2020/2007 = change proportion, and the percentage of the catchment area upstream of the gauge affected for Artificial surfaces, Cropping and Natural vegetation (grazing and woodland).

	Artificial Surface		Cropping		Natural Vegetation	
Site name	Change	Catchment %	Change	Catchment %	Change	Catchment %
Bremer River at Walloon	2.3	0.05	2.6	3.9	0.97	95.3
Warrill Creek at Amberley	3.6	0.03	2.0	4.7	0.97	94.1
Lockyer Creek at Rifle Range Road	2.2	0.09	1.8	3.9	0.97	94.2
Laidley Creek at Mulgowie	0	0.00	0.9	2.9	1.00	96.9
Laidley Creek at Warrego	2.1	0.21	1.2	4.1	0.98	93.6
Logan River at Yarrahappini	3.1	0.06	3.0	5.5	0.95	93.1
Caboolture River at Upper Caboolture	2.0	0.00	0.9	13.3	1.02	86.6
Coochin Creek at Mawsons Road	2.8	0.66	0.8	12.7	1.01	82.7

3.2 Riparian forest cover

Previously, to estimate the extent of riparian forest the proportion of stream draining remnant woody vegetation in each sub-catchment was determined using the Survey and Mapping of Vegetation Communities and Regional Ecosystems of Queensland, Version 6.0b (Queensland Herbarium, 2009). This time mapped riparian forest cover has been used based on the Sentinel-2 2019 woody vegetation extent layer (Healy, 2022). This provides a more accurate assessment of the riparian forest extent. The proportion (percentage) of stream draining remnant woody vegetation in each sub-catchment and the mapped riparian forest cover proportion (percentage) are highly correlated with an r^2=0.81 and an intercept of 25% (Figure 2).

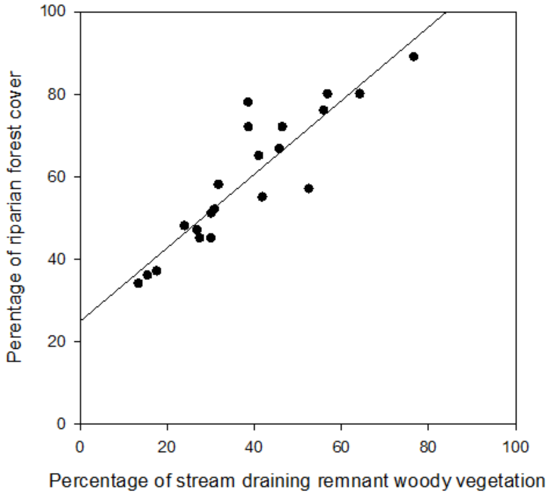


Figure 2: Correlation between percentage of stream draining remnant vegetation (QH, 2009) and

percentage of riparian forest cover (Healy, 2022) in catchment areas above the 21 event monitoring stations.

The intercept of 25% shows that the average of the latest riparian forest cover extend is 25% when the former remnant woody vegetation extend is equal to 0%. This indicates the former remnant woody vegetation extend underestimated riparian forest cover by about one quarter of the stream length in catchment areas. The implications of using the more accurate and up-to-date extents are that Olley et al., (2015) underestimated the extent of riparian forest and therefore overestimated its effectiveness in controlling sediment and nutrient loads.

4.0 Changes in load-discharge relationship with time

Results of the flow and loads calculations for each site are reported in Appendices A to G. Flow (ML/hr) and sample collection points on the hydrographs for the period November 2007 to 2022 are shown in Figures A1 to G1. In most cases there is very good coverage of both low flow periods, and event flows, with samples being collected through the hydrographs. In total 5694 water quality samples were collected and analysed.

Tables A1 to G1 present flow, sediment, nitrogen and phosphorus loads for the total year and for event flows in that year for each catchment. Total loads were calculated for 374 events across the eight catchments (Table 1). Log event loads are strongly correlated with the log of discharge with adjusted r^2>0.80 (Figures A2 to G2) and examples shown for Warrill Creek and Laidley Creek in Figures 3 and 4 respectively. The event data were divided into pre and post 1-1-2012, separating the data from the major floods in 2011, from those in 2013 and 2022. ANOVA tests were used to see if the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods. Results are reported in Table 3. Only two sites showed a clear change in the log load to log discharge relationships; sediment loads declined by 2.6 times (ie 1/0.38) for Laidley Creek at Warrego Highway, and total phosphorus increased by 1.6 times in Coochin Creek.

Table 3: Changes in log load vs log discharge, pre and post 1-1-2012, and proportional change in event loads (Factor).

	TSS		TP		TN	
Site name	Change	Factor	Change	Factor	Change	Factor
Bremer River at Walloon	NO	NIL	NO	NIL	NO	NIL
Warrill Creek at Amberley	NO	NIL	NO	NIL	NO	NIL
Lockyer Creek at Rifle Range Road	NO	NIL	NO	NIL	NO	NIL
Laidley Creek at Mulgowie	NO	NIL	Possibly		NO	NIL
Laidley Creek at Warrego	YES	x0.38	NO	NIL	NO	NIL
Logan River at Yarrahappini	NO	NIL	NO	NIL	NO	NIL
Caboolture River at Upper Caboolture	NO	NIL	NO	NIL	NO	NIL
Coochin Creek at Mawsons Road	NO	NIL	NO	NIL	YES	x1.6

4.1 Changes in sediment-discharge relationship with time at the Warrego Highway gauge on Laidley Creek

Log sediment/area, log total nitrogen/area, and log total phosphorus/area event loads versus log discharge/area for the Laidley Creek at Warrego Highway and Laidley Creek at Mulgowie area presented in Figure 3. Note the data has been normalised for area to enable direct comparison of events from the gauges at different points along the creek line (catchment areas of 167km^{2}and 450km^2). The ANOVA test showed little or no change in the load relationships with discharge at the

Mulgowie site (Appendix D). The data from the Warrego Highway site are divided pre (grey points) and post 1-1-2012 (black points). For TN and TP the pre and post data sets shared a common slope and intercept, indicating no change in yields between the two periods, and there is also no difference with the data from the upstream site at Mulgowie. This indicates the same nutrient yields (t/km^2) per unit of runoff (ML/km^2) at the two sites.

In comparison the Warrego Highway TSS data shows a marked decrease in loads per unit of area for a given discharge per unit of area in the post period. The post period data is consistent with the upstream Mulgowie data indicating in this period a similar sediment yield (t/km^2) per unit of runoff (ML/km^2) at these sites. The pre 1-1-2012 data at the Warrego Highway gauge had a much higher (2.6 times) sediment yield per unit of runoff.

This change is not the result of changes in the relationship between gauge height and discharge at the gauging station. Pre and post 1-1-2012 gauge and discharge measurements are shown in Figure 5. The data sets are consistent and indicate no change in the stage height discharge relationship at the gauge.

Figure 6 shows data from two similar sized events in the pre and post periods. The major different between the two sets of data is the very high sediment concentrations in the samples collected on the rising limb of the hydrograph in the pre-2012 data (11,000mg/L compared to 360mg/L in the post event).

Figure 7 shows the full discharge record and sediment concentrations in the first two samples collected for events measured at the Warrego Highway gauge on Laidley Creek. The dashed lines indicate the median values for the two sampling periods (830 and 315mg/L respectively). High sediment concentrations on the rising limb of the hygrograph are indicative of sediments being mobilised from within the channel. These data suggest that channel condition has improved between the two periods, though further studies are required to confirm this attribution. The lack of change in the TN and TP loads indicates that this change in sediment loads results primarily from a decrease in the coarser sediments (nutrient concentration are higher on finer sediments).

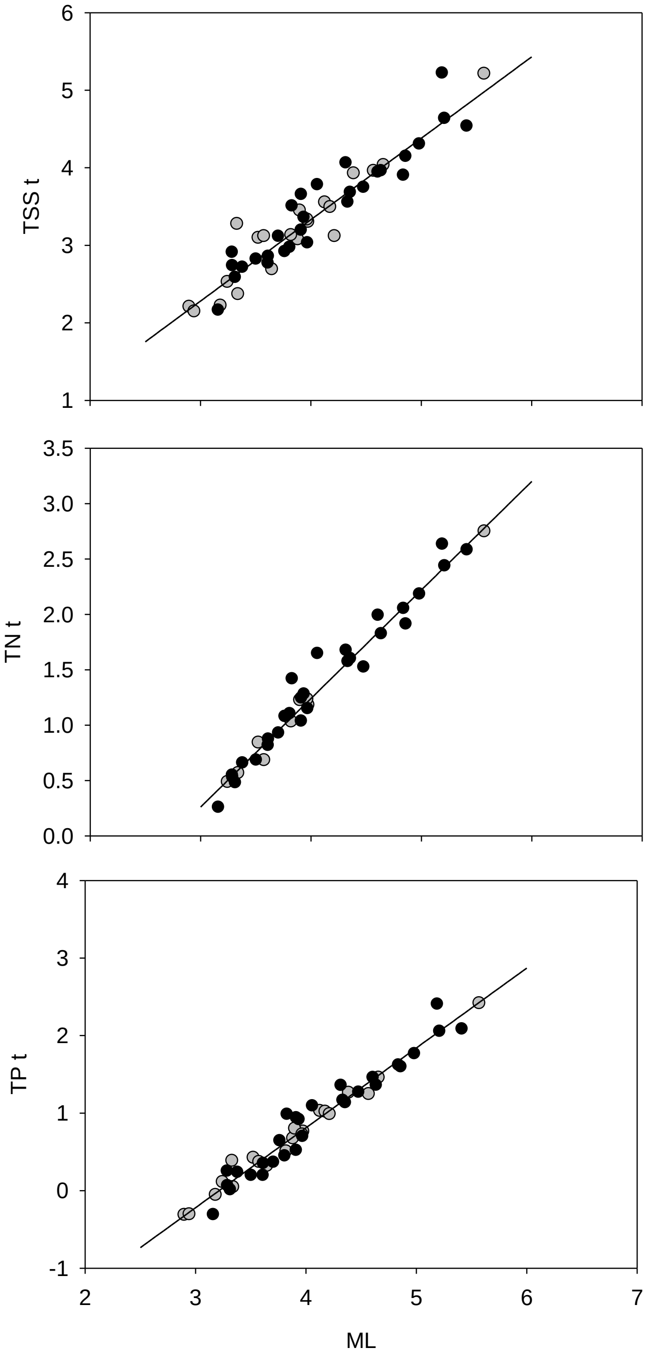


Figure 3. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for Warrill Creek at Amberley. Correlations shown are linear regression fitted through the data set. Data are divided pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods.

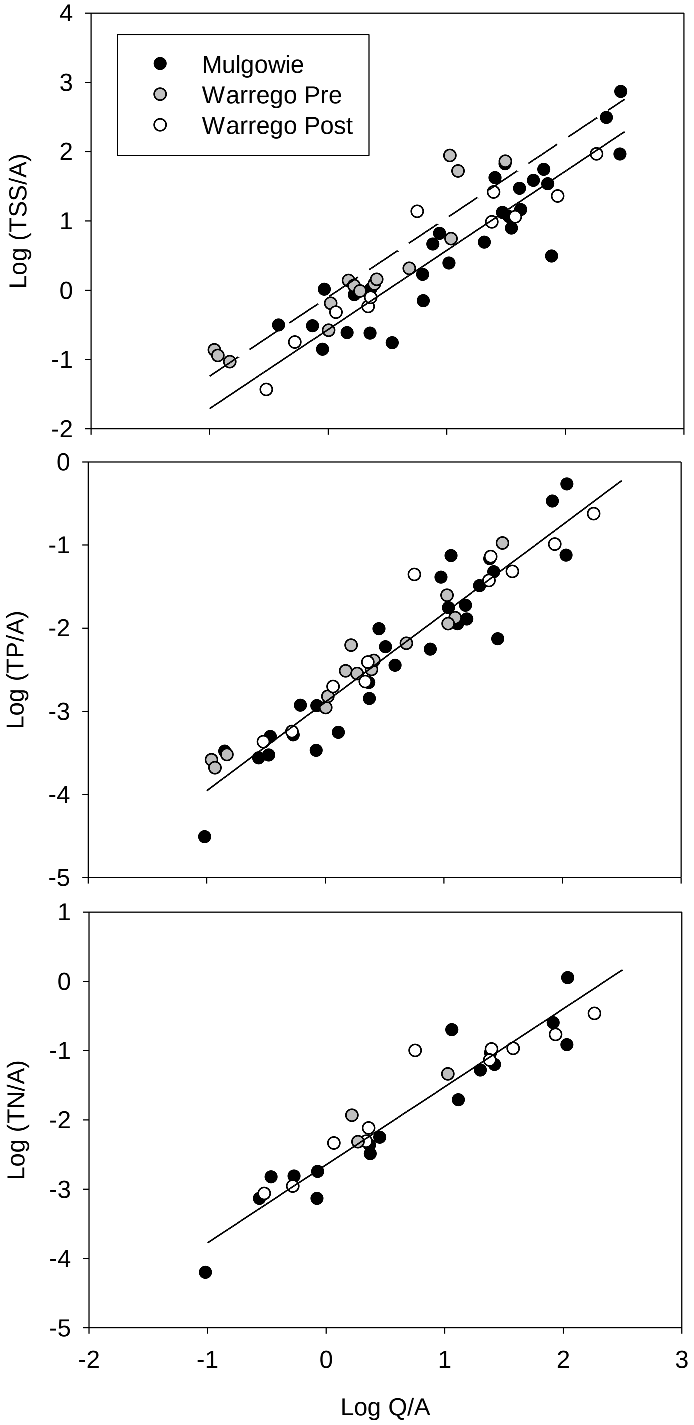


Figure 4. Log sediment/area, total nitrogen/area, and total phosphorus/area event loads versus log discharge/area for the Laidley Creek at Warrego Highway and Mulgowie. Correlations shown are linear regression fitted through the data sets. The data from the Warrego Highway site are divided pre (grey points) and post 1-1-2012 (black points). For TN and TP, the pre and post data sets shared a common slope and intercept, indicating no change in yields between the two periods. Note for TN this comparison is based on just three data points for the early period. The TSS data shows a marked decrease in loads for a given discharge in the post period.

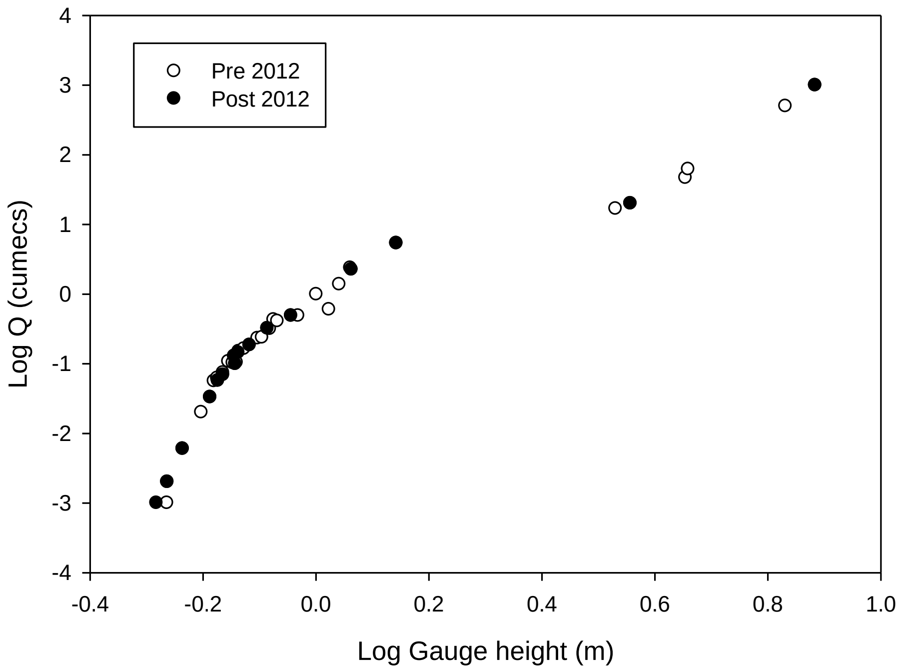


Figure 5: Pre and post 1-1-2012 gauge and discharge measurements at the Warrego Highway gauging site on Laidley Creek. The data sets are consistent and indicate no change in the stage height discharge relationship at the gauge.

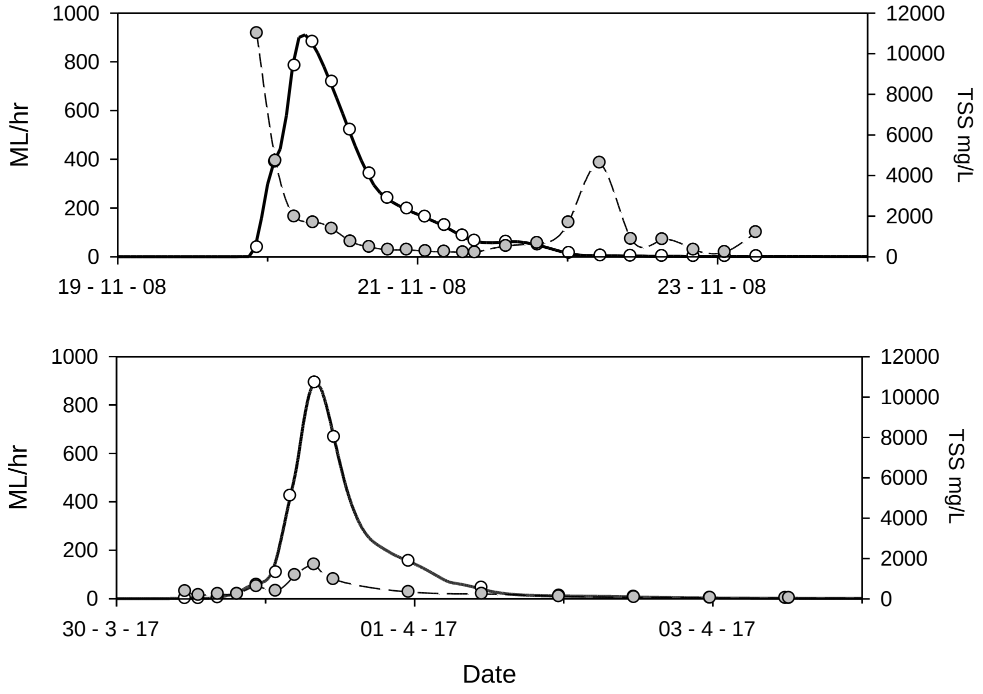


Figure 6: Discharge (solid line), sampling times (open circles) and sediment concentrations (grey circles - dashed line) for two events measured at the Warrego gauge on Laidley Creek.

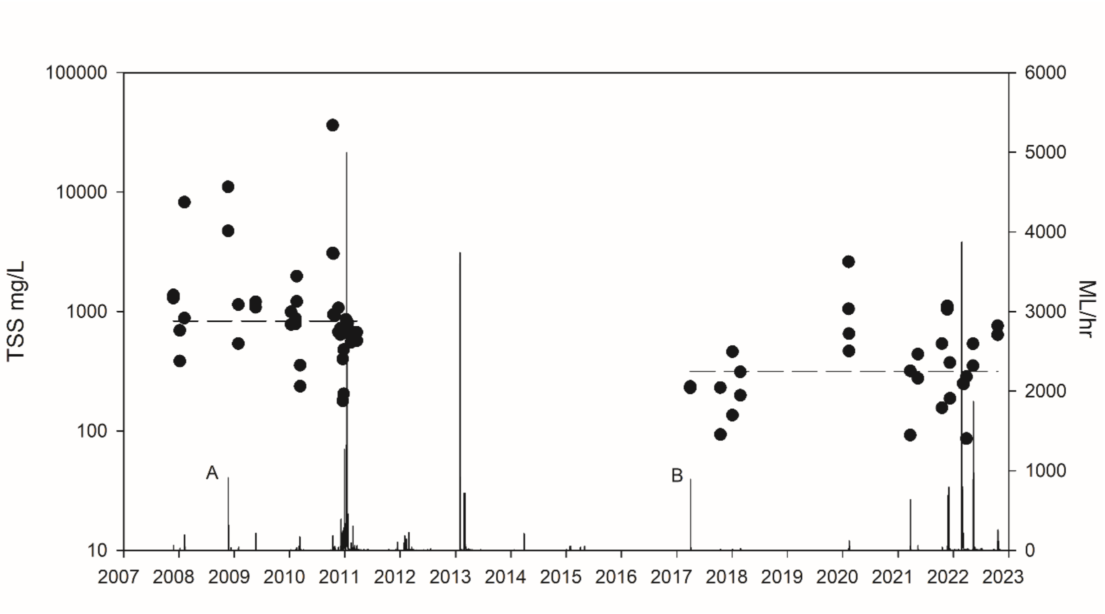


Figure 7: Discharge (solid line), sediment concentrations (black circles) in the first two samples collected for events measured at the Warrego Highway gauge on Laidley Creek. The dashed lines indicate the median values for the two sampling periods. The letters indicate the events shown in Figure 5, A-the upper figure, B- the lower.

4.2 Changes in total phosphorus-discharge relationship with time at Coochin Creek

Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for Coochin Creek at Mawsons Road are shown in Figure 8. ANOVA tests showed that for TSS and TN the pre and post 1-1-2012 data sets shared a common slope and intercept indicating no change in yields between the two periods. The TP data have the same slopes but different intercepts indicating a change (Figure 8, bottom panel). Phosphorus loads have increased by an average of 1.6 times. This change is the result of a significant ($p<0.001$ Mann-Whitney test) change in the median TP concentrations from 0.18 to 0.24mg/L (Figure 9). In both the pre and post periods the peak event TP concentrations are associated with the peak discharge. Indicating that the source of the phosphorus is likely to be surface runoff from higher in the catchment.

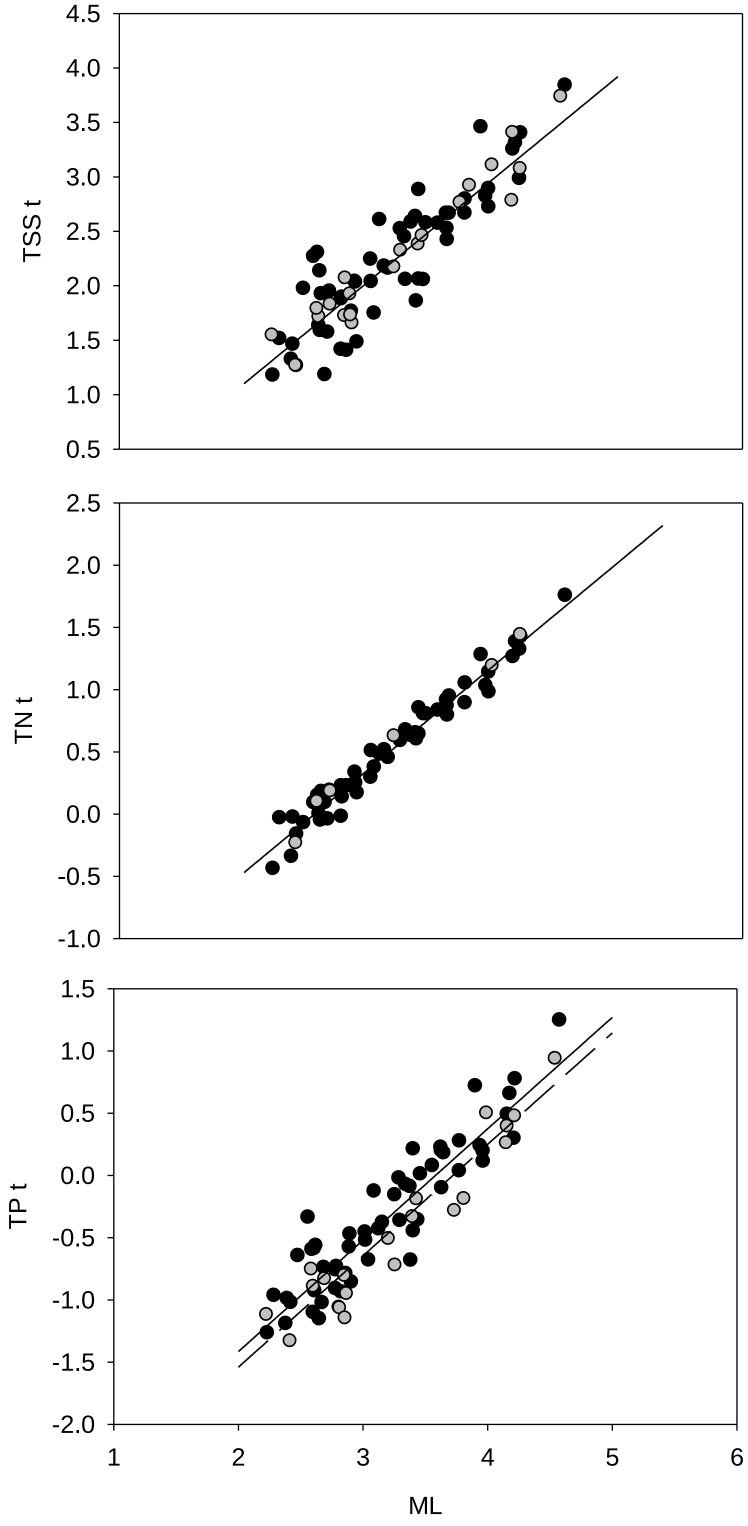


Figure 8. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for Coochin Creek at Mawsons Road. Correlations shown are linear regression fitted through the data set. Data are divided into pre (grey points) and post 1-1-2012 (black points).

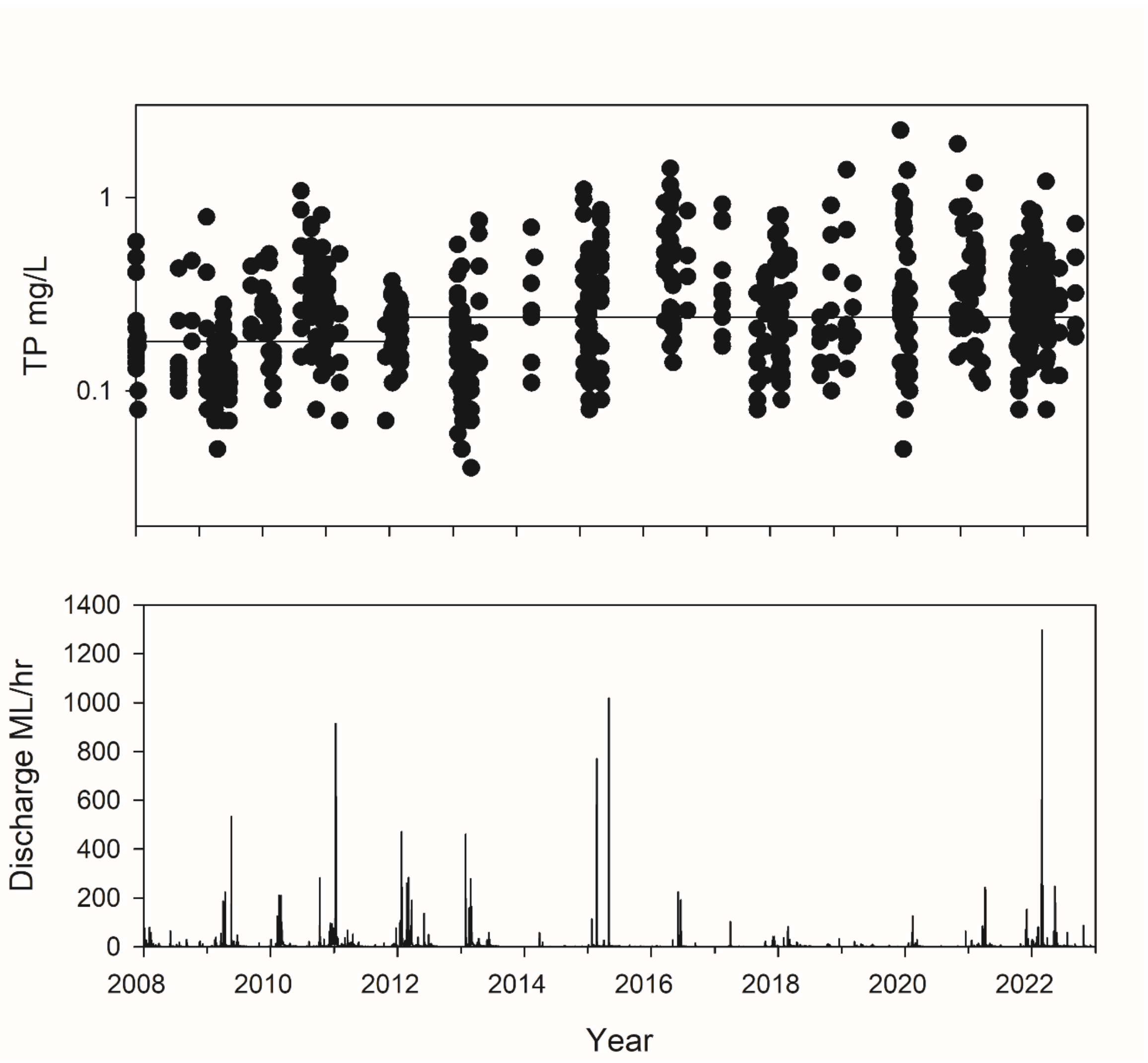


Figure 9: TP concentration for event flows measured in samples collected from Coochin Creek and measured hourly discharge. The solid lines in the top panel indicate the median values for the periods pre and post 1-1-2012.

5.0 The relationship between loads, discharge, and riparian forest.

To enable catchments of different sizes to be compared all event loads and discharges were normalised to area and expressed as load per square kilometre (t/km^2), and discharge per unit area (ML/km^2). The slopes and intercepts of the log (L/A) loads data and log (ML/A) discharge were compared (ANOVA) to test whether the relationship between load (dependent variable) and flow (independent variable) was homogeneous. The expectation being that the slopes would be homogeneous but the intercept different. The difference in intercepts being due changes in catchment attributes. The slopes were homogenous for sediments across all catchments, and for TN and TP for all catchments with the exclusion of Coochin Creek. For this reason, events from Coochin Creek were excluded from the regression analysis described below for TN and TP.

Following Olley et al., (2015) we used multiple linear regression to determine the relationship between loads per unit area, discharge per unit area and proportion of the channel and riparian zone covered by riparian forest. Load per unit area (t/km^2) of total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN) are plotted against event-discharge per unit area (ML/km^2) for each event for which loads were calculated and are shown in Figure 10. For this analysis we also included the data from now discontinued sites used in Olley et al, (2015) (Figure 1 and Table1). The symbol size relates to the proportion of riparian forest within a 50m buffer either side of the stream; the largest symbols represent 89%, the smallest 34% (Table 1).

The best fit equation from the regression analysis gives the area weighted load (L/A) in t/km^2 for any event as:

$$\left(\frac{L}{A}\right) = \left(10^{a+b.P}\right)\left(\frac{Q}{A}\right)^{c} \qquad \text{Equation 1}$$

where L is the load (t), A is area (km^2), *P* is the proportion of the stream riparian zone covered by riparian forest, Q is the event discharge (ML), and *a, b,* and *c* are regression coefficients determined by multiple linear regression. The regression coefficients are presented in Table 4.

Equation 1 can be rearranged to estimate loads in relation to discharge such that:

$$L = \left(10^{a+b.P}\right)(Q^{c})(A^{1-c}) \qquad \text{Equation 2}$$

Table 4: Regression coefficients *a, b,* and *c* for calculation of loads of TSS, TP and TN for catchments in SEQ and their standard error estimates.

TSS n = 510				Adjusted r^2 = 0.68
Coefficient		Value	Std. Error	Significance P
A	Intercept	-0.367	0.0880	<0.001
B	Riparian forest	-0.860	0.144	<0.001
C	Discharge	1.114	0.0337	<0.001
TP n = 413				Adjusted r^2 = 0.77
A	Intercept	-2.711	0.0718	<0.001
B	Riparian forest	-1.214	0.106	<0.001
C	Discharge	1.044	0.0277	<0.001
TN n = 370				Adjusted r^2 = 0.83
A	Intercept	-2.564	0.0655	<0.001
B	Riparian forest	-0.486	0.108	<0.001
C	Discharge	1.063	0.0256	<0.001

Using Equation 2 we have predicted the change in load per unit area of TSS, TP and TN as a function of the proportion of the riparian zone covered by forest (Figure 1). The data are presented as a ratio to the load per unit area expected from a catchment in which the entire stream length is within riparian forest. The sediment yield per unit area from a catchment containing no riparian forest is predicted to be between 5 and 10 times that of a fully vegetated channel network, with a best estimate of 7 times (Figure 8 top). For total phosphorus (TP) this is between 12 and 21 with a best estimate of 16 times (Figure 3 middle), and for total nitrogen (TN) between 2.4 and 3.9 with a best estimate of 3.0 times (Figure 3 bottom). The decrease in sediment and nutrient loads by increasing riparian cover from current condition to 100% for the event monitoring catchments analysed in this study are presented in Table 5.

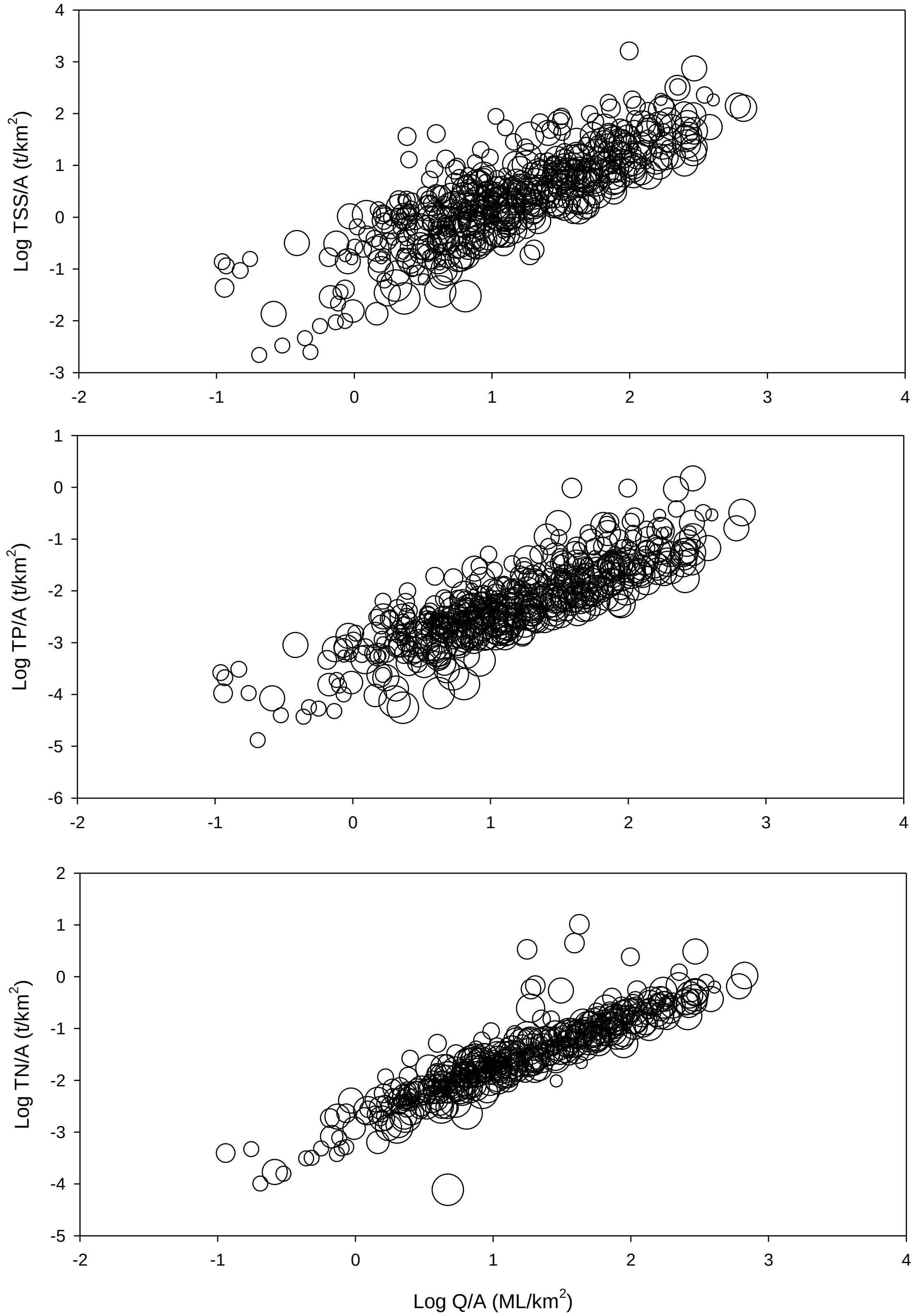


Figure 10: Log Load per unit area (t/km2) of a) TSS, b) TP, and c) TN plotted against Log runoff (ML/km^2) for each event monitored within catchments. Symbol size relates to the proportion of the stream network in the catchment draining remnant woody vegetation; the largest symbols represent 89%, the smallest 34%.

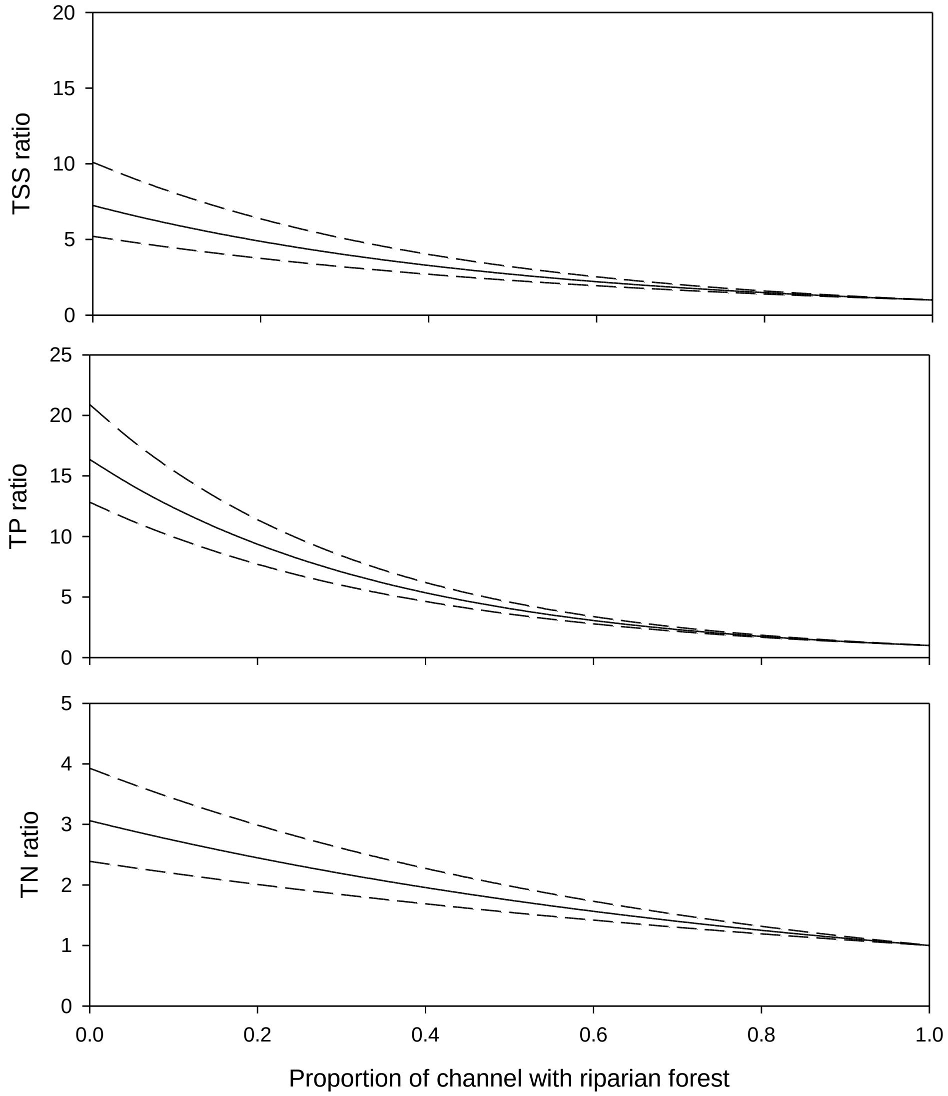


Figure 11: The ratio of load per unit area of (top) TSS, (middle) TP, and (bottom) TN as a function of the proportion of the stream riparian zone covered by forest, where the ratio for a stream completely vegetated by forest is 1. The solid lines indicate the best estimate and the dashed lines plus and minus one standard error.

Table 5: Decrease in sediment and nutrient loads by increasing riparian cover from current condition to 100% for the event monitoring catchments analysed in this study.

					Decrease in load		
Abbreviation	Site name	Area (km^2)	Stream (km)	Riparian Forest	TSS	TP	TN
WAL	Bremer River at Walloon	622	1440.6	34%	4.0	7.1	2.2
AMB	Warrill Creek at Amberley	914	1954.6	37%	3.6	6.2	2.1
LOC	Lockyer Creek at O'Reilly's Weir	2965	6059.2	55%	2.4	3.5	1.7
MUL	Laidley Creek at Mulgowie	167	394.3	72%	1.8	2.3	1.4
WAR	Laidley Creek at Warrego Highway	450	965.2	48%	3.0	4.7	1.9
YAR	Logan River at Yarrahappini	2416	5285.1	47%	3.0	4.7	1.9
CAB	Caboolture River at Upper Caboolture.	94	204.9	72%	1.8	2.3	1.4
COO	Coochin Creek at Mawsons Road	56	133.0	76%	1.6	2.0	1.3
ALB	Albert River at Bromfleet	544	1188.0	58%	2.4	3.5	1.7
BRO	Logan River at Bromelton Weir	1364	2978.4	51%	2.7	4.0	1.7
EMU	Emu Creek at Boat Mt	915	1934.4	45%	3.0	4.7	1.9
EUD	Eudlo Creek at Kiels Mountain	62	144.9	80%	1.5	1.7	1.3
GRE	Brisbane River at Gregor's	3866	8035.6	45%	3.0	4.7	1.9
HEL	Lockyer Creek at Helidon Number 3	357	771.9	80%	1.5	1.7	1.3
KIL	Kilcoy Creek at Kilcoy	131	292.9	57%	2.4	3.5	1.7
KOB	Kobble Creek at Mt Samson Rd	47	83.0	89%	1.3	1.5	1.2
NPR	North Pine River at Dayboro STP	189	416.4	65%	2.0	2.7	1.5
OVR	Teviot Brook at the Overflow	503	1121.0	36%	3.6	6.2	2.1
PET	Petrie Creek at Warana Bridge	38	91.1	80%	1.5	1.7	1.3
ROU	Logan River at Round Mountain	1262	2760.5	52%	2.7	4.0	1.7
STA	Stanley River at Woodford	249	557.4	75%	1.6	2.0	1.3

7.0 Comparison with other catchments

The annual sediment yield (t/yr) for each of the eight catchments are shown against catchment areas in Figure 12. For comparison, data from catchments in SE Australia (Wasson, 1994) are shown; these data are for extensively degraded catchments in the southern tablelands. Yields are generally higher from the eight catchments with data from Laidley Creek showing particularly high yields in comparison.

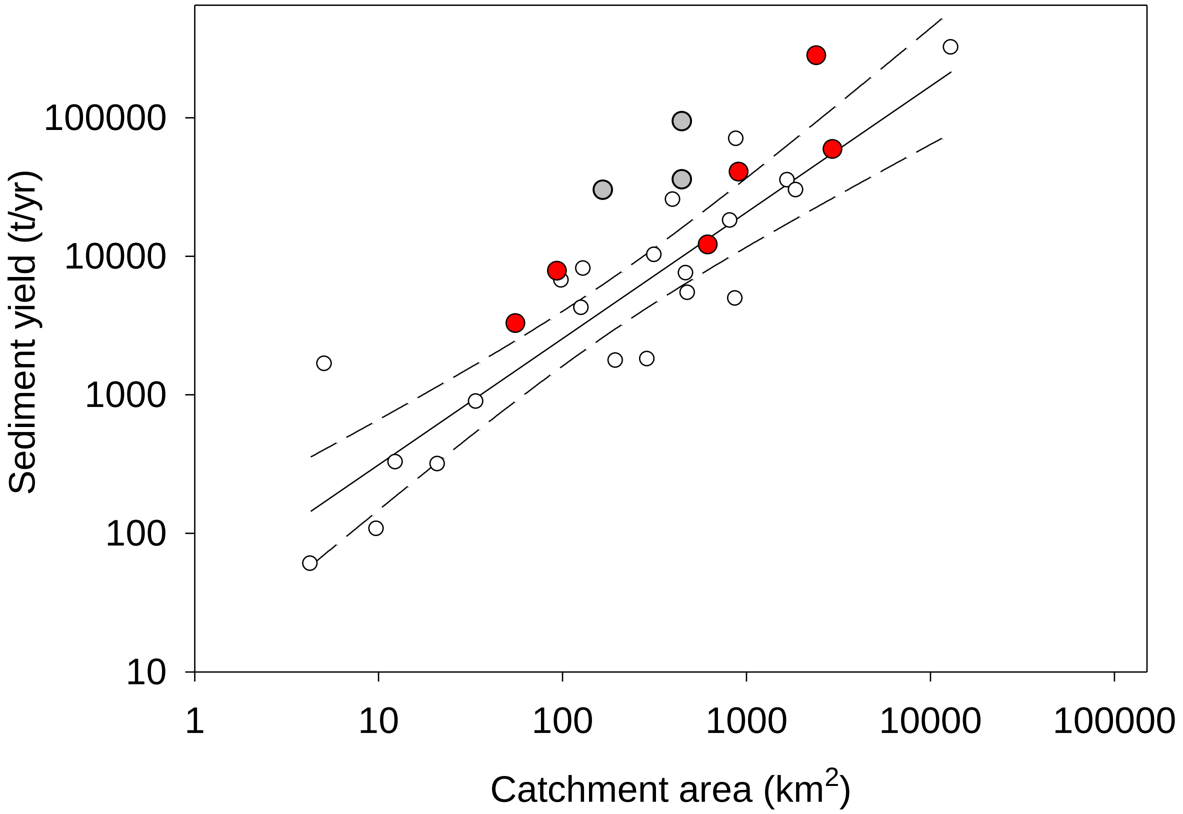


Figure 12: Estimates of sediment yield (t/yr) plotted against catchment area (km^2) for the eight catchments (red and grey data points – grey are data from the Laidley catchment including the pre and post 1-1-2012 data from the Warrego Highway gauge). For comparison a subset of the Southern Tablelands data Wasson, (1994) is shown (open circles). Solid lines are lines of best fit. Dashed lines show 95% confidence limits.

8.0 The next phase of water quality monitoring

All of the sites, with the exception of Lockyer Creek, have good event and low flow water quality sample coverage with most events being sampled through the rise and fall of the hydrograph. These data indicate that in general there has been very little change in the discharge load relationships. The lack of any significant change at most sites is not surprising given that there has been very little change in landuse in the catchments during the monitoring period. It has been proposed to address the decline in the health of Moreton Bay, sediment loads need to be decreased by 50% (Leigh et al., 2013). The analysis above shows that increasing riparian forest cover can significantly decrease sediment and nutrient loads. These data sets offer the opportunity to examine the effectiveness of riparian revegetation on loads. This has not yet been done at a catchment scale anywhere.

Despite the large body of research into the relationship between riparian vegetation and water quality (Peterjohn and Correll, 1984; Kondolf, 1996; Jenkinson et al., 2006; Bernhardt and Palmer, 2011) and the existence of large programs that promote restoration of riparian vegetation, there have been few direct studies of the responses of stream water chemistry to both the loss of riparian vegetation and its restoration (Dosskey et al., 2010).

The above analysis and data enable testable hypotheses to be proposed. As an example, Figure 13 shows log sediment (t) to log discharge relationships for Warrill Creek under current conditions, 37% riparian forest cover, and scenarios of 65% and 100% riparian forest cover. There are 1955km of channel in the catchment of which 723km is well vegetated. Currently the annual sediment load is 40,143t/yr. Increasing the riparian forest cover by 550km to 65% would decrease the annual load by ~50% to 22,500 t/yr; increasing to 100% cover would drop this to 11,300 t/yr. These statements are all testable by continuing the water quality and stream flow monitoring while revegetating the riparian zone. Examining how many events would need to be measured following the establishment of riparian forest cover indicates that between 6 and 10 events would be sufficient to determine the effect.

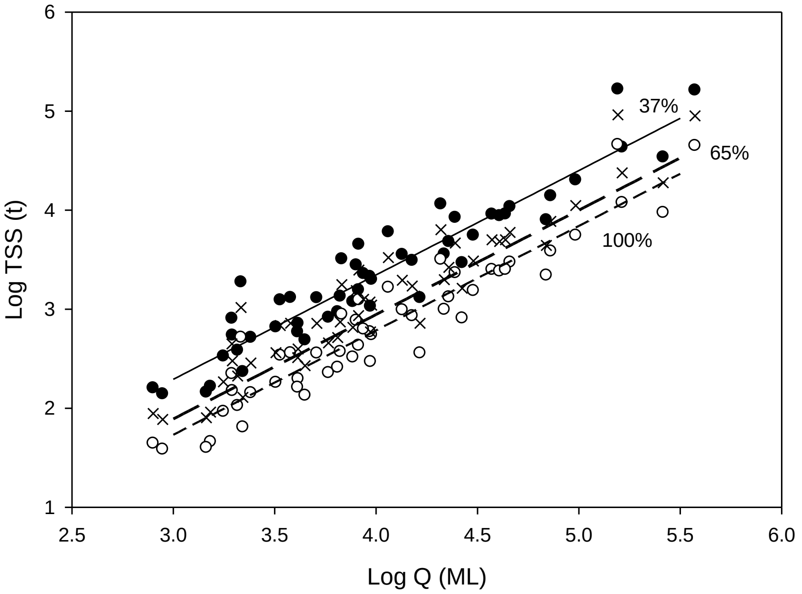


Figure 13: Log sediment (t) to log discharge relationships for Warrill Creek under current conditions, 37% riparian forest cover, and scenarios of 65% and 100% riparian forest cover. The lines have a common slope but different intercepts.

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Appendix A: Bremer River gauge - 143107A

Flow (ML/hr) and sample collection points on the hydrographs for the period November 2007 to 21st October 2021 for the Bremer River at Walloon are shown in Figure A1. There is good coverage up to 2021 of both low flow periods, and event flows, with samples being collected through the hydrographs, with just the 2011 and 2013 events being under-sampled. Note sampling ceased on the Bremer River in 2021 due to the site being repeatedly vandalised. In total 915 water quality samples were collected and analysed.

Tables A1 present flow, sediment, nitrogen and phosphorus loads for the total year and for event flows in that year. In the Bremer River 90% of the discharge, 96% of the sediment load and 94% of the TN load are associated with event flows, which occur in <4% of the time. The nitrogen load is dominated by particulate nitrogen, with on average just 8% of the TN being DIN. The average annual sediment load is 11,960t/yr which is comparable to annual sediment loads predicted using the load area relationship from Olley and Wasson 2003 of 13,250t/yr. For TN the range is 0.7t to 417t with an annual average of 139t, and for TP the annual average is 41.2t with a range of 0.7t to 140t.

In total 44 events were sampled in the Bremer River. Event loads are strongly correlated with the log of discharge with adjusted r^2>0.80 (Figure A2 and Table A2). Data were divided into pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods. There is also no strong relationship between discharge and DIN/TN, with the average DIN/TN ratio being 0.11 across all flows (Table A1).

The two largest floods were poorly sampled for water quality. However, we can estimate the peak TN load from the relationship with discharge shown in figure A2. From the relationship with discharge the maximum is estimated to be 405t in 2011. This value is close to that calculated from the infilled water quality data and discharge reported in Table A2, 388t. Similarly, the flow estimated value is 251t for the 2013 event which compares to 262t. These indicate that despite the poor sampling through the hydrograph the infilled water quality data and discharge data estimated loads are reasonable.

Figure A1: Flow (ML/hr – solid lines) and sample collection points on the hydrographs (open circle) for the period Jan 2007 to Dec 2022 for Bremer River at Walloon.

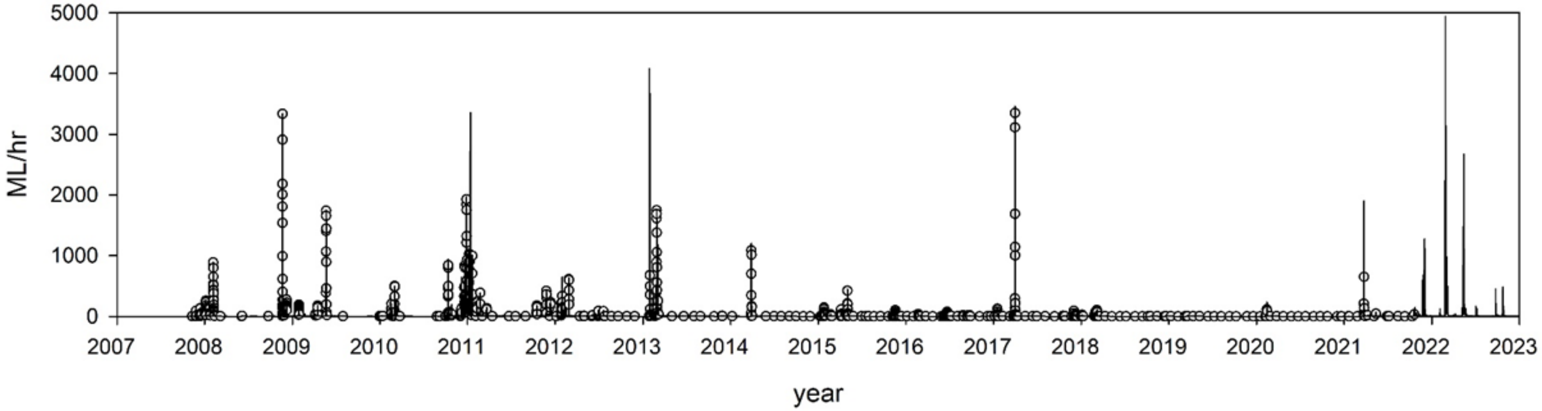

Table A1: Bremer River at Walloon flow, sediment, nitrogen and phosphorus loads. Loads are calculated from hourly estimates of flow (ML) and historic water quality data.

	Annual Totals							Event							Proportion of year low flow
Year	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	
2008	111084	38387	257	11.9	2.3	0.12	60.8	104124	37519	244.5	11.3	2.1	0.04	57.6	0.95
2009	64341	10856	126	8.3	1.8	0.04	27.2	54597	10278	111.5	7.7	1.5	0.05	23.2	0.97
2010	215535	21677	358	12.0	4.3	0.11	140	204311	21095	341.3	11.2	4.1	0.06	134.1	0.88
2011*	246338	31348	417	9.0	2.9	0.13	113	221882	29496	388.4	6.8	2.5	0.06	104.4	0.89
2012	63231	3537	90	3.0	1.5	0.10	18.9	48266	3049	73.3	1.8	1.2	0.06	13.4	0.95
2013*	195417	17817	277	7.1	7.9	0.12	75.7	181830	17557	262.9	5.0	7.6	0.05	71.1	0.96
2014	18554	7199	49	5.1	0.6	0.07	17.9	17322	7140	47.3	4.7	0.5	0.18	17.4	0.99
2015	26244	2353	43	5.0	0.7	0.06	14.6	19494	1988	33.8	4.3	0.5	0.11	11.2	0.97
2016	5718	286	8.6	1.3	0.2	0.09	3.5	1424	119	2.5	0.6	0.0	0.23	0.9	0.99
2017	72100	20363	146	14.3	1.3	0.07	52.4	67118	20224	139.7	13.9	1.2	0.08	49.4	0.97
2018	9274	372	14	0.5	0.2	0.03	5.6	5133	175	7.9	0.2	0.1	0.05	3.2	0.99
2019	339	38	0.7	0.2	0.0	0.04	0.2	0	0	0.0	0.0	0.0	NC	0.0	1.00
2020	7262	1264	19	4.9	0.3	0.05	5.3	6441	1216	17.9	4.8	0.2	0.32	4.8	0.99
2021**	42157	6514	100	20.6	1.8	0.06	30.7	39482	6437	95.9	20.3	1.7	0.14	29.4	0.97
Average	79649	11961	139	6.3	1.8	0.08	41.2	71688	11527	128.5	5.6	1.7	0.11	37.7	0.96

*peak event samples missing, **Partial year to 20-10-2021

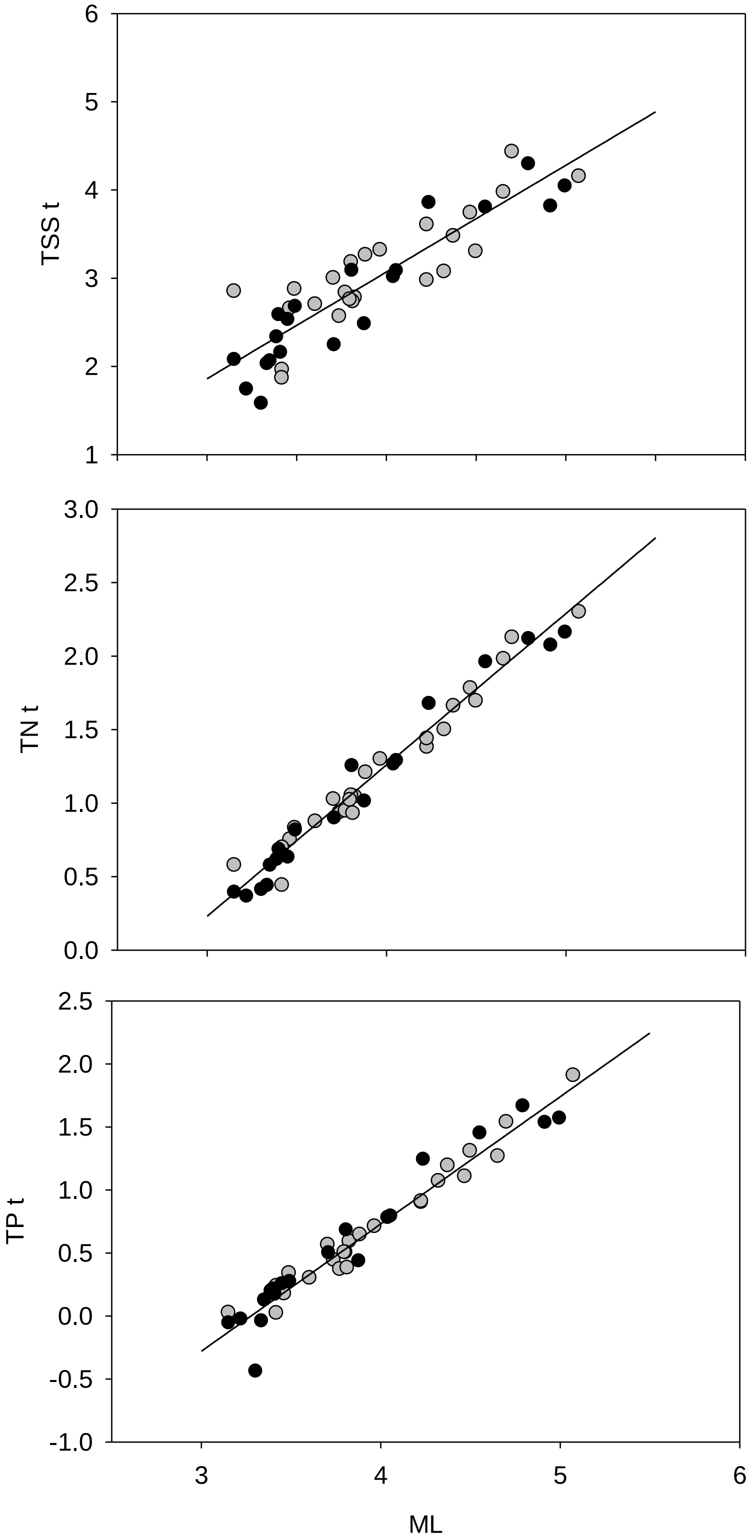

Figure A2. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for the Bremer River at Walloon. Correlations shown are linear regression fitted through the data set. Data are divided pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods.

Appendix B: Warrill Creek gauge - 143108A

Flow (ML/hr) and sample collection points on the hydrographs for the period January 2007 to December 2022 for Warrill Creek at Amberley are shown in Figure B1. In total 1106 water quality samples were collected and analysed. There is good coverage up to 2022 of both low flow periods, and event flows, with samples being collected through the hydrographs, with just the 2011 event being under-sampled. The under-sampling means that load estimates for flow events in 2011 will be underestimates.

Tables B1 present flow, sediment, nitrogen and phosphorus loads for the Warrill Creek at Amberley for full year sampling years 2008-2022. During this period 82% of the discharge, 95% of the sediment load, 89% of the nitrogen load and 90% of the phosphorus loads are associated with event flows, which occur 4% of the time. The nitrogen load is dominated by particulate nitrogen, with on average just 13% of the TN being DIN.

The average annual sediment load is 40,143t/yr but is highly variable ranging from 15t in the low flow year 2019, to 181,077t in the 2013 flood year. For comparison annual sediment loads predicted using the load area relationship from Olley and Wasson (2003) is 18,800t/yr. Their predictions are for highly degraded catchments in Southeastern Australia. The much higher sediment yield from Warrill Creek indicates the very degraded nature of this catchment. For TN the range is 1.4t to 864t for the same years with an annual average of 216t, and for TP the annual average is 90t with a range of 0t to 298t.

In total 51 events were sampled. In each case the log of event loads (TSS, TN, and TP) are strongly correlated with the log of discharge with r^2=0.89, 0.93 and 0.97 respectively (Figure B2 and Table B2). Data were divided into pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods. There is also no strong relationship between discharge and DIN/TN, with the average DIN/TN ratio being 0.13 across all flows (Table B1).

Figure B1: Flow (ML/hr – solid lines) and sample collection points on the hydrographs (open circle) for the period Jan 2007 to Dec 2022 for Warrill Creek at Amberley.

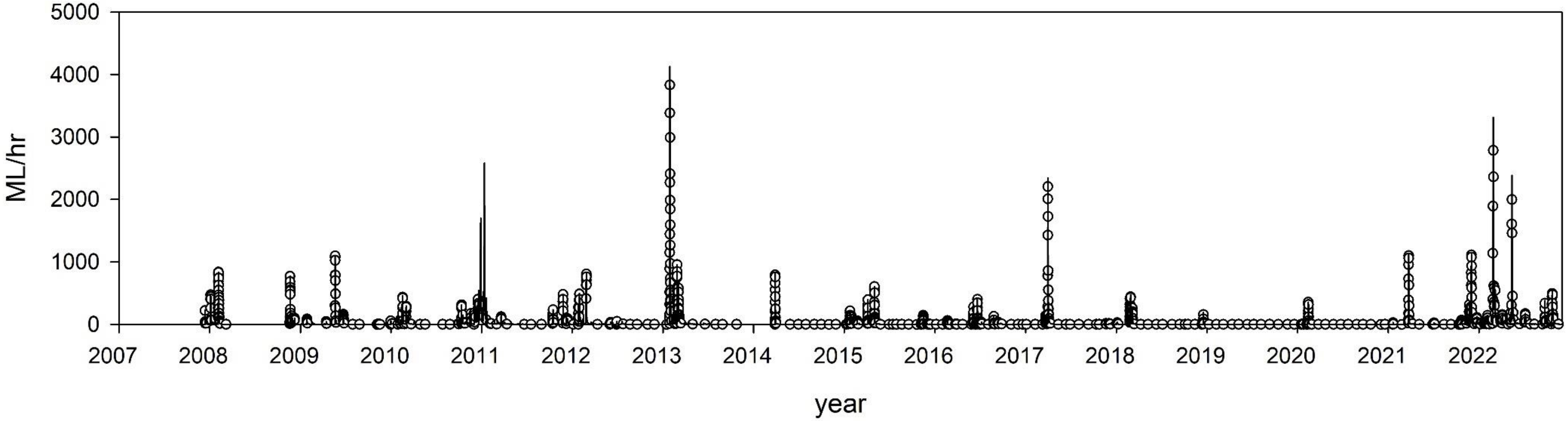

Table B1: Warrill Creek at Amberley flow, sediment, nitrogen and phosphorus loads. Loads are calculated from hourly estimates of flow (ML) and historic water quality data.

	Annual Totals							Event							Proportion of year low flow
Year	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	
2008*	108980	26159		11.1	3.5		72	92979	24121		9.3	2.9		63	0.95
2009*	58819	11162		11.1	2.6		26	42658	9711		9.3	2.2		20	0.98
2010*	278087	79502		20.6	4.4		170	243150	77174		17.6	3.9		156	0.89
2011**	271460	106882	396	27.6	7	0.27	176	226826	102486	349	18.5	4.1	0.11	160	0.92
2012	98695	16177	72	6	1.4	0.17	47	36876	6907	44	2.6	1	0.09	22	0.98
2013	257744	181077	526	28	4.2	0.18	299	228563	179915	510	23.7	3.8	0.07	293	0.94
2014	24726	11794	51	7.1	0.7	0.07	24	20891	11502	47	6.5	0.5	0.15	23	0.99
2015	58196	11486	90	9.2	1.5	0.1	34	38930	10741	70	7.2	1	0.11	28	0.97
2016	30653	4038	50	7.9	1	0.11	18	16581	3486	34	5.7	0.6	0.19	14	0.98
2017	115540	21186	171	13.3	2.5	0.08	64	100644	20855	159	11.8	2.2	0.11	60	0.97
2018	45712	6847	71	4.7	1.1	0.08	24	34654	6379	58	3.6	0.8	0.08	20	0.97
2019	2685	15	1.4	0	0	0.03	0	0	0	0	0	0	NC	0	
2020	16761	6275	54	13.7	0.6	0.03	14	11505	6011	44	11.9	0.5	0.23	12	0.99
2021	135349	19344	248	32.2	2.7	0.12	83	109861	16716	210	25.5	2	0.11	70	0.95
2022	563195	100203	864	97.5	10.0	0.26	298	499233	93898	787	79.0	8.7	0.15	277	0.85
Average	137773	40143	216	19.3	2.9	0.13	90	113557	37993	193	15.5	2.3	0.13	81	0.96

* No TN measurements, ** peak event samples missing

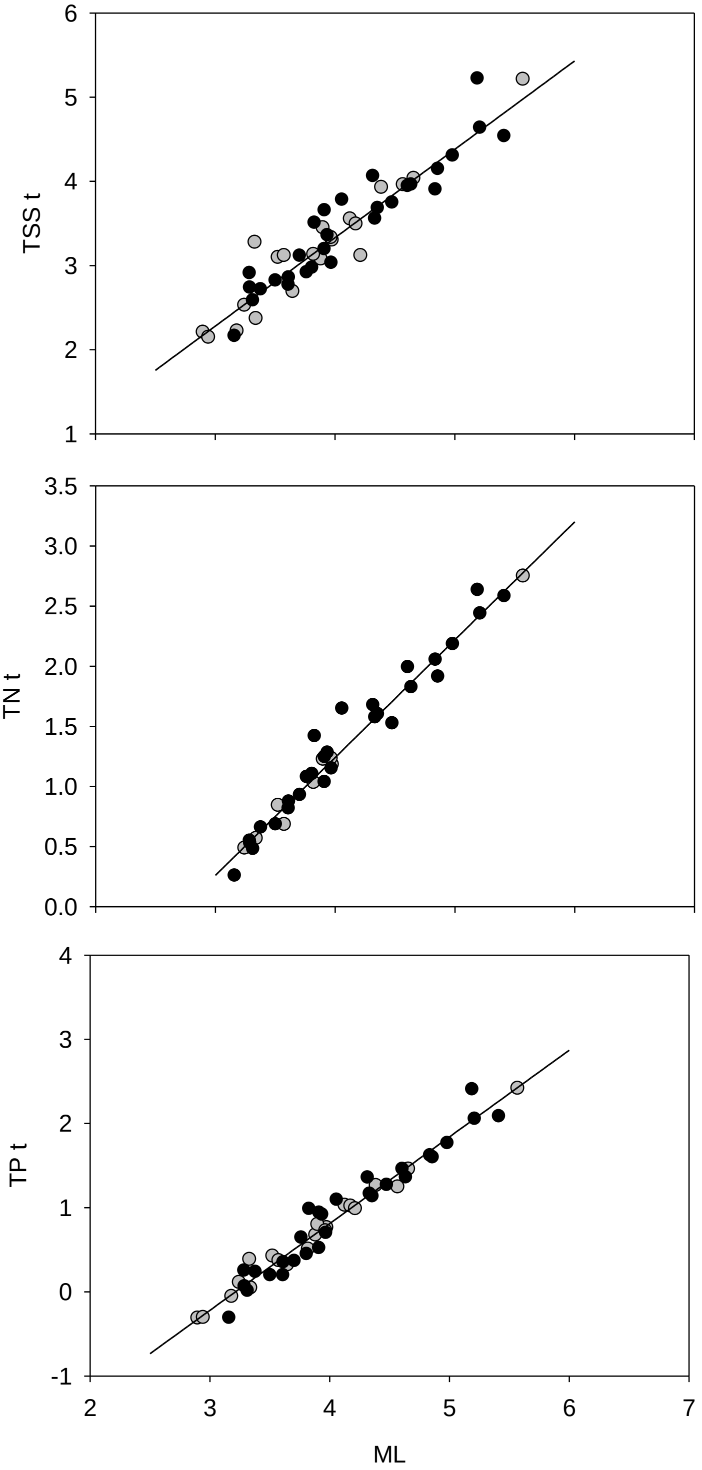

Figure B2. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for the Warrill Creek at Amberley. Correlations shown are linear regression fitted through the data set. Data are divided pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods.

Appendix C: Lockyer Creek gauge - 143210B

Flow (ML/hr) and sample collection points on the hydrographs for the period November 2011 to December 2022 for Lockyer Creek at Rifle Range Road are shown in Figure C1. In total 299 water quality samples were collected and analysed. There is good coverage from December 2011 to July 2018 both low flow periods, and event flows, with samples being collected through the hydrographs. Post 2019 all event flows were under-sampled. The was little or no flow in the years 2018, 2019 and 2020.

Tables C1 present flow, sediment, nitrogen and phosphorus loads; because of the under-sampling of event flows years 2021 and 2022 have not been included in the averages. During the period 2012 to 2021 97% of the discharge, 94% of the sediment load, 92% of the TN and 99% of the phosphorus loads are associated with event flows, which occur in 3% of the time. The nitrogen load is dominated by particulate nitrogen, with on average just 16% of the TN being DIN.

The average annual sediment load is 58,542t/yr but is highly variable ranging from 0t in the low flow year 2019, to 448,620t in the 2013 flood year. For comparison annual sediment loads predicted using the load area relationship from Olley and Wasson (2003) is 54,900t/yr. For TN the range is 0t to 1563t for the same years with an annual average of 206t, and for TP the annual average is 98.9t with a range of 0t to 814.4t.

In total 10 events were sampled. In each case the log of event loads (TSS, TN, and TP) are strongly correlated with the log of discharge with r^2=0.95, 0.96 and 0.97 respectively (Figure C2). Only one event was sampled in the pre 1-1-2012, in all cases (TSS, TP and TN) loads are consistent with the regressions fitted through the post 2012 (black points) data.

Figure C1: Flow (ML/hr – solid lines) and sample collection points on the hydrographs (open circle) for the period Nov 2011 to Dec 2022 for Lockyer Creek at Rifle Range Road.

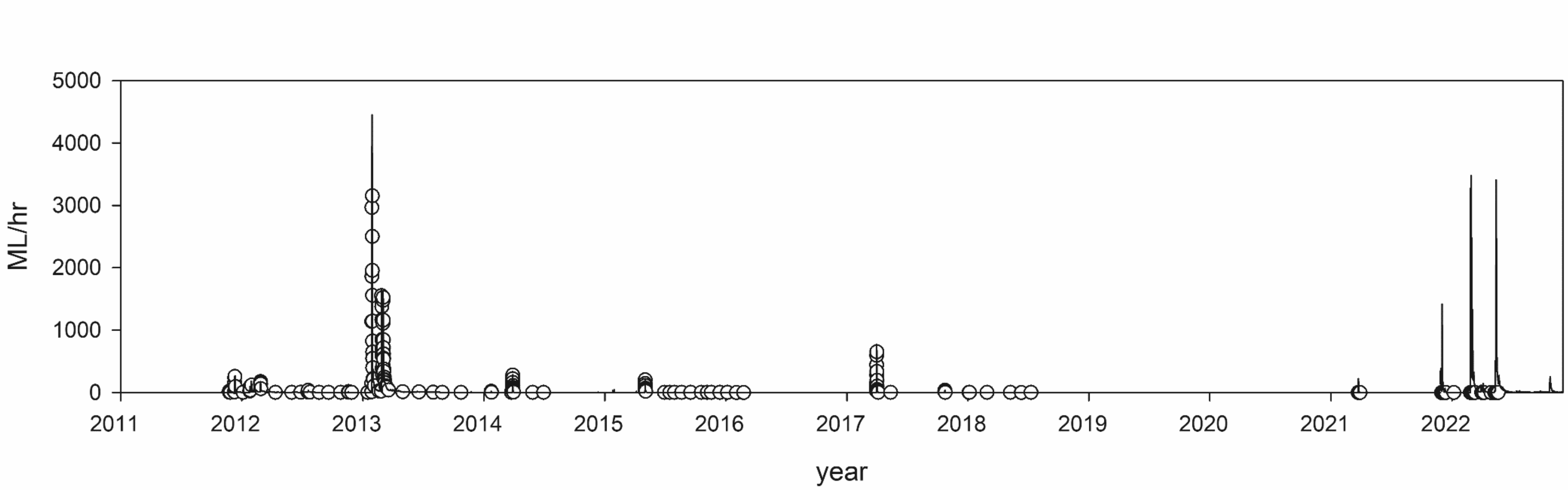

Table C1: Lockyer Creek at Rifle Range Road, sediment, nitrogen and phosphorus loads. Loads are calculated from hourly estimates of flow (ML) and historic water quality data. The grey background indicates data affected by extreme under-sampling during event flows – these have not been included in the averages.

	Annual Totals							Event							Proportion of year low flow
Year	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	
2012	63781	44534	146	2.9	16.7	0.26	3.6	25141	16928	57	1.2	5.3	0.18	1.3	0.95
2013	453675	448620	1563	39.1	64.3	0.42	814.4	415131	447573	1519	36.6	43.0	0.22	808.0	0.83
2014	11406	6446	27	0.4	4.0	0.18	13.9	6321	6096	21	0.1	3.2	0.16	12.8	0.99
2015	10239	3437	22	0.3	3.5	0.12	7.4	4808	3239	16	0.1	2.5	0.18	6.4	0.99
2016	126	0	0	0.0	0.0	0.62	0.0	0	0	0	0.0	0.0	NC	0.0	1.00
2017	16901	23830	94	0.7	5.6	0.27	51.0	16480	23802	93	0.7	5.5	0.06	50.7	0.98
2018	388	9	1	0.0	0.0	NC	0.1	0	0	0	0.0	0.0	NC	0.0	1.00
2019	0	0	0	0.0	0.0	NC	0.0	0	0	0	0.0	0.0	NC	0.0	1.00
2020	0	0	0	0.0	0.0	NC	0.0	0	0	0	0.0	0.0	NC	0.0	1.00
2021	68911	16769	194	3.2	11.7	0.06	78.9	56998	16710	169	1.8	11.6	0.08	67.7	0.96
2022	666024	559708	2492	33.9	218	0.30	1090.8	630056	558071	2422	32.8	192.3	0.23	1071.0	0.78
Average	61835	58542	206	4.8	10.5	0.21	98.9	51987	55293	190	4.3	6.6	0.16	97.7	0.97

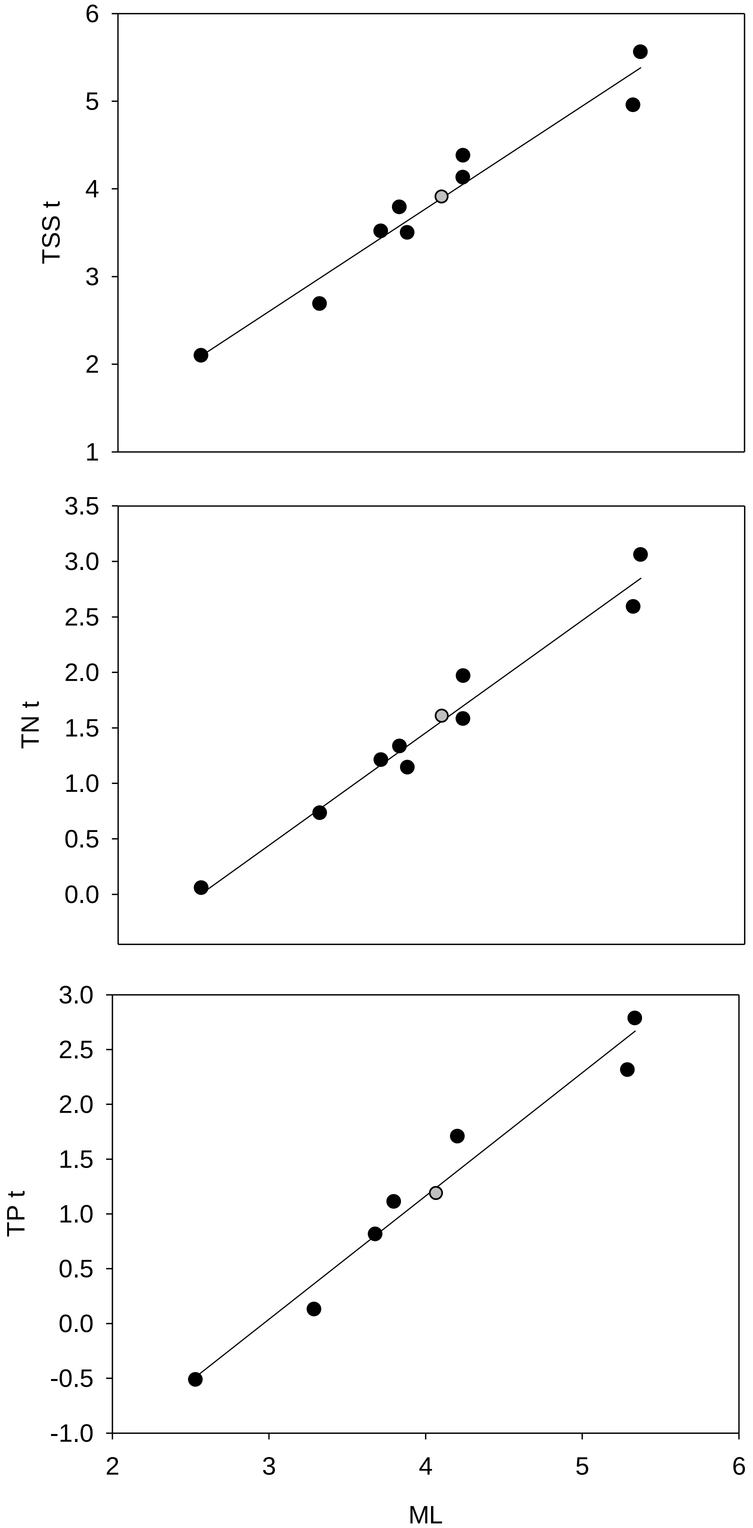

Figure C2. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for the Lockyer at Rifle Range Road. Correlations shown are linear regression fitted through the data set. Data are divided pre (grey point) and post 1-1-2012 (black points. The pre 2012 point is consistent with the regression fitted through the post data.

Appendix D: Laidley Creek at Mulgowie gauge - 143209B

Flow (ML/hr) and sample collection points on the hydrographs for the period November 2007 to 1-1-2023 are shown in Figure D1. Water quality samples were collected over two periods: 26-11-2007 to 19-7-2011 and 14-12-2015 into 2023 (on-going). In total 421 water quality samples were collected and analysed. In total 30 events were sampled well enough to enable load calculations: sixteen in the first period and fourteen in the second.

Tables D1 present flow, sediment, nitrogen and phosphorus loads for the total year and for event flows in that year: 88% of the discharge, 98% of the sediment load and 98% of the TN and TP loads are associated with event flows, which occur in <11% of the time. The nitrogen load is dominated by particulate nitrogen, with on average 26% of the TN being DIN. The average annual sediment load is 29,700t/yr which very high compared to annual sediment loads predicted using the load area relationship from Olley and Wasson 2003 of 4000t/yr.

Event loads are strongly correlated with the log of discharge with adjusted r^2>0.80 (Figure D2). Data were divided into pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that for TSS and TN the pre and post data sets shared a common slope and intercept, indicating no change in yields between the two periods. Note for TN this comparison is based on just three data points for the early period. The TP data shows an increase in TP loads per events in the post period for flows above 1000ML.

Figure D1: Flow (ML/hr – solid lines) and sample collection points on the hydrographs (open circle) for the period Nov 2007 to Dec 2022 for Laidley Creek at Mulgowie gauge.

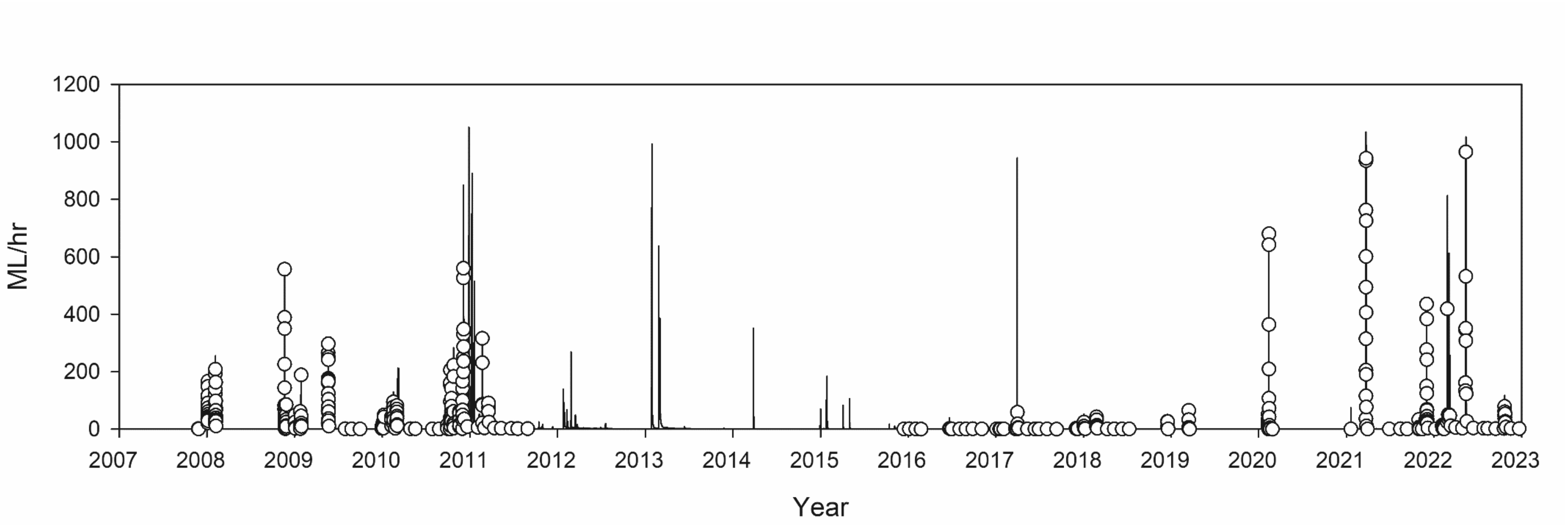

Table D1: Laidley Creek at Mulgowie, sediment, nitrogen and phosphorus loads. Loads are calculated from hourly estimates of flow (ML) and historic water quality data.

	Annual Totals							Event							Proportion of year low flow
Year	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	
2008	15883	11054		3.9	0.6		27.3	12912	10267		3.7	0.6		26.3	0.95
2009	19433	7830		7.6	0.5		16.6	12785	6694		5.4	0.4		13.9	0.95
2010	85108	20960	60.5	21.0	1.5	0.37	58.7	75528	20047	57.5	17.5	1.3	0.33	54.6	0.78
2011	82749														
2012	30044														
2013	65224														
2014	3676														
2015	13486														
2016	1874														
2017	10199														
2018	3286	367	3.8	0.9	0.1	0.25	1.8	1708	324	2.9	0.6	0.0	0.23	1.4	0.98
2019	157	168	0.7	0.1	0.0	0.15	0.2	157	168	0.7	0.1	0.0	0.15	0.2	1.00
2020	5343	10826	88.2	38.3	0.4	0.44	32.8	5250	10821	87.5	37.7	0.4	0.44	32.7	0.98
2021	25668	14704	70.9	11.5	0.6	0.17	51.9	23298	14631	68.7	10.5	0.5	0.16	51.3	0.96
2022	103823	171702	633.5	216.4	4.9	0.35	393.4	93627	171671	613.8	198.3	4.8	0.33	392.2	0.63
average	31064	29701	142.9	37.5	1.1	0.27	72.8	28158	29328	138.5	34.2	1.0	0.25	71.6	0.90

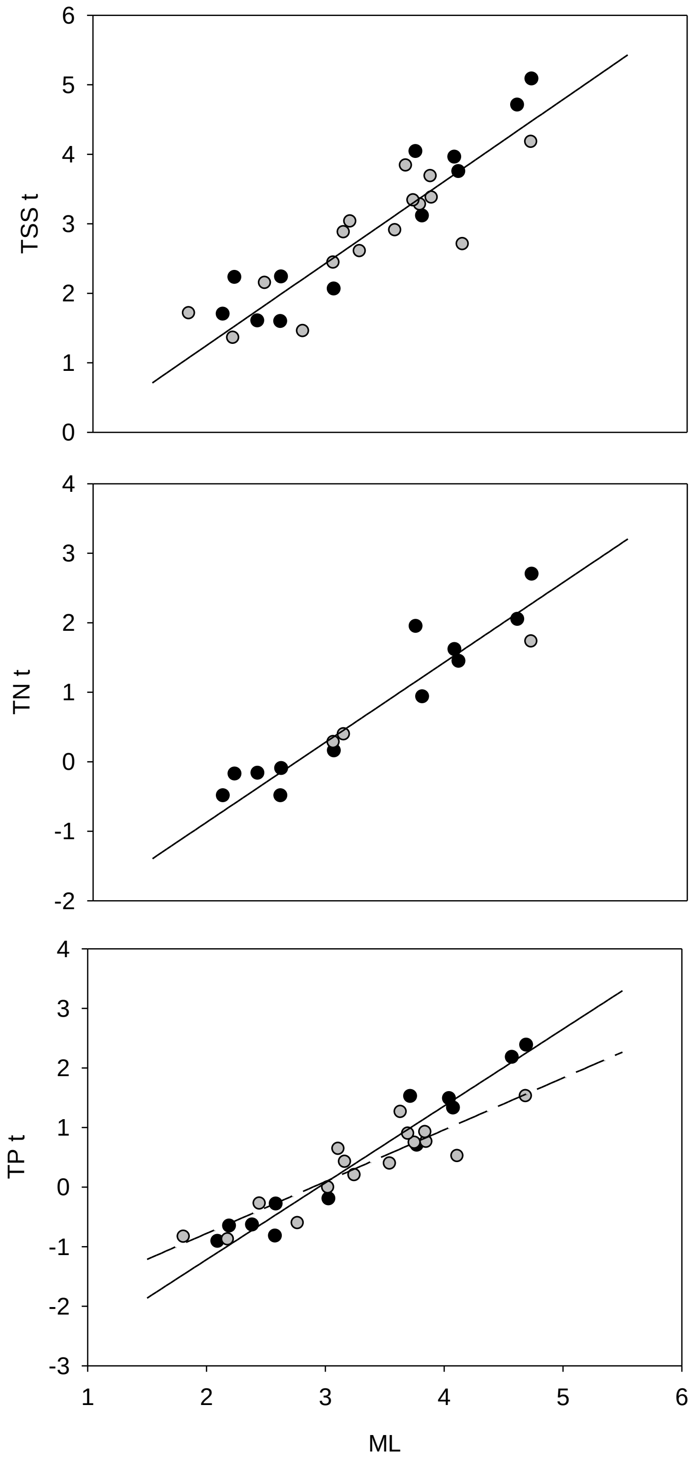

Figure D2. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for the Laidley Creek at Mulgowie. Correlations shown are linear regression fitted through the data sets. Data are divided pre (grey points) and post 1-1-2012 (black points). For TSS and TN the pre and post data sets shared a common slope and intercept, indicating no change in yields between the two periods. Note for TN this comparison is based on just three data points for the early period. The TP data shows an increase in TP loads per events in the post period for flows above 1000ML.

Appendix E: Laidley Creek at Warrego Highway gauge - 143229A

Flow (ML/hr) and sample collection points on the hydrographs for the period November 2007 to 1-1-2023 are shown in Figure E1. Water quality samples were collected over two periods: 24-11-2007 to 19-7-2011 and 14-12-2015 into 2023 (on-going). In total 507 water quality samples were collected and analysed. In total 26 events were sampled well enough to enable load calculations: fifteen in the first period and eleven in the second.

Tables E1 present flow, sediment, nitrogen and phosphorus loads for the total year and for event flows in that year: 94% of the discharge, 98% of the sediment load and 97% of the TN and TP loads are associated with event flows, which occur in <11% of the time. The nitrogen load is dominated by particulate nitrogen, with on average 22% of the TN being DIN. The average annual sediment load is 24,180t/yr which very high compared to annual sediment loads predicted using the load area relationship from Olley and Wasson 2003 of 9870t/yr.

Event loads are strongly correlated with the log of discharge with adjusted r^2>0.80 (Figure E2). Data were divided into pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that for TP and TN the pre and post data sets shared a common slope and intercept, indicating no change in yields between the two periods. Note for TN this comparison is based on just three data points for the early period. The TSS data shows a decrease in loads per events in the post period, by a factor of ~2.6.

Figure E1: Flow (ML/hr – solid lines) and sample collection points on the hydrographs (open circle) for the period Nov 2007 to Dec 2022 for Laidley Creek at Warrego Highway gauge.

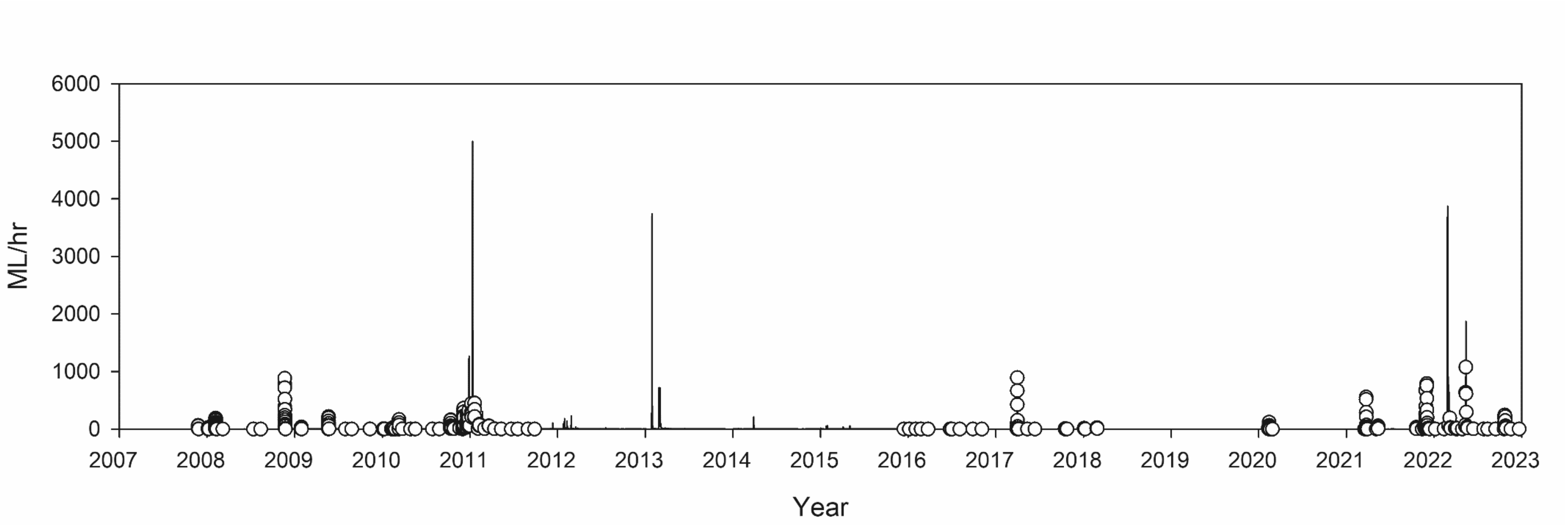

Table E1: Laidley Creek at Warrego Highway, sediment, nitrogen and phosphorus loads. Loads are calculated from hourly estimates of flow (ML) and historic water quality data.

	Annual Totals							Event							Proportion of year low flow
Year	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	
2008	22455	56862		7.4	1.0		57.1	20459	55016		7.3	0.8		53.0	0.95
2009	10451	4792		2.4	2.5		11.4	6126	3056		1.8	1.7		6.8	0.95
2010	101345	60470	158.3	15.9	2.7	0.12	93.8	91408	59587	155.2	13.1	2.5	0.10	90.3	0.78
2011	186120	34910	290.5	38.1	2.5	0.14	145.3	175956	34801	279.0	31.5	2.4	0.12	143.7	
2012	34688														
2013	158046														
2014	4645														
2015	8528														
2016	801														
2017	12652	11483	48.2	6.4	0.5	0.14	33.1	11469	11447	46.5	6.3	0.3	0.14	32.1	
2018	1641	438	3.7	1.0	0.0	0.27	1.8	1230	333	2.6	0.7	0.0	0.26	1.3	
2019	0	0	0.0	0.0	0.0	NC	0.0	0	0	0.0	0.0	0.0	NC	0.0	1.00
2020	2636	6056	44.7	15.3	0.1	0.35	19.6	2572	6013	44.0	14.9	0.1	0.34	19.5	0.98
2021	53209	14845	114.8	17.6	2.9	0.18	65.3	51902	14784	111.9	16.8	2.8	0.18	64.0	0.96
2022	262116	51944	318.0	108.0	4.7	0.35	171.3	253085	51689	305.0	99.3	4.5	0.34	169.3	0.63
average	57289	24180	122.3	21.2	1.7	0.22	59.9	61421	23672	118.0	19.2	1.5	0.21	58.0	0.89

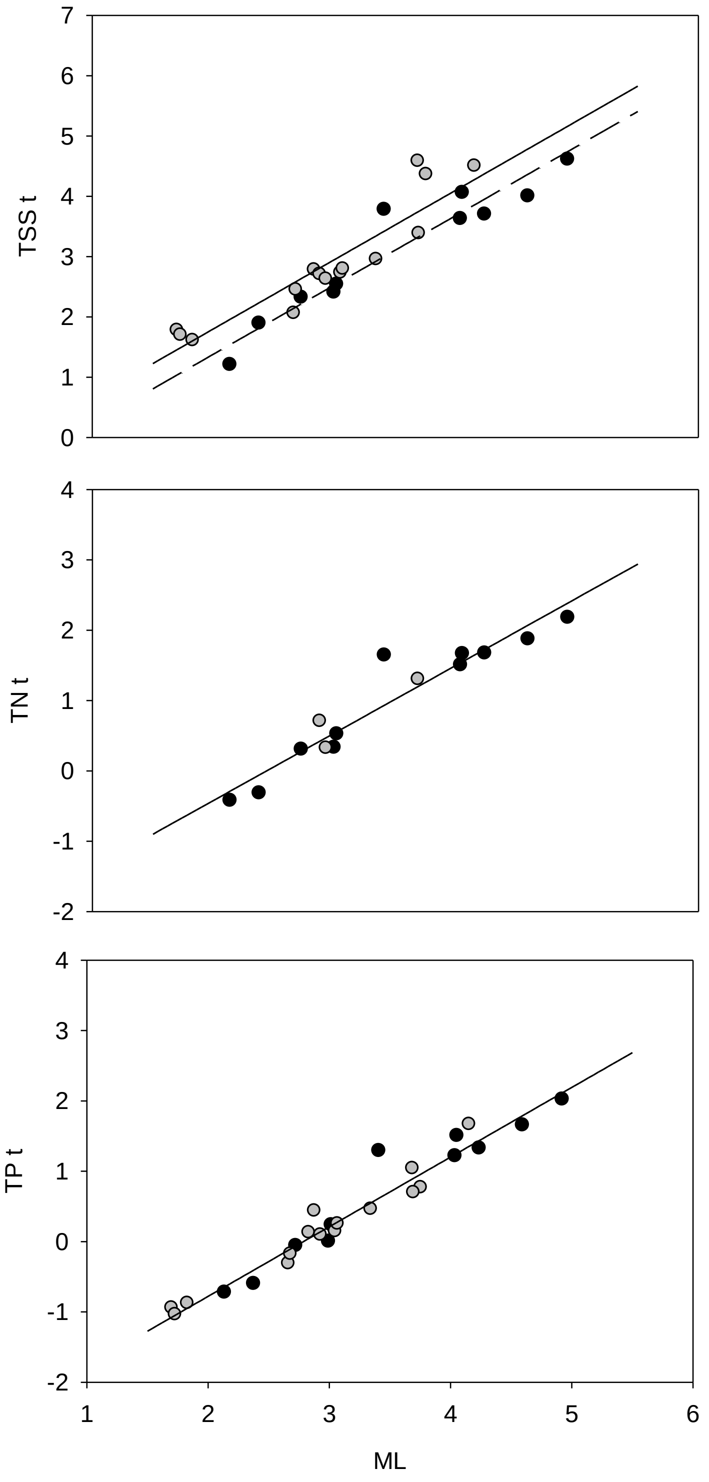

Figure E2. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for the Laidley Creek at Warrego Highway. Correlations shown are linear regression fitted through the data sets. Data are divided pre (grey points) and post 1-1-2012 (black points). For TN and TP the pre and post data sets shared a common slope and intercept, indicating no change in yields between the two periods. Note for TN this comparison is based on just three data points for the early period. The TSS data shows a marked decrease in loads for a given discharge in the post period.

Appendix F: Logan River at Yarrahappini gauge - 145014A

Flow (ML/hr) and sample collection points on the hydrographs for the period January 2007 to March 2023 for gauge 145014A - Logan River at Yarrahappini are shown in Figure F1. In total 1158 water quality samples were collected and analysed. There is good coverage of both low flow periods, and event flows, with samples being collected through the hydrographs.

Tables F1 present flow, sediment, nitrogen and phosphorus loads for full year sampling years 2008-2022. During this period 80% of the discharge, 95% of the sediment load, 91% of the TN and 94% of the phosphorus loads are associated with event flows, which occur in 8% of the time. The nitrogen load is dominated by particulate nitrogen, with on average just 24% of the TN being DIN.

The average annual sediment load is 277,500t/yr but is highly variable ranging from 33,450t in the low flow year 2019, to 1,184,576t in the 2022 flood year. For comparison annual sediment loads predicted using the load area relationship from Olley and Wasson (2003) is 45,500t/yr. Their predictions are for highly degraded catchments in Southeastern Australia. The much higher sediment yield from the Logan River indicates the very degraded nature of this catchment. For TN the range is 79t to 3400t for the same years with an annual average of 1030t, and for TP the annual average is 360t with a range of 15t to 1660t.

In total 58 events were sampled. In each case the log of event loads (TSS, TN, and TP) are strongly correlated with the log of discharge with r^2=0.81, 0.90 and 0.92 respectively (Figure F2). Data were divided into pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods. There is also no strong relationship between event discharge and DIN/TN, with the average DIN/TN ratio being 0.14 across all event flows (Table F1). Low flow DIN/TN ratios tend to be higher.

Figure F1: Flow (ML/hr – solid lines) and sample collection points on the hydrographs (open circle) for the period Nov 2007 to March 2023 for Logan River at Yarrahappini.

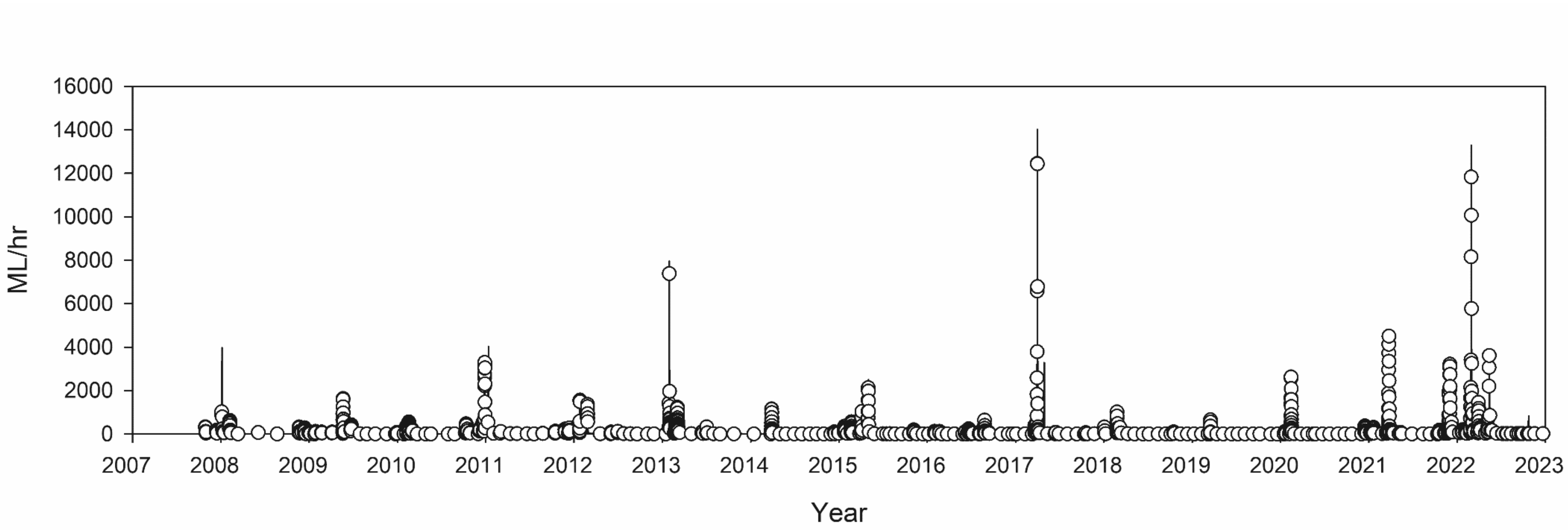

Table F1: Logan River at Yarrahappini, sediment, nitrogen and phosphorus loads. Loads are calculated from hourly estimates of flow (ML) and historic water quality data.

	Annual Totals							Event							Proportion of year low flow
Year	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	
2008	328938	439339		63.0	34.9		511	242871	424334		50.8	32.4		488	0.93
2009	183482	245109		21.3	5.1		146	100190	221366		3.5	0.7		114	0.95
2010	414849	231033	781	24.1	11.1	0.12	356	307791	192605	703	14.6	8.9	0.04	321	0.90
2011	508519	100285	741	92.9	27.4	0.45	212	358106	85192	566	40.4	16.0	0.13	169	0.92
2012	303461	103290	593	40.0	16.7	0.23	15	207027	89546	485	21.6	11.7	0.07	0	0.89
2013	662456	157777	1120	80.9	27.1	0.27	293	562231	153071	1045	58.3	24.5	0.15	275	0.89
2014	66353	68543	214	7.4	1.2	0.13	83	35090	66343	184	4.5	0.2	0.08	77	0.99
2015	306776	134473	573	28.4	9.8	0.26	188	208389	126525	479	6.7	4.0	0.12	166	0.93
2016	108871	66008	281	19.6	5.8	0.30	108	40753	55800	182	3.9	1.2	0.11	85	0.96
2017	772630	774390	3037	62.4	37.4	0.30	930	695721	770457	2977	46.8	35.2	0.16	915	0.94
2018	134998	118521	262	17.7	3.7	0.18	107	93038	115820	226	9.2	1.9	0.08	97	0.94
2019	16431	33453	79	7.8	1.3	0.12	27	6096	30141	62	4.1	0.6	0.10	23	1.00
2020	198145	174537	615	129.2	10.1	0.17	190	181299	173278	591	119.4	9.5	0.35	186	0.89
2021	672485	331201	1682	164.0	32.5	0.25	589	561286	313275	1552	127.0	27.8	0.23	560	0.88
2022	1610020	1184576	3415	246.5	64.0	0.33	1657	1431161	1158506	3217	181.1	52.2	0.24	1611	0.73
Average	419228	277502	1030	67.0	19.2	0.24	361	335403	265084	943.9	46.1	15.1	0.14	339	0.92

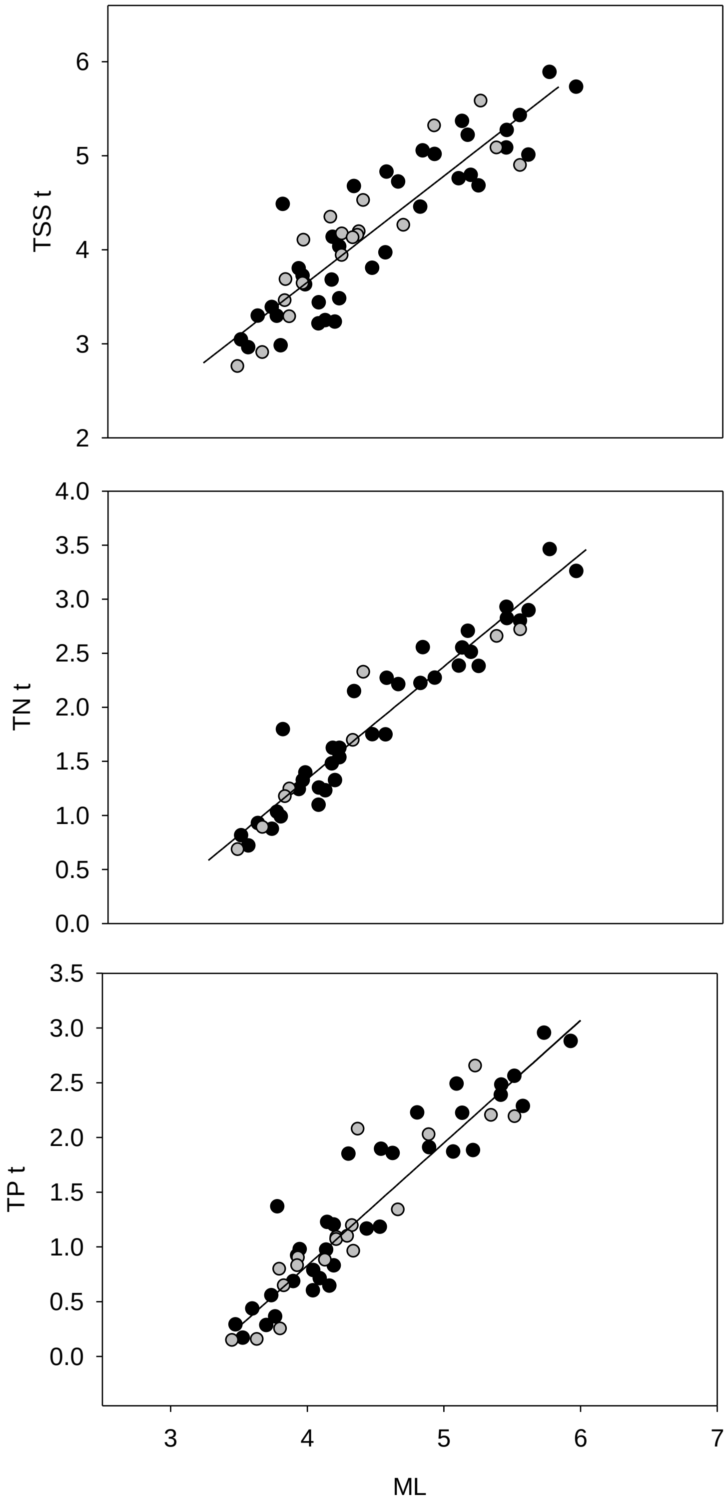

Figure F2. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for the Logan River at Yarrahappini. Correlations shown are linear regression fitted through the data set. Data are divided pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods.

Appendix G: Caboolture River at Upper Caboolture gauge - 142001A

Flow (ML/hr) and sample collection points on the hydrographs for the period January 2007 to January 2023 for gauge 142001A - Caboolture River at Upper Caboolture are shown in Figure G1. In total 1144 water quality samples were collected and analysed. There is good coverage of both low flow periods, and event flows, with samples being collected through the hydrographs.

Tables G1 present flow, sediment, nitrogen and phosphorus loads for full year sampling years 2008-2022. During this period 81% of the discharge, 97% of the sediment load, 90% of the TN and 93% of the phosphorus loads are associated with event flows, which occur in 6% of the time. The nitrogen load is dominated by particulate nitrogen, with on average just 13% of the TN being DIN.

The average annual sediment load is 7,740t/yr but is highly variable ranging from 1,007t in 2018, to 20,907t in the 2022 flood year. For comparison annual sediment loads predicted using the load area relationship from Olley and Wasson (2003) is 2,400t/yr. For TN the range is 9t to 126t with an annual average of 44t, and for TP the annual average is 8t with a range of 1.3t to 25t.

In total 82 events were sampled. In each case the log of event loads (TSS, TN, and TP) are strongly correlated with the log of discharge with r^2=0.80, 0.93 and 0.90 respectively (Figure G2). Data were divided into pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods. There is also no strong relationship between event discharge and DIN/TN, with the average DIN/TN ratio being 0.13 across all event flows (Table G1).

Figure G1: Flow (ML/hr – solid lines) and sample collection points on the hydrographs (open circle) for the period Nov 2007 to March 2023 for Caboolture River at Upper Caboolture.

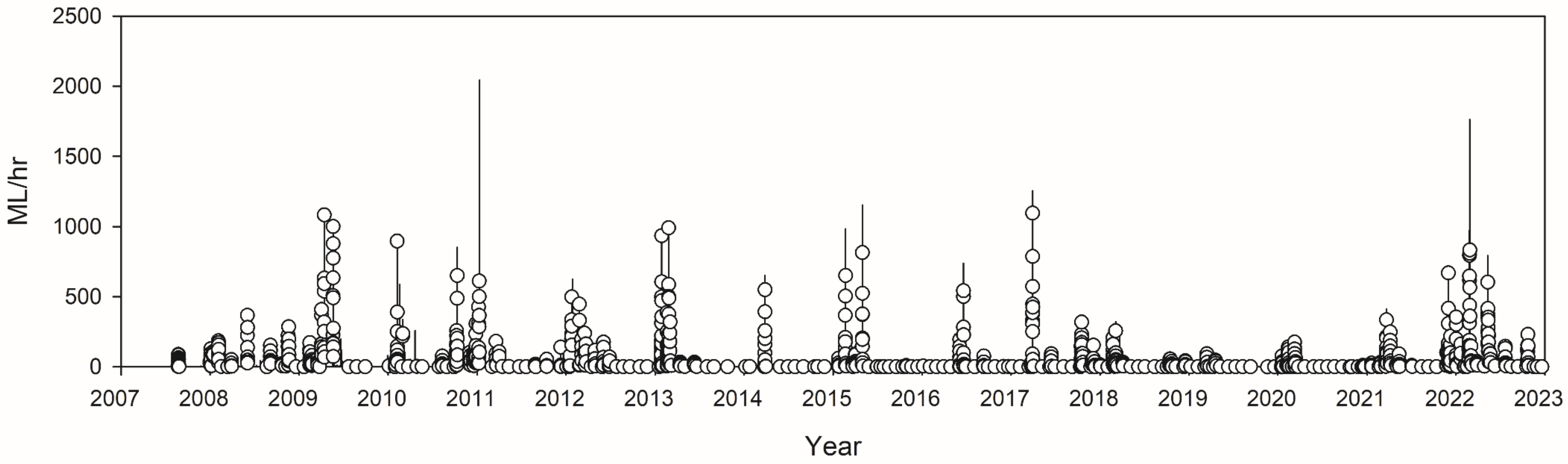

Table G1: Caboolture River at Upper Caboolture, sediment, nitrogen and phosphorus loads. Loads are calculated from hourly estimates of flow (ML) and historic water quality data.

	Annual Totals							Event							Proportion of year low flow
Year	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	
2008	35571	4781		4.6	0.7		5.1	26982	4152		3.1	0.5		4.2	0.94
2009	56773	18074		7.8	1.5		9.5	46148	17082		6.4	1.3		8.6	0.94
2010	88370	12588	62.9	9.3	1.1	0.17	15.3	76369	12084	58.2	8.1	1.0	0.16	14.4	0.85
2011	63116	8029	22.9	3.1	0.5	0.16	11.5	51642	7730	18.7	2.3	0.4	0.14	10.6	0.92
2012	59991	7237	59.9	6.5	1.1	0.13	8.7	48182	6730	50.5	4.2	1.0	0.10	7.7	0.90
2013	62757	13576	64.5	6.5	0.9	0.12	12.2	51726	13521	60.6	5.5	0.8	0.10	11.8	0.94
2014	8390	1689	11.1	1.3	0.2	0.13	1.7	5858	1656	9.8	1.0	0.1	0.11	1.6	0.99
2015	29652	7636	39.6	3.6	0.5	0.10	6.7	24861	7588	37.0	3.0	0.4	0.09	6.5	0.97
2016	11260	2118	16.9	1.9	0.3	0.13	2.8	6713	2086	14.5	1.4	0.2	0.11	2.6	0.99
2017	35467	6918	50.7	5.2	0.5	0.11	8.1	29965	6859	47.3	4.3	0.4	0.10	7.8	0.95
2018	21136	1007	17.6	1.6	0.5	0.12	2.1	14708	953	14.3	1.3	0.4	0.11	1.7	0.95
2019	5361	1212	8.8	0.6	0.1	0.08	1.3	3137	1189	7.6	0.5	0.1	0.07	1.2	0.99
2020	12346	2282	20.4	4.4	0.2	0.22	2.1	8936	2205	17.4	3.5	0.1	0.21	1.9	0.97
2021	37843	8055	66.3	5.5	0.4	0.09	8.7	30181	7949	59.8	4.3	0.3	0.08	8.2	0.94
2022	137031	20907	126	15.3	1.6	0.13	25	114333	20452	114.6	12.2	1.3	0.12	23.9	0.85
Average	44338	7741	43.6	5.2	0.7	0.13	8.1	35983	7482	39.2	4.1	0.6	0.12	7.5	0.94

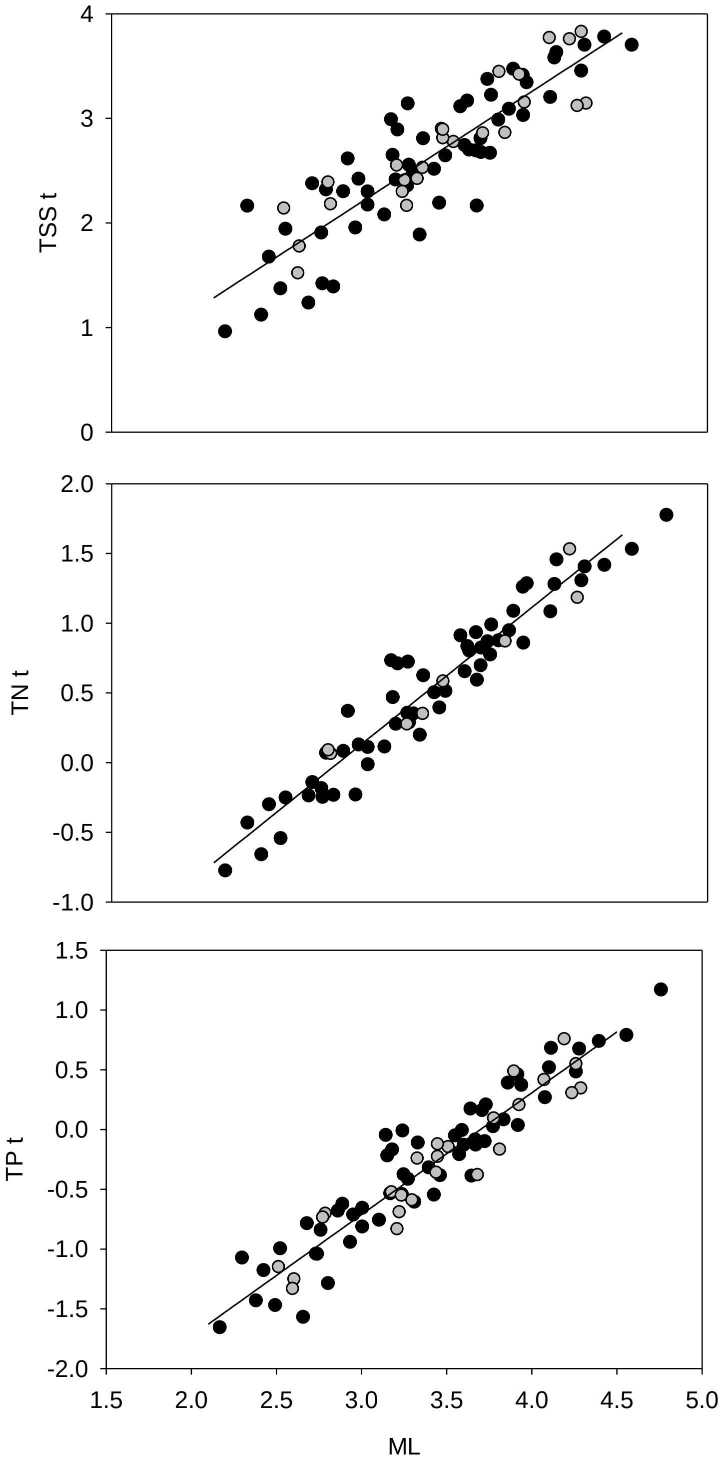

Figure G2. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for the Caboolture River at Upper Caboolture. Correlations shown are linear regression fitted through the data set. Data are divided pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that in each case the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods.

Appendix H: Coochin Creek at Mawsons Road gauge - 141010A

Flow (ML/hr) and sample collection points on the hydrographs for the period January 2007 to January 2023 for gauge 141010A - Coochin Creek at Mawsons Road are shown in Figure H1. In total 1069 water quality samples were collected and analysed. There is good coverage of both low flow periods, and event flows, with samples being collected through the hydrographs.

Tables H1 present flow, sediment, nitrogen and phosphorus loads for full year sampling years 2008-2022. During this period 57% of the discharge, 86% of the sediment load, 47% of the TN and 81% of the phosphorus loads are associated with event flows, which occur in 6% of the time. The nitrogen load is dominated by DIN, with on average 64% of the TN being DIN.

The average annual sediment load is 3235t/yr but is highly variable ranging from 177t to 10,675t. For comparison annual sediment loads predicted using the load area relationship from Olley and Wasson (2003) is 1,480t/yr. For TN the range is 13t to 170t with an annual average of 67t, and for TP the annual average is 7t with a range of 0.6t to 27t.

In total 75 events were sampled. In each case the log of event loads (TSS, TN, and TP) are strongly correlated with the log of discharge with r^2=0.80, 0.93 and 0.90 respectively (Figure H2). Data were divided into pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that for TSS and TN the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods. The TP data have different intercepts indicating a change with an increase of 1.6 times. There is also no strong relationship between event discharge and DIN/TN, with the average DIN/TN ratio being 0.40 across all event flows (Table H1), and 0.64 for all flows.

Figure H1: Flow (ML/hr – solid lines) and sample collection points on the hydrographs (open circle) for the period Nov 2007 to March 2023 for Coochin Creek at Mawsons Road.

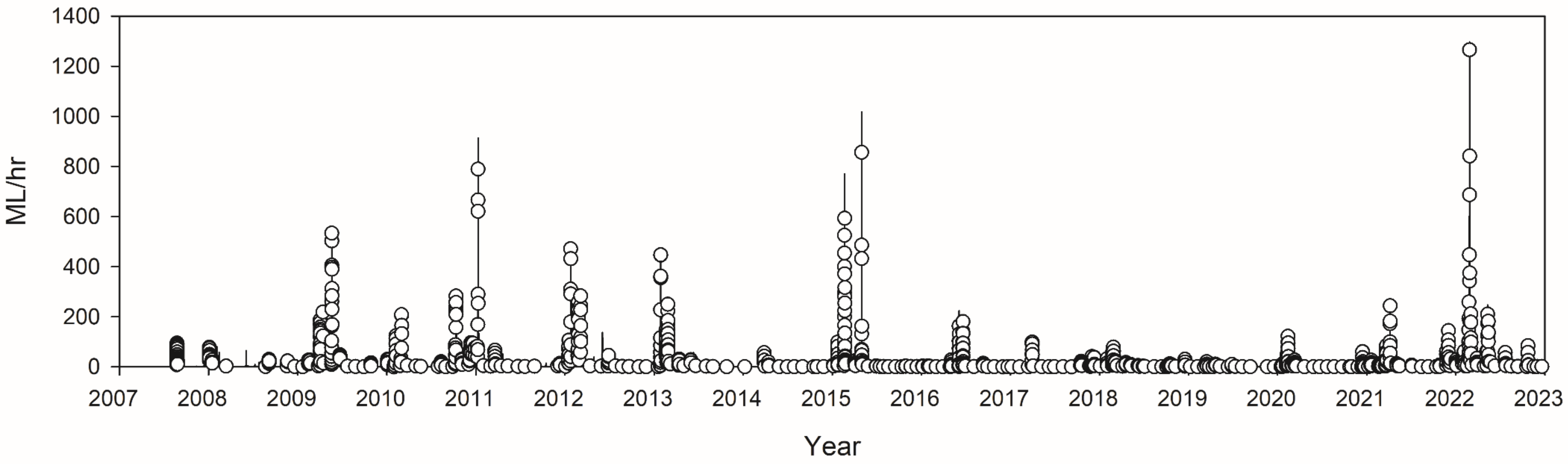

Table H1: Coochin Creek at Mawsons Road, sediment, nitrogen and phosphorus loads. Loads are calculated from hourly estimates of flow (ML) and historic water quality data.

	Annual Totals							Event							Proportion
Year	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	Q (ML)	TSS (t)	TN (t)	NOx (t)	NH4 (t)	DIN/TN	TP (t)	of year low flow
2008	30670	1632		40.1	1.3		2.6	4547	456		3.9	0.4		0.7	0.97
2009	50074	5769		45.3	1.6		5.7	29722	4344		17.5	1.1		4.1	0.93
2010	63695	4231	66.6	49.7	3.4	0.80	11.1	43252	3492	44.0	18.4	2.9	0.48	8.9	0.85
2011	61594	6061	77.3	58.6	1.4	0.78	11.7	38159	5682	12.9	5.4	0.4	0.45	9.2	0.94
2012	68611	4632	122.0	69.3	2.4	0.59	10.4	42692	3703	52.5	13.4	1.8	0.29	8.0	0.89
2013	54937	2313	90.6	59.7	2.4	0.69	5.0	31180	1998	44.9	20.0	1.9	0.49	4.3	0.91
2014	4819	177	13.0	9.0	0.6	0.74	0.6	1319	127	3.9	1.6	0.5	0.53	0.4	0.99
2015	41488	5884	86.8	40.0	1.9	0.48	12.9	27176	5734	51.1	12.1	1.3	0.26	12.0	0.97
2016	12023	1505	31.7	17.9	0.6	0.58	3.3	5518	1425	13.9	4.3	0.4	0.34	2.8	0.98
2017	13570	786	30.9	17.5	0.8	0.59	2.6	6339	698	13.7	5.0	0.4	0.40	2.0	0.97
2018	20852	991	52.8	32.7	1.0	0.64	3.9	7482	756	16.1	6.1	0.5	0.41	2.3	0.95
2019	7056	224	20.1	15.4	0.4	0.79	1.0	661	105	2.0	0.8	0.1	0.51	0.3	0.99
2020	16134	1446	40.1	22.8	0.8	0.59	4.2	8989	1361	18.7	6.6	0.5	0.38	3.5	0.95
2021	31682	2294	69.3	34.6	1.1	0.52	8.0	15813	1612	30.8	10.6	0.6	0.37	5.7	0.95
2022	86210	10564	170.5	86.8	2.7	0.53	27.3	63120	10052	103.6	35.0	1.9	0.36	25.2	0.89
Average	37561	3234	67.0	40.0	1.5	0.64	7.3	21731	2770	31.4	10.7	1.0	0.40	6.0	0.94

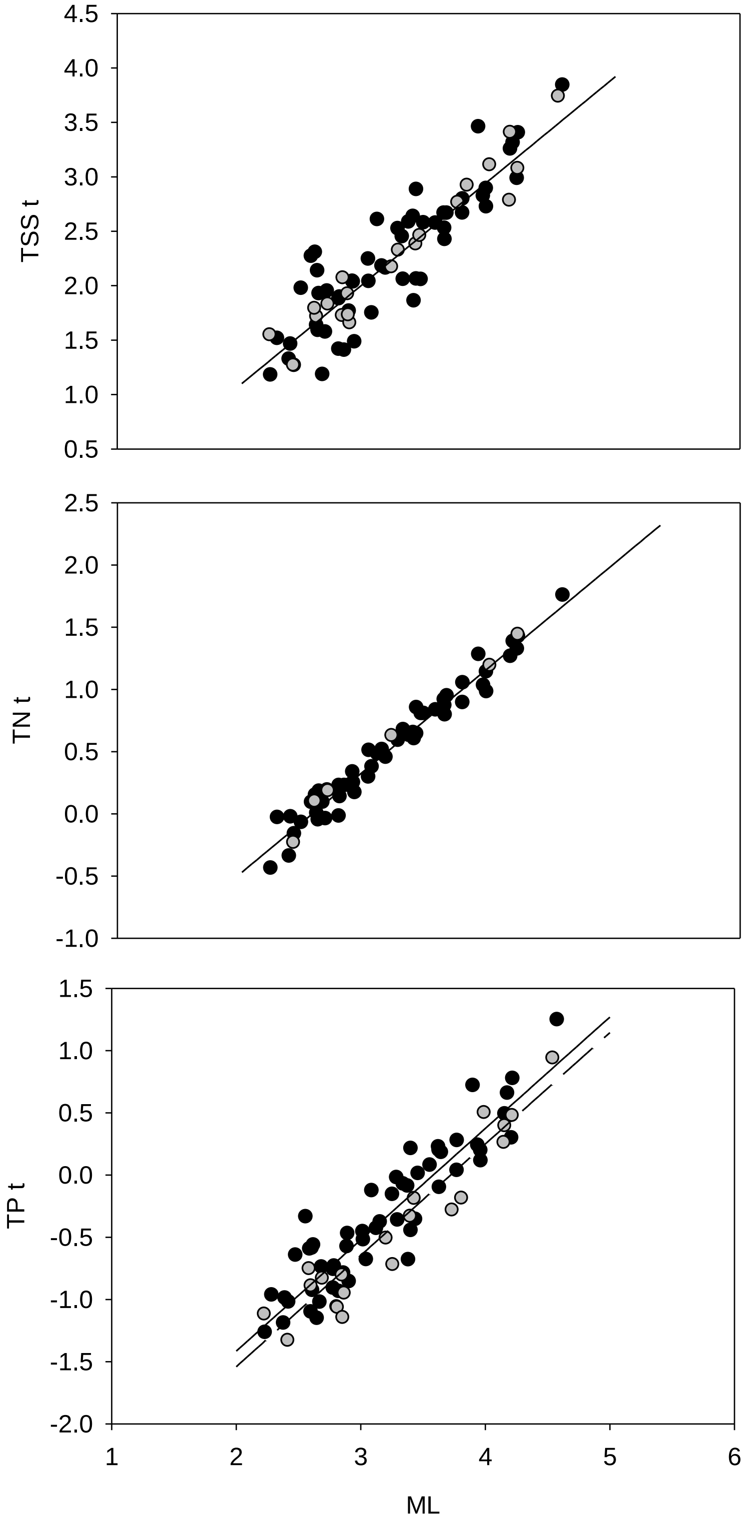

Figure H2. Log sediment, total nitrogen, and total phosphorus event loads versus log discharge for Coochin Creek at Mawsons Road. Correlations shown are linear regression fitted through the data set. Data are divided pre (grey points) and post 1-1-2012 (black points). ANOVA tests showed that for TSS and TN the pre and post data sets shared a common slope and intercept indicating no change in yields between the two periods. The TP data have different intercepts indicating a change.