SYNTHESIZING HISTORICAL LAND USE CHANGE, FERTILISER AND PESTICIDE USAGE AND POLLUTANT LOAD DATA IN THE REGULATED CATCHMENTS TO QUANTIFY BASELINE AND CHANGING LOADS EXPORTED TO THE GREAT BARRIER REEF.

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Report No. 14/20

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A Report for the Queensland Department of Environment and Heritage Protection

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Information should be cited as:

Lewis, S., Brodie, J., Endo, G., Lough, J. Furnas, M. & Bainbridge, Z 2014 'Synthesizing historical land use change, fertiliser and pesticide usage and pollutant load data in the regulated catchments to quantify baseline and changing loads exported to the Great Barrier Reef.' Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Technical Report 14/20, James Cook University, Townsville, 105 pp.

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This publication has been compiled by the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University.

Acknowledgments:

We thank Rebecca Bartley (CSIRO), Rob Dehayr (DSITIA), Bob Congdon (JCU) and Andrew Johnston (CSIRO) for supplying concentration/load data and usage data. We are thankful to the Department of Science Information Technology Innovation and the Arts State Loads Monitoring Team who provided load data for the 2009/10 and 2010/11 water years. This research was funded by Reef Water Quality, Department of Environment and Heritage Protection, Queensland Government under project RP71 "Synthesizing historical land use change data, fertiliser and pesticide usage data and pollutant load data in the regulated catchments to quantify baseline and changing pollutant loads exported to the Great Barrier Reef".

EXECUTIVE SUMMARY

Loads of suspended sediment, nitrogen, phosphorus and pesticides delivered to the Great Barrier Reef (GBR) have increased several fold since European settlement (c. 1850) of the adjacent catchment and the resultant conversion of native lands for agricultural, industrial and urban developments (e.g. Kroon et al., 2012). These increased loads have been implicated in declining water quality in the GBR and associated impacts upon keystone ecosystems such as coral reefs (Furnas, 2003; Brodie et al., 2005; Fabricius et al., 2010). While several studies have estimated 'average' loads (i.e. 20 to 30 year mean loads) for 'current' and pre-European settlement conditions, no study has examined the variability in loads at an annual time scale for each of these periods and those in between. Capturing the annual variability in loadings to the GBR allows 'unusual or extreme' events to be examined. Indeed these extreme events have a confounding effect on the health of the GBR and we need to better understand linkages with historical coral reef degradation (e.g. Roff et al., 2012) and to identify key pollutants which may have caused negative impacts. While we have a reasonable estimate of loads prior to 1850 and mean annual loads from ~1980 onwards, we do not have an estimate of how annual loads varied from 1850 to 1980. This period encompasses historical changes in the catchments such as the construction of dams, agricultural expansion and changed management practices.

This project compiled, for the first time, a wealth of statistical data from across the Wet Tropics, Burdekin and Mackay Whitsunday NRM regions that included land use change, hydrological data, measured contaminant loads and fertiliser and herbicide application data. We then established a relationship (or validation) with the measured load and statistical data at a basin scale (e.g. relationship between measured dissolved inorganic nitrogen (DIN) loads and the amount of nitrogen fertiliser applied in that basin) in order to examine rates of contaminant loss and hind cast historical loads for each basin. For example, historical DIN loads can be hind cast through time for most of these basins with medium to high confidence, which is critical given the influence of DIN on crown of thorns starfish outbreaks (e.g. Brodie et al., 2005; Fabricius et al., 2010). Our hind casting for other parameters was more variable in terms of accuracy and depend on the available measured load data for validation, although our outputs provide a reasonable estimation on the temporal variability of loads and at the very worst an examination of the relative change in loads from year to year. Further our method provides an independent comparison with previous modelling exercises to examine how well we can quantify pollutant loadings to the GBR and to determine how much loads have increased since European settlement.

Interestingly, our findings show that the average amounts of nitrogen fertiliser lost as DIN is variable across the basins of the Wet Tropics which range from 1% of applied nitrogen fertiliser lost in the Barron to 16-30% lost in the Johnstone. At this stage we do not fully understand why these variable losses occur, although we postulate it may be due to the slopes within the catchments (and hence increased surface hydrological delivery potential of the catchment). Furthermore, the Tinaroo Dam could also influence the lower rates lost in the Barron Basin. Our results also support the Source Catchments modelling which found variable losses of nitrogen fertiliser of similar magnitude across these same basins (Waters et al., in press). However, we note this may also be an artefact of an auto-correlation with the validation of the measured load data. Our study also suggests that fertiliser application amounts may have a considerable influence on the loads of dissolved inorganic phosphorus, particulate nitrogen and particulate phosphorus. This is an interesting finding and needs further analysis. The hind casting of herbicide loads was less reliable given the lack of available application data for each basin (as well as limited measured load data) and hence we have lower confidence in these outputs. It is likely that with reliable herbicide application data and additional measured loads, the model outputs would have much higher confidence. Suspended loads were much more difficult to hind cast using our simplified model and need to be predicted using more sophisticated modelling tools.

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1 INTRODUCTION

The calculation of loads transported through waterways is critical in water quality studies to identify pollutants of greatest concern, to quantify trends in water quality due to in-catchment actions, to set water quality targets and to assess the validity of predictive models. In the Great Barrier Reef (GBR) catchment area, considerable investment has been made into the accurate calculation of 'current loads' of suspended sediment, nutrients and PSII inhibitor herbicides through various monitoring and modelling exercises (e.g. Belperio, 1983; Furnas, 2003; Kroon et al., 2012) and estimation of pre-European loads (c. pre 1850). These loads are generally expressed as an annual mean over a specified period of time (~ 30 years) to account for the considerable inter-annual flow variability in this catchment area located largely in the Wet and Dry Tropics of Australia. Hence the reported 'mean annual' loads do not capture the 'unusual or extreme' events such as the loads during exceptionally high runoff, rainfall events that often follow extended drought periods or unseasonal rains. While we have a reasonable estimate of suspended sediment and nitrogen and phosphorus loads prior to 1850 and mean annual loads from ~1980, we do not have an estimate of how annual loads have varied from 1850 to 1980. This period encompasses historical changes in the catchments such as the construction of dams, land clearing, agricultural expansion and changed management practices. Indeed, an estimate of annual loadings of suspended sediments, nitrogen, phosphorus and herbicides to the GBR is critical to better understand linkages with historical coral reef degradation (e.g. Roff et al., 2012) and to identify key pollutants which may have caused negative impacts.

The aim of this project is to collect statistical land use change (and fertiliser and pesticide application) data over the regulated GBR catchments (i.e. Wet Tropics, Burdekin and Mackay Whitsunday Natural Resource Management regions) and compare these data with available historical load data. Relationships between these two datasets will be established to address the Reef Water Quality (RWQ) Science program's priority questions 'How is water quality management changing, how do we measure trends in management and their impact on water quality?' Indeed a critical knowledge gap is improving the accuracy of how inflated the current loads delivered to the GBR are and from what sources they come from.

2 BACKGROUND

As part of Reef Plan, the RWQ Science program is tasked with reducing run-off of agricultural pollutants to the GBR from cane growing and cattle grazing through improved understanding, extension and policy development. RWQ's Cane sciences sub-program and Grazing sciences sub-program therefore fund projects to identify sources of pollution and develop management solutions that can be adopted at least cost by cane growers and graziers. More broadly, the RWQ Science Program prioritisation and delivery sub-program seeks information on how efforts should be directed to produce *Least Cost Abatement* (LCA); that is the greatest improvement in Reef water quality at the least cost (to farmers and the public) and in the shortest time. This will inform the strategy to widespread adoption of improved management options to improve production, profitability and water quality outcomes consistent with LCA.

A few studies have examined the relationship between cattle and sheep numbers and sediment loads from the Burdekin River using coral core records (see McCulloch et al., 2003; Lewis et al., 2007a). Pre-European 'baseline' sediment and nutrient loads have been estimated using the limited monitoring dataset that existed up to 2003 (Brodie et al., 2003; Furnas, 2003). These estimates could not examine how these pollutant loads have changed over time (i.e. on the annual to decadal scales) and under different management practices/land use change. The wealth of monitoring data collected since 2003 under several sub-catchment scale programs (but particularly the Water Quality Improvement Plan's e.g. Rohde et al., 2008; Bainbridge et al., 2009) can also be used to provide a more robust estimate of pre-European loads (i.e. data from 'pristine sites' to construct reliable event mean concentration data for our model).

Some data exist on changing nitrogen, phosphorus and herbicide usage in sugar lands (Pulsford, 1996; Johnson and Ebert, 2000) but these data are now old (lack the last 15 to 20 years) and are limited to selected catchments (e.g. only the Herbert catchment covered for pesticide usage). This project is designed to fill in these gaps and bring key data together to provide a valuable resource for resource managers, industry stakeholders and scientists. The compilation of such land use change and fertiliser and pesticide application data can also be used in conjunction with changing pollutant load data to reconstruct historical changes in loads over time (e.g. 'new' data from Incitec Pivot, McMahon and Hurney, 2008 etc.).

This synthesis project builds upon previous research that has compiled data on land use change in the RWQ Science Program focus 'regulated' catchments (including stocking of cattle and sheep numbers), fertiliser and pesticide usage and existing pollutant loads to document changing loads over time. A synthesis of these data is crucial for studies that investigate changing erosion rates in grazing and sugar cane lands, fertiliser runoff and pesticide losses, and the outputs of this project are likely to be valuable for a number of other proposed projects within RWQ R&D.

3 PROJECT METHODOLOGY

This project was conducted in five sections:

1. Compile historical land use data for the regulated catchments (i.e. Wet Tropics, Burdekin and Mackay Whitsunday NRM regions) from the Queensland statistical registers;

We compiled the land use statistical data from the Police districts/statistical areas that were related to the Wet Tropics, Burdekin and Mackay Whitsunday NRM Regions. The complied data included information on total area of agriculture, sugar, bananas, cotton, grains and other crops, the total numbers of cattle, sheep, horses and pigs and the yields of gold, tin and coal. In some cases, the 'other crops' category needed to be adjusted upwards as there was a higher area of 'total agriculture' reported in the statistical data than the total sum of the of sugar, banana, cotton, grains and other crops areas. This adjustment was mainly applied for the Johnstone and Barron Basins, which are known to contain a higher diversity of crops than the other basins examined in this study).

Once the data for each statistical division were compiled, we assigned them to a specific basin of the Wet Tropics, Burdekin and Mackay Whitsunday regions. This was not a trivial task as there are limited data on the boundaries of the 'older' statistical divisions and quite a few divisions overlapped across basin areas (see Table 1 for final statistical area allocations to each basin). The best approach was to initially allocate the statistical land use areas to a basin based on their name and approximate location and then add up the total area of sugar. We then compared the area of sugar to data from QLUMP reported in Brodie et al. (2003: QLUMP 1999) and Lewis and Brodie (2011a, 2011b, 2011c: QLUMP 2004). We noted that the QLUMP land use data tends to overestimate the area of sugar cultivation in the basins by 10 to 30% (J. Brodie personal communication, 2013) and so we ensured that our data for each basin was within this range. For example, one of the easier basins to assign, the Tully-Murray of the Wet Tropics Region, is entirely within the Cardwell statistical division. The area of cane in this area in 1999 was 7.9% while the QLUMP 1999 area is reported as 12.8% (i.e. a difference in area of 26% higher than reported). Other statistical areas needed to be split across basins to best match the reported land use. For example, the Port Douglas district overlapped with both the Daintree and Mossman Basins and so we allocated 30% of this area to the Daintree Basin and the remaining 70% to the Mossman Basin which best matched the sugar area (see Table 1). The Queensland Government 'Wetlands' website -http://wetlandinfo.ehp.qld.gov.au/wetlands/facts-maps/ provided some guidance on where boundaries could be assigned as local government divisions could be overlaid on drainage basins.

Table 1. List of of statistical land use areas used in the compilation.

Region	Basin	Included statistical land areas	Established	Last record
Wet Tropics	Daintree	Port Douglas (30%)	1883	2006
		Daintree	2011	2011
	Mossman	Port Douglas (70%)	1883	2006
		Clifton/Kewarra	2011	2011
		Yorkey's Knob	2011	2011
	Barron	Mareeba	1895	2006
		Atherton	1919	2011
		Cairns (Pt.A)	1996	2006
		Cairns (N. Suburbs)	1997	2006
		Cairns (Barron)	1997	2006
		Kuranda	2011	2011
		Freshwater/ Stratford	2011	2011
		Redlynch	2011	2011
		Smithfield	2011	2011
	Russell Mulgrave	Cairns Council	1885	1995
		Mulgrave	1945	1995
		Cairns (Pt.B)	1996	2006
		Cairns (city)	1997	1997
		Cairns (C. Suburbs)	1997	2006
		Cairns (W. Suburbs)	1997	2006
		Cairns (Trinity)	1997	2006
		Mt. Whitfield	2001	2011
		Babinda	2011	2011
		Edmonton	2011	2011
		Gordonvale	2011	2011
		Lamb Range	2011	2011
		Mount Sheridan	2011	2011
		Westcourt	2011	2011
		White Rock	2011	2011
		Whitfield	2011	2011
	Johnstone	Mourilyan	1885	1923
		Innisfail	1924	1939
		Johnstone	1945	2006
		Malanda/ Yungaburra	2011	2011
		Eacham	1945	2006
	Tully-Murray	Cardwell	1867	2006
		Tully	2011	2011
	Herbert	Ingham	1885	1939
		partial*	2011	2011
		Herberton	1892	2006
		Hinchinbrook	1945	2006
		Ingham regional	2011	2011

Region	Basin	Included statistical land areas	Established	Last record
Burdekin	Haughton	Ayr (55%)	1885	1974
		→Burdekin	1983	2011
		Townsville (25%)	1939	2011
		Dalrymple (5%)	1945	2011
		→Charters Towers	1875	1939
	Burdekin	Ayr (35%)	1885	1974
		→Burdekin	1983	2011
		Dalrymple (85%)	1945	2011
		→Charters Towers	1875	1939
		Whitsunday (27%)	1990	2006
		→Proserpine	1909	1989
		→Airlie	2011	2011
		→Cape Conway	2011	2011
Mackay Whitsunday	Proserpine	Proserpine	1909	1989
		→Whitsunday (73%)	1990	2006
		→Airlie	2011	2011
		→Cape Conway	2011	2011
	O'Connell	Mackay (40%)	1866	1945
		Mackay (II)	1987	1994
		Mackay (Pt.A)	1995	2006
		Mackay (Pt.B)	1995	2006
		Proserpine	1909	1989
		→Whitsunday	1990	2006
		→Airlie	2011	2011
		→Cape Conway	2011	2011
	Pioneer	Mirani	1945	2006
		Pioneer	1945	1974
		→Pioneer (Pt.B)	1982	1994
		Pioneer (Pt.A)	1987	1994
		Mackay (20%)	1866	1945
		→Andergrove	2011	2011
		→Eimeo/Rural view	2011	2011
		→Eungella Hinterland	2011	2011
		→Mackay (Pt.A&B)	2011	2011
		→N.Mackay	2011	2011
		→W.Mackay	2011	2011
		→Ooralea/Baker's Ck.	2011	2011
		→Seaforth/Calen	2011	2011
		→Shoal Point/Bucasia	2011	2011
		→Walkerston/Eton	2011	2011
	Plane	Sarina	1945	2011
		Mackay (40%)	1866	1945
		Isaac (Broadsound - all sugar)	1945	2011

Similarly, the area of land used for grazing was calculated using the grazing area reported for each basin in the QLUMP data (Brodie et al., 2003) and using the number of head of cattle for that year to calculate a stocking rate. This stocking rate (i.e. number of cattle per km^2) was used to project back through time. We note that stocking rates likely would have changed over the years, although no reliable data have yet been recovered to better estimate the changes in grazing area. We also needed to adjust some values as using a consistent stocking rate for some basins led to a grazing area that was greater than the total basin area. In those cases we made modifications based on our best knowledge available (i.e. in most cases grazing area is unlikely to have decreased over time) and adjustments were made to best match the time-series. Indeed the changes in the area of grazing and conservation land use are the most uncertain in our record. For parameters such as dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP), the uncertainty in these land use areas will not have a large effect on the confidence of our load estimates (as the event mean concentrations between the two land uses are similar); however, the load calculations for particulate nitrogen and phosphorus and suspended sediment will have greater uncertainty due to a larger variation in event mean concentrations.

Once land use areas had been calculated for each basin, we linearly interpolated across the gaps in the statistical records to make a time series of land use for each basin. For example, no data were available for several of the war years (1939-1945). Land use for conservation areas was estimated as the difference between the sum of all classified uses and the total basin area.

2. Compile fertiliser and herbicide usage data for the regulated catchments (where available)

The total nitrogen and phosphorus fertiliser application for each basin up to 1990 was compiled from Pulsford (1996). This document compiled the total application of nitrogen and phosphorus for all cropping lands within the basins from 1910 to 1990. The data from 1910 to 1960 were presented in 5 yearly increments and so we linearly interpolated the data in between these time points. To estimate total application of nitrogen and phosphorus fertiliser after 1990 we used a combination of average application rate data supplied by Incitec Pivot (2011: data range from 1996 to 2011) for sugarcane land use for each NRM region and average application rates for banana land use from 1996 to 2011 supplied from Daniells (1995), DPI&F (2007) and J. Armour (personal communication, 2013). For the basins that had considerable 'other crops' (i.e. > 10 km^2: in particular the Johnstone and Barron Basins), we used the banana rate to estimate application in the Johnstone Basin and rates of 100 $kg.Ha^{-1}$ of nitrogen fertiliser and 20 $kg.Ha^{-1}$ of phosphorus fertiliser for the Barron Basin (based on an 'average' of rates for maize, potato and peanut crops). We then linearly interpolated data for the period between 1990 and 1996. This approach appeared to work well in all basins as there was not a great difference between the amount applied in 1990 and our calculations for 1996 using this method.

Herbicide application data were compiled from Johnson and Ebert (2000) for the Herbert Basin. Data for this basin were available from 1949 to 1995 for diuron, atrazine, ametryn and 2,4-D. Unfortunately no data were available (to date) for hexazinone and no herbicide application data existed (or were freely available) for any other basins. Hence we used the yearly amount applied divided by the corresponding area of sugar for that year in the Herbert Basin to calculate mean application rates. The respective rates calculated for 1995 were projected forward to estimate application of these herbicides to 2011 using the changing sugar area. These rates were then applied to the other basins. We note this is a considerable limitation to this component of the study, although this is the best that could be done with the available data.

3. Compile pre-existing suspended sediment, nitrogen, phosphorus and herbicide load data for the regulated catchments

We compiled all relevant load data available (suspended sediment, nitrogen, phosphorus and herbicide loads) for the studied basins from previous studies as well as recalculated loads for rivers where overlapping data from different programs (e.g. AIMS long-term monitoring, DNR&M) or newly uncovered data became available. Loads were calculated using a linear interpolation method (see Lewis et al., 2007b) with the exception of suspended sediment loads for the Burdekin River, which applied the LRE model (Kuhnert et al., 2012). Once the load data were compiled, we realised that there were only enough data from the Barron (Joo et al., 2012; Turner et al., 2012, 2013; AIMS, unpublished data), Johnstone (South and North Johnstone River: Hunter et al., 2001; Hunter and Walton, 2008; Joo et al., 2012; Turner et al., 2012, 2013; AIMS, unpublished data), Tully-Murray (Tully River: Mitchell et al., 2006a; Joo et al., 2012; Turner et al., 2012, 2013), Herbert (Bramley and Muller, 1999; Bramley and Roth, 2002; AIMS, unpublished data; Turner et al., 2012, 2013), Haughton (Barratta Creek: Congdon and Lukacs, 1996; R. Congdon, unpublished data; Bainbridge et al., 2006a, 2006b, 2007, 2008; TropWATER, unpublished data; Lewis et al., 2011; Turner et al., 2012, 2013) and Pioneer (Mitchell et al., 2005; Rohde et al., 2006, 2008; Turner et al., 2012, 2013) Basins to calibrate our model in the validation section. The limited (to no) load data for the Daintree, Mossman, Russell Mulgrave, Proserpine, O'Connell and Plane Basins precluded a validation to be performed for these areas, although where appropriate we compared the available load data with our model outputs. In these cases, we used the most appropriate validation that had the most similar characteristics to that basin (e.g. The Russell Mulgrave Basin has similar characteristics to the Tully-Murray Basin and so we used the validation from the Tully at Euramo site to reconstruct loads for the Russell Mulgrave Basin). While there has been a long-term monitoring program in the Burdekin Basin, it captures very little of the sugarcane (i.e. fertilised) area and hence no validation could be performed.

4. Compile and reconstruct freshwater discharge data for each basin

The relevant discharge data for each basin were compiled (Table 2; DNRM, 2013). The total annual discharge for each gauge was then up-scaled using the difference between the gauged area and the total basin area to estimate flow for each basin. The key assumption for this calculation is that rainfall was spread relatively evenly over the entire basin for each year. For example, the Daintree River at Bairds gauge only measures 44% of the Daintree Basin and so the annual discharge for this basin was estimated by multiplying the gauged annual flow by a factor of 2.4. We were able to examine this assumption further by comparing our mean annual basin discharge with those produced by the Source Catchments model (Waters et al., in press) over the common period 1987 to 2009 (Table 3). The data show reasonable agreement (generally within 10%) for most basins with the exception of the Russell-Mulgrave, Tully-Murray, Proserpine and O'Connell Basins (we note there are discrepancies between the individual Daintree and Mossman Basins, although when considered jointly there was little difference).

In these cases, we could reasonably explain the differences in these data. For example, our reconstruction for the Russell-Mulgrave Basin used the Mulgrave River to upscale for the whole basin. This process cannot account for the Russell River, which receives more rainfall than the Mulgrave and so our basin flow estimates are 26% lower than those of the Source Catchments model. A similar scenario occurs in the O'Connell Basin. In contrast, our Tully-Murray flow reconstruction used the 'wetter' Tully River, which is why the mean flows were 16% higher than Source Catchments. The largest difference between the models occurred in the Proserpine Basin where our reconstruction was 120% lower than the Source Catchments flow. Our reconstruction used the Proserpine River, which is considerably affected by the Peter Faust Dam. Based on these data we modified the annual basin flows by the percentage difference in these specified basins so our outputs should better align (and hence be directly compared) with the Source Catchments model outputs. We note that we did not change any of the other basins including the Pioneer where the mean annual flow was 16% lower in our model. This particular discrepancy was not easily explained as the gauged catchment area captures 95% of the whole basin.

Coral luminescence reconstructions of the annual discharge for the Herbert, Burdekin and Pioneer Rivers were used to hind cast annual discharge from these basins back to the year 1800 AD (Lough, 2007: note these reconstructions are based on the relevant gauge measurements and not on the whole basin and so the up-scaling factor was also used). Linear relationships were then established between the gauged annual discharge of the Herbert River and the other basins of the Wet Tropics (Daintree, Mossman, Barron, Russell Mulgrave and Tully-Murray) to reconstruct annual discharge for each basin back to 1800 AD. The same approach was used for the relationship between the Burdekin River and the Haughton River gauges and the Pioneer River and the Proserpine River, O'Connell River and Sandy Creek gauges.

Table 2. Details of flow gauges used to reconstruct from the each basin area.

Region	Basin	Gauge	% of Basin area	Established
Wet Tropics	Daintree	Daintree River at Bairds	42%	1969
	Mossman	Mossman River at Mossman	23%	1949 (but incomplete record)
	Barron	Barron River at Myola	91%	1916
	Russell Mulgrave	Mulgrave River at Peets Bridge	26%	1916
	Johnstone	Sth Johnstone River at Central Mill	17%	1917
	Tully-Murray	Tully River at Euramo	52%	1973
	Herbert	Herbert River at Ingham	87%	1917
Burdekin	Haughton	Haughton River at Powerline	44%	1971
	Burdekin	Burdekin River at Clare/Inkerman	100%	1922
Mackay Whitsunday	Proserpine	Proserpine River at Peter Faust Dam Tailwater (at Proserpine from 1991)	14%	1957
	O'Connell	O'Connell River at Staffords Crossing (Caping Siding)	14%	1970
	Pioneer	Pioneer River at Pleystowe	95%	1917
	Plane	Sandy Creek at Homebush	13%	1967

Table 3. Comparison of mean annual flows (ML) for the period 1986/87 to 2008/09 between this study and the Source Catchments model. Highlighted values represent the flows that were adjusted by this factor in our model to compare with the Source Catchments outputs.

Basin	Mean flow this study	Mean flow Source Catchments	Difference
Daintree	1,742,093	2,639,319	41%
Mossman	1,163,763	507,886	-78%
Daintree-Mossman	2,905,856	3,147,205	8%
Barron	713,326	793,802	11%
Russell-Mulgrave	2,845,030	3,684,046	26%
Johnstone	4,476,224	4,559,029	2%
Tully-Murray	5,597,626	4,779,073	-16%
Herbert	3,932,815	4,273,490	8%
Haughton	957,296	1,045,169	9%
Burdekin	8,589,994	8,913,702	4%
Proserpine	310,146	1,243,837	120%
O'Connell	1,106,658	1,475,735	29%
Pioneer	701,533	822,186	16%
Plane	1,237,831	1,264,564	2%

5. Calculation of runoff per land use area and application of relevant event mean concentration data to calculate land use specific loads

We used the percentage of the major land use areas (conservation/minimal use, grazing, sugar, bananas and other crops) in each basin for each year coupled with the annual discharge to calculate the volume of water leaving each land use. The key assumption is that the rainfall for each year was spread evenly across the basin area. We note that because we are using the discharge from the basin we are somewhat accounting for water that does not leave the land use area (through infiltration, damming, evaporation etc).

Once the water volume allocation for each year was established we could then apply event mean concentrations for the conservation and grazing land uses based on relevant monitoring data. Specifically, the data from sub-catchment monitoring programs in the Johnstone (Hunter et al., 2001; Hunter and Walton, 2008), Tully (Bainbridge et al., 2009), Herbert (O'Brien et al., 2013, in press), Haughton/Burdekin (Bainbridge et al., 2006a, 2006b, 2007, 2008; TropWATER unpublished), Proserpine/Pioneer/O'Connell/Plane (Rohde et al., 2006, 2008) Basins were used to calculate event mean concentrations (EMCs) as well as the broader-scale datasets presented in Brodie and Mitchell (2006) and Bartley et al. (2012). We could now progress to the data validation/calibration step.

4 LOAD VALIDATION/CALIBRATION

Once all annual available statistical data had been compiled, interpolated and constructed as a time series, we were then able to estimate loads and validate these against measured load data. To perform this step we needed to adjust our statistical data for the basin down to the gauged area (i.e. data reduction). Fortunately, we had the upstream land use data available for each of the monitored sites and we were able to use these data (for the particular year that they were available) to produce a reasonable estimate of the likely land use change upstream of these monitoring sites. This validation step provides a level of confidence for our modelled reconstructions over time. For example, if a strong linear relationship was observed between our modelled results and the measured loads, we could have relatively higher confidence in these data. We note that loads reconstructed for the basins where no validations with measured load data could be performed would be of relatively lower confidence.

4.1 Wet Tropics Region

Measured load data (suspended sediment, nitrogen, phosphorus and herbicide loads) from the Tully-Murray, Barron, Johnstone and Herbert Basins were available to validate/calibrate our modelling results.

Load data for the Tully River at Euramo are available for 18 years (1987/88 to 1999/00 and 2006/07 to 2010/11; although note that not all parameters were measured each year) and reported in Mitchell et al. (2006a), Joo et al. (2012) and Turner et al. (2012, 2013). From the available dataset we were able to calibrate our model to estimate the loads of dissolved inorganic nitrogen (DIN), particulate nitrogen (PN), dissolved inorganic phosphorus (DIP), particulate phosphorus (PP) and total suspended solids (TSS). For conservation/minimal use lands in the Tully-Murray Basin we used EMCs of 44 $\mu g.L^{-1}$, 80 $\mu g.L^{-1}$, 3 $\mu g.L^{-1}$, 7 $\mu g.L^{-1}$ and 10 $mg.L^{-1}$ for DIN, PN, DIP, PP and TSS, respectively. For grazing lands in the Tully-Murray Basin we used EMCs of 50 $\mu g.L^{-1}$, 150 $\mu g.L^{-1}$, 15 $\mu g.L^{-1}$, 25 $\mu g.L^{-1}$ and 15 $mg.L^{-1}$ for DIN, PN, DIP, PP and TSS, respectively. These EMCs are based on averages from sampling sites that reflect these respective dominant land uses in the Tully-Murray Basin from the monitoring program reported in Bainbridge et al. (2009) as well as summaries provided by Brodie and Mitchell (2006) and Bartley et al. (2012). We used an average loss of 4 t/Ha of TSS from banana lands applying our flow factor (see below) and an average loss of 4 t/Ha of TSS from sugarcane lands (1987 to 2011) with the flow factor. Prior to 1987, we used an average loss of 7 t/Ha for sugarcane lands to account for the time before Green Cane Trash Blanketing was introduced and minimal tillage. We note the estimates of Prove et al. (1995) and Sallaway (1980) suggest that the soil losses could be much higher during these periods (42 to 505 t/Ha), although we note that many of these studies were conducted on areas with high slopes and are not representative of the whole catchment areas. In that regard, we note that our estimates of erosion from sugar lands prior to 1987 are on the conservative side and that suspended sediment loads may have been up to 10 fold higher, although we note this would depend on the susceptibility of the landscape to erosion.

To take into account that higher loads would be lost in high flow years compared to drought years, we applied a 'flow factor' to our load model. For example, if we assume that, during an average year 10% of the nitrogen fertiliser applied is lost to surface runoff then 20% would be lost in a year where the discharge is double the average. Alternatively, in a drier year only 5% would be lost when the discharge is half the average flow. We note that the application of this flow factor considerably improved the comparison between our model results and the measured loads and is in line with previous studies that suggest that increased flows generally coincide with increased pollutant loads (e.g. Mitchell et al., 2006a, 2006b). We adjusted the amount of fertiliser lost to achieve a curve slope of 1:1 between the measured and modelled loads.

There is a very strong, positive 1:1 relationship between the modelled loads for DIN and the measured loads for the Tully River at Euramo site when we apply an 11% average loss of the applied nitrogen fertiliser (that leaves the paddock as DIN) with our flow factor (Fig. 1A). This relationship and the high r^2 value (0.86) between the measured and modelled values suggest that we can have high confidence in our reconstruction of DIN loads for the Tully-Murray Basin. As an example, we have performed a reconstruction of the DIN loads just for this site with what the 'natural pre-European' load would have been as well as the measured load data (Fig. 2). Our data show that the modelled average annual DIN load over the past 30 year period (1982 to 2011) was 405 tonnes compared to an average annual load of 157 tonnes for the 30 year period 1800 to 1829 (the 'natural' load would have been 130 tonnes over the same 1982 to 2011 period). This increase of 2.6 fold is lower than some of the previous modelled estimates that suggest dissolved inorganic nitrogen loads have increased for the Tully Basin by 4.9 fold (Kroon et al., 2012), although it is similar to the more recent modelled estimates by the Source Catchments model which suggests an increase of 2.0 fold (Waters et al., in press).

A 1.5% average loss of P fertiliser as DIP produced the best 1:1 fit for our model for the Tully River at Euramo site. However, the relationship between the measured and modelled loads for DIP was much weaker (r^2 = 0.36) than for DIN (Fig. 1B). Hence we have relatively lower confidence in our DIP reconstruction for the Tully-Murray Basin.

Conversely, we obtained a stronger relationship between the measured and modelled loads for PN (r^2 = 0.86: Fig. 3A) and PP (r^2 = 0.85: Fig. 3B) when using average losses of applied N (11%) and P (20%) fertiliser, respectively. In this case, we can have reasonable confidence in our reconstructions for PN and PP for the Tully-Murray Basin. Our predictability of TSS loads for the Tully River at Euramo site is much weaker (r^2 = 0.32: Fig. 3C) and so we have much lower confidence in the prediction of TSS loads through time for the Tully-Murray Basin.

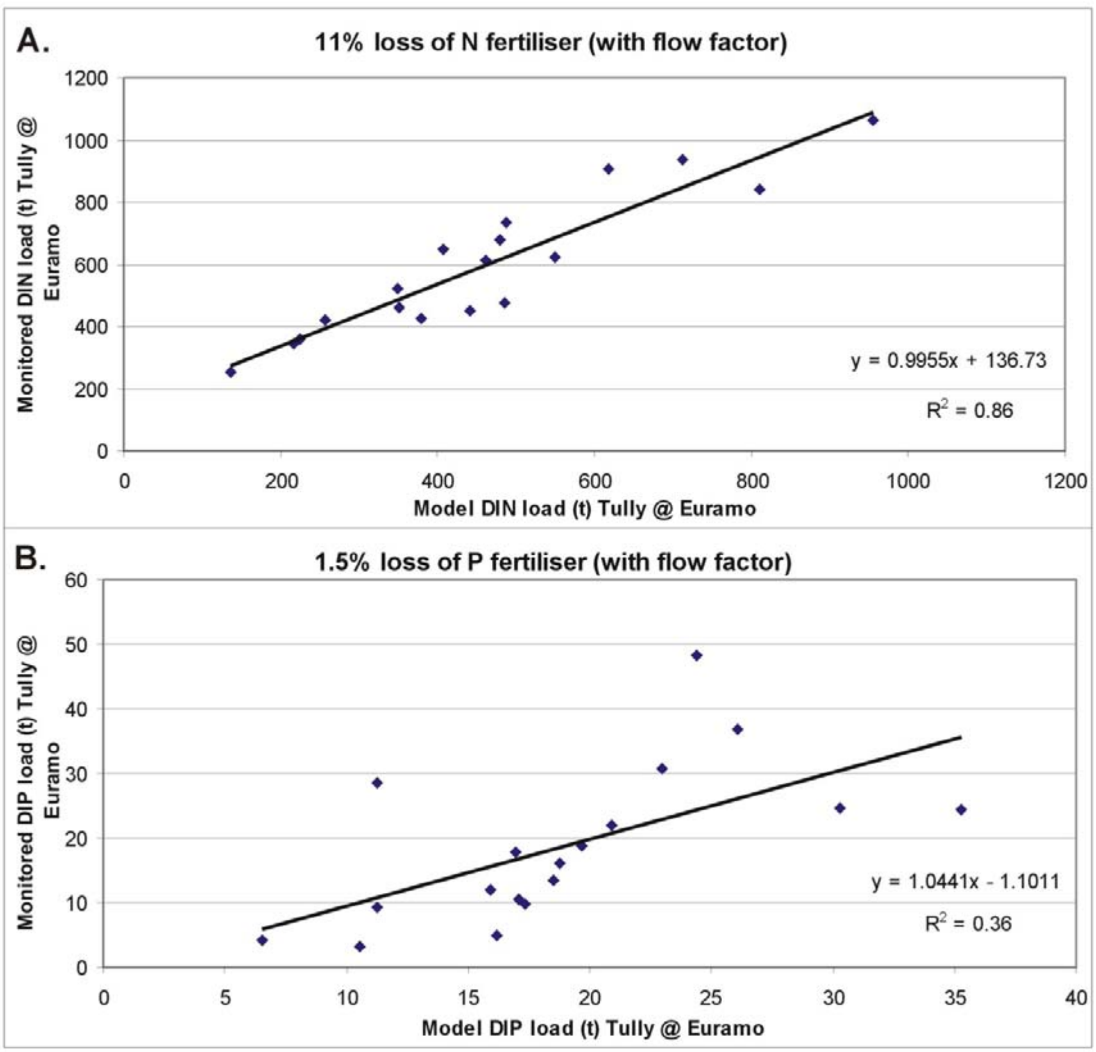

Figure 1. Validation for measured versus modelled loads of DIN (A) and DIP (B) for the Tully River at Euramo site.

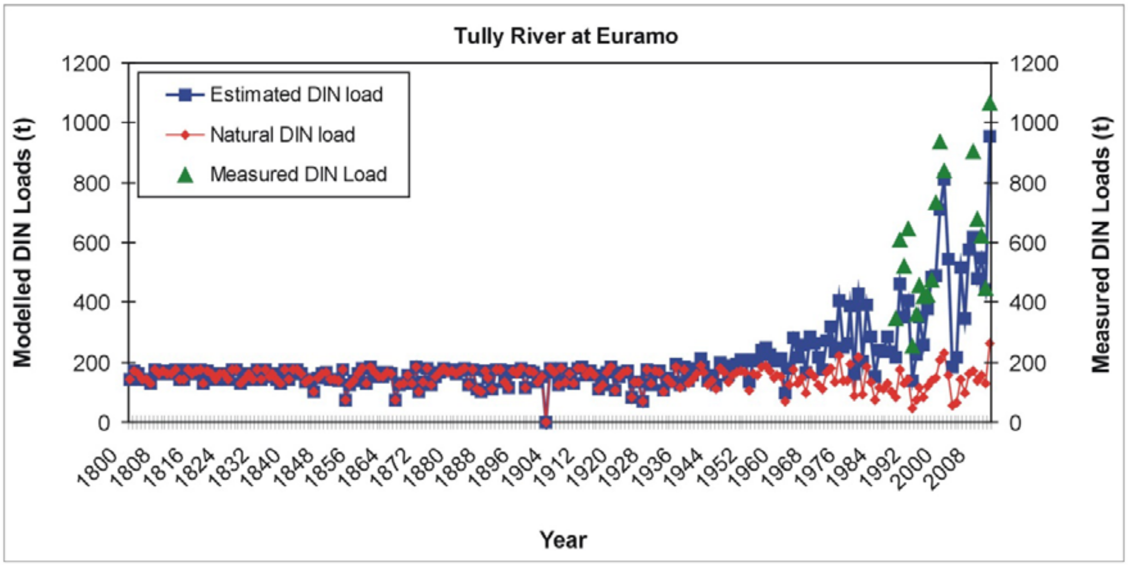

Figure 2. Example of how DIN loads have changed at the Tully River at Euramo site since 1800. Note the comparison between the measured (green triangles) and the modelled loads (blue squares).

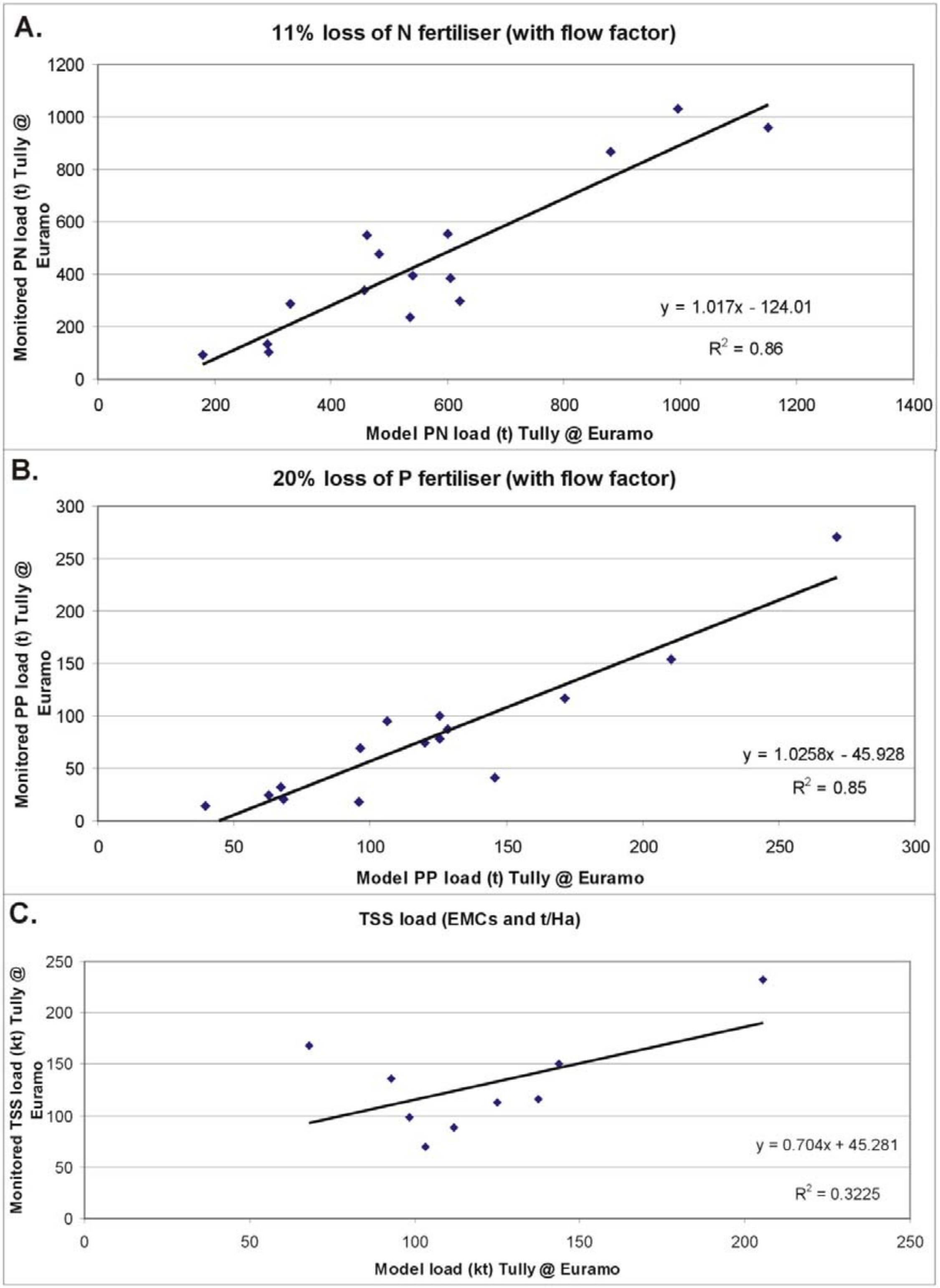

Figure 3. Validation for measured versus modelled loads of PN (A), PP (B) and TSS (C) for the Tully River at Euramo site.

Load data for the Barron River at Myola are available for 10 years (1989/90; 1991/92 to 1994/05; 2006/07 to 2010/11; although note that not all parameters were measured each year) and reported by the Australian Institute of Marine Science (unpublished data), Joo et al. (2012) and Turner et al. (2012, 2013). From the available dataset we were able to calibrate our model to reconstruct the loads of dissolved inorganic nitrogen (DIN), particulate nitrogen (PN), dissolved inorganic phosphorus (DIP) and particulate phosphorus (PP). For conservation/minimal use lands in the Barron Basin we used EMCs of 44 $\mu g.L^{-1}$, 100 $\mu g.L^{-1}$, 6 $\mu g.L^{-1}$, 16 $\mu g.L^{-1}$ and 46 $mg.L^{-1}$ for DIN, PN, DIP, PP and TSS, respectively. For grazing lands in the Barron Basin we used EMCs of 50 $\mu g.L^{-1}$, 490 $\mu g.L^{-1}$, 15 $\mu g.L^{-1}$, 170 $\mu g.L^{-1}$ and 60 $mg.L^{-1}$ for DIN, PN, DIP, PP and TSS, respectively. These EMCs are based on averages from sampling sites that reflect these respective dominant land uses reported in Brodie and Mitchell (2006) and Bartley et al. (2012). We used an average loss of 4 t/Ha of TSS from banana lands applying our flow factor (see below) and an average loss of 4 t/Ha of TSS from sugarcane lands (1987 to 2011) with the flow factor. Prior to 1987, we used an average loss of 7 t/Ha for sugarcane lands to account for the time before Green Cane Trash Blanketing was introduced and minimal tillage. We note the estimates of Prove et al. (1995) and Sallaway (1980) suggest that the soil losses could be much higher during these periods (42 to 505 t/Ha), although we note that many of these studies were conducted on areas with high slopes and may not be fully representative of the whole catchment areas. In that regard, we note that our estimates of erosion from sugar lands prior to 1987 are on the conservative side and that suspended sediment loads may have been up to 10 fold higher. We note that we can also not account for the increased erosion from the widespread clearing of rainforest in the Barron Basin following European settlement. We also applied the same 'flow factor' methodology as described in the Tully-Murray validation.

There is a very strong, positive 1:1 relationship between the modelled loads for DIN and the measured loads for the Barron River at Myola site when we apply a 1% average loss of the applied nitrogen fertiliser (that leaves the paddock as DIN) with our flow factor (Fig. 4A). This relationship and the high r^2 value (0.87) between measured and modelled values suggest that we can have high confidence in our reconstruction of DIN loads for the Barron Basin.

A 4% average loss of P fertiliser as DIP produced the best 1:1 fit for our model for the Barron River at Myola site and also displayed a high regression coefficient (r^2 = 0.86). Hence we also have high confidence in our DIP reconstruction for the Barron River (Fig. 4B).

We also obtained a strong relationship between the measured and modelled loads for PN (r^2 = 0.87: Fig. 5A) and PP (r^2 = 0.87: Fig. 5B) when using average losses of applied N (65%) and P (90%) fertiliser, respectively. However, the upper curve is only constrained by one data point and hence the confidence for PN and PP reconstructed loads using these data are considered low. Hence for the calculation of PN and PP loads for the Barron Basin we used the 11% and 20% losses, respectively as modelled for the Tully-Murray Basin. While our predictability of TSS loads for the Barron River at Myola site is weaker (r^2 = 0.71: Fig. 5C) than for PN and PP, the upper curve is constrained by a couple of points and so we have medium confidence in the prediction of TSS loads through time for the Barron Basin.

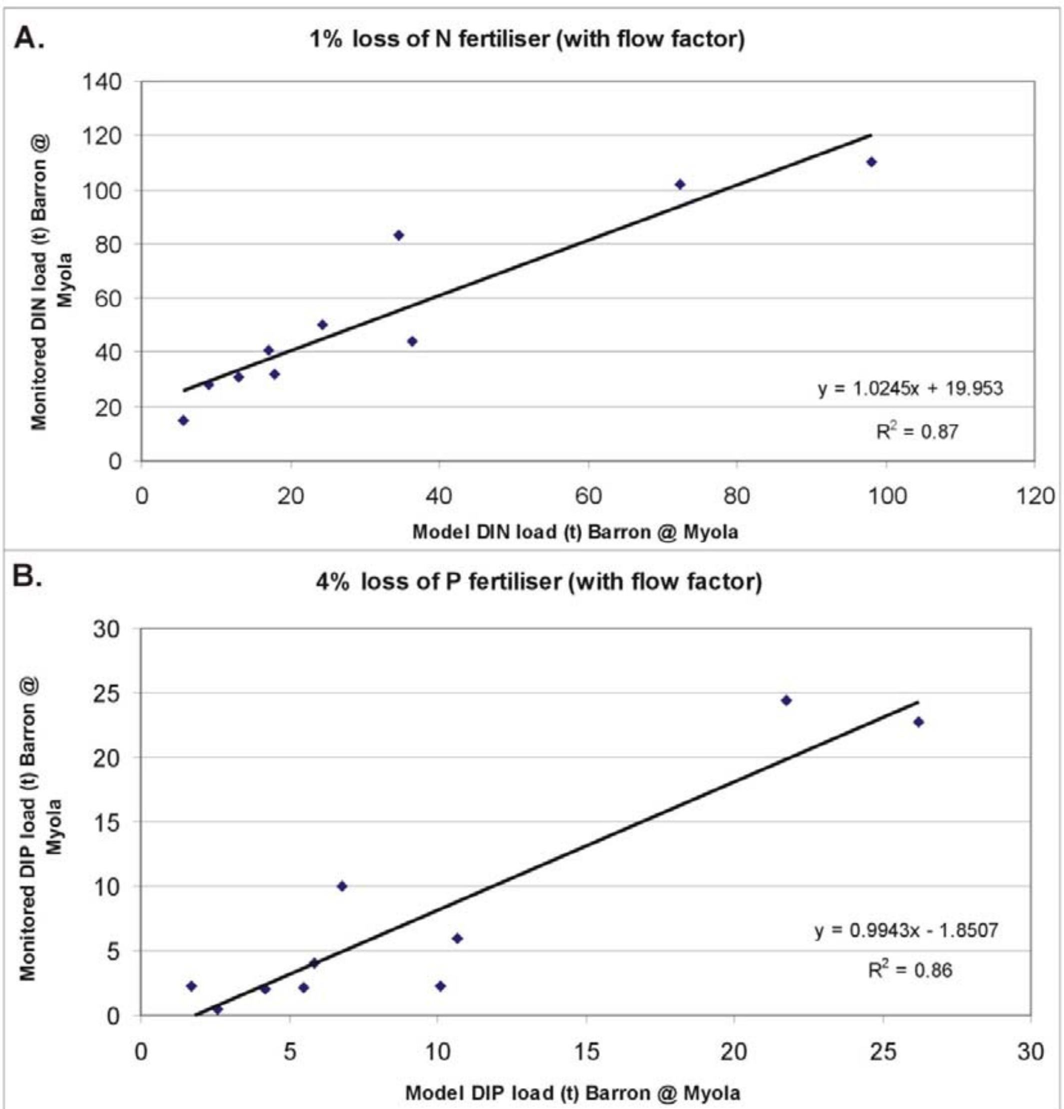

Figure 4. Validation for measured versus modelled loads of DIN (A) and DIP (B) for the Barron River at Myola site.

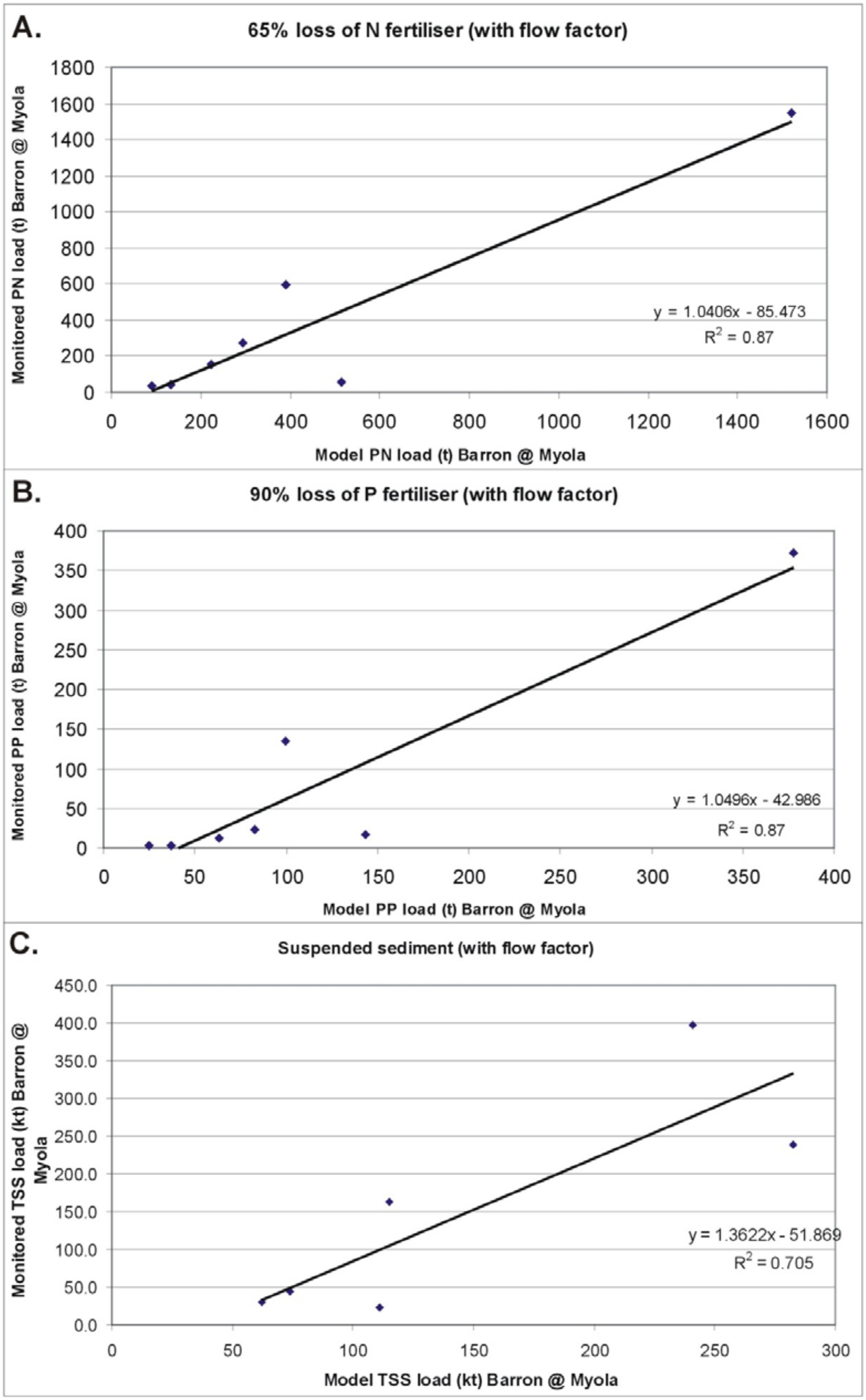

Figure 5. Validation for measured versus modelled loads of PN (A), PP (B) and TSS (C) for the Barron River at Myola site.

Load data for the South Johnstone River at Central Mill site are available for 12 years (1988/89 to 1994/95 and 2006/07 to 2010/11; although note that not all parameters were measured each year) and reported in Hunter et al. (2001), Hunter and Walton (2008), Department of Natural Resources and Mines (unpublished data), the Australian Institute of Marine Science (unpublished data), Joo et al. (2012) and Turner et al. (2012, 2013). From the available dataset we were able to calibrate our model to reconstruct the loads of dissolved inorganic nitrogen (DIN), particulate nitrogen (PN), dissolved inorganic phosphorus (DIP), particulate phosphorus (PP) and total suspended solids (TSS). For conservation/minimal use lands in the Johnstone Basin we used EMCs of 44 $\mu g.L^{-1}$, 100 $\mu g.L^{-1}$, 6 $\mu g.L^{-1}$, 16 $\mu g.L^{-1}$ and 46 $mg.L^{-1}$ for NO_x, PN, DIP, PP and TSS, respectively. For grazing lands in the Johnstone Basin we used EMCs of 100 $\mu g.L^{-1}$, 490 $\mu g.L^{-1}$, 15 $\mu g.L^{-1}$, 170 $\mu g.L^{-1}$ and 60 $mg.L^{-1}$ for DIN, PN, DIP, PP and TSS, respectively. These EMCs are based on averages from sampling sites that reflect these respective dominant land uses in the Johnstone Basin from the monitoring program reported in Hunter et al. (2001) and Hunter and Walton (2008) as well as from broader monitoring data (e.g. Brodie and Mitchell, 2006; Bartley et al., 2012). We note that the higher levels of phosphorus in the basin compared to the Tully-Murray Basin likely reflect the influence of basaltic soils in this area (see McCulloch et al., 2003b). We used an average loss of 4 t/Ha of TSS from banana lands applying our flow factor and an average loss of 4 t/Ha of TSS from sugarcane lands (1987 to 2011) with the flow factor. Prior to 1987, we used an average loss of 7 t/Ha for sugarcane lands to account for the time before Green Cane Trash Blanketing was introduced and minimal tillage.

There is a very strong, positive 1:1 relationship between the modelled loads for DIN and the measured loads for the South Johnstone River at Central Mill site when we apply a 30% average loss of the applied nitrogen fertiliser (that leaves the paddock as DIN) with our flow factor (Fig. 6A). This relationship and the high r^2 value (0.81) between measured and modelled values suggest that we can have high confidence in our reconstruction of DIN for the Johnstone Basin. The much higher losses at this location compared to the Tully River at Euramo site may reflect the higher slopes in this catchment, although paddock monitoring programs would help resolve these differences. A higher average loss of P fertiliser as DIP (6%) was also observed for the South Johnstone River at Central Mill site compared to the Barron and Tully-Murray sites. However, the relationship between the measured and modelled loads for DIP was weaker ($r^2 = 0.65$) than for DIN (Fig. 6B). Hence we have relatively lower confidence in our DIP reconstruction for the Johnstone Basin.

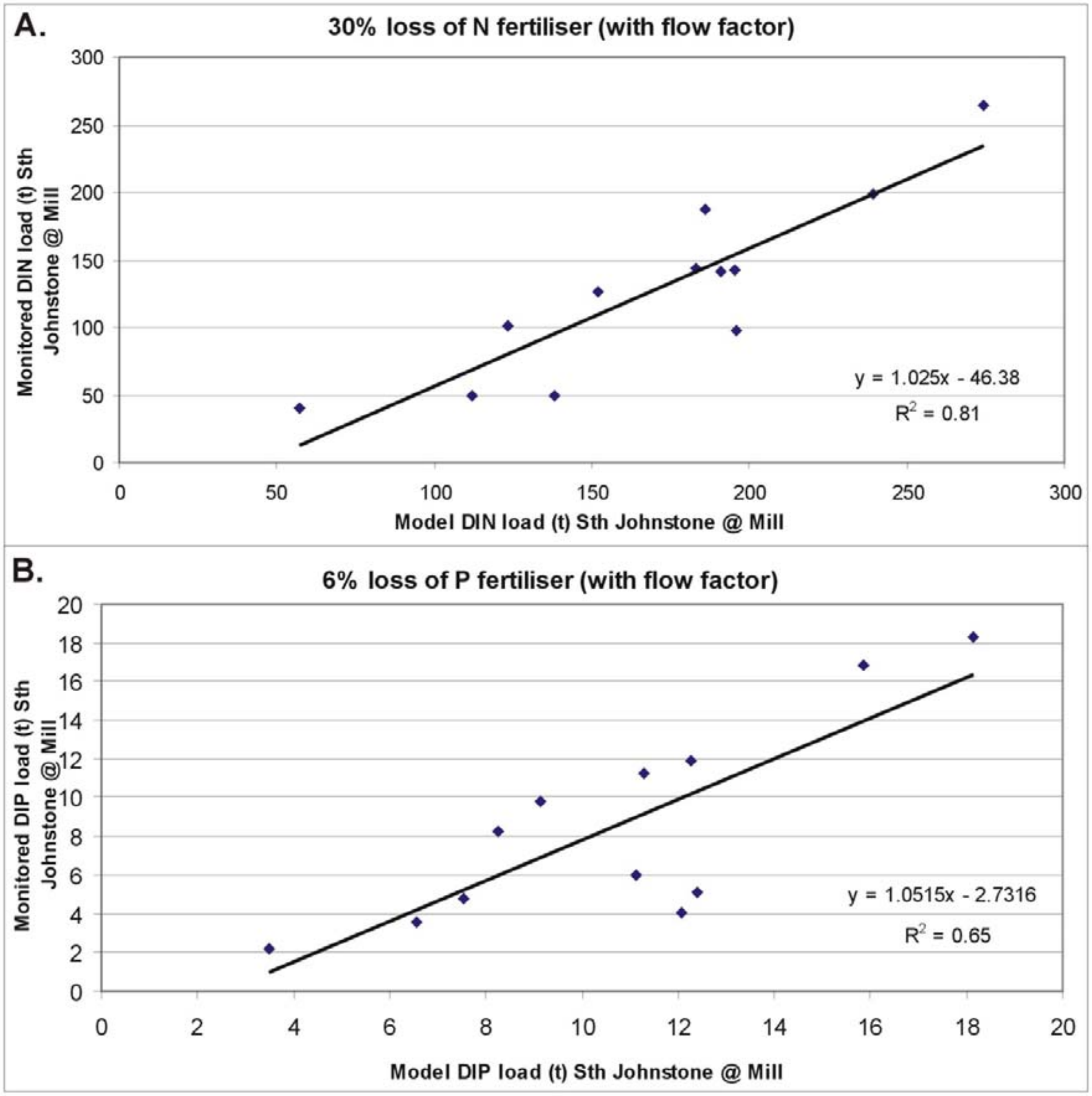

Figure 6. Validation for measured versus modelled loads of DIN (A) and DIP (B) for the South Johnstone River at Central Mill site.

We obtained much weaker relationships between measured and monitored loads for PN (r^2 = 0.46: Fig. 7A) and PP (r^2 = 0.23: Fig. 7B) at South Johnstone River at Central Mill site when compared to the Tully River at Euramo. To achieve a 1:1 relationship we calculated very high average losses of N (85%) and P (100%) fertiliser, respectively (which is unrealistic). In this case, we can have lower confidence in our reconstructions for PN and PP for the Johnstone Basin. While the relationship between measured and modelled TSS loads was relatively high for the South Johnstone River at Central Mill (r^2 = 0.84: Fig. 7C), we failed to achieve a 1:1 relationship and so we have lower confidence in the prediction of TSS loads through time for the Johnstone Basin.

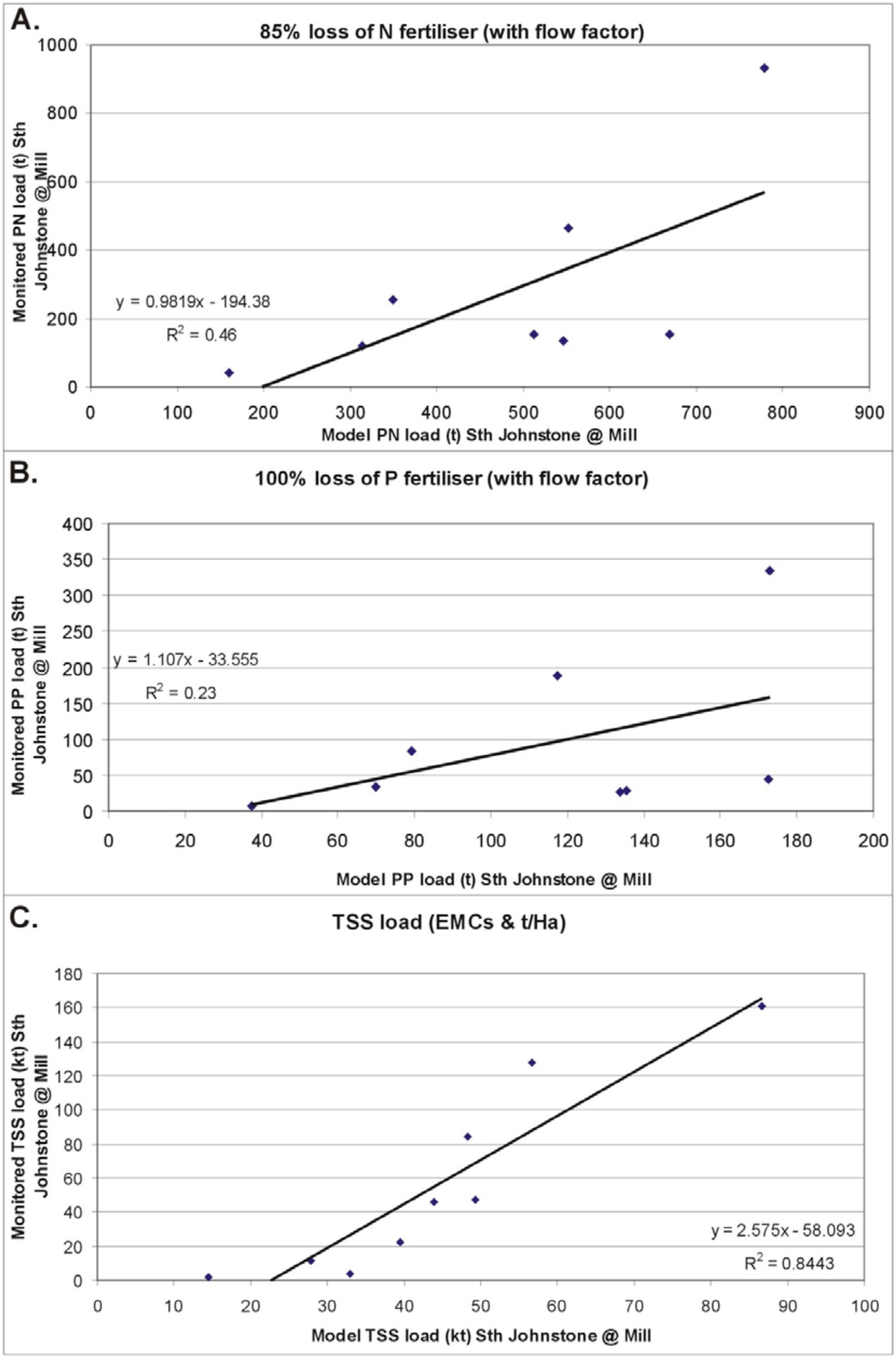

Figure 7. Validation for measured versus modelled loads of PN (A), PP (B) and TSS (C) for the South Johnstone River at Central Mill site.

We also attempted to perform our validations for the Johnstone Basin using load data from the North Johnstone River at Tung Oil site available for 10 years (1989/90; 1991/92 to 1994/95 and 2006/07 to 2010/11; although note that not all parameters were measured each year) and reported in Hunter et al. (2001), Hunter and Walton (2008), Department of Natural Resources and Mines (unpublished data), the Australian Institute of Marine Science (unpublished data), Joo et al. (2012) and Turner et al. (2012, 2013). In this case a stronger relationship was obtained between measured and monitored loads for DIN (r^2 = 0.86: Fig. 8A) and DIP (r^2 = 0.85: Fig. 8B), although the upper curve is only constrained by one data point in both cases. There is very little sugar cane (1.5%) or bananas (1.8%) grown upstream of this catchment and the area of dairy (12%: reported in Hunter and Walton, 2008) is much more significant. While the 16% loss of N fertiliser as DIN appears reasonable at this site, to achieve the 1:1 validation for DIP required a 0% loss of P fertiliser. This result suggested that the EMCs used for DIP may need refining. Similarly, the validations for PN, PP and TSS for the North Johnstone site (Fig. 9) showed that high r^2 values were able to be achieved, although the losses of N and P fertilisers needed to be >100% and hence these are unrealistic. In particular, the area of fertilised crops upstream of the South Johnstone monitoring site (sugar area 4.8% and bananas 1%) is higher than the North Johnstone.

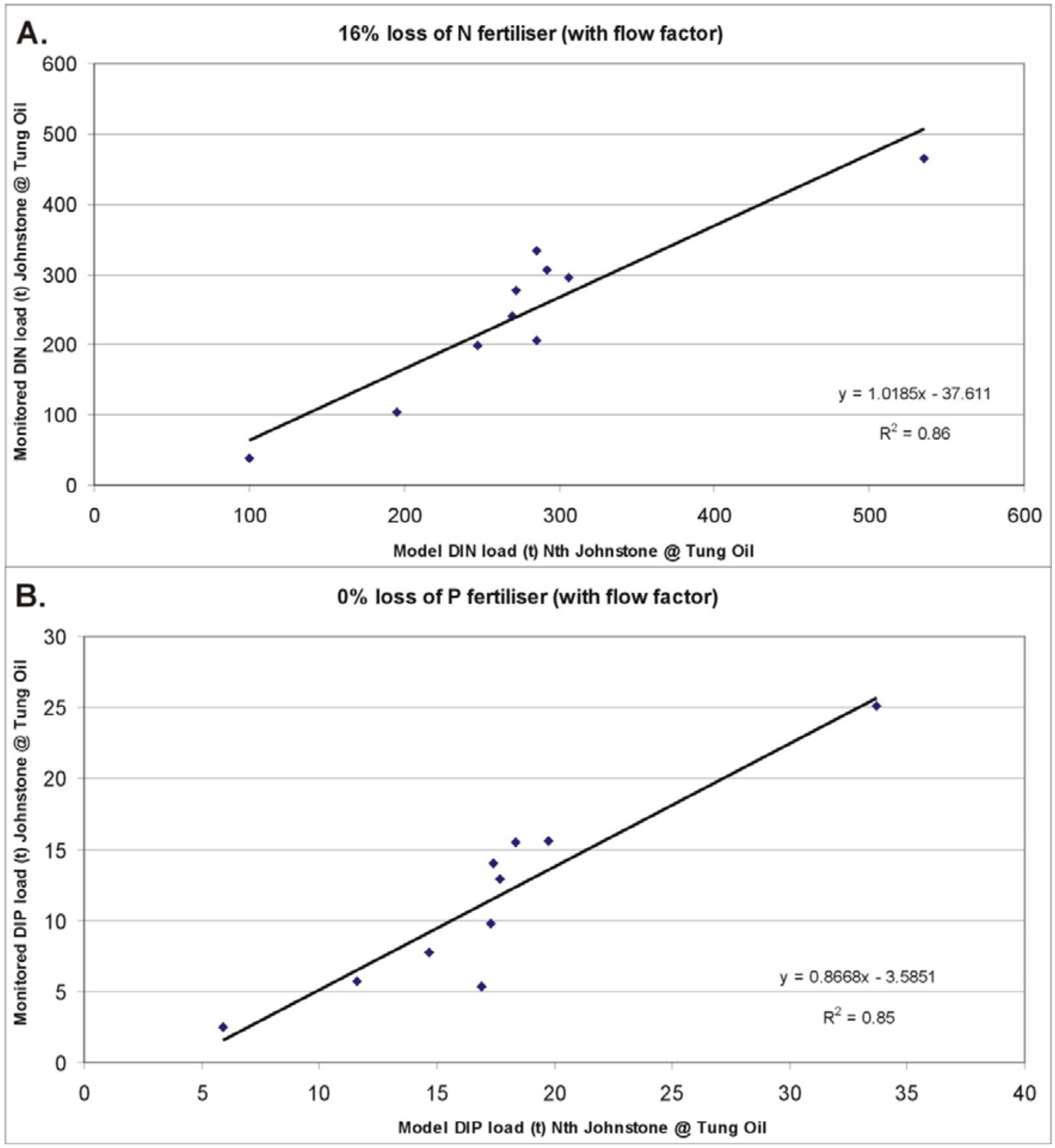

Figure 8. Validation for measured versus modelled loads of DIN (A) and DIP (B) for the North Johnstone River at Tung Oil site.

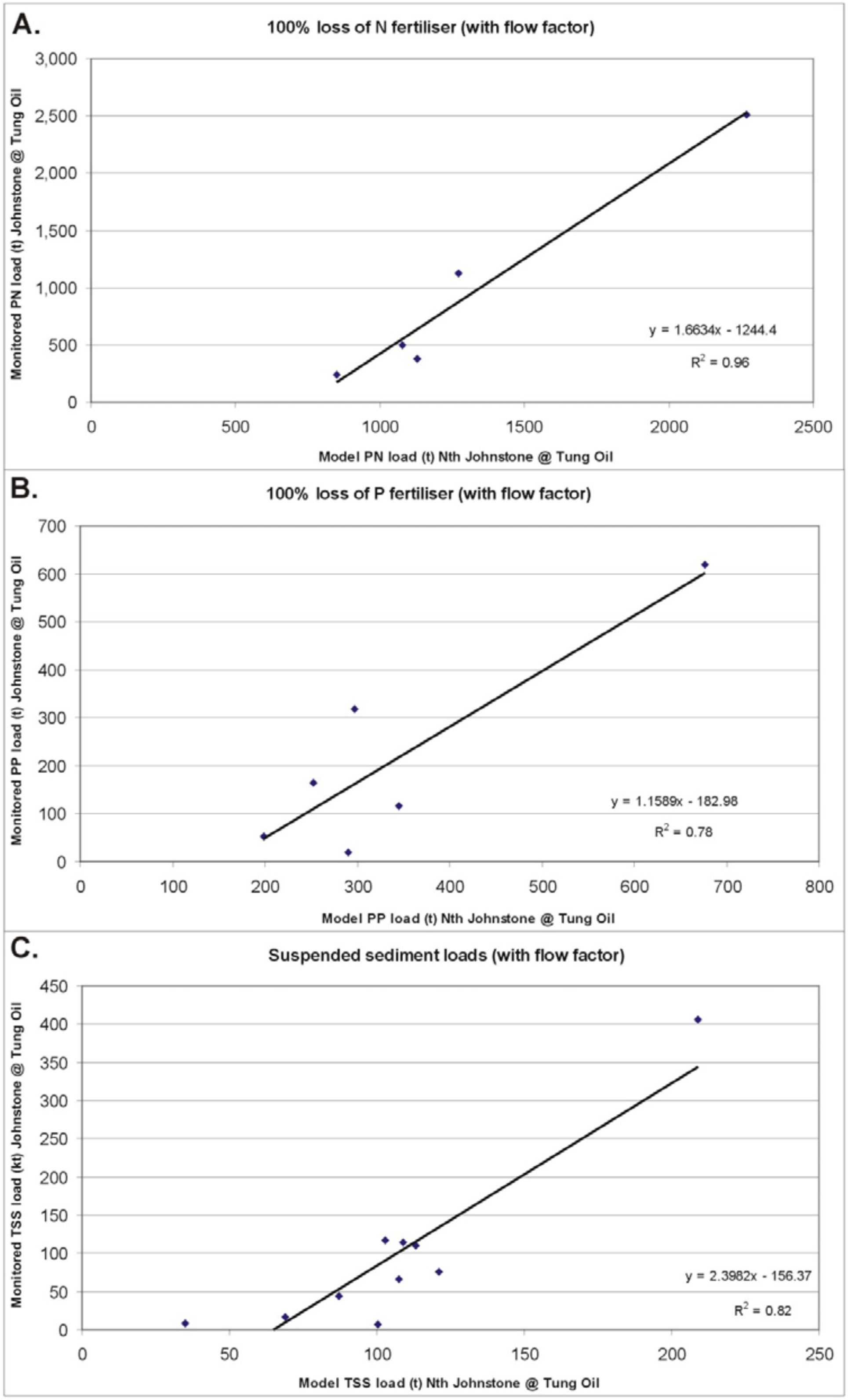

Figure 9. Validation for measured versus modelled loads of PN (A), PP (B) and TSS (C) for the North Johnstone River at Tung Oil site.

Load data for the Herbert River at Ingham are available for 11 years (1989/90 to 1994/95; 2006/07 to 2010/11; although note that not all parameters were measured each year) and are based on new calculations we have made from data in Bramley and Muller (1999), the Australian Institute of Marine Science (unpublished), Joo et al. (2012) and Turner et al. (2012, 2013). From the available datasets we were able to calibrate our model to reconstruct the loads of dissolved inorganic nitrogen (DIN), particulate nitrogen (PN), dissolved inorganic phosphorus (DIP), particulate phosphorus (PP) and total suspended solids (TSS). For conservation/minimal use lands in the Herbert Basin we used EMCs of 44 $\mu g.L^{-1}$, 80 $\mu g.L^{-1}$, 3 $\mu g.L^{-1}$, 16 $\mu g.L^{-1}$ and 30 $mg.L^{-1}$ for DIN, PN, DIP, PP and TSS, respectively. For grazing lands in the Herbert Basin we used EMCs of 50 $\mu g.L^{-1}$, 150 $\mu g.L^{-1}$, 15 $\mu g.L^{-1}$, 40 $\mu g.L^{-1}$ and 160 $mg.L^{-1}$ for DIN, PN, DIP, PP and TSS, respectively. These EMCs are based on averages from sampling sites that reflect these respective dominant land uses in the Herbert Basin from the monitoring program by TropWATER and Terrain NRM (O'Brien et al., 2013, in press; unpublished data from the RP27 'The Herbert catchment water quality monitoring project) as well as broader scale data (Brodie and Mitchell, 2006; Bartley et al., 2012). We used an average loss of 4 t/Ha of TSS from banana lands applying our flow factor and an average loss of 4 t/Ha of TSS from sugarcane lands (1987 to 2011) with the flow factor. Prior to 1987, we used an average loss of 7 t/Ha for sugarcane lands to account for the time before Green Cane Trash Blanketing was introduced and minimal tillage.

The relationship between measured and modelled DIN loads for the Herbert River at Ingham site was strong (r^2 = 0.81: Fig. 10A) with an average nitrogen fertiliser loss of 8% (that leaves the paddock as DIN) producing the closest 1:1 relationship. Based on this relationship, we can have high confidence in our reconstruction of DIN for the Herbert Basin. While the r^2 value for the measured and modelled loads for DIP was high (r^2 = 0.77; Fig. 10B), to achieve a 1:1 relationship we would need to have a negative loss of DIP from fertilised lands. This result suggests that further catchment-specific monitoring data are required for this site to refine our model.

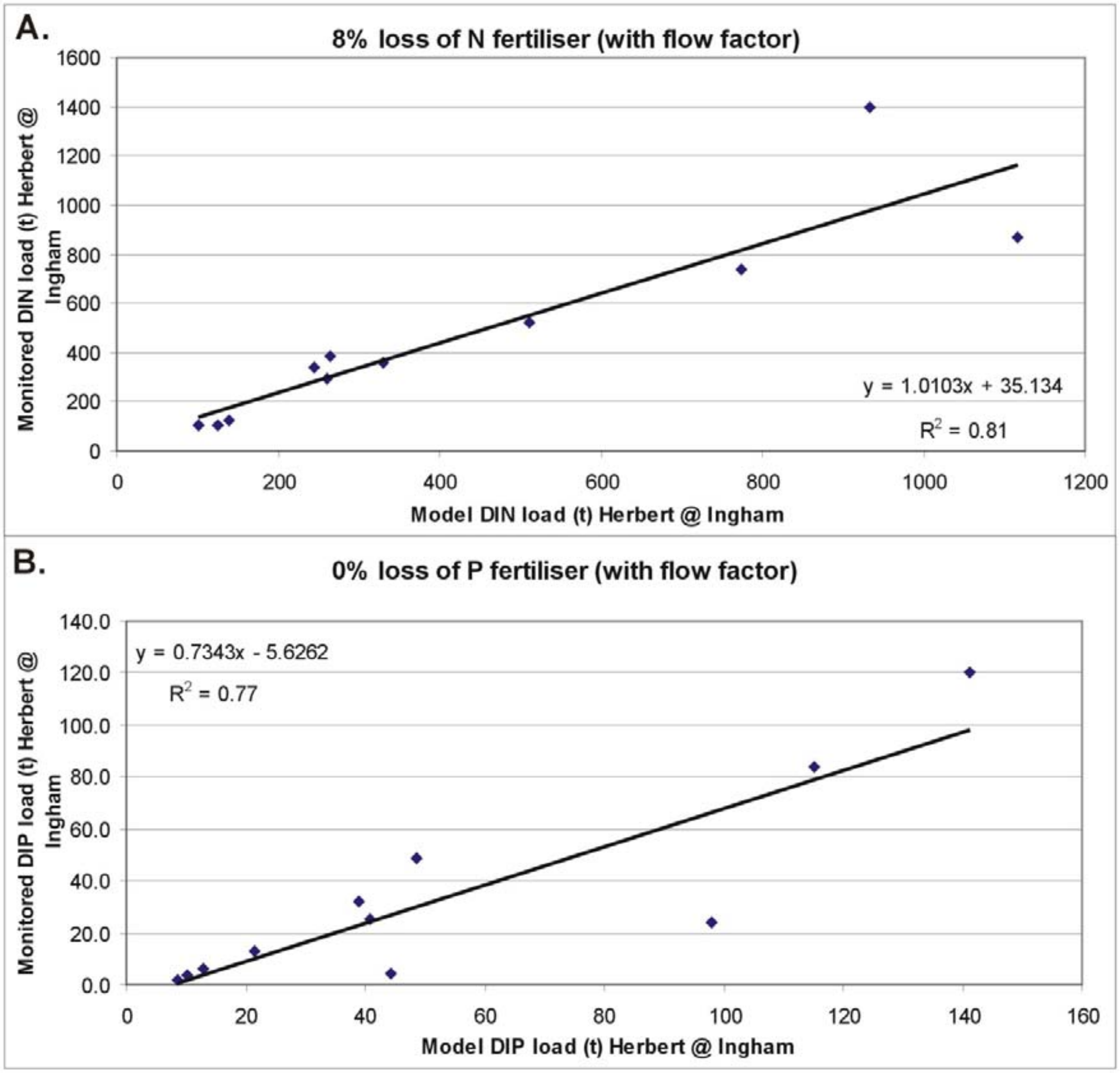

Figure 10. Validation for measured versus modelled loads of DIN (A) and DIP (B) for the Herbert River at Ingham site.

While the relationships between measured and modelled loads for PN (r^2 = 0.50: Fig. 11A) and PP (r^2 = 0.58: Fig. 11B) produced reasonable r^2 values, the upper limits of both of these curves are only constrained by two quite variable data points. This point was the loads from the 1990/91 flood, which was a very large event; however, it was not a large as the 2010/11 water year. Indeed the limited sampling frequency conducted during the 1990/91 event would likely lead to a higher uncertainty in our data. Hence we need to view these two validations with caution and subsequently we have lower confidence in our reconstructions for PN and PP for the Herbert Basin. To achieve a 1:1 relationship we calculated losses of N (23%) and P (50%) fertiliser as PN and PP, respectively. While the relationship between measured and modelled TSS loads was relatively high for the Herbert River at Ingham (r^2 = 0.83: Fig. 11C), the upper points are constrained by few data points and so we have a medium to low confidence in the prediction of TSS loads through time for the Herbert Basin.

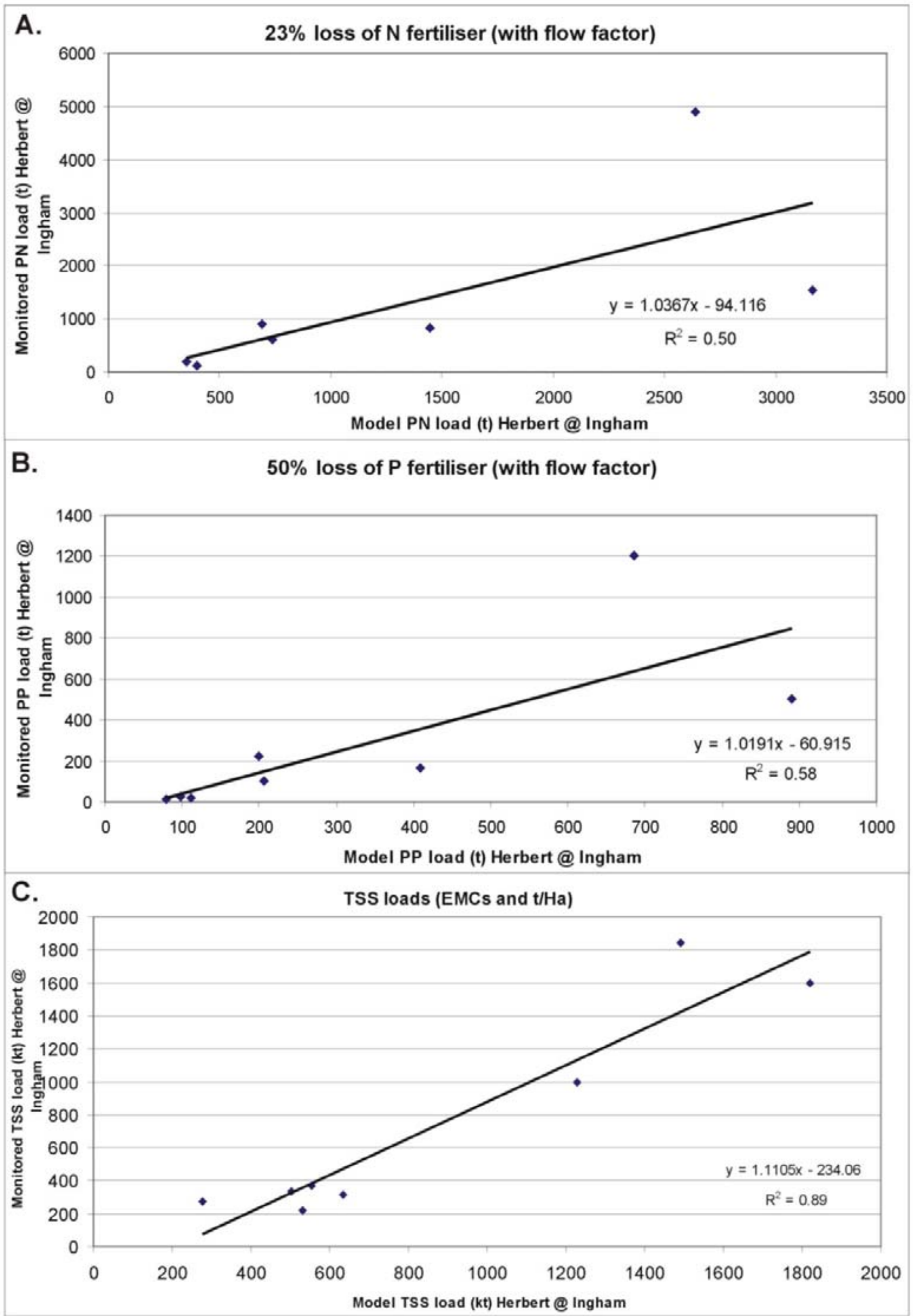

Figure 11. Validation for measured versus modelled loads of PN (A), PP (B) and TSS (C) for the Herbert River at Ingham site.

4.2 Burdekin Region

Despite the large amount of historical load data (17 years: 1988/89 to 1998/99; 2004/05 to 2007/08; 2009/10 to 2010/11) from the Barratta Creek at Northcote site that captured the development of the Burdekin-Haughton Irrigation Area, a relatively poor relationship exists between the measured and modelled DIN load, with around 3 large outliers (Fig. 12A). The relationship between measured and modelled DIP loads is better and the data suggest very little P fertiliser is lost as DIP (Fig. 12B). Much less data exist to validate the loads of PN, PP and TSS for the Barratta Creek at Northcote site and while much better relationships could be established between the measured and modelled loads (Fig. 13), we have less confidence in these data as they are mainly constrained by only one high data point. While there is also a large dataset for measured Burdekin River loads available, the site captures very little of the fertilised land use (i.e. sugar cane on the delta) and hence validations for this site will not provide any additional information.

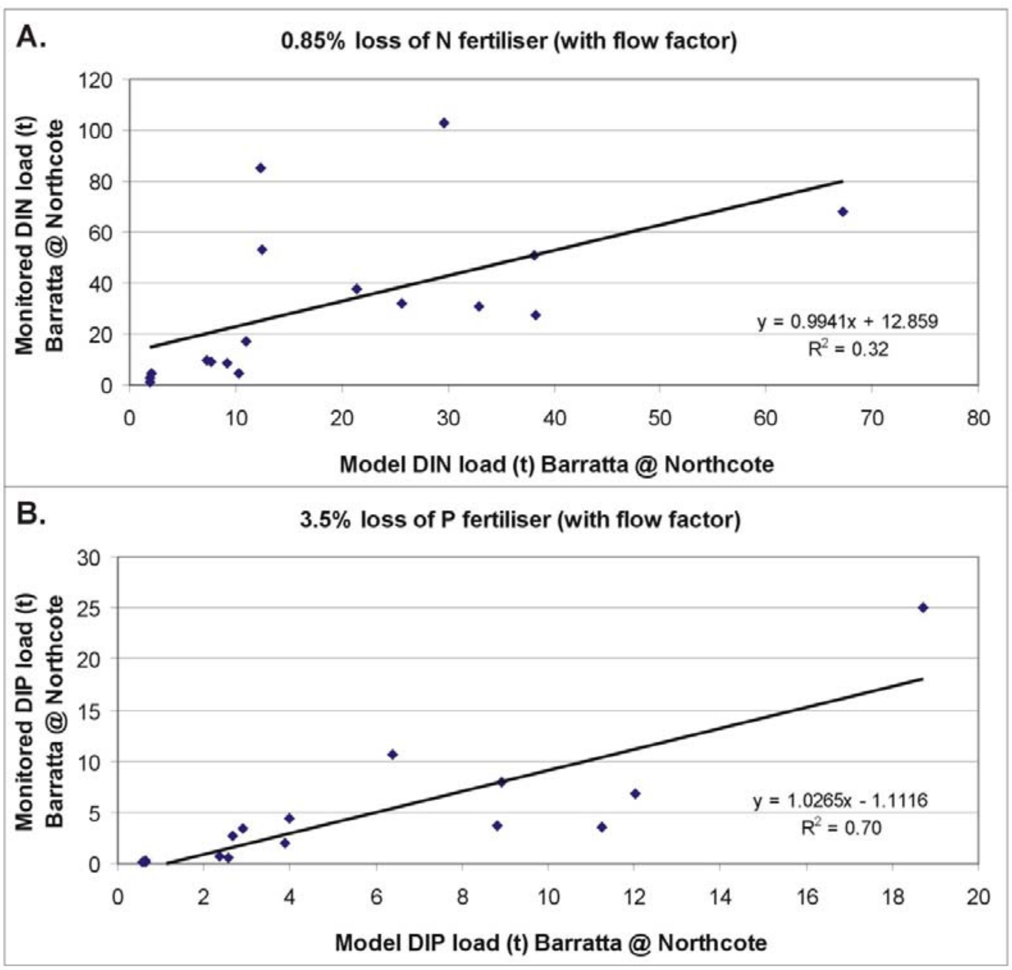

Figure 12. Validation for measured versus modelled loads of DIN (A) and DIP (B) for the Barratta Creek at Northcote site.

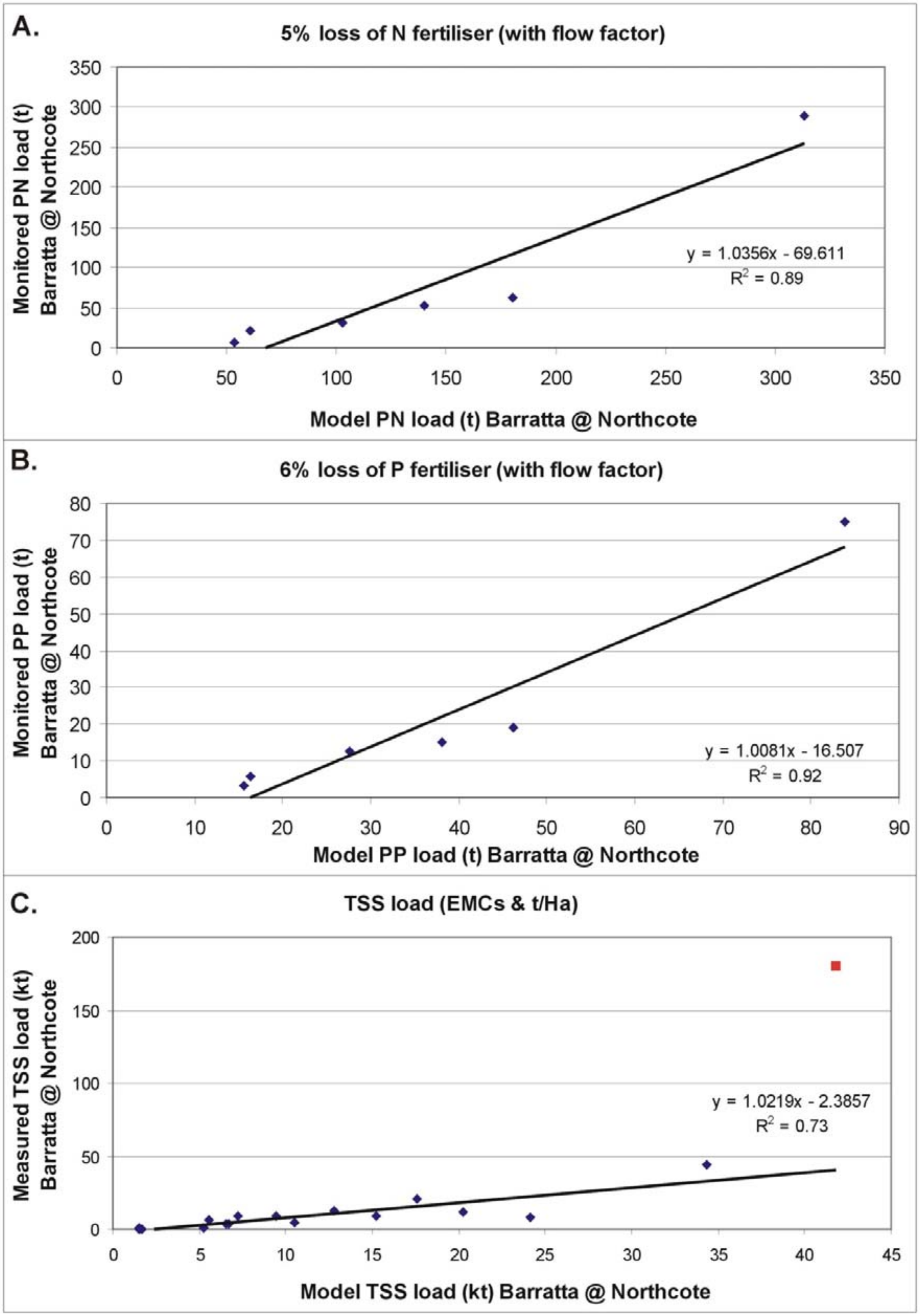

Figure 13. Validation for measured versus modelled loads of PN (A), PP (B) and TSS (C) for the Barratta Creek at Northcote site.

4.3 Mackay Whitsunday Region

While a much stronger relationship (e.g. r^2 value) appeared to exist between the measured and modelled DIN and DIP loads for the Pioneer River at Pleystowe (Dumbleton Weir tailwater) site (Fig. 14) compared to the Barratta Creek site, there were not enough variable points to be confident in the reconstruction. Furthermore, the lack of measured PN and PP data for the site prevented any validation for these parameters. It was decided to use the validations for the Herbert River as the losses of N and P fertiliser for DIN, PN and DIP and PP, respectively as the Herbert floodplain resembles the closest to the basins of the Mackay Whitsunday region. However, the EMCs of the parameters for the basins in the Mackay Whitsunday NRM region used monitoring data from this area reported in Rohde et al. (2008) as well as data reported in Brodie and Mitchell (2006). EMCs of 44 $\mu g.L^{-1}$, 80 $\mu g.L^{-1}$, 20 $\mu g.L^{-1}$, 40 $\mu g.L^{-1}$, and 10 $mg.L^{-1}$ were applied to represent conservation/minimal use lands in the basins of the Mackay Whitsunday region for DIN, PN, DIP, PP and TSS, respectively. Values of 50 $\mu g.L^{-1}$, 150 $\mu g.L^{-1}$, 80 $\mu g.L^{-1}$, 80 $\mu g.L^{-1}$, and 90 $mg.L^{-1}$ were used as EMCs for grazing lands of the basins in the Mackay Whitsunday region for DIN, PN, DIP, PP and TSS respectively.

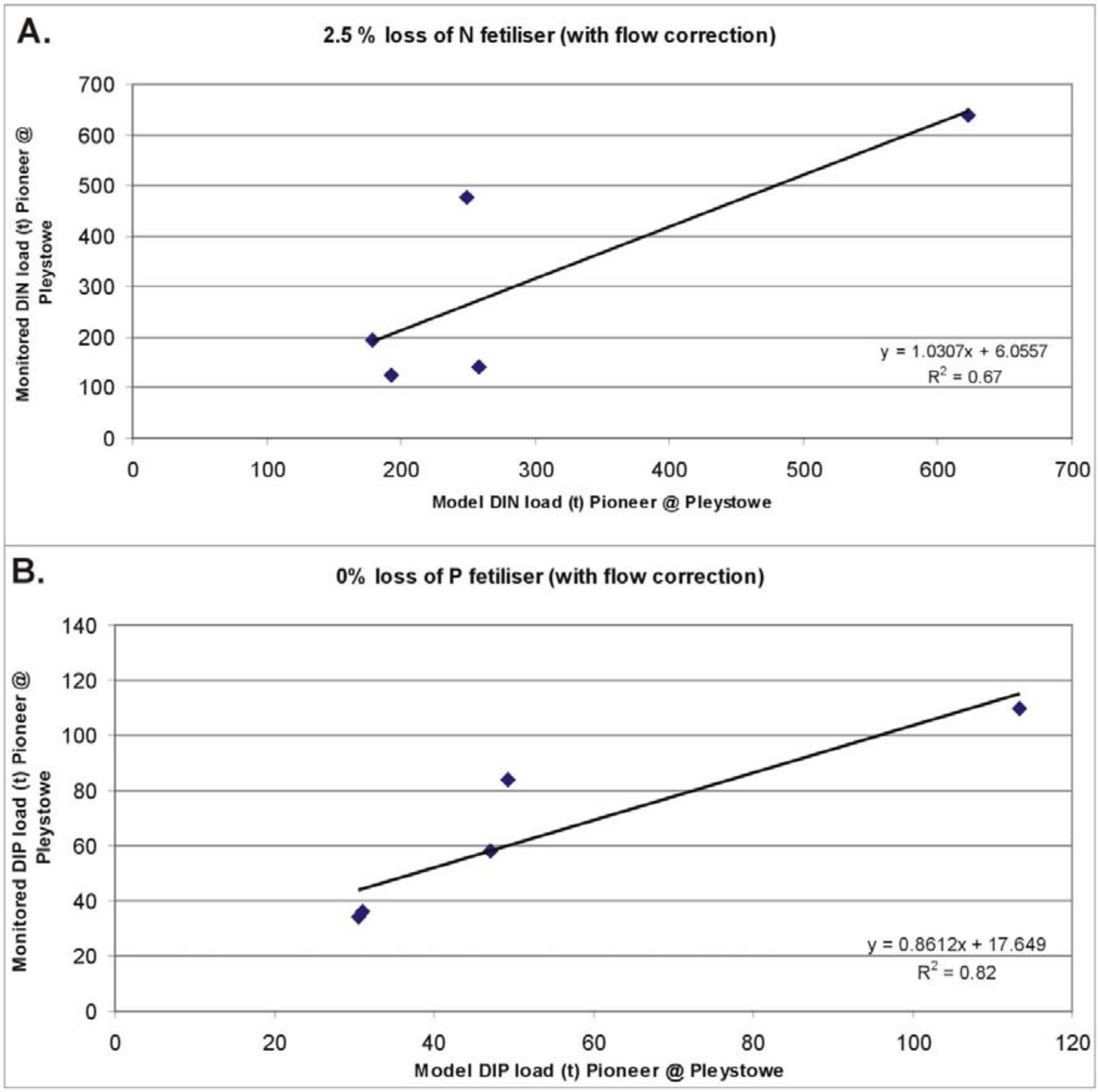

Figure 14. Validation for measured versus modelled loads of DIN (A) and DIP (B) for the Pioneer River at Pleystowe site.

5 LOAD RECONSTRUCTIONS

5.1 Wet Tropics Region

Daintree Basin

We used the validation for the Tully River at Euramo site to estimate historical loads from the Daintree Basin as we believe that this site best matches (that we can perform validations on) the characteristics of this basin. Based on the performance of the model for the Tully (Euramo) and the fact that there are few monitoring data from the Daintree Basin we consider that the model estimation of DIN, PN and PP has medium confidence, DIP has low confidence and TSS has very low confidence for the Daintree Basin. The EMCs used for the conservation and grazing lands for each of the basins are presented in Table 4.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Daintree Basin were 89 tonnes for DIN, 6 tonnes for DIP, 162 tonnes for PN, 14 tonnes for PP and 20 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 126 tonnes (1.4 fold increase), 8 tonnes (1.3 fold increase), 200 tonnes (1.2 fold increase), 30 tonnes (2.1 fold increase) and 32 ktonnes (1.6 fold increase) for DIN, DIP, PN, PP and TSS, respectively (Figs. 15 & 16).

Our predicted loads for DIN, DIP, PN, PP and TSS for the Daintree Basin are all much lower than those predicted in the other most recent model runs (Tables 5 to 9; Kroon et al., 2012; Waters et al., in press), although we note there is a large discrepancy between flow volumes in our model (41% lower) and the Source Catchments model (Table 3). When the Daintree-Mossman Basin loads are combined, our model outputs closely match with those from the Source Catchments model for PN, PP and TSS. In the absence of long-term monitoring data, we cannot evaluate these results, although the results from the one year of monitoring the Daintree River at Bairds gauge (42% of the basin area) suggested that the load estimates from our model are likely to be underestimates. For example, for the 2003/04 wet season (an average to above-average freshwater discharge year for the Daintree River) the measured DIN load at this gauge was 252 tonnes; for this same year our model calculated a load of 221 tonnes for the whole basin. We predict there should have been a large reduction in TSS loads since the introduction of minimal tillage and Green Cane Trash Blanketing (see Prove et al., 1995), although this cannot be directly quantified. Based on a reduction from 7 tonnes per hectare loss to 4 tonnes per hectare, we calculate that sediment loads from the Daintree Basin have reduced by ~ 15% since the introduction of these practices. We caution that our loads of TSS do not include trapping (or bank erosion etc.) and are based on very simple principles.

In these cases, the results produced by the more complex Source Catchments model should be adopted exclusively.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Daintree Basin and the rates applied in the Herbert Basin over time to calculate an annual application of active ingredient (Fig. 17). Hence we have lower confidence in these data, although our estimates agree reasonably well with the model of Lewis et al. (2011: Table 10). The best 'calibration' we could do based on the Herbert data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine.

Table 4. EMC values for the water quality parameters for each basin.

Parameter	EMC conservation/ minimal use	EMC grazing
DIN - All basins with exception of Johnstone & Burdekin ($\mu g.L^{-1}$)*	44	50
DIN Johnstone Basin ($\mu g.L^{-1}$)**	44	100
DIN Burdekin Basin ($\mu g.L^{-1}$)***	44	215
DIP - Daintree, Mossman, Russell Mulgrave, Tully-Murray & Herbert ($\mu g.L^{-1}$)*	3	15
DIP - Barron, Johnstone, Haughton, Burdekin ($\mu g.L^{-1}$)**	6	15
DIP - Mackay Whitsunday Basins ($\mu g.L^{-1}$)****	20	80
PN - All basins with exception of Barron, Johnstone & Burdekin ($\mu g.L^{-1}$)*	80	150
PN - Barron, Johnstone Basins ($\mu g.L^{-1}$)**	100	490
PN Burdekin Basin ($\mu g.L^{-1}$)***	80	290
PP - Daintree, Mossman, Russell Mulgrave, Tully-Murray ($\mu g.L^{-1}$)*	7	25
PP Herbert ($\mu g.L^{-1}$)*****	16	40
PP - Barron, Johnstone ($\mu g.L^{-1}$)**	16	170
PP - Haughton, Burdekin ($\mu g.L^{-1}$)***	16	150
TSS - Daintree, Mossman, Russell Mulgrave, Tully-Murray ($mg.L^{-1}$)*	10	15
TSS - Barron, Johnstone ($mg.L^{-1}$)**	46	60
TSS Herbert ($mg.L^{-1}$)*****	30	160
TSS Haughton ($mg.L^{-1}$)***	12	150
TSS Burdekin ($mg.L^{-1}$)***	27	800
TSS - Mackay Whitsunday Basins ($mg.L^{-1}$)****	10	90

*Bainbridge et al. (2009); Bartley et al. (2012); Brodie and Mitchell (2006); **Hunter et al. (2001); Hunter and Walton (2008); Bartley et al. (2012); Brodie and Mitchell (2006); ***Bainbridge et al. (2006a, 2006b, 2007, 2008); ****Rohde et al. (2006, 2008); *****O'Brien et al. (2013, in press)

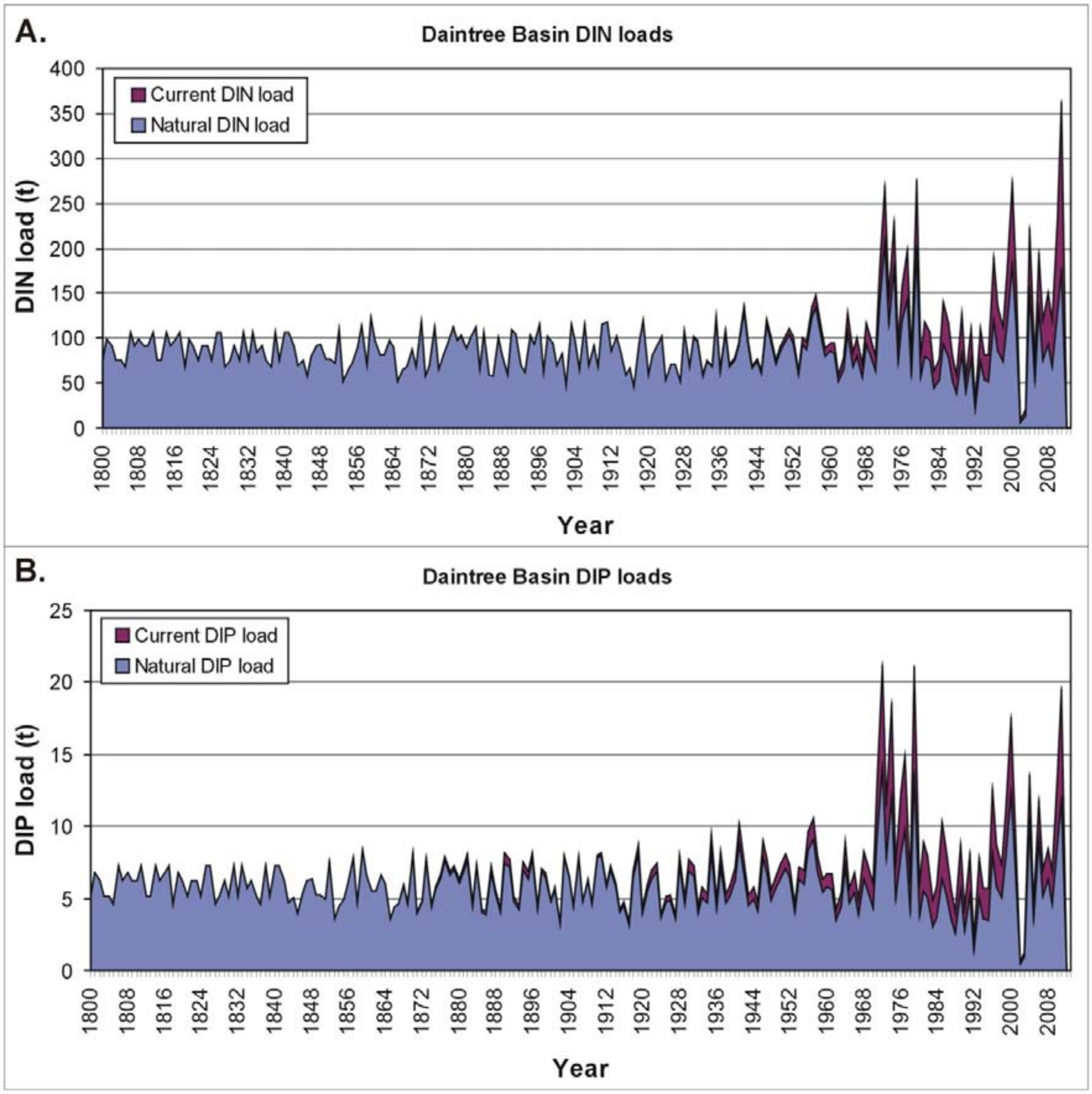

Figure 15. The modelled loads of DIN (A) and DIP (B) for the Daintree Basin.

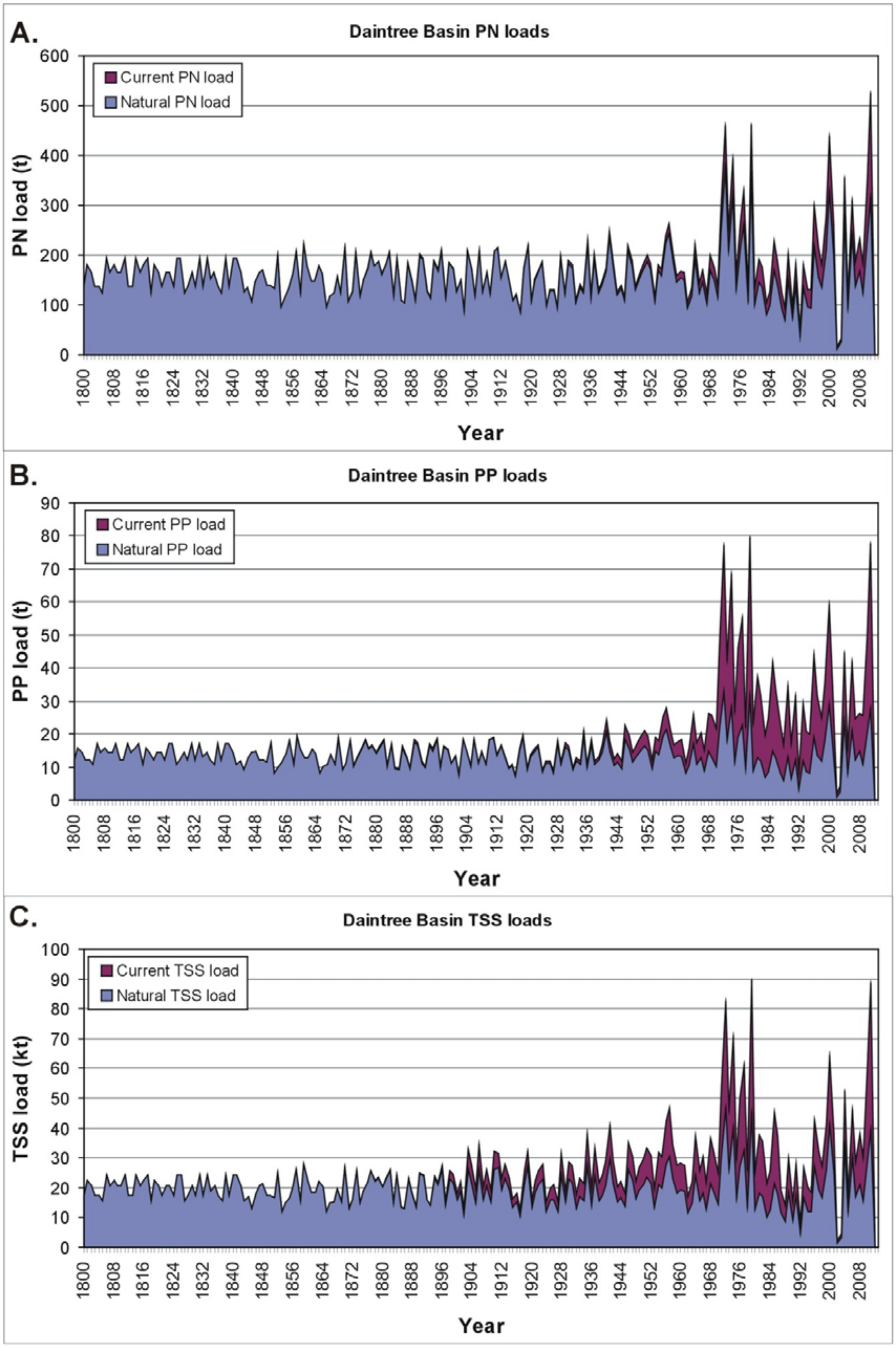

Figure 16. The modelled loads of PN (A) and PP (B) and TSS (C) for the Daintree Basin.

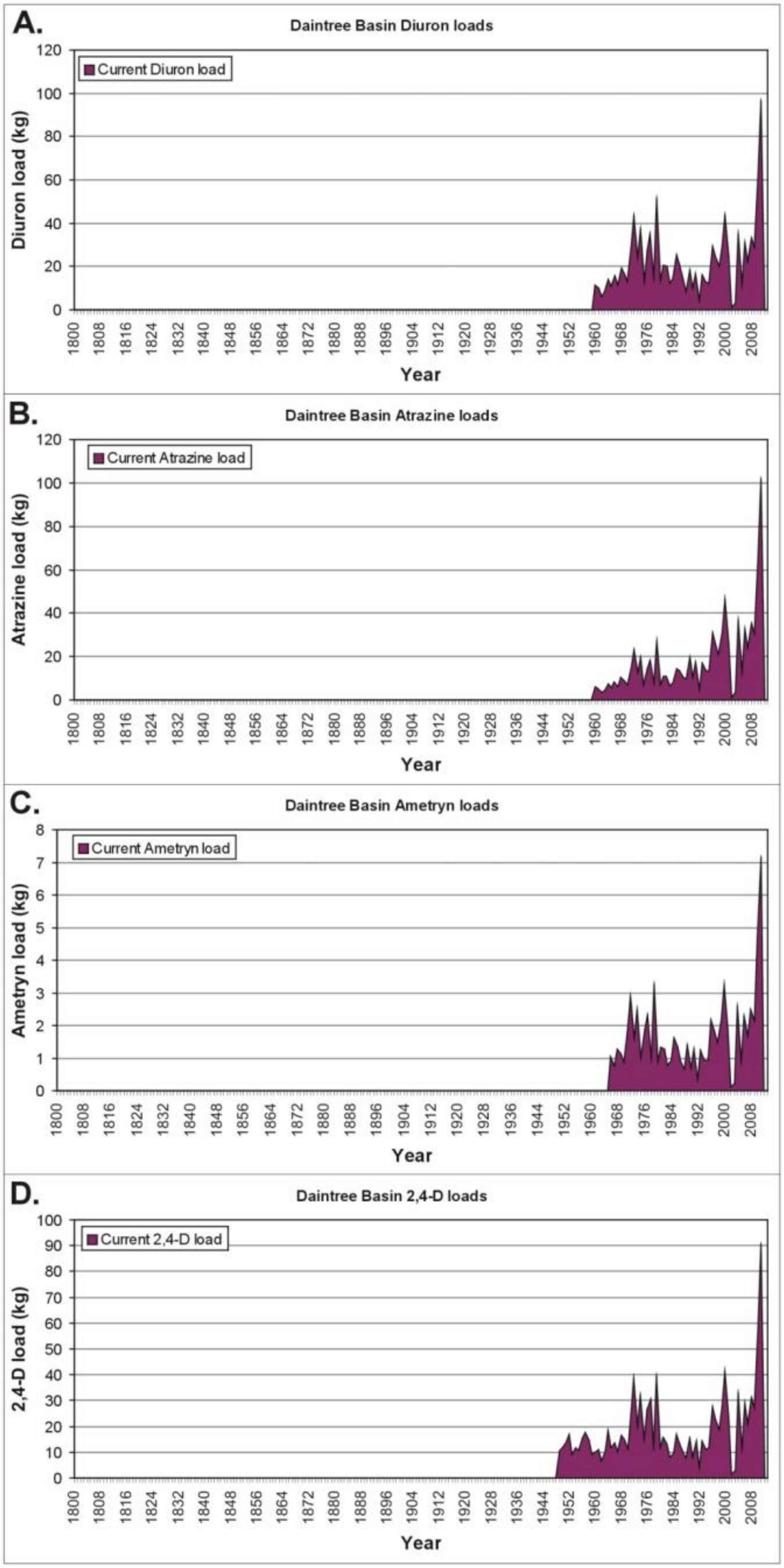

Figure 17. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Daintree Basin.

Table 5. Comparisons of mean loads for the current load of DIN (t) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Daintree	117	Medium	385	450	Tully River @ Euramo
Mossman	138	Medium	106	130	Tully River @ Euramo
Daintree-Mossman	255	Medium	491	580	Tully River @ Euramo
Barron	35	High	90	50	Barron River @ Myola
Russell Mulgrave	690	Medium	673	1700	Tully River @ Euramo
Johnstone	1278	High	1357	2100	North Johnstone River @ Tung Oil
Tully-Murray	559	High	948	1310	Tully River @ Euramo
Herbert	1019	High	878	1300	Herbert River @ Ingham

Table 6. Comparisons of mean loads for the current load of DIP (t) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Daintree	8	Low	26	31	Tully River @ Euramo
Mossman	7	Low	7	5	Tully River @ Euramo
Daintree-Mossman	15	Low	33	36	Tully River @ Euramo
Barron	18	Medium	13	10	Barron River @ Myola
Russell Mulgrave	25	Low	42	60	Tully River @ Euramo
Johnstone	52	Low	48	46	Tully River @ Euramo
Tully-Murray	36	Medium	50	40	Tully River @ Euramo
Herbert	62	Low	46	32	Tully River @ Euramo

Table 7. Comparisons of mean loads for the current load of PN (t) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Daintree	187	Medium	281	980	Tully River @ Euramo
Mossman	183	Medium	64	290	Tully River @ Euramo
Daintree-Mossman	370	Medium	345	1270	Tully River @ Euramo
Barron	315	Medium	184	440	Tully River @ Euramo
Russell Mulgrave	826	Medium	528	1500	Tully River @ Euramo
Johnstone	1109	Medium	1113	2200	Tully River @ Euramo
Tully-Murray	794	High	584	630	Tully River @ Euramo
Herbert	1632	Medium	1160	930	Tully River @ Euramo

Table 8. Comparisons of mean loads for the current load of PP (t) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Daintree	27	Medium	52	220	Tully River @ Euramo
Mossman	40	Medium	16	64	Tully River @ Euramo
Daintree-Mossman	67	Medium	68	284	Tully River @ Euramo
Barron	115	Medium	64	77	Tully River @ Euramo
Russell Mulgrave	173	Medium	143	540	Tully River @ Euramo
Johnstone	1627	Medium	375	550	Tully River @ Euramo
Tully-Murray	163	High	140	122	Tully River @ Euramo
Herbert	383	Medium	360	180	Tully River @ Euramo

Table 9. Comparisons of mean loads for the current load of TSS (kt) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Daintree	28	Very Low	61	180	N/A
Mossman	34	Very Low	16	41	
Daintree-Mossman	62	Very Low	77	221	
Barron	94	Medium	92	100	
Russell Mulgrave	159	Very Low	126	210	
Johnstone	318	Low	260	320	
Tully-Murray	119	Low	155	133	
Herbert	679	High	482	380	

Table 10. Comparisons of mean loads for the current load of diuron, atrazine and ametryn (kg) (period 1986 to 2009)

Basin	This study (diuron)	Lewis et al. (2011) diuron	This study (atrazine)	Lewis et al. (2011) atrazine	This study (ametryn)	Lewis et al. (2011) ametryn
Daintree	20	12	21	12	1	0
Mossman	44	27	46	26	3	0
Daintree-Mossman	64	39	67	38	4	0
Barron	13	4	14	20	1	0
Russell Mulgrave	236	261	248	255	17	0
Johnstone	216	350	226	345	16	0
Tully-Murray	116	231	122	229	9	0
Herbert	443	555	467	551	33	0

Mossman Basin

We used the validation for the Tully River at Euramo site to estimate historical loads from the Mossman Basin as we believe that this site best matches (that we can perform validations on) the characteristics of this basin. Based on the performance of the model for the Tully (Euramo) and the fact that there are no (known) monitoring data from this basin we consider that the model estimation of DIN, PN and PP have medium confidence, DIP has low confidence and TSS has very low confidence for the Mossman Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Mossman Basin were 54 tonnes for DIN, 4 tonnes for DIP, 99 tonnes for PN, 9 tonnes for PP and 12 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 139 tonnes (2.6 fold increase), 7 tonnes (1.8 fold increase), 185 tonnes (1.9 fold increase), 40 tonnes (4.4 fold increase) and 37 ktonnes (3.1 fold increase) for DIN, DIP, PN, PP and TSS respectively (Figs. 18 & 19).

Our predicted loads for DIN, DIP, PN, PP and TSS for the Mossman Basin either sit in between those predicted by the Source Catchments model (Waters et al., in press) and Kroon et al. (2012) or are similar to the two models (Tables 5 to 9; Kroon et al., 2012; Waters et al., in press). In the absence of long-term monitoring data, we cannot fully evaluate these results, although we note there is a large discrepancy between the discharge volumes in the two models (e.g. on an annual basis our model predicts flow volumes that are 78% higher than the Source Catchments model Table 3). In that regard, it is recommended that the outputs for the combined Daintree-Mossman Basin provide a much better 'direct' comparison with the Source Catchments model. We predict there should have been a large reduction in TSS loads since the introduction of minimal tillage and Green Cane Trash Blanketing in the sugar industry (see Prove et al., 1995), although this cannot be directly quantified. Based on a reduction from 7 tonnes per hectare sediment loss to 4 tonnes per hectare, we calculate that sediment loads from Mossman Basin have reduced by ~ 30% since the introduction of these practices. We caution that our loads of TSS do not include trapping, are based on very simple principles and the estimated reduction in erosion may be on the conservative side (see Prove et al., 1995). In these cases, the results produced by the more complex Source Catchments model should be adopted exclusively.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Mossman Basin and the rates applied in the Herbert Basin over time to calculate an annual application of active ingredient (Fig. 20). Hence we have lower confidence in these data, although our estimates agree reasonably well with the model of Lewis et al. (2011: Table 10). The best 'calibration' we could do based on the Herbert data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine.

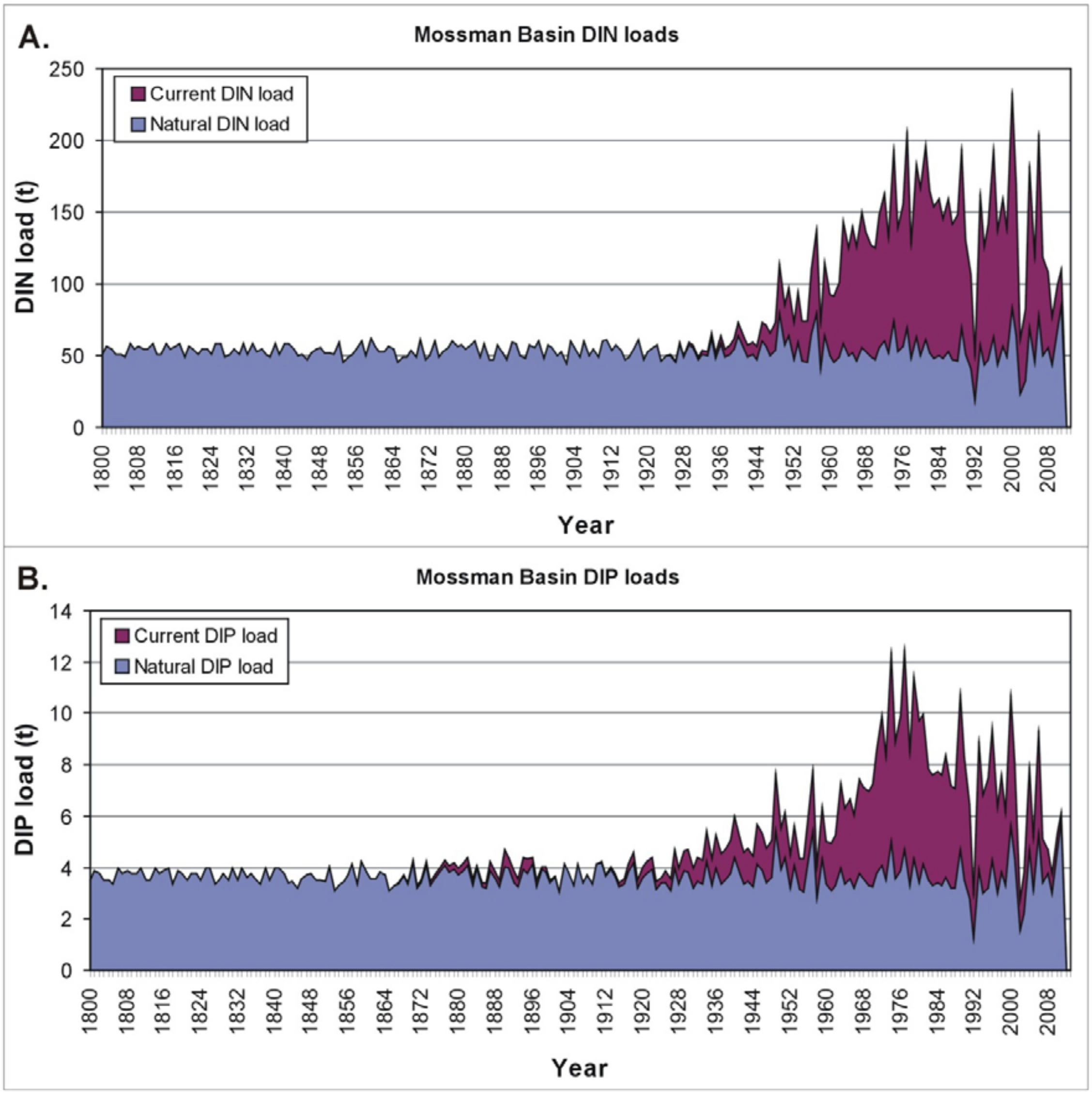

Figure 18. The modelled loads of DIN (A) and DIP (B) for the Mossman Basin.

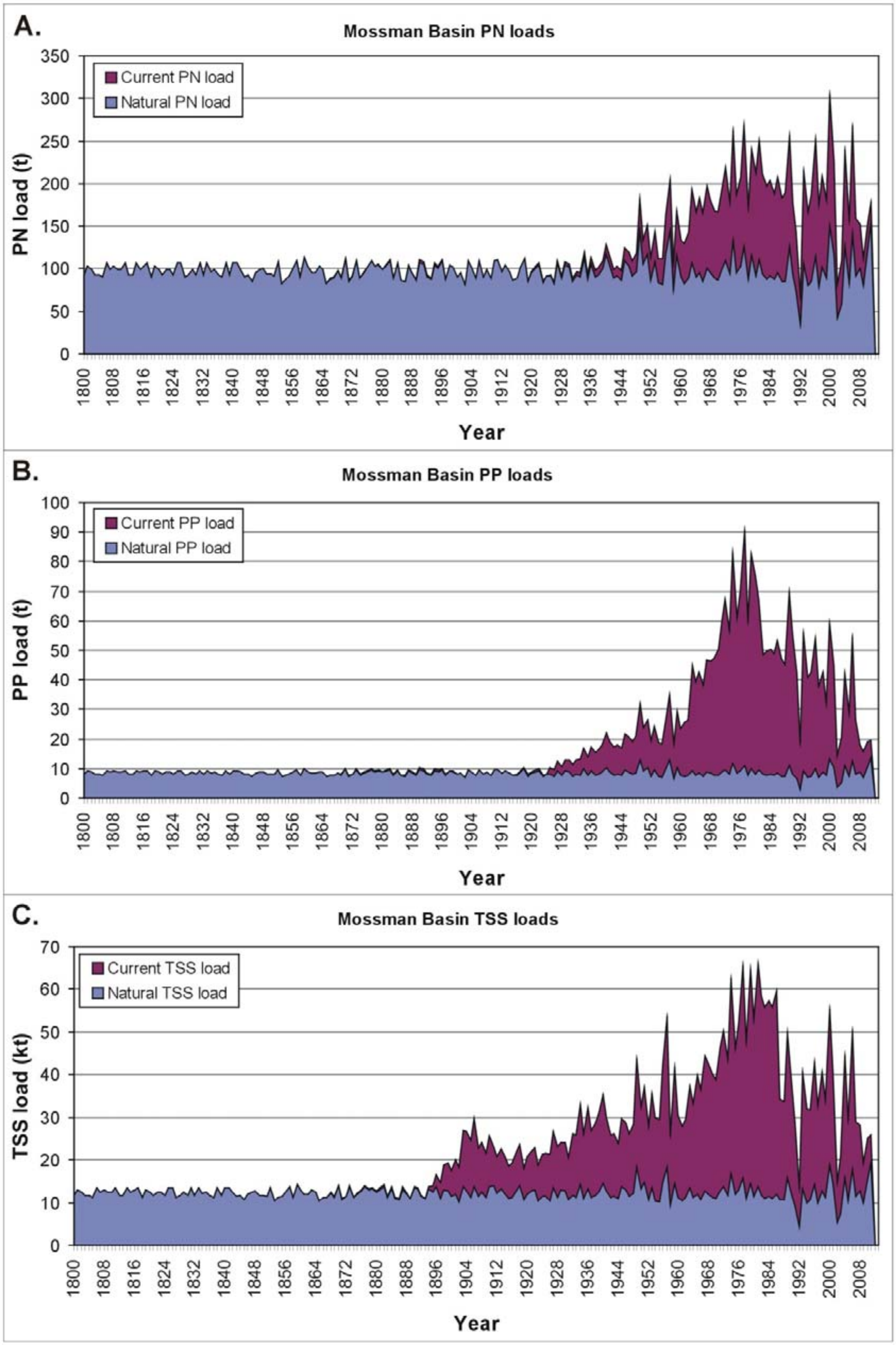

Figure 19. The modelled loads of PN (A) and PP (B) and TSS (C) for the Mossman Basin.

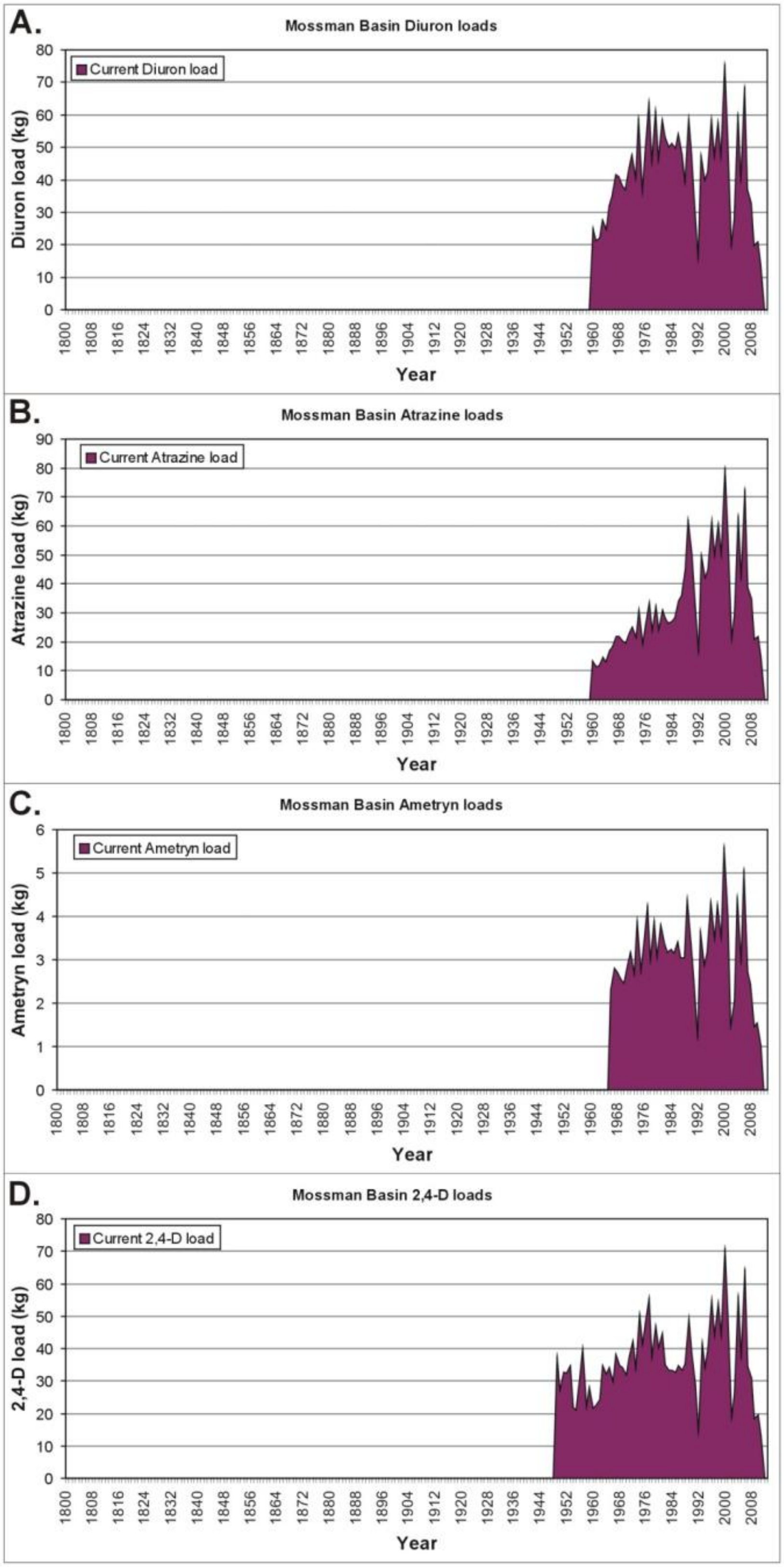

Figure 20. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Mossman Basin.

Barron Basin

We used the validation for the Barron River at Myola site to estimate historical DIN and DIP loads from the Barron Basin while for PN and PP load reconstructions we used the Tully (Euramo) validation. Based on the performance of the validation model we consider that the model estimation for the Barron Basin has high confidence, there is medium confidence in the outputs for DIP, PN, PP and TSS loads.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Barron Basin were 40 tonnes for DIN, 5 tonnes for DIP, 91 tonnes for PN, 15 tonnes for PP and 42 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 35 tonnes (1.1 fold decrease), 18 tonnes (3.6 fold increase), 302 tonnes (3.3 fold increase), 113 tonnes (7.5 fold increase) and 93 ktonnes (2.2 fold increase) for DIN, DIP, PN, PP and TSS, respectively (Figs. 21 & 22). Our predicted loads for DIN, DIP, PN, PP and TSS for the Barron Basin are generally comparable to those predicted by the Source Catchments (Waters et al., in press) and Kroon et al. (2012) models (Tables 5 to 9).

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar cane area in the Barron Basin and the rates applied in the Herbert Basin over time to calculate an annual application of active ingredient (Fig. 23). Hence we have lower confidence in these data (particularly in light of no load data in this basin and no idea of what herbicides are applied in the 'other crops'), although our estimates agree reasonably well with the model of Lewis et al. (2011: Table 10). The best 'calibration' we could do based on the Herbert data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine.

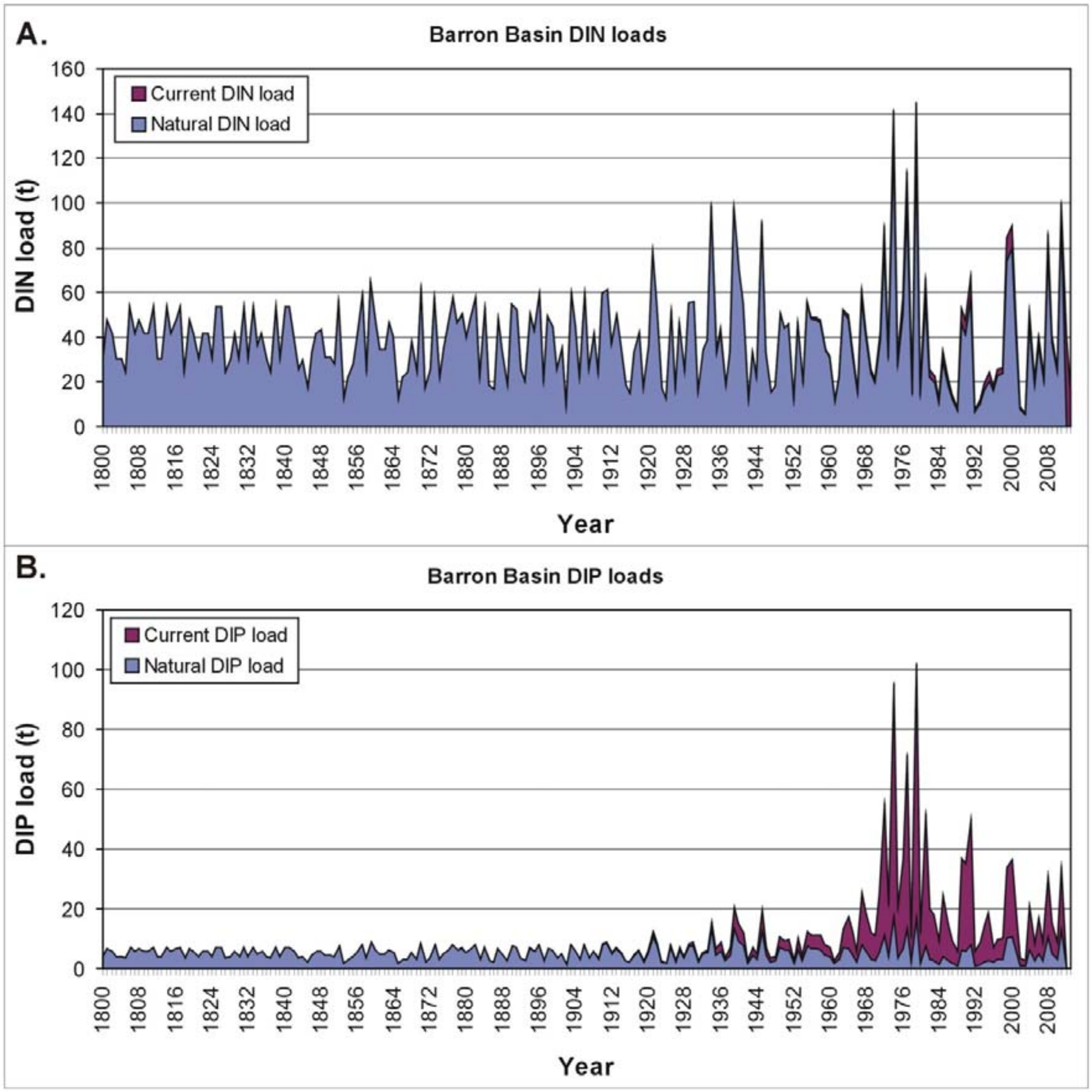

Figure 21. The modelled loads of DIN (A) and DIP (B) for the Barron Basin.

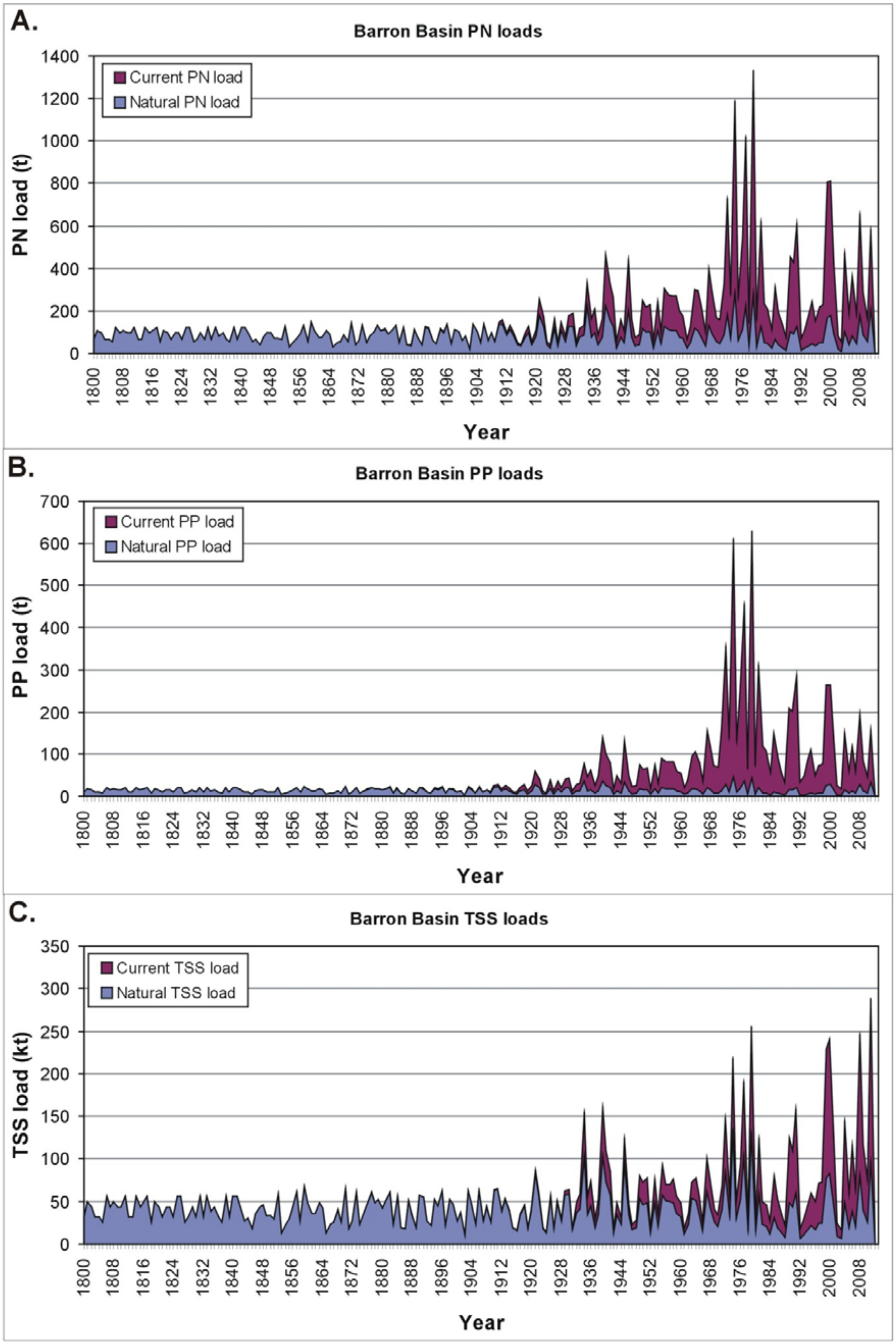

Figure 22. The modelled loads of PN (A) and PP (B) and TSS (C) for the Barron Basin.

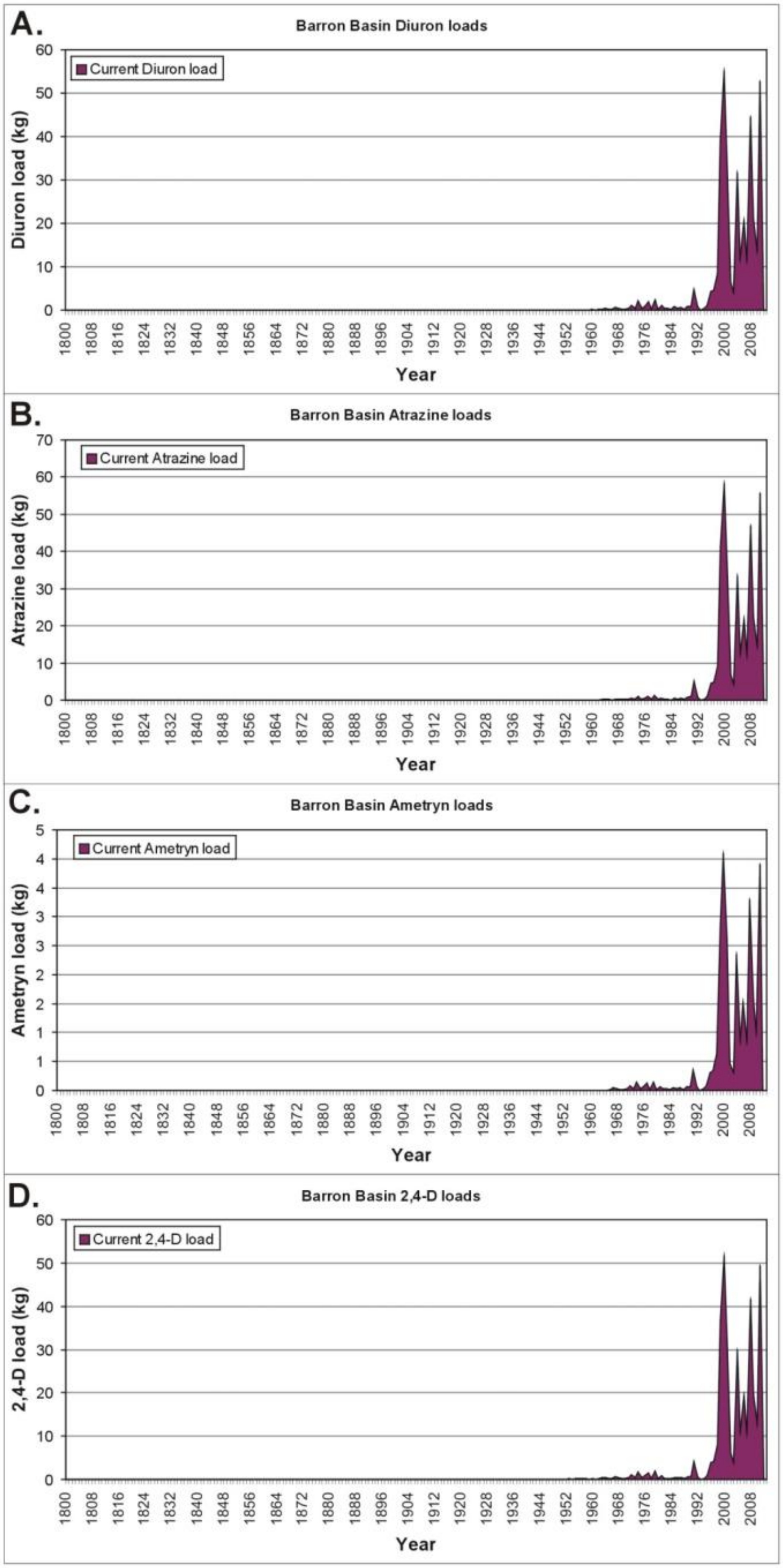

Figure 23. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Barron Basin.

Russell Mulgrave Basin

We used the validation for the Tully River at Euramo site to estimate historical loads from the Russell Mulgrave Basin as we believe that this site best matches (that we can perform validations on) the characteristics of this basin. Based on the performance of the model for the Tully River (Euramo) and that there are limited monitoring data (of high quality to produce load estimations) from this basin we consider that the model estimation of DIN, PN and PP has medium confidence, DIP has low confidence and TSS has very low confidence for the Russell Mulgrave Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Russell Mulgrave Basin were 171 tonnes for DIN, 12 tonnes for DIP, 310 tonnes for PN, 27 tonnes for PP and 39 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 715 tonnes (4.2 fold increase), 25 tonnes (2.1 fold increase), 853 tonnes (2.8 fold increase), 179 tonnes (6.6 fold increase) and 179 ktonnes (4.6 fold increase) for DIN, DIP, PN, PP and TSS, respectively (Figs. 24 & 25).

Our predicted loads for the Russell Mulgrave Basin generally align with those predicted by the Source Catchments model (Waters et al., in press), while the loads are much lower than those of the Kroon et al. (2012) model (Tables 5 to 9). The limited monitoring data available from the Russell River and Mulgrave River suggests that the loads (low reliability) compare more closely with our model and the Source Catchments model. We predict there should have been a large reduction in TSS loads since the introduction of minimal tillage and Green Cane Trash Blanketing in the sugarcane industry (see Prove et al., 1995), although this cannot be directly quantified. Based on a reduction from 7 tonnes per hectare loss to 4 tonnes per hectare (implemented in 1987 to align with the Source Catchments outputs), we calculate that sediment loads from the Russell Mulgrave Basin have reduced by ~ 35% since the introduction of these practices. We caution that our loads of TSS do not include trapping and are based on very simple principles, although provide some indication on the benefits of these practices on reducing TSS loads.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Russell Mulgrave Basin and the rates applied in the Herbert Basin over time to calculate an annual application of active ingredient (Fig. 26). Our estimates agree reasonably well with the model of Lewis et al. (2011: Table 10). The best 'calibration' we could do based on the Herbert data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine.

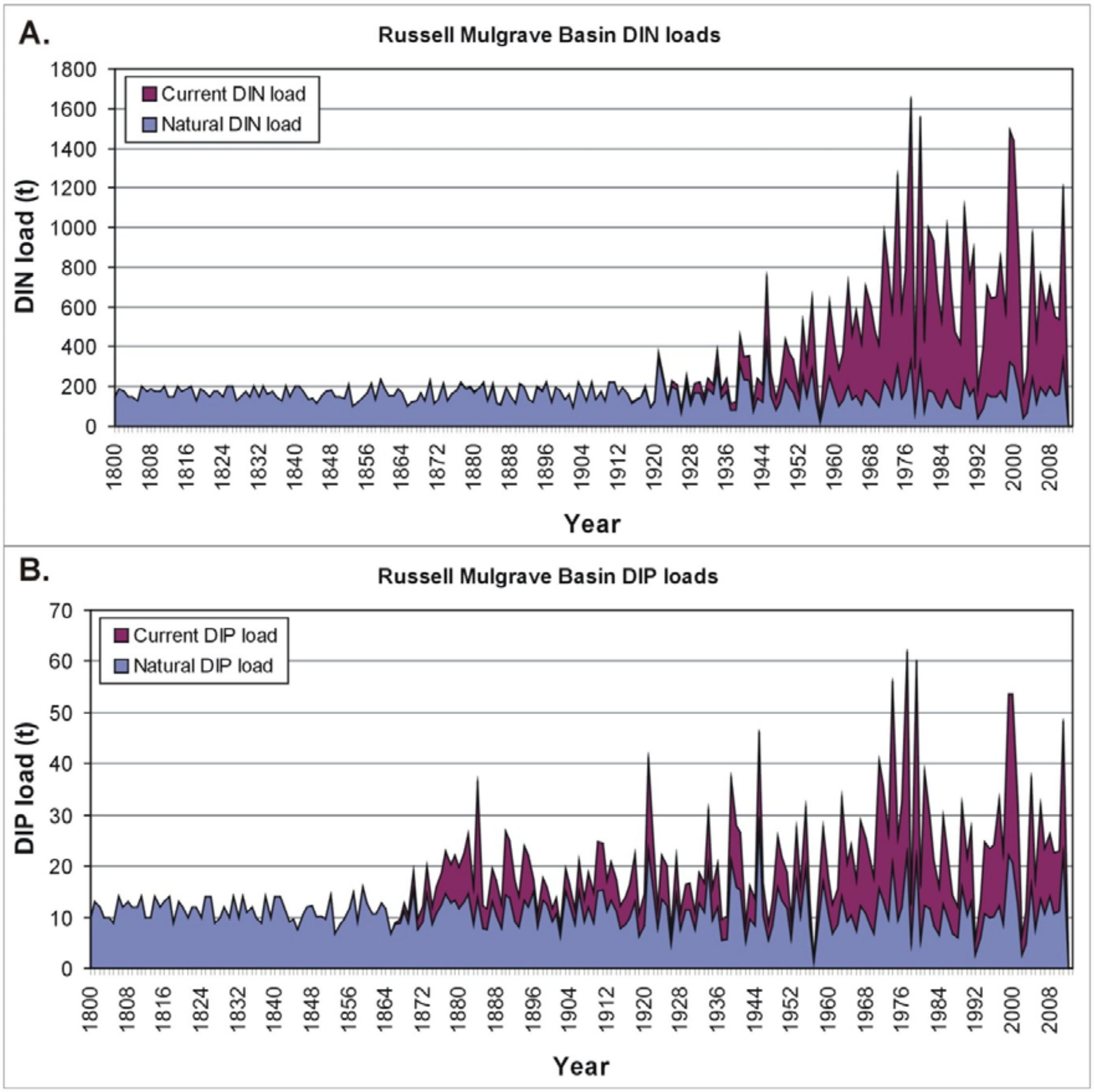

Figure 24. The modelled loads of DIN (A) and DIP (B) for the Russell Mulgrave Basin.

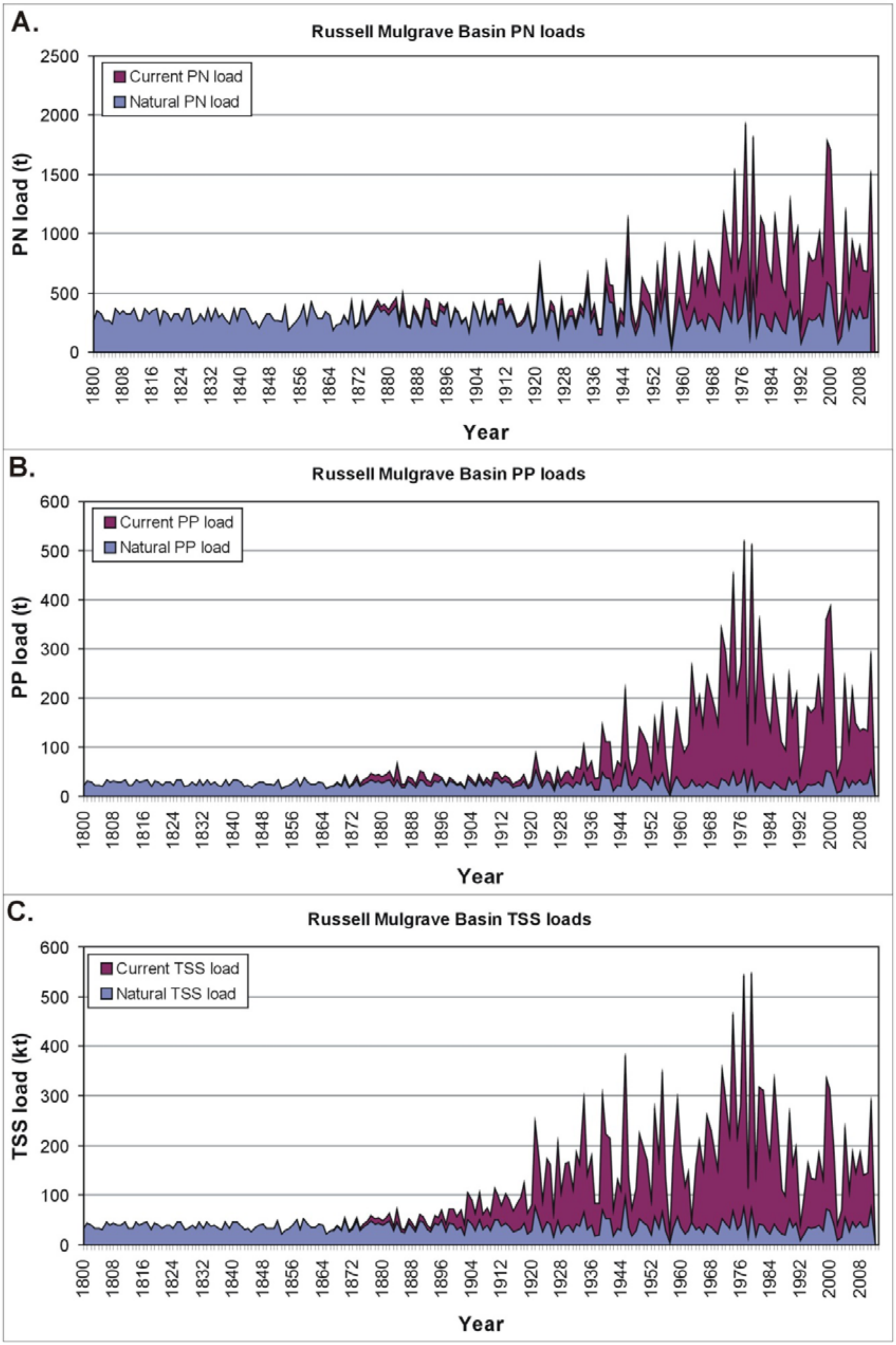

Figure 25. The modelled loads of PN (A) and PP (B) and TSS (C) for the Russell Mulgrave Basin.

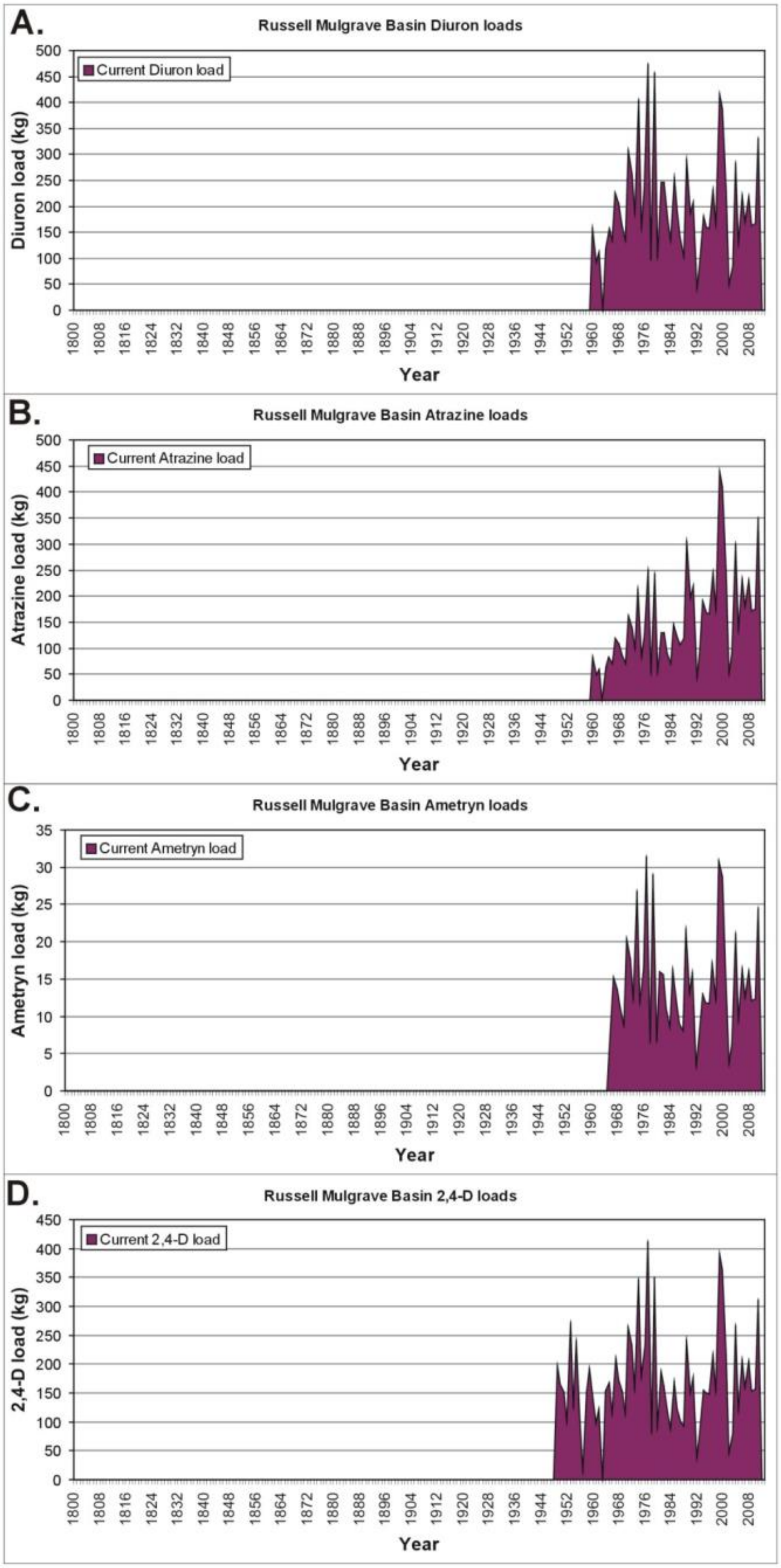

Figure 26. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Russell Mulgrave Basin.

Johnstone Basin

As previously stated in the validation process for the North Johnstone River at Tung Oil site, we consider that the model outputs for DIN are of *high* confidence, PN and PP loads are of *medium* confidence and DIP and TSS are of *low* confidence for the Johnstone Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Johnstone Basin were 212 tonnes for DIN, 29 tonnes for DIP, 385 tonnes for PN, 77 tonnes for PP and 221 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 1348 tonnes (6.4 fold increase), 55 tonnes (1.9 fold increase), 1161 tonnes (3.0 fold increase), 1801 tonnes (23.4 fold increase) and 338 ktonnes (1.5 fold increase) for DIN, DIP, PN, PP and TSS respectively (Figs. 27 & 28).

Our predicted loads of TSS and DIP for the Johnstone Basin align closely with those predicted by the Kroon et al. (2012) model, which is unsurprising given that this model was also based on the same monitoring data. Our model loads for DIN, DIP and PN closely matched the Source Catchments model while PP loads are much higher than predicted by the Source Catchments model (Waters et al., in press) and by Kroon et al. (2012) model (Tables 5 to 9). We predict there should have been a large reduction in TSS loads since the introduction of minimal tillage and Green Cane Trash Blanketing in the sugarcane industry (see Prove et al., 1995). As the Prove et al. (1995) study was conducted in the Johnstone Basin, we would have the highest confidence in this TSS reconstruction compared to the other basins. Based on a change from 7 tonnes per hectare loss to 4 tonnes per hectare (implemented in 1987 to align with the Source Catchments outputs), we calculate that sediment loads from the Johnstone Basin have reduced by ~ 20 since the introduction of these practices, although given the slopes in this catchment, the actual erosion reduction is likely to be much higher (e.g. the lower erosion losses reported in Prove et al. (1995) was 47 t/ha). We caution that our loads of TSS do not include trapping and are based on very simple principles, although provide some indication on the benefits of these practices on reducing TSS loads.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Johnstone Basin and the rates applied in the Herbert Basin over time to calculate an annual application of active ingredient (Fig. 29). Our estimates agree reasonably well with the model of Lewis et al. (2011: Table 9). The best 'calibration' we could do based on the Herbert data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine.

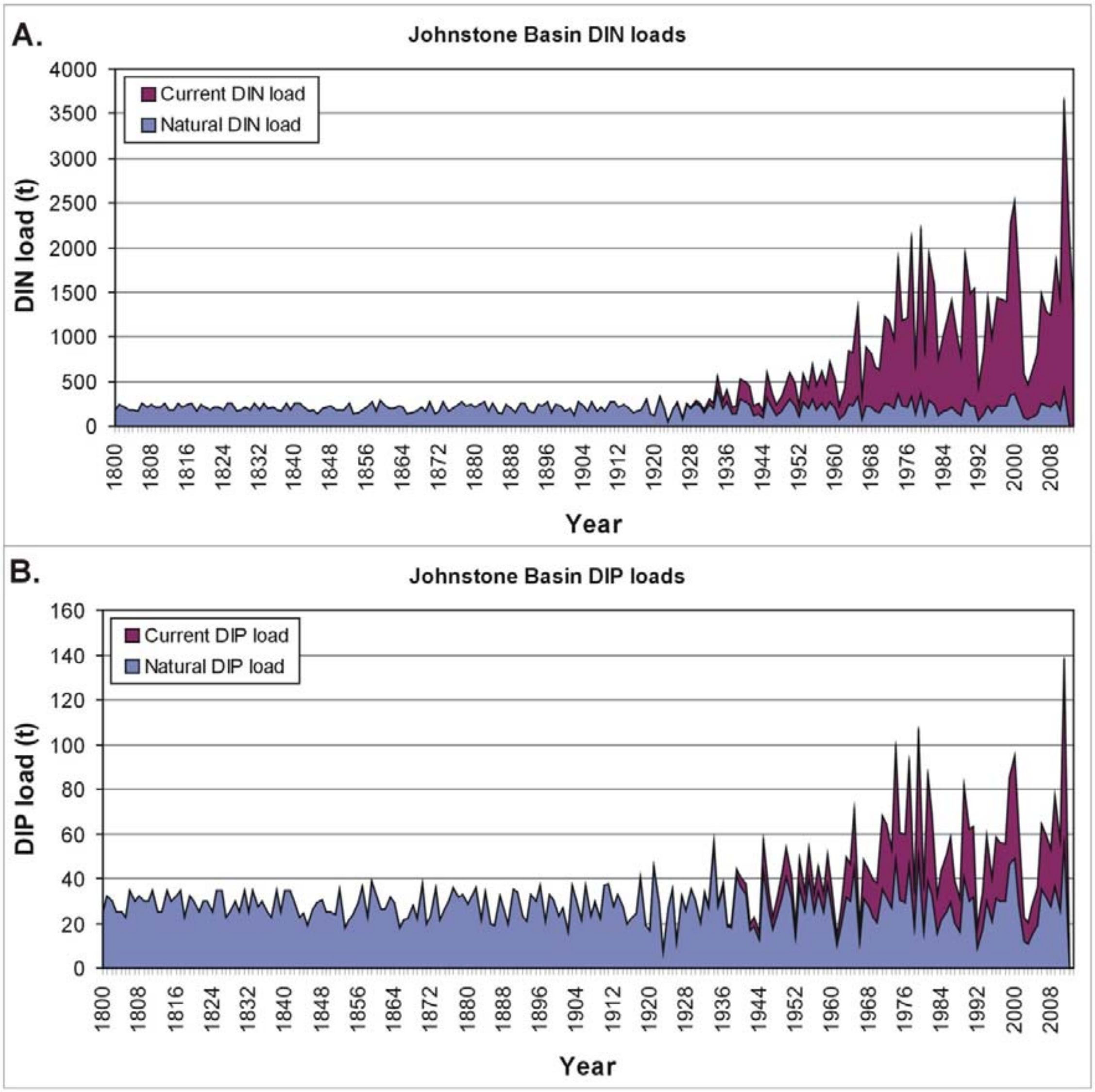

Figure 27. The modelled loads of DIN (A) and DIP (B) for the Johnstone Basin.

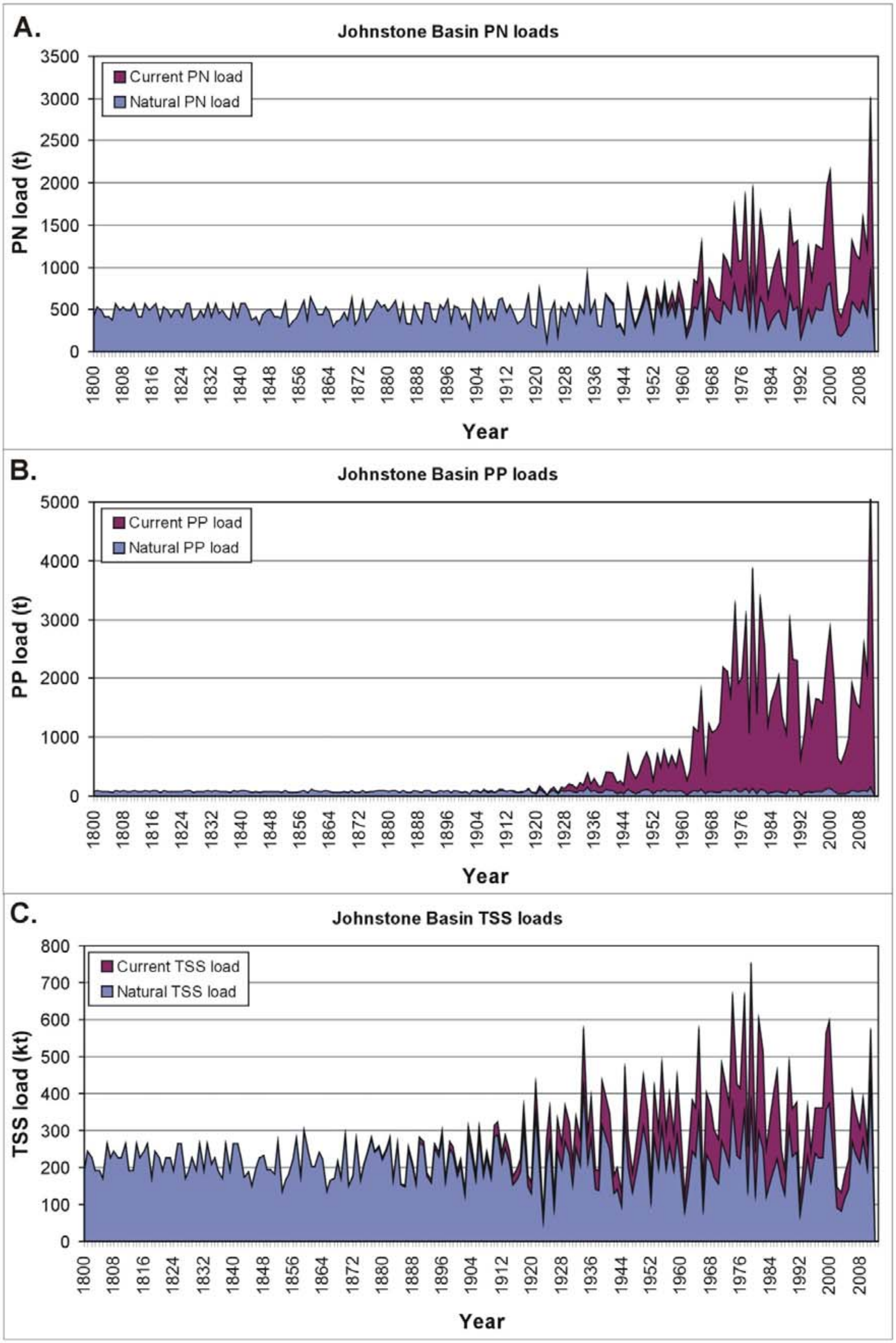

Figure 28. The modelled loads of PN (A) and PP (B) and TSS (C) for the Johnstone Basin.

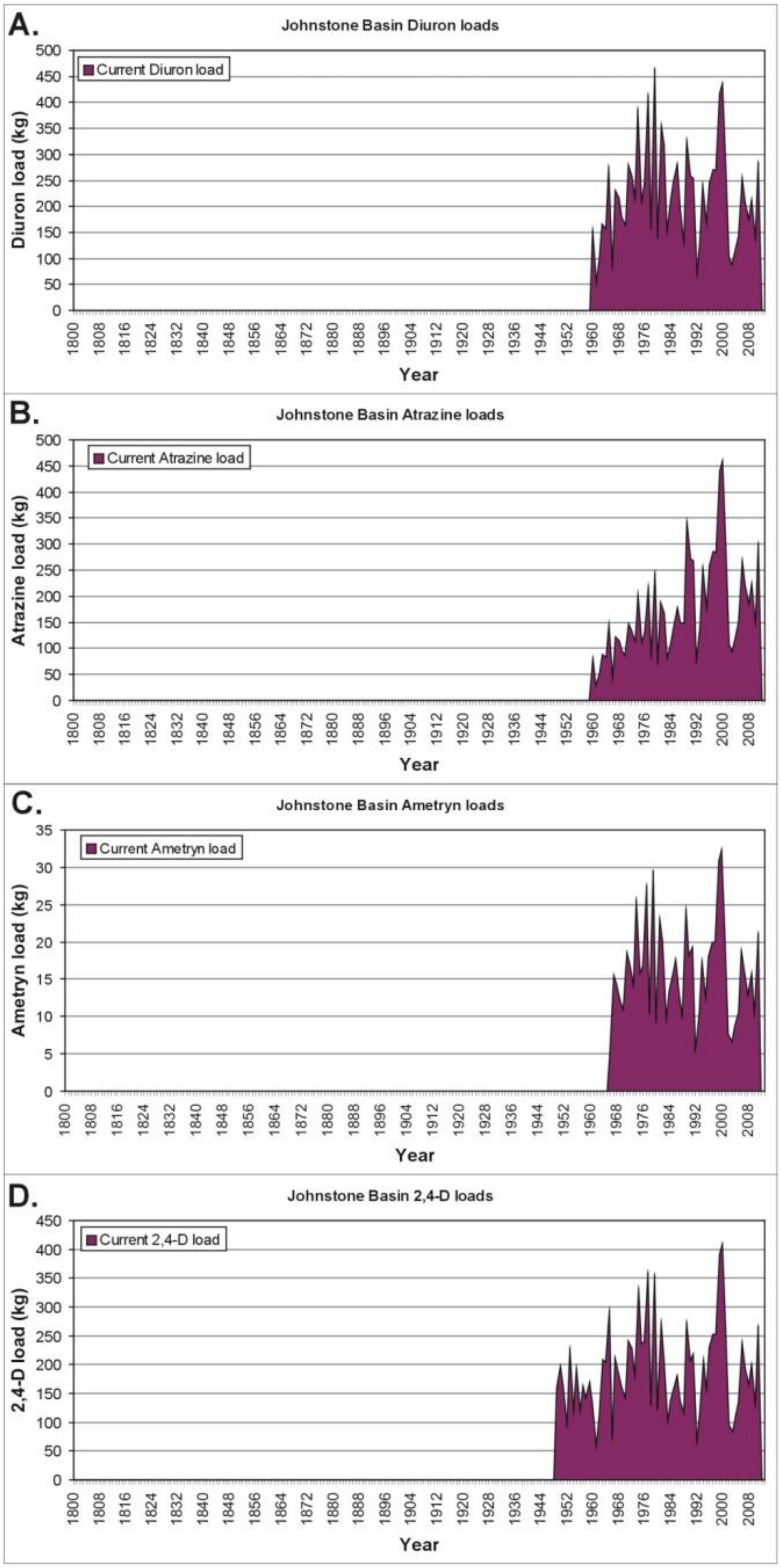

Figure 29. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Johnstone Basin.

Tully-Murray Basin

As previously stated in the validation process for the Tully River at Euramo site, we consider that the model outputs for DIN, PN and PP is of *high* confidence, DIP is of *medium* confidence and TSS is of *low* confidence for the Tully-Murray Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Tully-Murray Basin were 254 tonnes for DIN, 17 tonnes for DIP, 463 tonnes for PN, 40 tonnes for PP and 58 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 542 tonnes (2.1 fold increase), 37 tonnes (2.2 fold increase), 781 tonnes (1.7 fold increase), 164 tonnes (4.1 fold increase) and 122 ktonnes (2.1 fold increase) for DIN, DIP, PN, PP and TSS respectively (Figs. 30 & 31).

Our predicted DIN load for the Tully-Murray Basin is lower than those predicted by the Source Catchments model (Water et al., in press) and the Kroon et al. (2012) model (Table 5). This is an interesting finding, given that our model DIN loads are around half of those predicted by Kroon et al. (2012) who used the same water quality data. Indeed, we would have to increase our nitrogen fertiliser loss (as DIN) to 30% to match Kroon et al.'s (2012) loads compared to the 11% loss we used in our validation. Our loads for DIP, PN, PP and TSS loads were similar to both models (Table 6-9). We predict there should have been a large reduction in area-specific TSS loads since the introduction of minimal tillage and Green Cane Trash Blanketing in the sugarcane industry (see Prove et al., 1995). Based on a change from 7 tonnes per hectare loss to 4 tonnes per hectare (implemented in 1987 to align with the Source Catchments outputs), we calculate that sediment loads from the Tully-Murray Basin have not reduced since the introduction of these practices. We caution that our estimated TSS loads do not include trapping (e.g. on floodplains etc) and are based on very simple principles, although provide some indication on the benefits of these practices on reducing TSS loads.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Tully-Murray Basin and the rates applied in the Herbert Basin over time to calculate an annual application of active ingredient (Fig. 32). Our estimates agree reasonably well with the model of Lewis et al. (2011: Table 10). The best 'calibration' we could do based on the Herbert data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine.

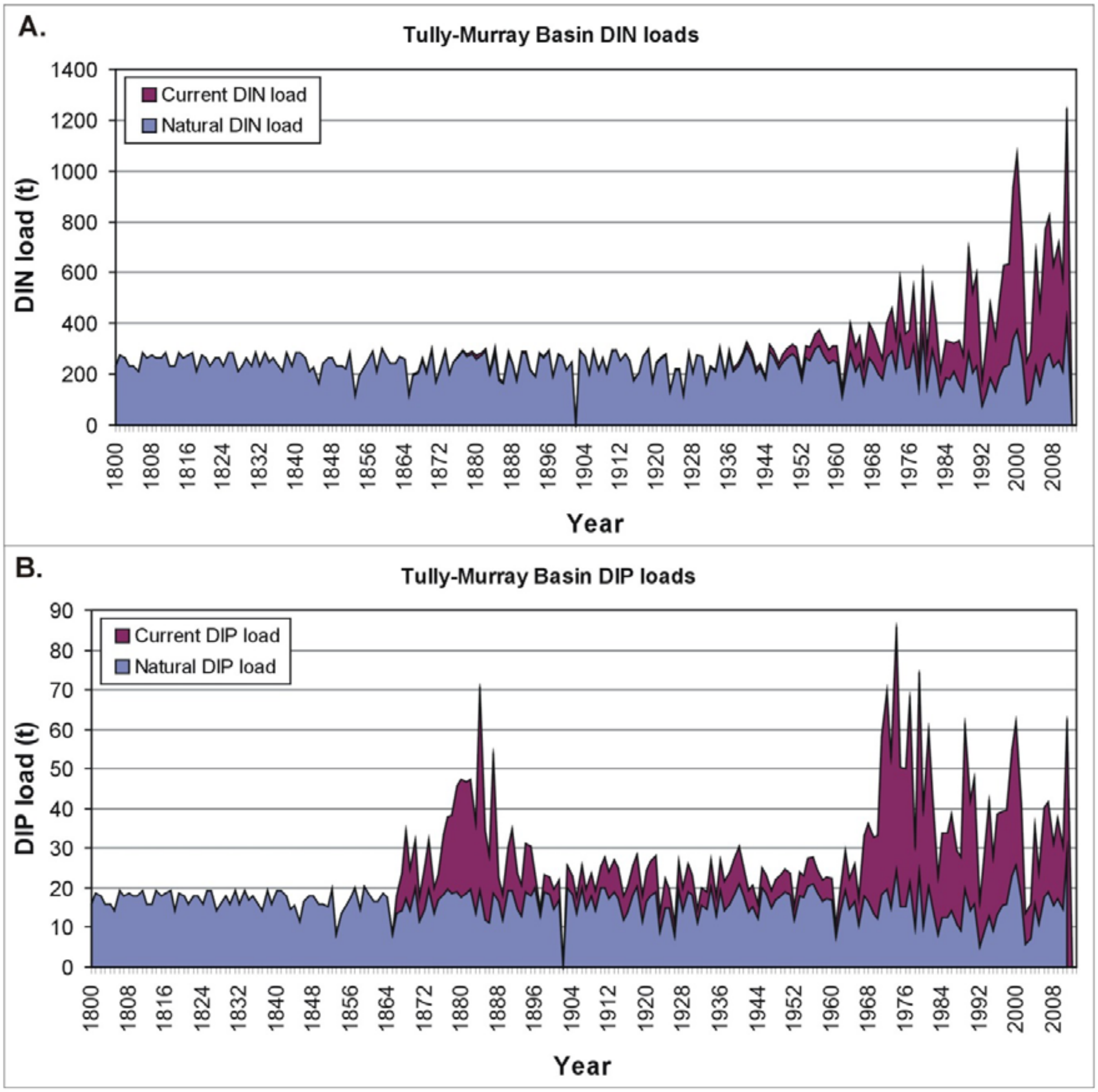

Figure 30. The modelled loads of DIN (A) and DIP (B) for the Tully-Murray Basin.

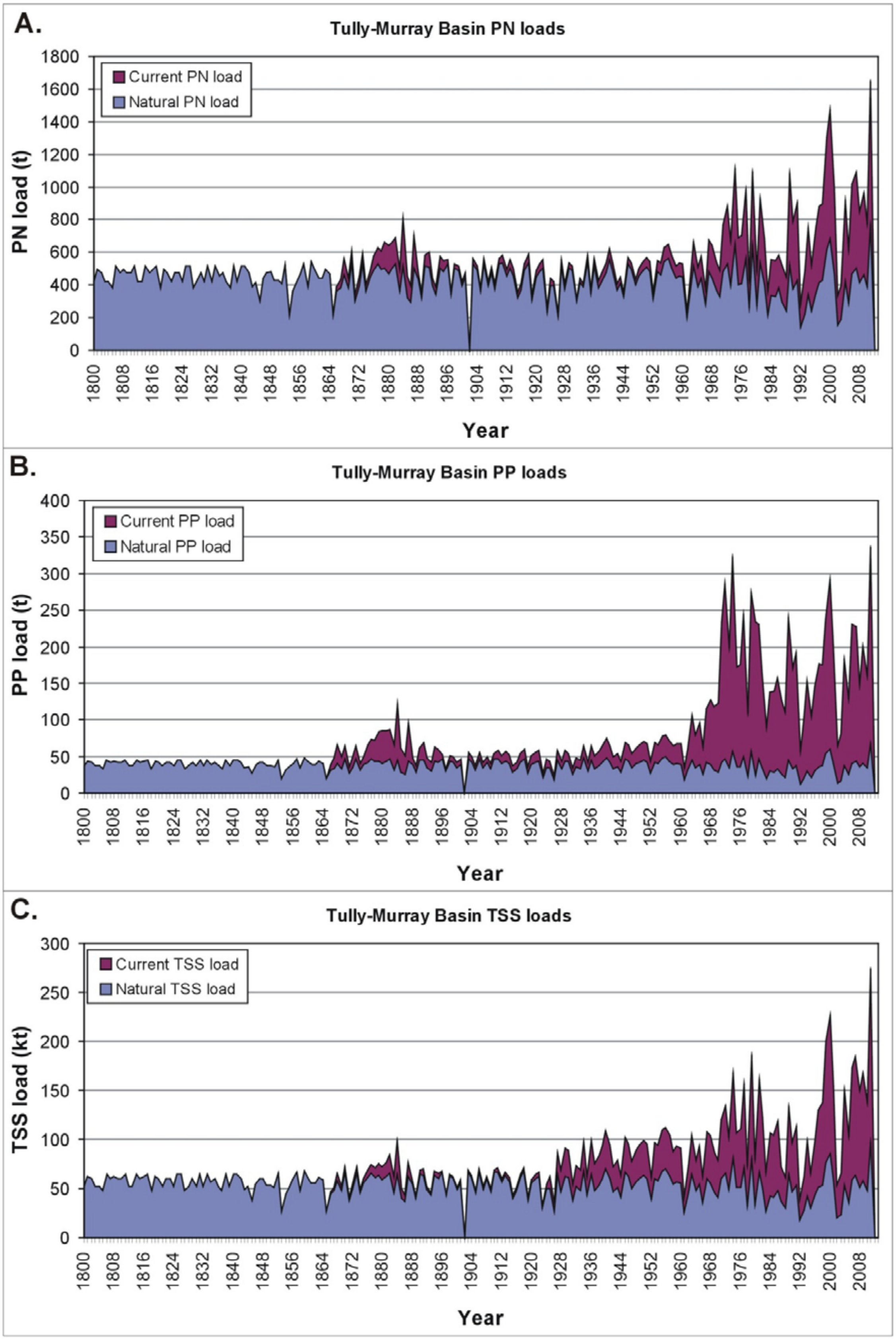

Figure 31. The modelled loads of PN (A) and PP (B) and TSS (C) for the Tully-Murray Basin.

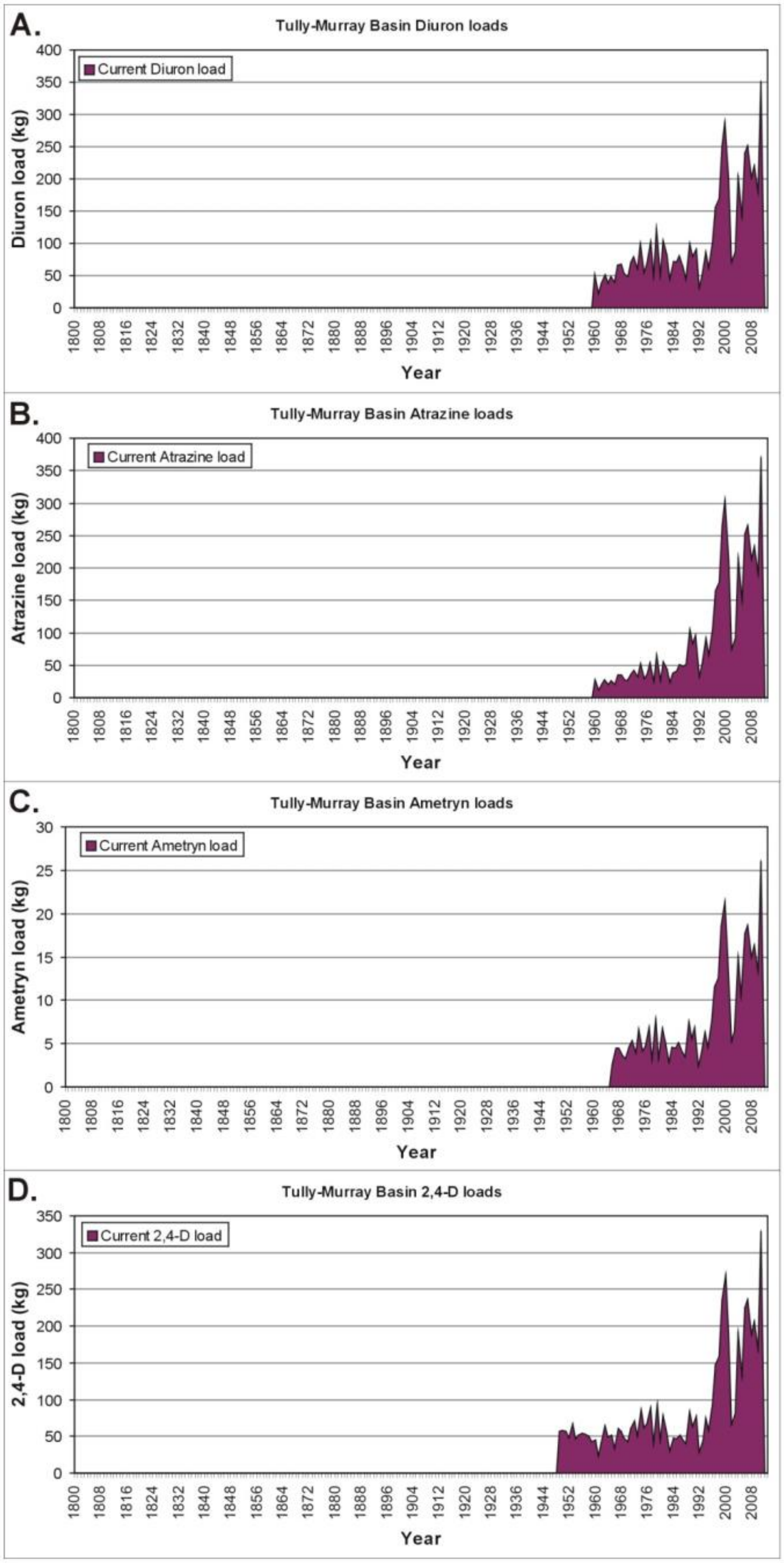

Figure 32. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Tully-Murray Basin.

Herbert Basin

As previously stated in the validation process for the Herbert River at Ingham site, we consider that the model outputs for DIN and TSS loads are of *high* confidence and PN and PP loads are of *medium* confidence and DIP loads are of *low* confidence for the Herbert Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Herbert Basin were 188 tonnes for DIN, 13 tonnes for DIP, 342 tonnes for PN, 68 tonnes for PP and 128 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 983 tonnes (5.2 fold increase), 62 tonnes (4.8 fold increase), 1589 tonnes (4.6 fold increase), 377 tonnes (5.5 fold increase) and 703 ktonnes (5.5 fold increase) for DIN, DIP, PN, PP and TSS respectively (Figs. 33 & 34).

Our predicted DIN load for the Herbert Basin falls in between the loads predicted by the Source Catchments (Water et al., in press) and Kroon et al. (2012) models, which applied the same water quality data (Table 5). Indeed, our model also closely matches the Source Catchment loads of DIP and PP for the Herbert Basin (Tables 6 and 8) while our predicted PN and TSS loads were higher than the other models (Tables 7 and 9). We predict there should have been a large reduction in TSS loads since the introduction of minimal tillage and Green Cane Trash Blanketing in the sugarcane industry (see Prove et al., 1995). However, based on a change from 7 tonnes per hectare loss to 4 tonnes per hectare (implemented in 1987 to align with the Source Catchments outputs), we calculate that sediment loads from the Herbert Basin have not reduced since the introduction of these practices. We caution that our loads of TSS do not include trapping and are based on very simple principles, although provide some indication on the benefits of these practices on reducing TSS loads.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Herbert Basin and the rates applied in the Herbert Basin from 1949 to 1995 to calculate an annual application of active ingredient (Fig. 35). Our estimates agree reasonably well with the model of Lewis et al. (2011: Table 10). The best 'calibration' we could do based on the limited Herbert data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine. We consider that the herbicide model for the Herbert Basin has the highest confidence compared to the other basins of the Wet Tropics, although the ability to perform any sort of validation is hampered by the limited monitoring data.

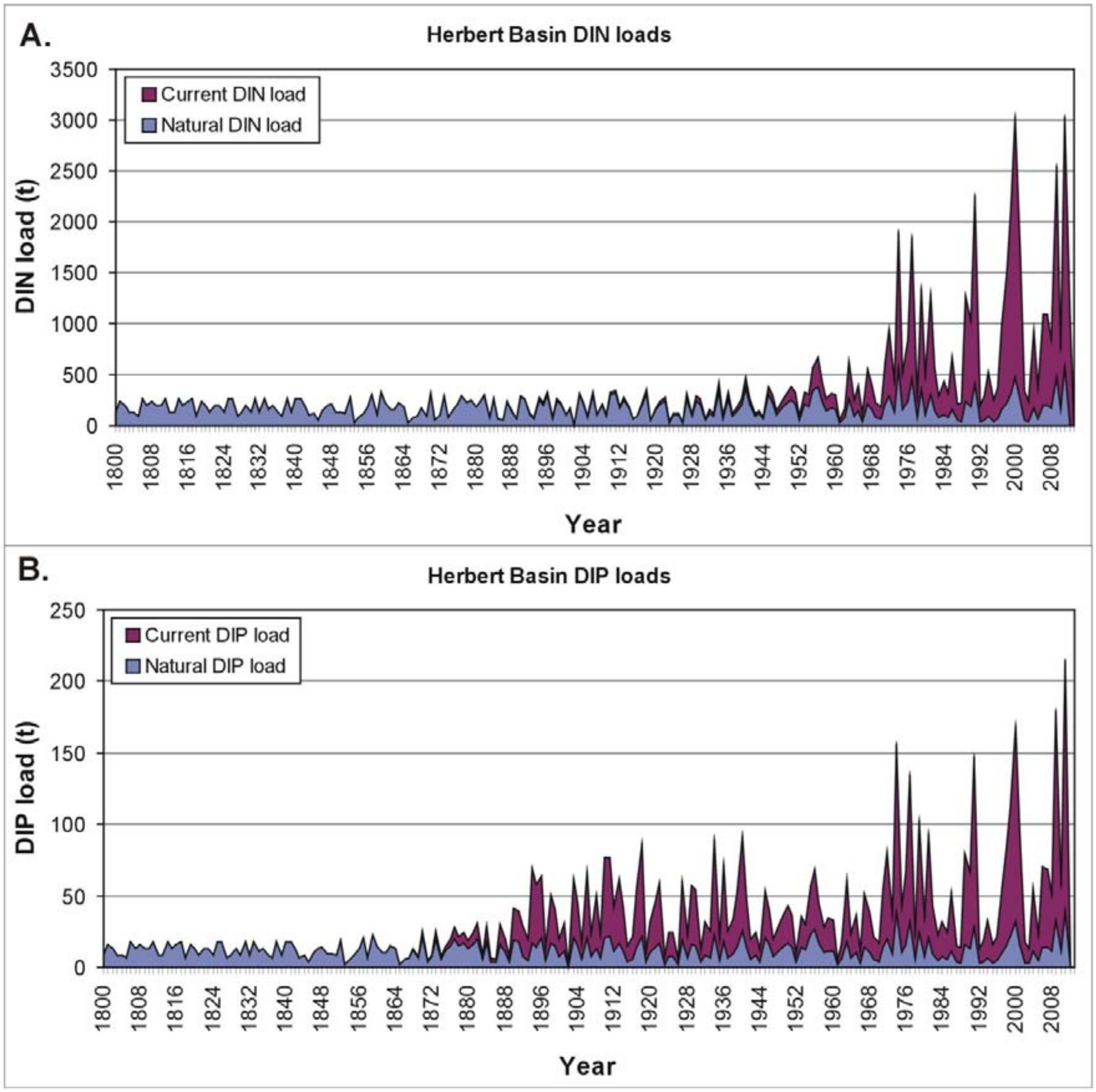

Figure 33. The modelled loads of DIN (A) and DIP (B) for the Herbert Basin.

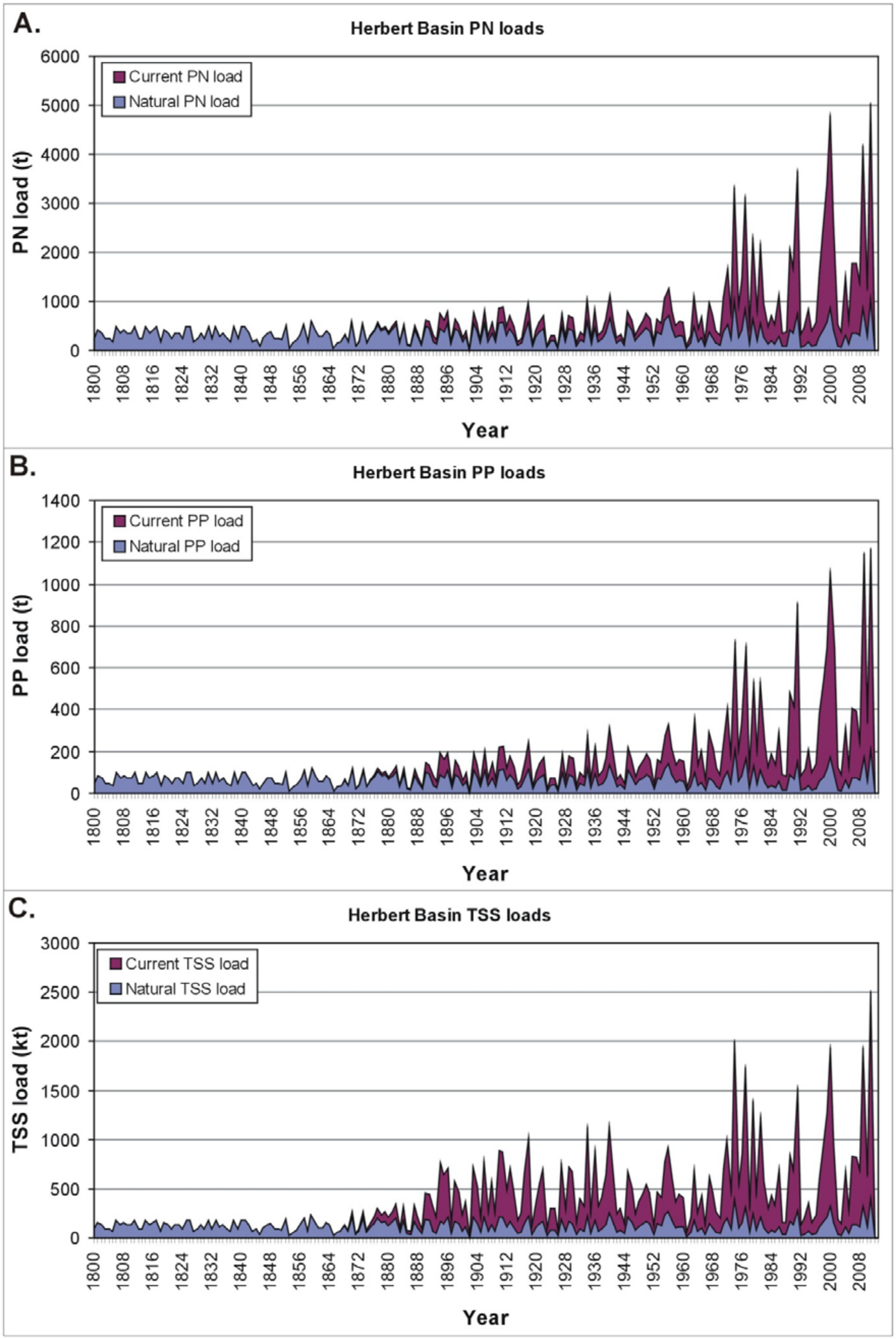

Figure 34. The modelled loads of PN (A) and PP (B) and TSS (C) for the Herbert Basin.

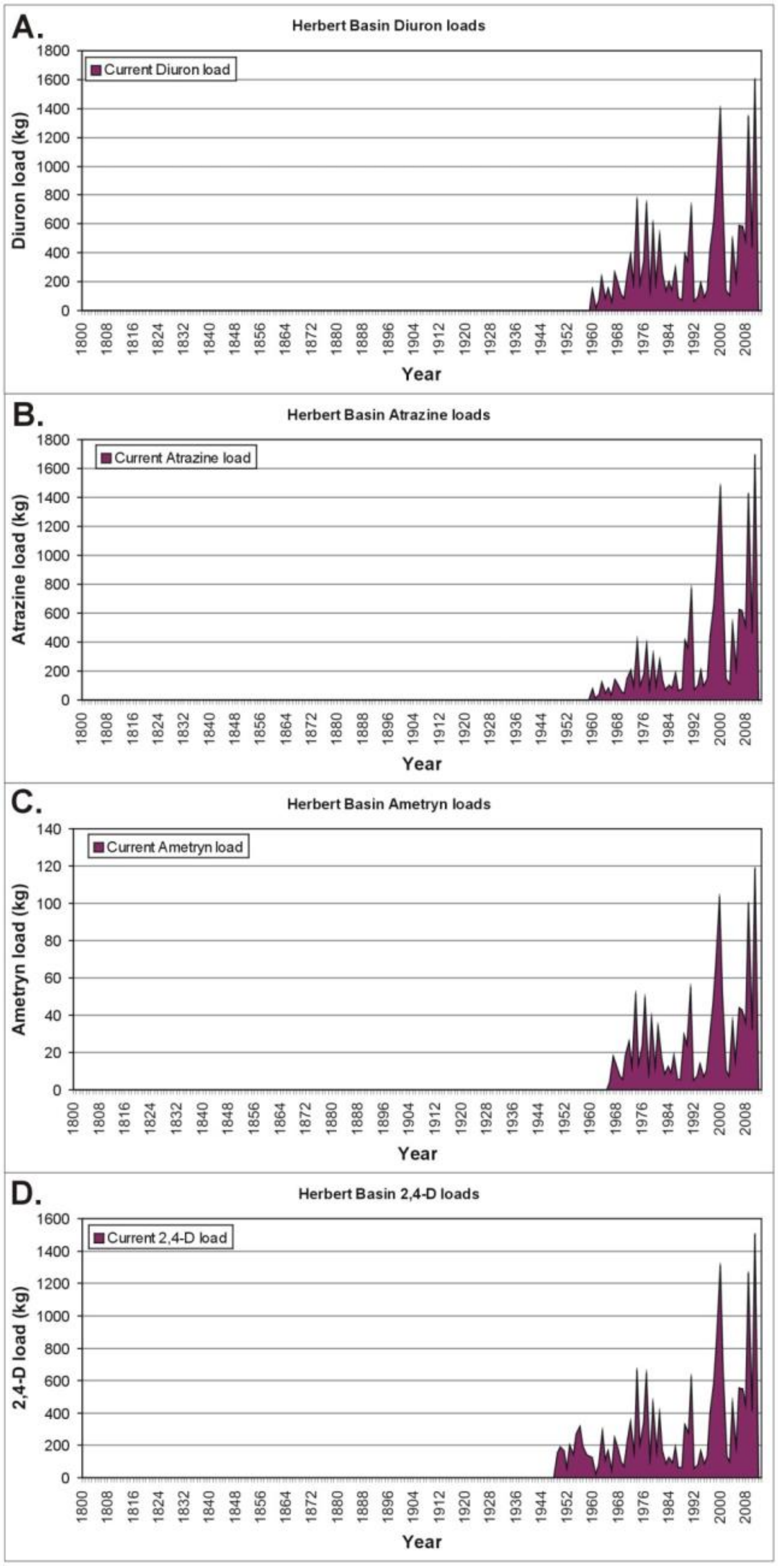

Figure 35. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Herbert Basin.

5.2 Burdekin Region

Haughton Basin

We used the validation for the Herbert River at Ingham site to estimate historical DIN loads and the Tully River at Euramo Site for DIP, PN and PP loads from the Haughton Basin as we believe that these sites best match (that we can perform validations on) the characteristics of this basin. Indeed the attempted validations using the long term monitoring data from Barratta Creek (Figs. 12 & 13 - as well as more limited data from the Haughton River – not shown) highlight the difficultly of modelling an extensive coastal floodplain. Based on the performance of the model, we consider that the model outputs of DIN, PN and PP has *medium* confidence, DIP has *low* confidence and TSS has *very low* confidence for the Haughton Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Haughton Basin were 45 tonnes for DIN, 6 tonnes for DIP, 83 tonnes for PN, 17 tonnes for PP and 12 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 744 tonnes (16.5 fold increase), 20 tonnes (3.3 fold increase), 1070 tonnes (12.9 fold increase), 218 tonnes (12.8 fold increase) and 117 ktonnes (9.8 fold increase) for DIN, DIP, PN, PP and TSS respectively (Figs. 36 & 37).

Our predicted DIN loads for the Haughton Basin are much higher than the load predicted by the Source Catchments (Water et al., in press) and Kroon et al. (2012) models (Table 11). Our modelled DIP and PP loads fall in between the Source Catchments and Kroon et al. (2012) loads (Table 12 & 14), while our PN loads (Table 13) are similar to Kroon et al. (2012) but substantially higher than Source Catchments. In this case, we believe our model is likely to better predict the loads of these pollutants for this extensive coastal floodplain. Our TSS loads are considerably lower than both models (Table 15) and based on our validations we have low confidence for our TSS loads.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Haughton Basin and the rates applied in the Herbert Basin from 1949 to 1995 to calculate an annual application of active ingredient (Fig. 38). Our estimates agree reasonably well with the model of Lewis et al. (2011: Table 16). The best 'calibration' we could do based on the limited Haughton data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine.

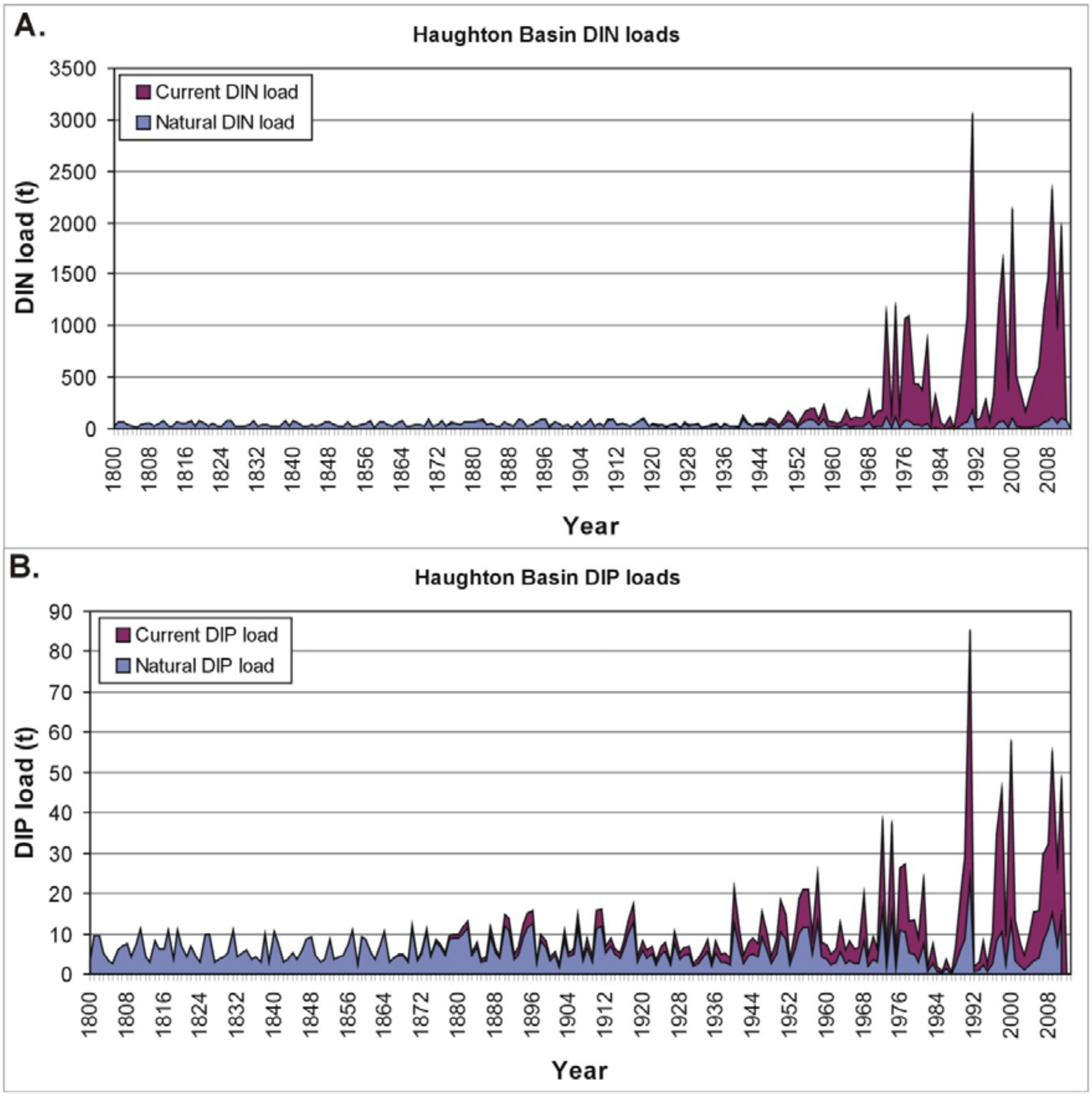

Figure 36. The modelled loads of DIN (A) and DIP (B) for the Haughton Basin.

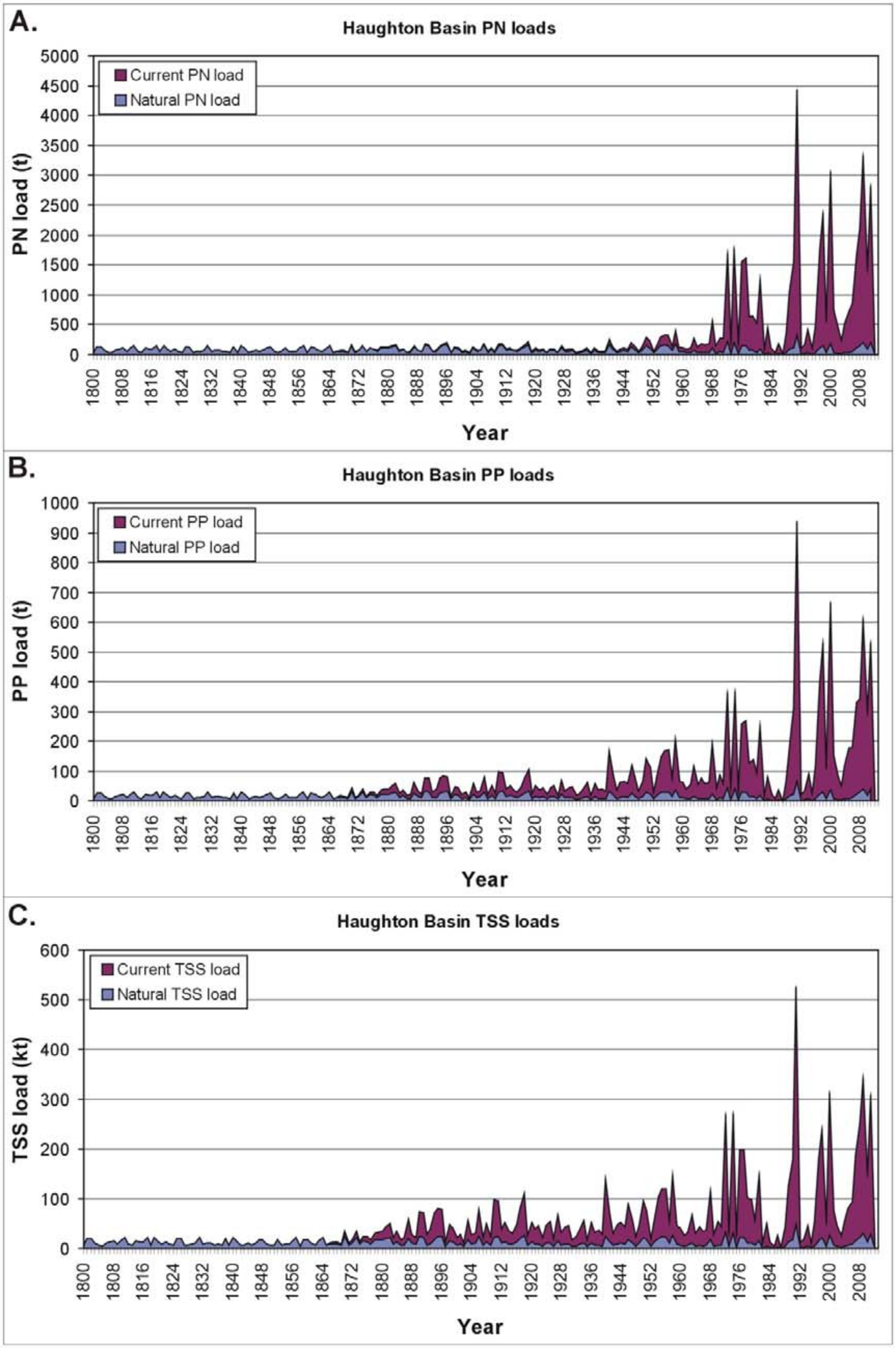

Figure 37. The modelled loads of PN (A) and PP (B) and TSS (C) for the Haughton Basin.

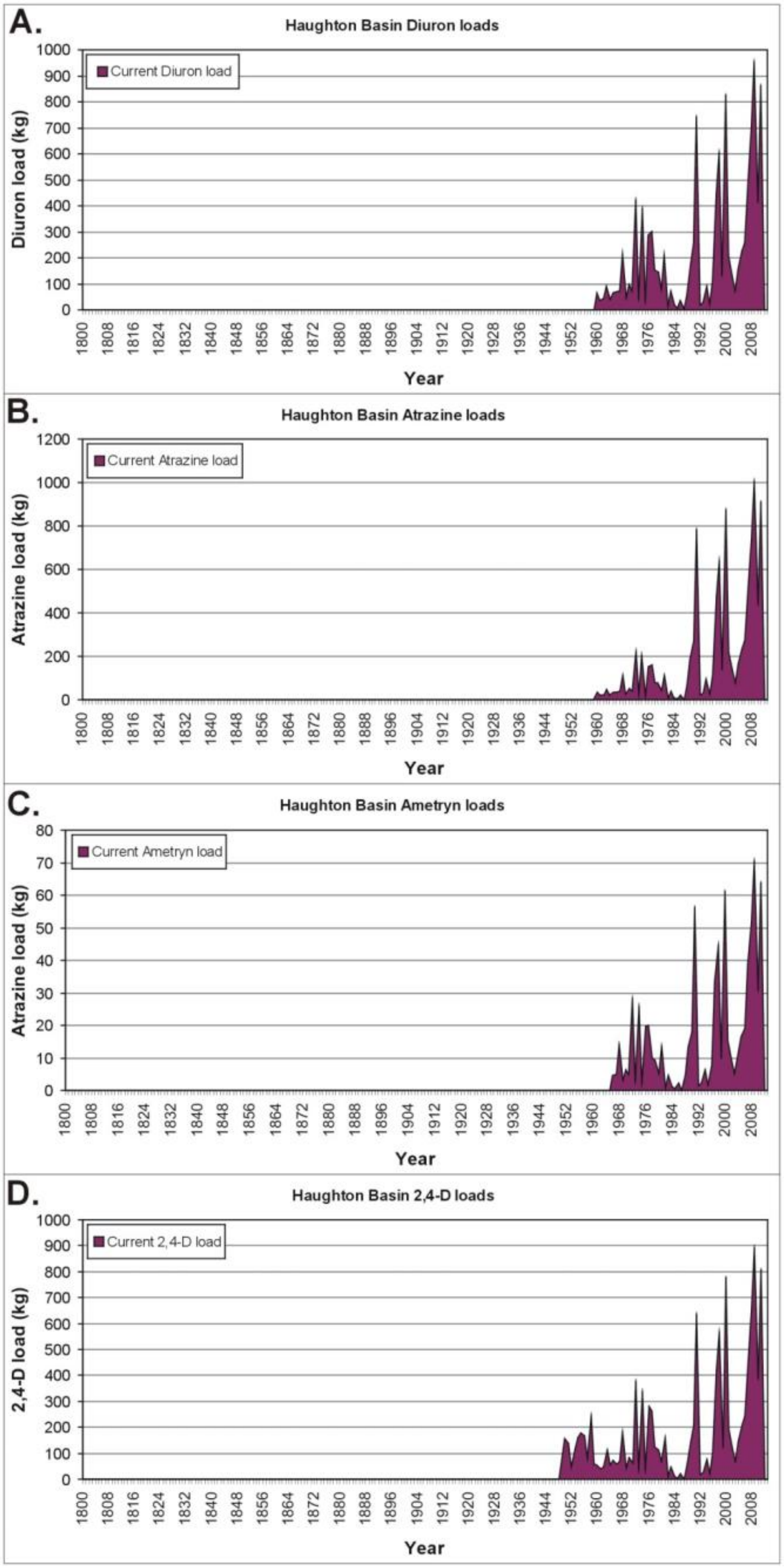

Figure 38. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Haughton Basin

Table 11. Comparisons of mean loads for the current load of DIN (t) (period 1986 to 2009)

Basin	This study		Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Haughton	816	Medium	558	340	Herbert River @ Ingham
Burdekin	1905	Medium	1358	1800	Herbert River @ Ingham
Proserpine	120	Medium	168	440	Herbert River @ Ingham
O'Connell	293	Medium	222	500	Herbert River @ Ingham
Pioneer	351	Medium	201	270	Herbert River @ Ingham
Plane	1522	Medium	309	540	Herbert River @ Ingham

Table 12. Comparisons of mean loads for the current load of DIP (t) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Haughton	22	Low	44	12	Tully River @ Euramo
Burdekin	122	Low	198	240	Tully River @ Euramo
Proserpine	58	Low	46	16	Tully River @ Euramo
O'Connell	67	Low	75	22	Tully River @ Euramo
Pioneer	31	Low	28	31	Tully River @ Euramo
Plane	57	Low	77	15	Tully River @ Euramo

Table 13. Comparisons of mean loads for the current load of PN (t) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Haughton	1174	Medium	272	1200	Tully River @ Euramo
Burdekin	2602	Medium	3256	5500	Tully River @ Euramo
Proserpine	222	Medium	128	1100	Tully River @ Euramo
O'Connell	464	Medium	173	1600	Tully River @ Euramo
Pioneer	506	Medium	281	250	Tully River @ Euramo
Plane	765	Medium	120	2300	Tully River @ Euramo

Table 14. Comparisons of mean loads for the current load of PP (t) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Haughton	242	Medium	140	260	Tully River @ Euramo
Burdekin	1182	Medium	1317	1500	Tully River @ Euramo
Proserpine	89	Medium	47	320	Tully River @ Euramo
O'Connell	142	Medium	77	570	Tully River @ Euramo
Pioneer	121	Medium	86	74	Tully River @ Euramo
Plane	195	Medium	48	970	Tully River @ Euramo

Table 15. Comparisons of mean loads for the current load of TSS (kt) (period 1986 to 2009)

Basin	This study	Confidence	Source catchments (Waters et al. in press)	Kroon et al. (2012)	Which validation was used
Haughton	128	Very Low	250	300	N/A
Burdekin	3992*	High	3306	4000	
Proserpine	72	Medium	79	310	
O'Connell	122	Medium	150	630	
Pioneer	122	Medium	193	52	
Plane	174	Medium	92	550	

Table 16. Comparisons of mean loads for the current load of diuron, atrazine and ametryn (kg) (period 1986 to 2009)

Basin	This study (diuron)	Lewis et al. (2011) diuron	This study (atrazine)	Lewis et al. (2011) atrazine	This study (ametryn)	Lewis et al. (2011) ametryn
Haughton	293	315	309	552	22	17
Burdekin	109	71	115	168	8	3
Proserpine	30	774	32	299	2	19
O'Connell	115	1085	122	419	9	26
Pioneer	183	1439	194	555	14	35
Plane	239	1737	253	670	18	42

Burdekin Basin

We used the validation for the Herbert River at Ingham site to estimate historical DIN loads and the Tully River at Euramo Site for DIP, PN and PP loads from the Burdekin Basin as we believe that these sites best match (that we can perform validations on) the characteristics of this basin. Based on the performance of the model, we consider that the model outputs of DIN, PN and PP has *medium* confidence, DIP has *low* confidence and TSS has *very low* confidence for the Burdekin Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Burdekin Basin were 482 tonnes of DIN, 66 tonnes of DIP, 877 tonnes of PN, 175 tonnes of PP and 296 ktonnes of TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 1951 tonnes (4.0 fold increase), 125 tonnes (1.9 fold increase), 2662 tonnes (3.0 fold increase), 1215 tonnes (6.9 fold increase) and 3306 ktonnes (11.2 fold increase) for DIN, DIP, PN, PP and TSS, respectively (Figs. 39 & 40).

Our predicted DIN loads for the Burdekin Basin are higher than the load predicted by the Source Catchments model (Water et al., in press), but similar to Kroon et al. (2012) (Tables 11). In this case, we believe our model is likely to better predict the loads of DIN for this extensive coastal floodplain. In contrast, our model PN and PP loads are much lower than Source Catchments and Kroon et al. (2012) modelled loads (Tables 13 & 14) while our DIP and TSS loads are comparable (Tables 12 & 15).

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Burdekin Basin and the rates applied in the Herbert Basin from 1949 to 1995 to calculate an annual application of active ingredient (Fig. 41). Our estimates agree reasonably well with the model of Lewis et al. (2011: Table 16). The best 'calibration' we could do based on the limited Burdekin data was to use a 1% loss of applied ametryn and 2,4-D, 1.5% loss of applied diuron and 0.5% loss of applied atrazine.

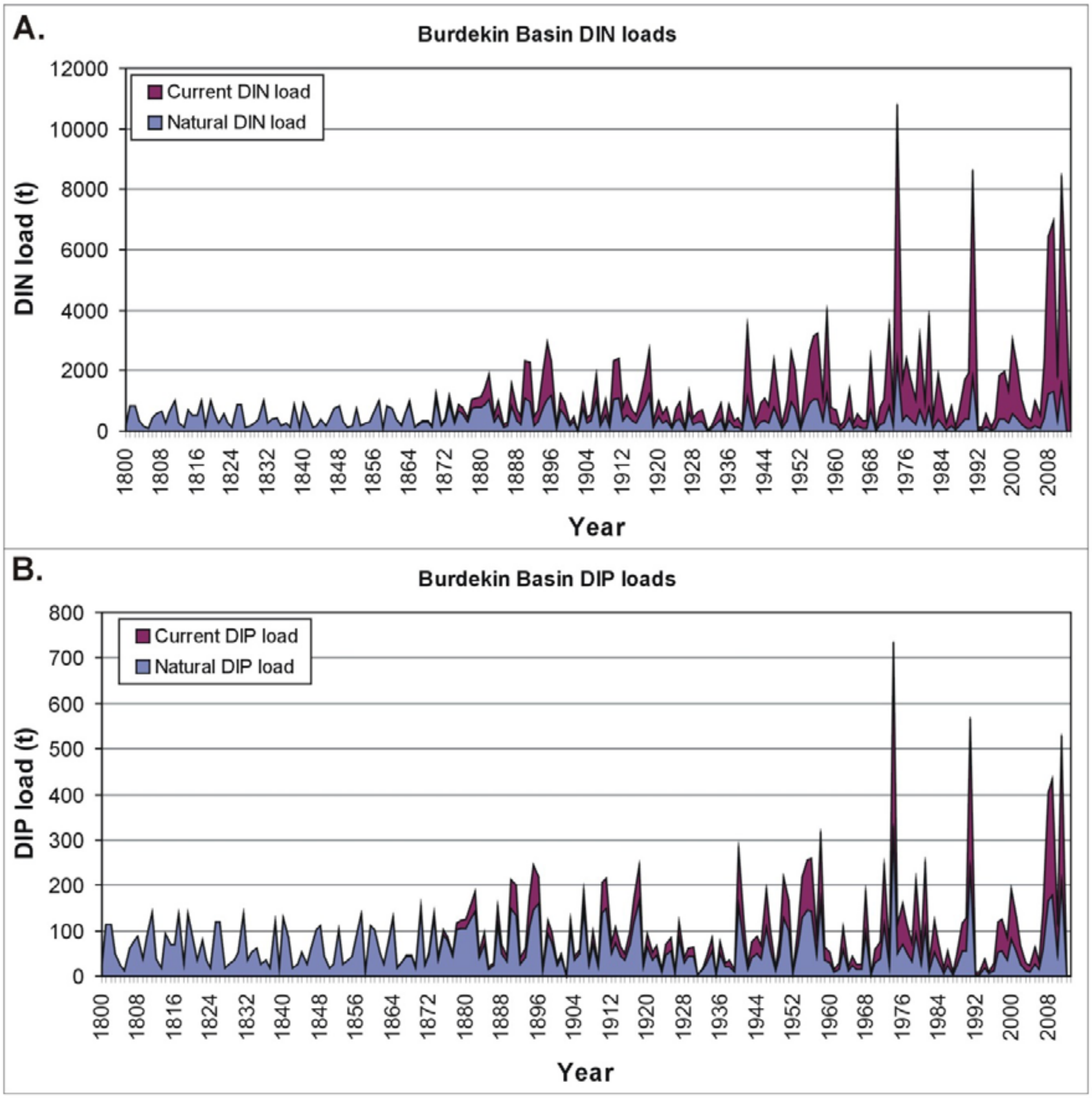

Figure 39. The modelled loads of DIN (A) and DIP (B) for the Burdekin Basin.

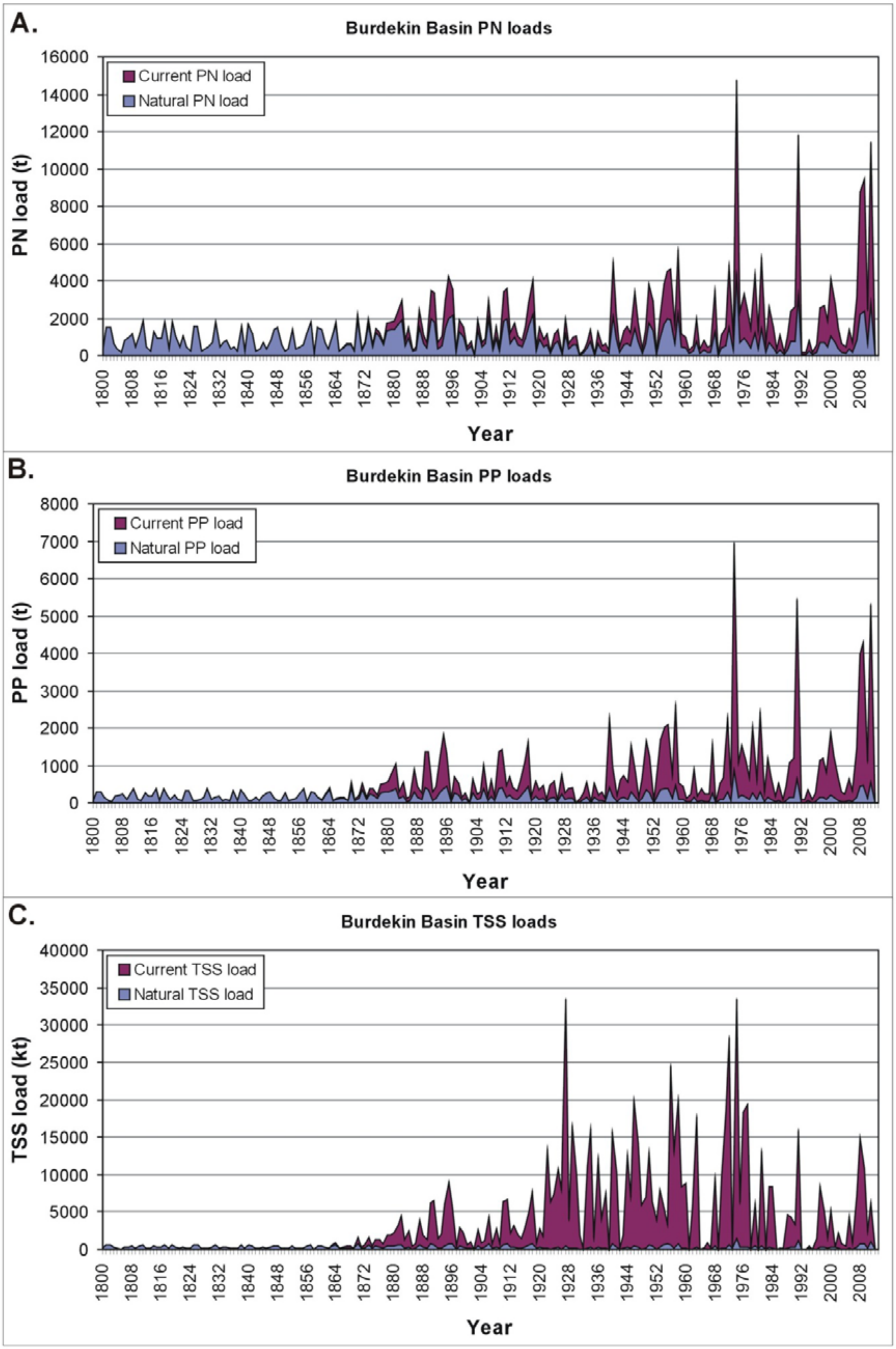

Figure 40. The modelled loads of PN (A) and PP (B) and TSS (C) for the Burdekin Basin.

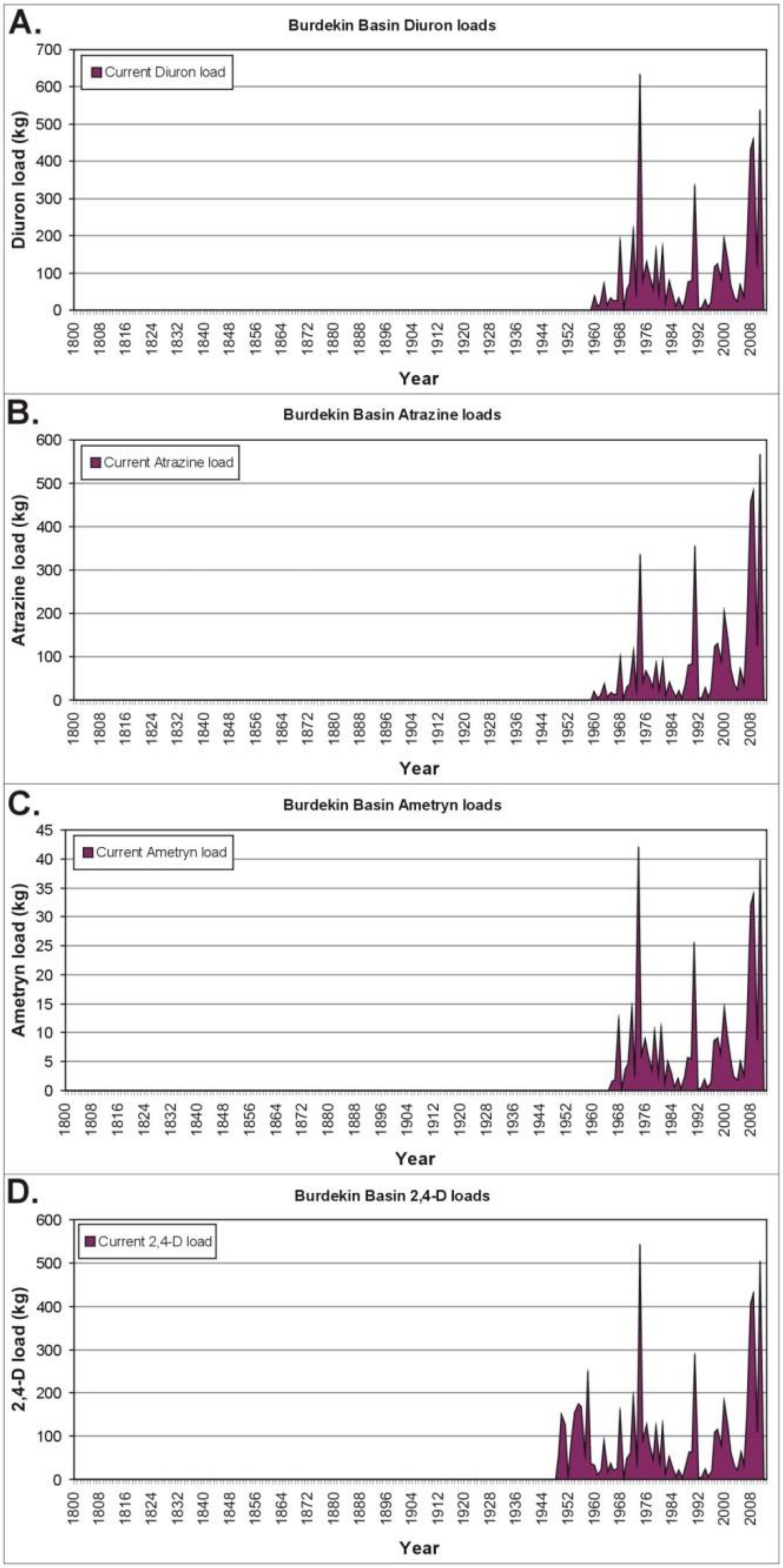

Figure 41. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Burdekin Basin

5.3 Mackay Whitsunday Region

Proserpine Basin

We used the validation for the Herbert River at Ingham site to estimate historical DIN loads and the Tully River at Euramo Site for DIP, PN and PP loads from the Proserpine Basin as we believe that these sites best match (that we can perform validations on) the characteristics of this basin. Based on the performance of the model, we consider that the model outputs of DIN, PN, PP and TSS has *medium* confidence and DIP has *low* confidence for the Proserpine Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Proserpine Basin were 232 tonnes for DIN, 105 tonnes for DIP, 422 tonnes for PN, 211 tonnes for PP and 53 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 137 tonnes (1.7 fold decrease), 66 tonnes (1.6 fold decrease), 253 tonnes (1.7 fold decrease), 101 tonnes (2.1 fold decrease) and 84 ktonnes (1.6 old increase) for DIN, DIP, PN, PP and TSS, respectively (Figs. 42 & 43).

Our predicted DIN load for the Proserpine Basin is lower than the load predicted by the Source Catchments model (Water et al., in press), and also much lower than in Kroon et al. (2012) (Table 11). Our mean DIP load is comparable with the Source Catchments model but is higher than the mean load in the Kroon et al. (2012) model (Table 12). Our PN, PP and TSS loads are comparable to those predicted in the Source Catchments model but are much lower than the Kroon et al. (2012) model (Tables 13, 14 & 15). In this case, we believe that our model and Source Catchment estimates for the particulate nutrients are likely to provide a better prediction as the Kroon et al. (2012) is based on ANNEX model outputs, which are known to be overestimated.

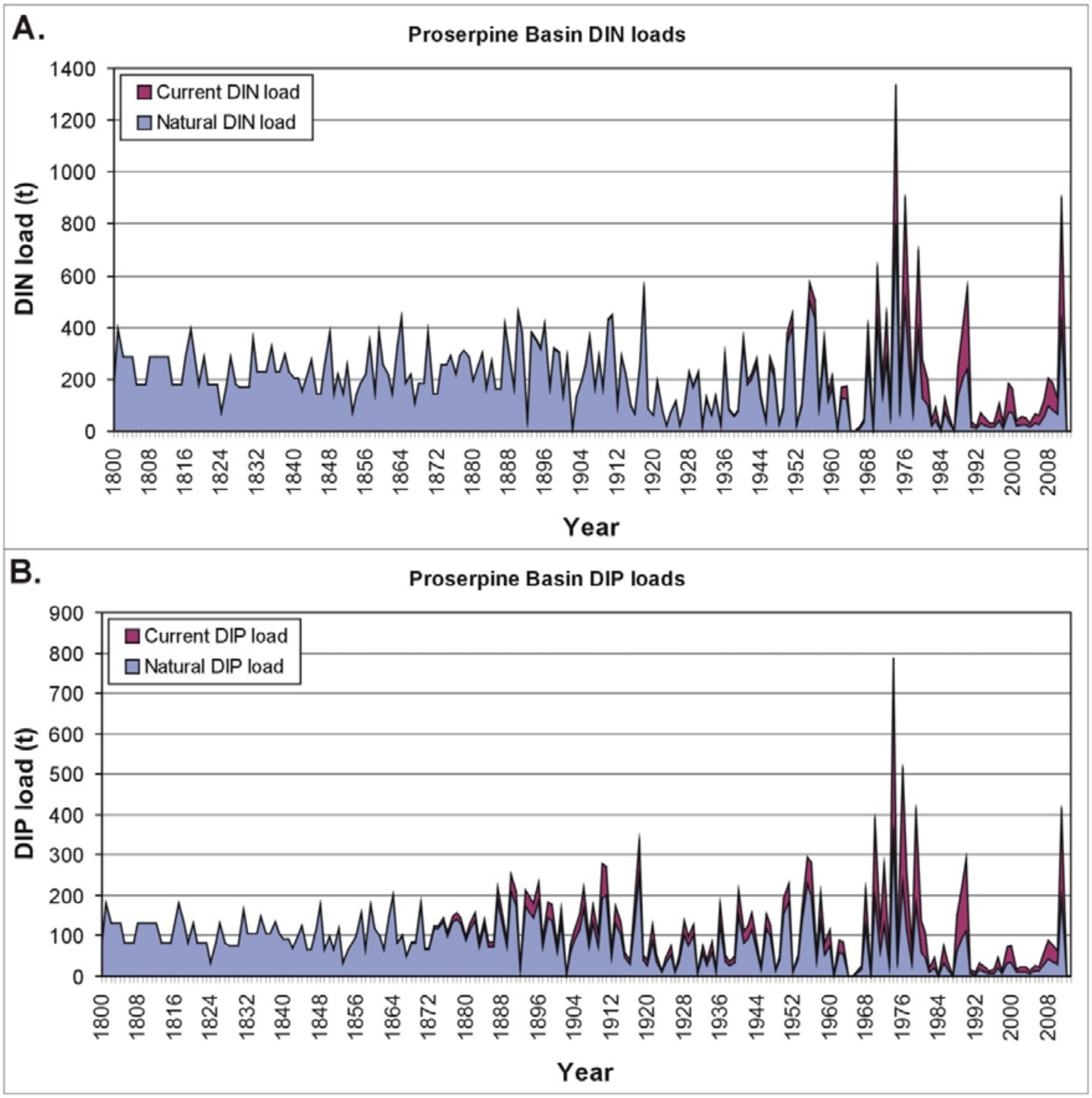

Figure 42. The modelled loads of DIN (A) and DIP (B) for the Proserpine Basin.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Proserpine Basin and the rates applied in the Herbert Basin from 1949 to 1995 to calculate an annual application of active ingredient (Fig. 44). Our estimates are much lower (order of magnitude) than the model of Lewis et al. (2011: Table 16) but align reasonably closely with the Source Catchments model (Waters et al., in press). The limited monitoring data from the Mackay Whitsunday region agree more closely with the Lewis et al. (2011) model, although the discrepancies highlight the high uncertainly we presently have to predict herbicide loads.

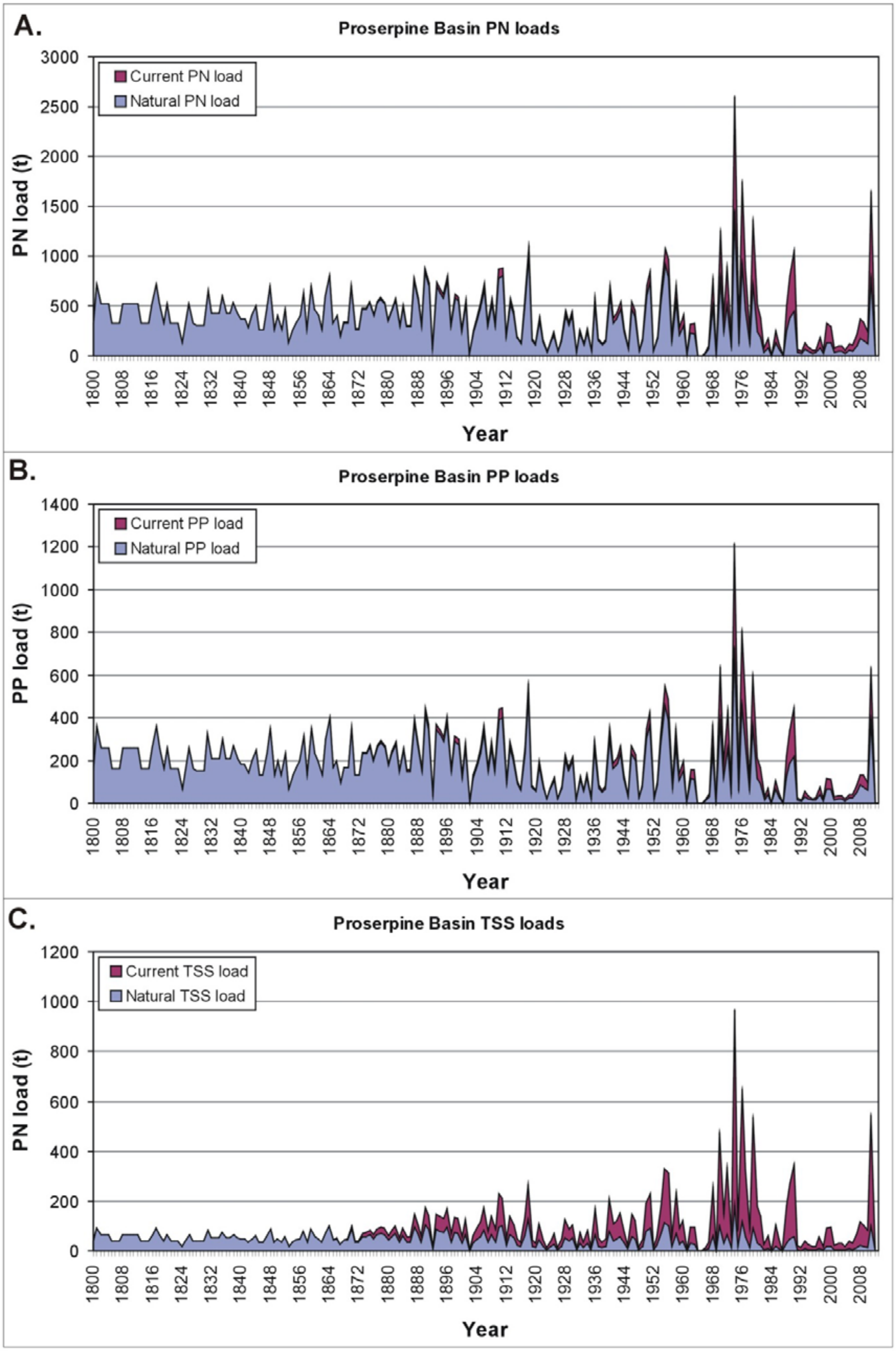

Figure 43. The modelled loads of PN (A) and PP (B) and TSS (C) for the Proserpine Basin.

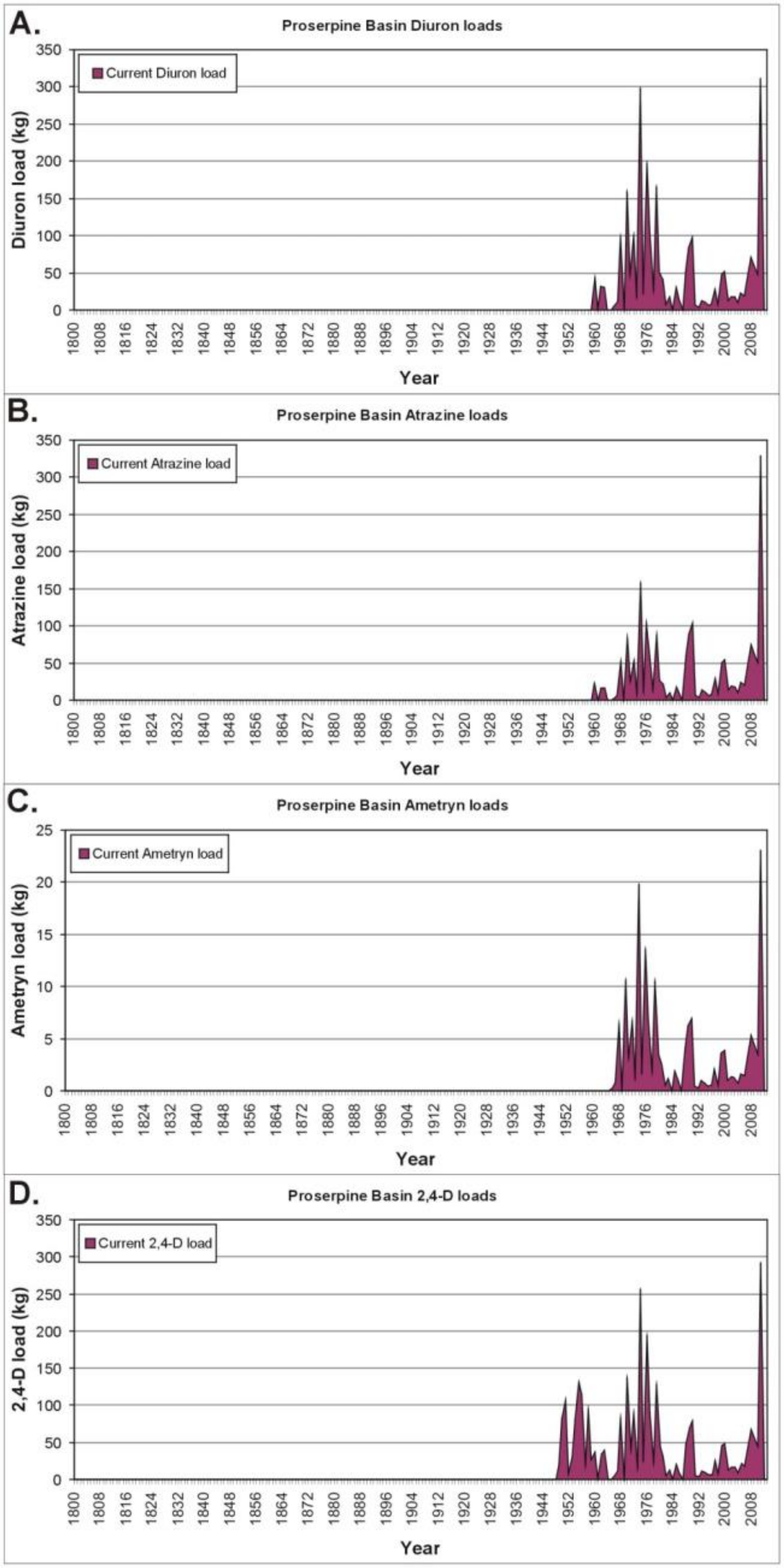

Figure 44. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Proserpine Basin.

O'Connell Basin

We used the validation for the Herbert River at Ingham site to estimate historical DIN loads and the Tully River at Euramo Site for DIP, PN and PP loads from the O'Connell Basin as we believe that these sites best match (that we can perform validations on) the characteristics of this basin. Based on the performance of the model, we consider that the model outputs of DIN, PN, PP and TSS has *medium* confidence and DIP has *low* confidence for the O'Connell Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the O'Connell Basin were 119 tonnes for DIN, 54 tonnes for DIP, 216 tonnes for PN, 108 tonnes for PP and 27 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 294 tonnes (2.5 fold increase), 67 tonnes (1.2 fold increase), 467 tonnes (2.2 fold increase), 142 tonnes (1.3 fold increase) and 128 ktonnes (4.7 fold increase) for DIN, DIP, PN, PP and TSS, respectively (Figs. 45 & 46).

Our predicted DIN, PN, PP and TSS loads for the O'Connell Basin are comparable to the loads predicted by the Source Catchments model (Water et al., in press) but are much lower than those reported in Kroon et al. (2012) (Tables 11, 13-15). DIP loads were also similar to the Source Catchments model but are higher than those reported in Kroon et al. (2012) (Table 12). In this case, we believe that our model and Source Catchment estimates for these parameters are likely to provide a better prediction as the Kroon et al. (2012) is based on older SedNet and ANNEX model outputs, which are known to be overestimated.

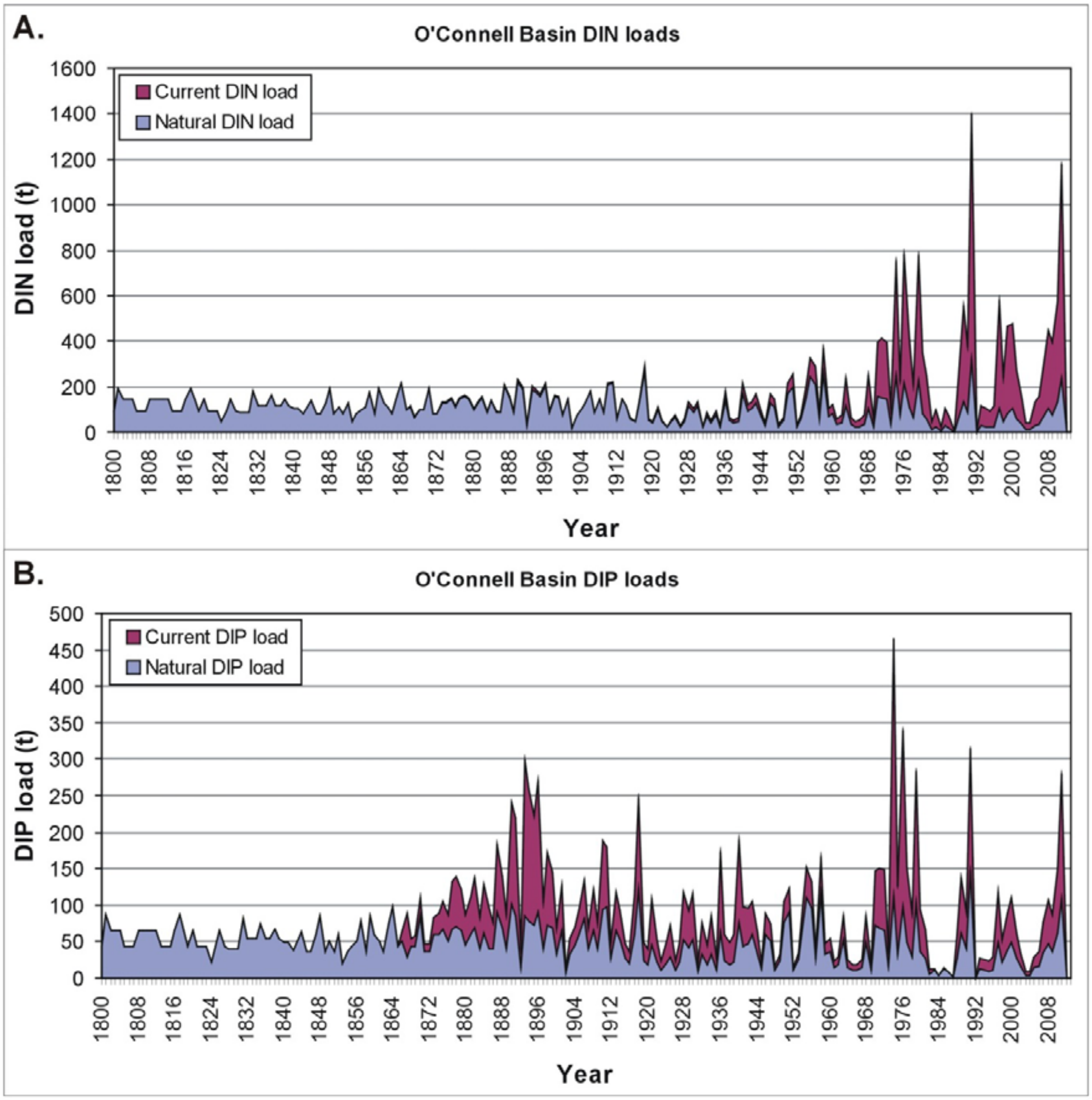

Figure 45. The modelled loads of DIN (A) and DIP (B) for the O'Connell Basin.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the O'Connell Basin and the rates applied in the Herbert Basin from 1949 to 1995 to calculate an annual application of active ingredient (Fig. 47). Our estimates are much lower (order of magnitude) than the model of Lewis et al. (2011: Table 16) but align reasonably closely with the Source Catchments model (Waters et al., in press). The limited monitoring data from the Mackay Whitsunday region agree more closely with the Lewis et al. (2011) model, although the discrepancies highlight the high uncertainly we presently have to predict herbicide loads.

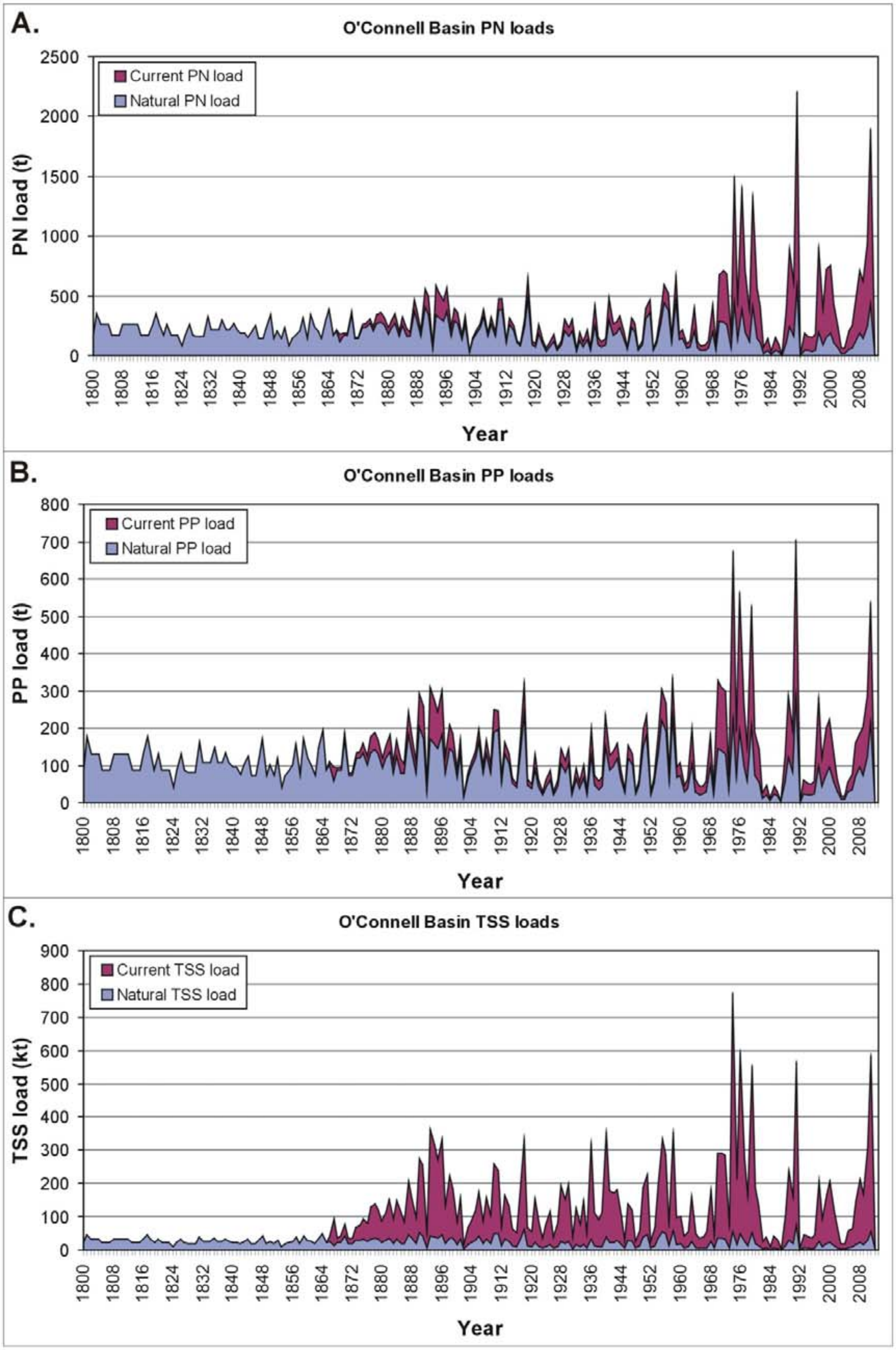

Figure 46. The modelled loads of PN (A) and PP (B) and TSS (C) for the O'Connell Basin.

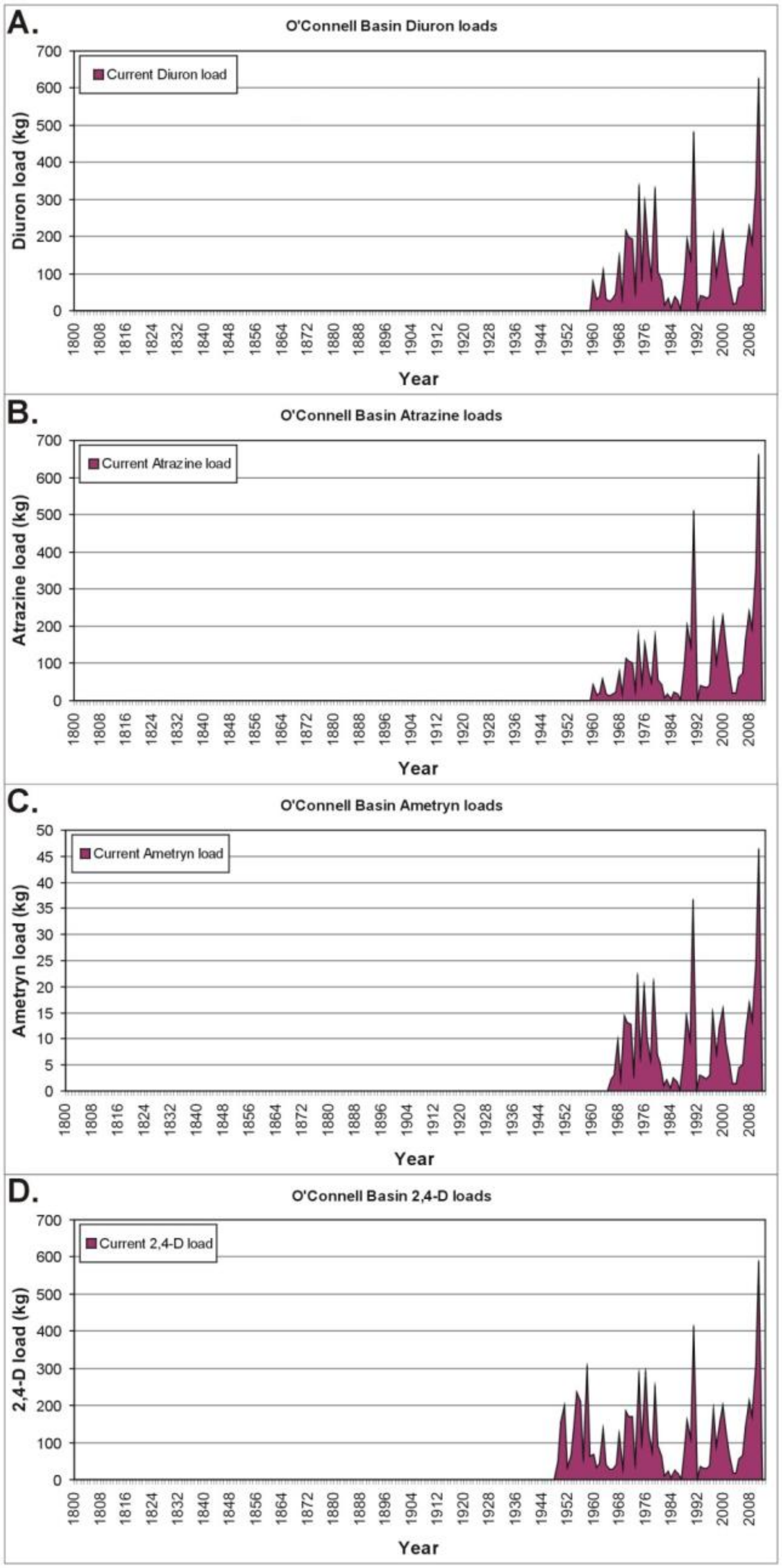

Figure 47. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the O'Connell Basin.

Pioneer Basin

We used the validation for the Herbert River at Ingham site to estimate historical DIN loads and the Tully River at Euramo Site for DIP, PN and PP loads from the Pioneer Basin as we believe that these sites best match (that we can perform validations on) the characteristics of this basin. Based on the performance of the model, we consider that the model outputs of DIN, PN, PP and TSS has *medium* confidence and DIP has *low* confidence for the Pioneer Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Pioneer Basin were 59 tonnes of DIN, 27 tonnes for DIP, 107 tonnes for PN, 53 tonnes for PP and 13 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 366 tonnes (6.2 fold increase), 32 tonnes (1.2 fold increase), 529 tonnes (4.9 fold increase), 125 tonnes (2.4 fold increase) and 132 ktonnes (10.2 fold increase) for DIN, DIP, PN, PP and TSS, respectively (Figs. 48 & 49).

Our predicted DIP loads for the Pioneer Basin are comparable to the loads predicted by the Source Catchments model (Water et al., in press) and those reported in Kroon et al. (2012) (Table 12) while our loads of DIN, PN and PP are higher than the other two models (Tables 11, 13 & 14). In contrast, our our TSS load lies between the predictions by the two other models (Table 15).

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Pioneer Basin and the rates applied in the Herbert Basin from 1949 to 1995 to calculate an annual application of active ingredient (Fig. 50). Our estimates are much lower (order of magnitude) than the model of Lewis et al. (2011: Table 16) but align reasonably closely with the Source Catchments model (Waters et al., in press). The limited monitoring data from the Mackay Whitsunday region agree more closely with the Lewis et al. (2011) model, although the discrepancies highlight the high uncertainly we presently have to predict herbicide loads.

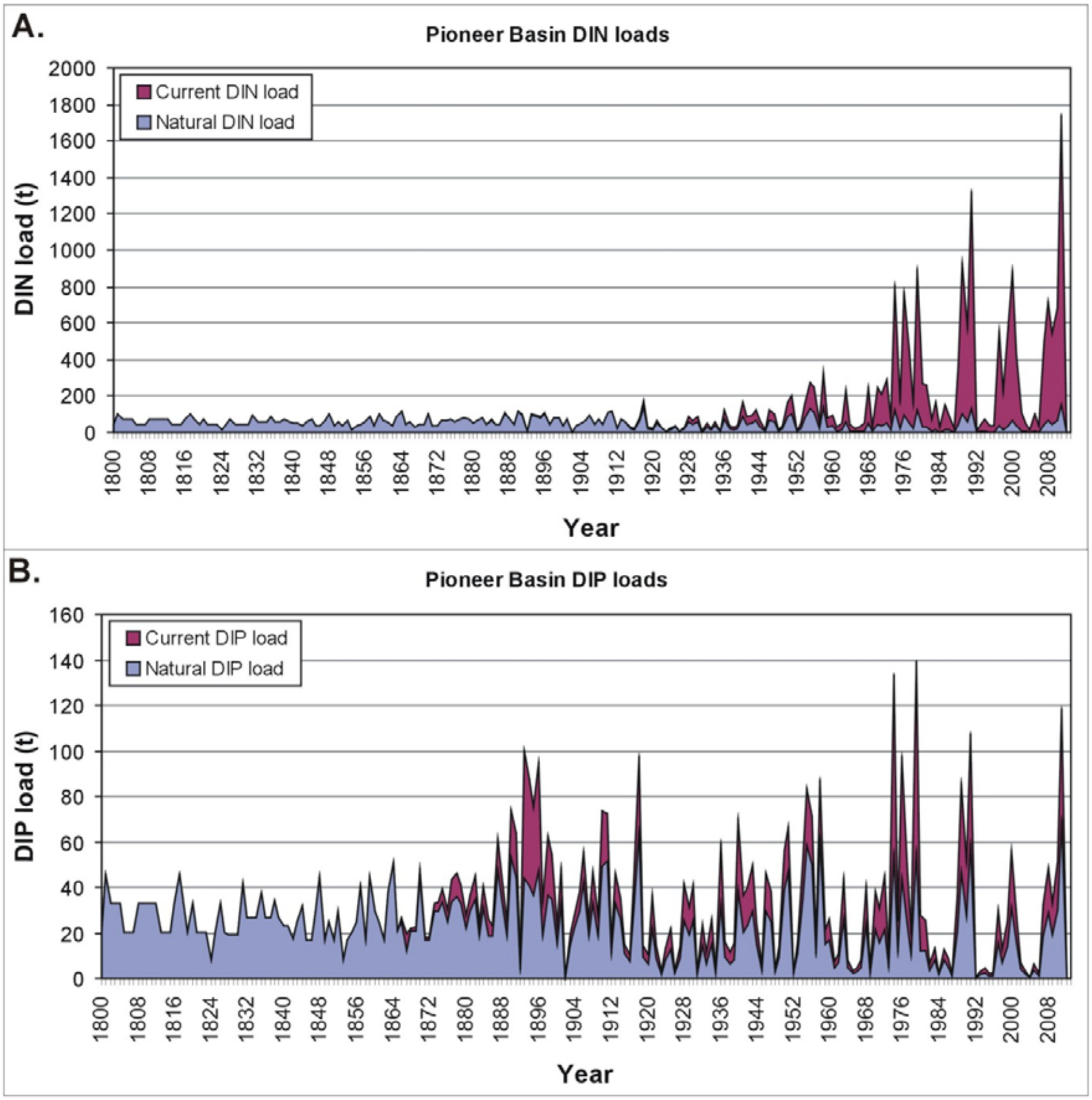

Figure 48. The modelled loads of DIN (A) and DIP (B) for the Pioneer Basin.

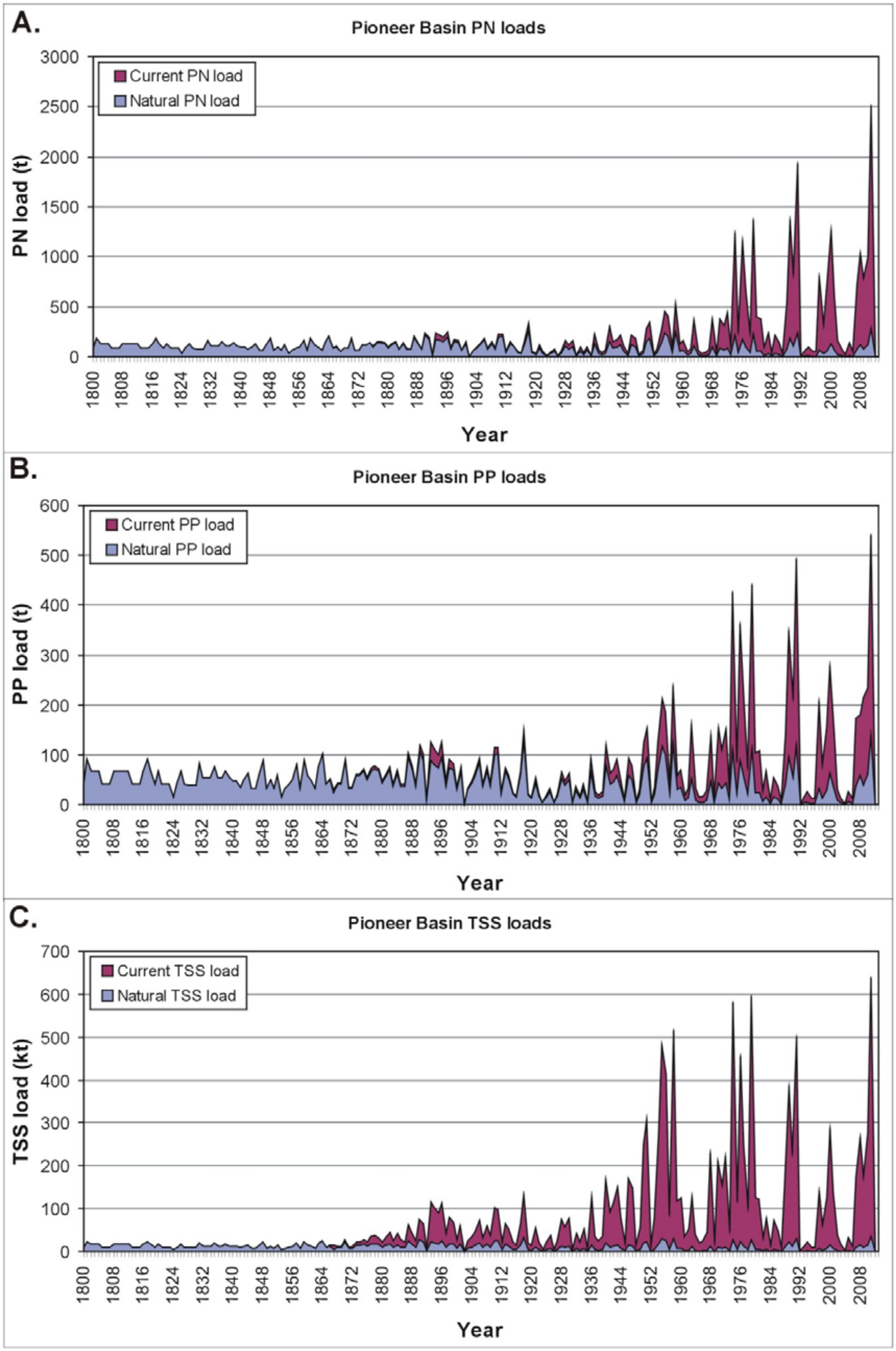

Figure 49. The modelled loads of PN (A) and PP (B) and TSS (C) for the Pioneer Basin.

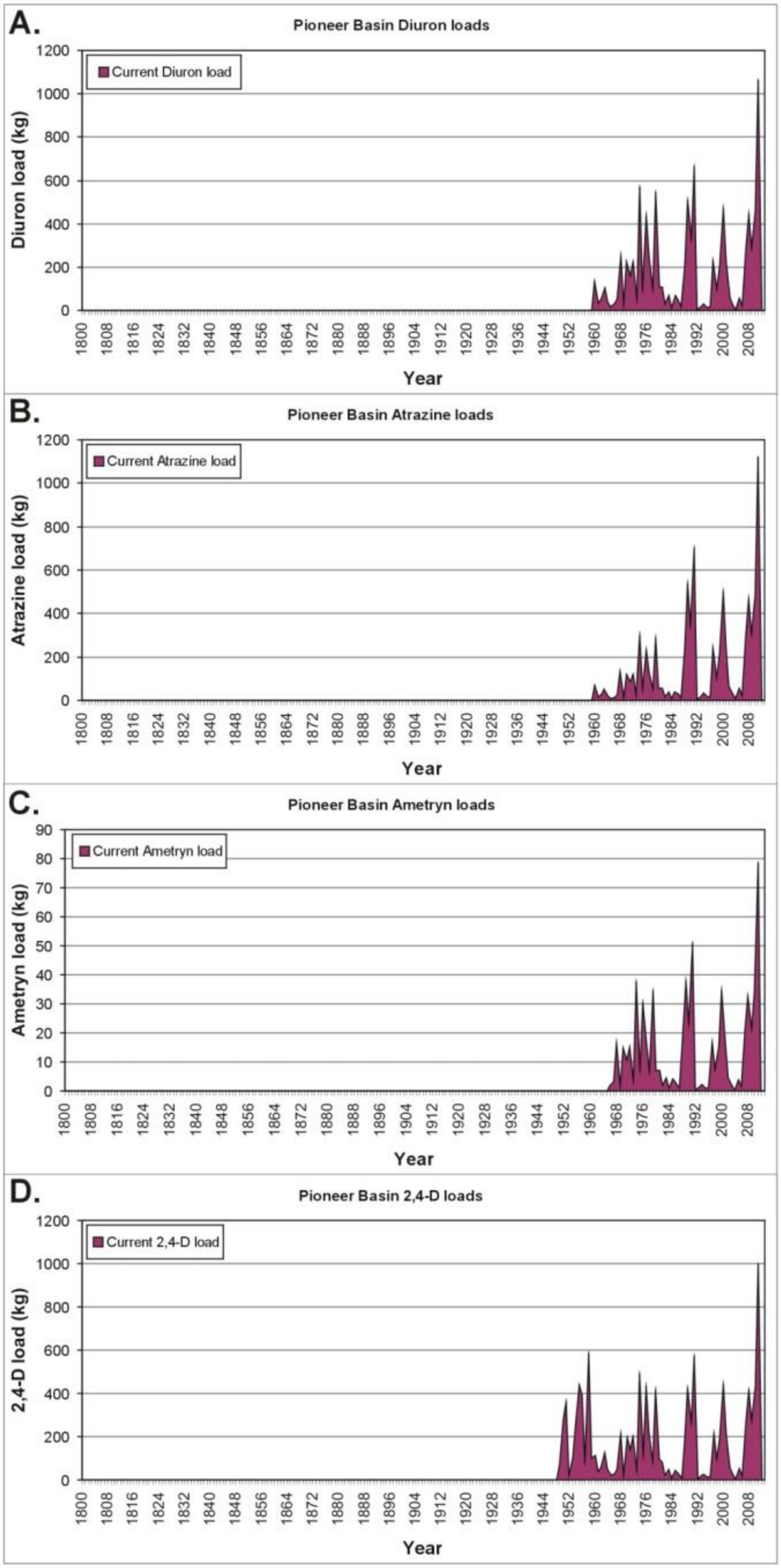

Figure 50. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Pioneer Basin.

Plane Basin

We used the validation for the Herbert River at Ingham site to estimate historical DIN loads and the Tully River at Euramo Site for DIP, PN and PP loads from the Plane Basin as we believe that these sites best match (that we can perform validations on) the characteristics of this basin. Based on the performance of the model, we consider that the model outputs of DIN, PN, PP and TSS has *medium* confidence and DIP has *low* confidence for the Plane Basin.

For the period 1800 to 1829 (30 year period), the 'baseline' mean of annual reconstructed loads for the Plane Basin were 89 tonnes for DIN, 40 tonnes for DIP, 161 tonnes for PN, 81 tonnes for PP and 20 ktonnes for TSS. In comparison, the average annual reconstructed loads for the past 30 years (1982 to 2011) were 534 tonnes (6.0 fold increase), 61 tonnes (1.5 fold increase), 785 tonnes (4.9 fold increase), 199 tonnes (2.5 fold increase) and 186 ktonnes (9.3 fold increase) for DIN, DIP, PN, PP and TSS, respectively (Figs. 51 & 52).

The DIN loads generated in our study were much higher than those predicted in the Source Catchments and Kroon et al. (2012) models (Table 11). Our predicted DIP, PN, PP and TSS loads for the Plane Basin generally fall in between the loads predicted by the Source Catchments (Water et al., in press) and Kroon et al. (2012) models (Tables 12-15). In particular, there is wide variation in the loads of PN and PP for the Plane Basin and in this case, the Kroon et al. (2012) model is based on older SedNet and ANNEX model outputs, which are known to be overestimated. Hence our model and Source Catchments likely represent the upper and lower bounds of the loads, respectively.

Our modelled loads for diuron, atrazine, ametryn and 2,4-D are based on the changing sugar area in the Plane Basin and the rates applied in the Herbert Basin from 1949 to 1995 to calculate an annual application of active ingredient (Fig. 53). Our estimates are much lower (order of magnitude) than the model of Lewis et al. (2011: Table 16) but align reasonably closely with the Source Catchments model (Waters et al., in press). The limited monitoring data from the Mackay Whitsunday region agree more closely with the Lewis et al. (2011) model, although the discrepancies highlight the high uncertainly we presently have to predict herbicide loads.

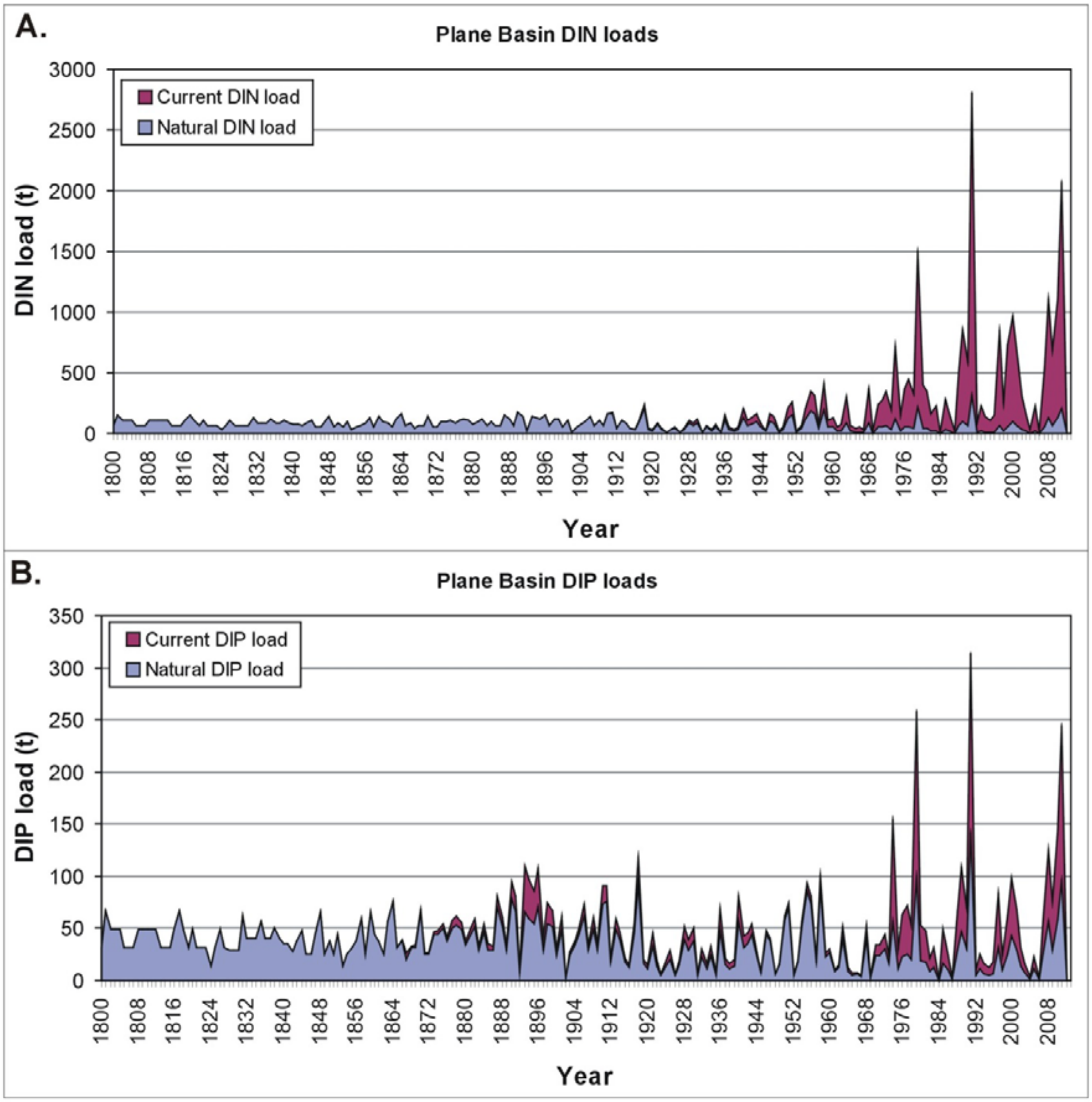

Figure 51. The modelled loads of DIN (A) and DIP (B) for the Plane Basin.

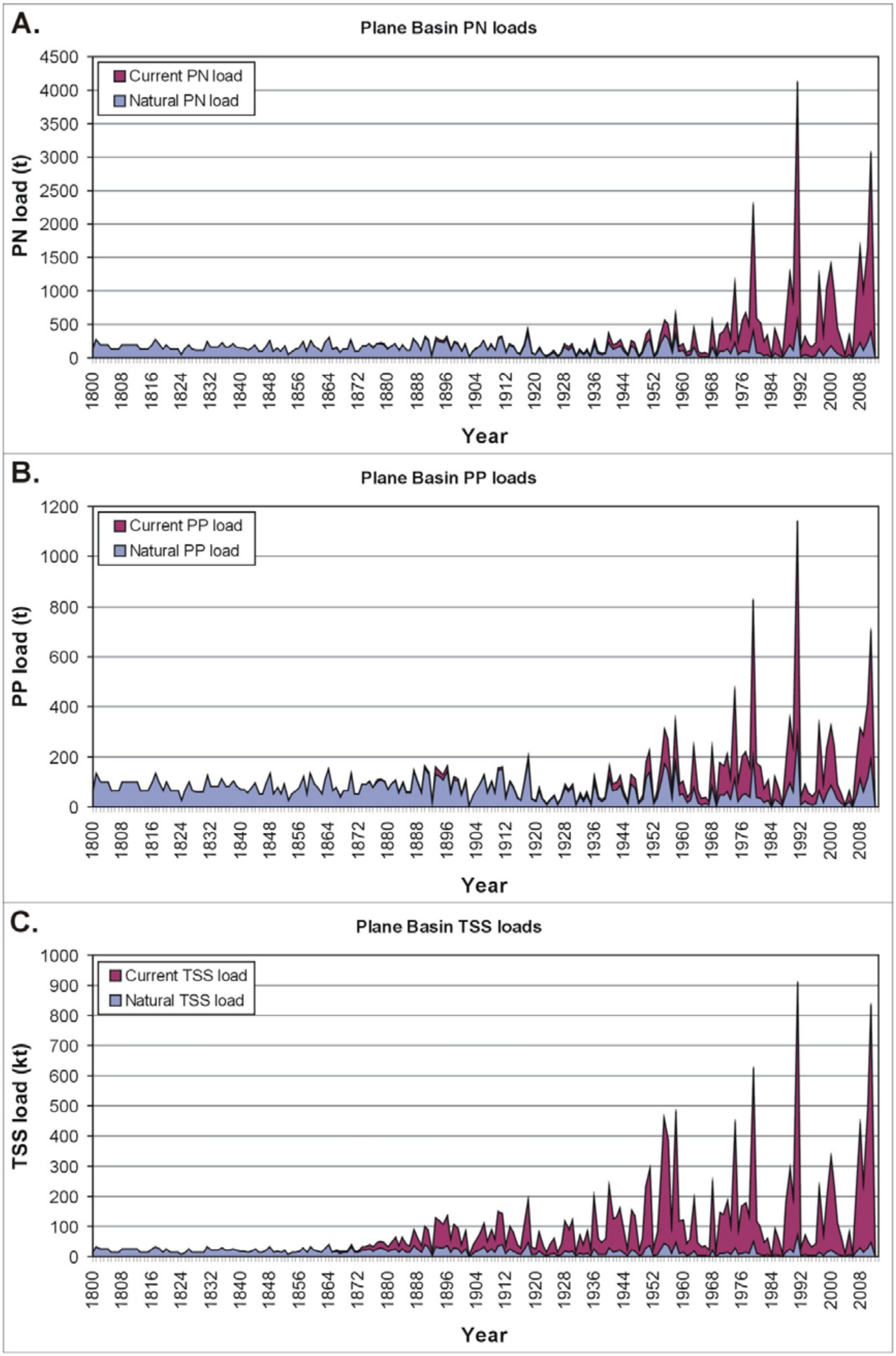

Figure 52. The modelled loads of PN (A) and PP (B) and TSS (C) for the Plane Basin.

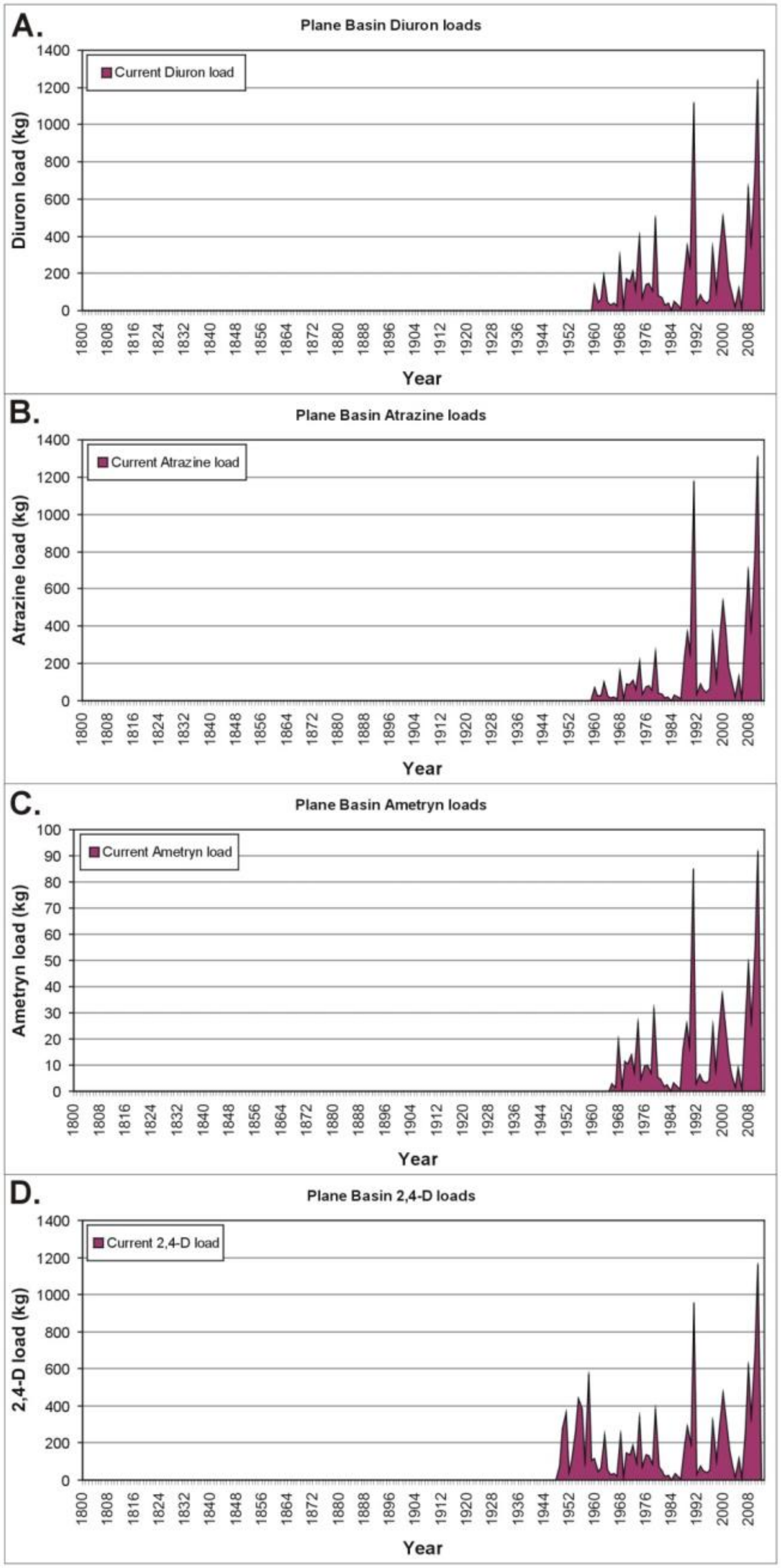

Figure 53. The modelled loads of Diuron (A), Atrazine (B), Ametryn (C) and 2,4-D (D) for the Plane Basin.

6 DISCUSSION

This project compiled, for the first time, a wealth of statistical data from across the Wet Tropics, Burdekin and Mackay Whitsunday NRM regions that included land use change, hydrological, measured load and fertiliser and herbicide application data. We show that where these data are available, loads can be hind cast with medium to high confidence. In that regard, the loads of DIN can be hind casted back through time for most of these basins, which is critical given its influence on COTS outbreaks (e.g. Brodie et al., 2005; Fabricius et al., 2010). Our hind casting for other parameters was more variable in terms of accuracy and depend on the available measured data for validation, although our outputs provide a reasonable estimation on the temporal variability of loads and at the very worst an examination of the relative change in loads from year to year. The summary Tables 17-20 compare the mean loads for the pre-European 30 year period (1800-1829) with the current 30 year period (1982-2011).

The ability to hind cast loads of DIN over time with, in our view, reasonable levels of confidence is not particularly surprising given the additional loadings of nitrogen fertiliser added on the catchment which are considerably above natural loadings. Indeed Mitchell et al. (2009) clearly showed a significant relationship between mean DIN concentration and fertilised land area in the Tully catchment. Interestingly, our analysis suggest that the average amounts of nitrogen fertiliser lost as DIN is variable across the basins of the Wet Tropics which range from 1% of applied nitrogen fertiliser lost in the Barron, 8% in the Herbert, 11% in the Tully and 16-30% in the Johnstone. At this stage we do not fully understand why these variable losses occur, although we postulate it may be due to the slopes within the catchments (and hence increased surface hydrological delivery potential of the catchment). Furthermore, the Tinaroo Dam could also influence the lower rates lost in the Barron Basin. Our results also support the Source Catchments modelling which also found variable losses of nitrogen fertiliser of similar magnitude across these same basins (Waters et al., in press). However, we note this may also be an artefact of an auto-correlation with the validation of the measured load data. Further statistical analysis of these data will be conducted to verify how significant these losses are for each basin based on the goodness of fit.

In contrast, the reconstructed loads for DIP have much lower confidence despite that relatively high r^2 regressions could be obtained between the measured and modelled data in the validations for several of the rivers. A strong relationship exists between the DIP loads and discharge, although the amount of P fertiliser lost as DIP appeared to be highly variable in the validations ranging from 0% to 6%. While there may be a relationship between the P fertiliser applied and DIP loads, there is likely to be local-scale variation in DIP EMCs for natural and grazing lands that we cannot currently account for. For our load reconstructions we modelled a loss of 1.5% P fertiliser as DIP (with the exception of the Barron where we used 4% loss).

Table 17. Comparison of average annual reconstructed 'baseline' and 'current' loads for the 30 year periods 1800-1829 and 1982-2011 for DIN and PN (tonnes).

Region	Basin	DIN (t)					PN (t)				
		Baseline	Current	Fold increase	Confidence	Kroon et al. (2012)	Baseline	Current	Fold increase	Confidence	Kroon et al. (2012)
Wet Tropics	Daintree	89	126	1.4	Medium	450	162	200	1.2	Medium	980
	Mossman	54	139	2.6	Medium	130	99	185	1.9	Medium	290
	Barron	40	35	-1.1	High	50	91	302	3.3	Medium	440
	Russell-Mulgrave	171	715	4.2	Medium	1700	310	853	2.8	Medium	1500
	Johnstone	212	1348	6.4	High	2100	385	1161	3.0	Medium	2200
	Tully-Murray	254	542	2.1	High	1310	463	781	1.7	High	630
	Herbert	188	983	5.2	High	1300	342	1589	4.6	Medium	930
Burdekin	Haughton	45	744	16.5	Medium	340	83	1070	12.9	Medium	1200
	Burdekin	482	1951	4.0	Medium	1800	877	2662	3.0	Medium	5500
Mackay Whitsunday	Proserpine	232	137	-1.7	Medium	440	422	253	-1.7	Medium	1100
	O'Connell	119	294	2.5	Medium	500	216	467	2.2	Medium	1600
	Pioneer	59	366	6.2	Medium	270	107	529	4.9	Medium	250
	Plane	89	534	6.0	Medium	540	161	785	4.9	Medium	2300

Somewhat surprisingly, we were able to obtain high r^2 values between measured and modelled PN and PP loads for some of the validations. While there may indeed be a relationship between the amount of N and P fertiliser applied and PN and PP loads, respectively, it is difficult to have high confidence in our modelling as there will be local variations in the EMCs related to the geology (particularly for PP) and catchment erosion rates. Furthermore, the historic PN and PP load data would have been measured using different methods and hence there is less confidence in these data. In any case, we have most confidence in the Tully validation due to the number of data points, the EMCs we were able to use based on sub-catchment monitoring program, and the high r^2 values that were generated in the validations. Hence we used these validations exclusively to model PN and PP loads for all basins. We note that our outputs for PN and PP loads were more comparable to the Source Catchments model outputs (Waters et al., in press) than the Kroon et al. (2012) model. This result is encouraging since the latter model is based on soil data within the ANNEX model which is known to greatly overestimate particulate nutrient loads in GBR catchments.

Table 18. Comparison of average annual reconstructed 'baseline' and 'current' loads for the 30 year periods 1800-1829 and 1982-2011 for DIP and PP (tonnes).

Region	Basin	DIP (t)					PP (t)				
		Baseline	Current	Fold increase	Confidence	Kroon et al. (2012)	Baseline	Current	Fold increase	Confidence	Kroon et al. (2012)
Wet Tropics	Daintree	6	8	1.3	Low	31	14	30	2.1	Medium	220
	Mossman	4	7	1.8	Low	5	9	40	4.4	Medium	64
	Barron	5	18	3.6	Medium	10	15	113	7.5	Medium	77
	Russell Mulgrave	12	25	2.1	Low	60	27	179	6.6	Medium	540
	Johnstone	29	55	1.9	Low	46	77	1801	23.4	Medium	550
	Tully-Murray	17	37	2.2	Medium	40	40	164	4.1	High	122
	Herbert	13	62	4.8	Low	32	68	377	5.5	Medium	180
Burdekin	Haughton	6	20	3.3	Low	12	17	218	12.8	Medium	260
	Burdekin	66	125	1.9	Low	240	175	1215	6.9	Medium	1500
Mackay Whitsunday	Proserpine	105	66	-1.6	Low	16	211	101	-2.1	Medium	320
	O'Connell	54	67	1.2	Low	22	108	142	1.3	Medium	570
	Pioneer	27	32	1.2	Low	31	53	125	2.4	Medium	74
	Plane	40	61	1.5	Low	15	81	199	2.5	Medium	970

Suspended sediment loads are much harder to predict and require much more complicated modelling (e.g. the Revised Universal Soil Loss Equation within Source Catchments) to achieve outputs with sufficient veracity. We believe that herbicide loads could be modelled using our technique, but the lack of application data currently constrains our ability to have any confidence in our current outputs.

Table 19. Comparison of average annual reconstructed 'baseline' and 'current' loads for the 30 year periods 1800-1829 and 1982-2011 for TSS (kt).

Region	Basin	TSS (kt)				
		Baseline	Current	Fold increase	Confidence	Kroon et al. (2012)
Wet Tropics	Daintree	20	32	1.6	Very Low	180
	Mossman	12	37	3.1	Very Low	41
	Barron	42	93	2.2	Medium	100
	Russell Mulgrave	39	179	4.6	Very Low	210
	Johnstone	221	338	1.5	Low	320
	Tully-Murray	58	122	2.1	Low	133
	Herbert	128	703	5.5	High	380
Burdekin	Haughton	12	117	9.8	Very Low	300
	Burdekin	296	3306	11.2	High	4000
Mackay Whitsunday	Proserpine	53	84	1.6	Medium	310
	O'Connell	27	128	4.7	Medium	630
	Pioneer	13	132	10.2	Medium	52
	Plane	20	186	9.3	Medium	550

Table 20. Comparison of average annual reconstructed ‘baseline’ and ‘current‘ loads for the 30 year periods 1800-1829 and 1982-2011 for the herbicides diuron, atrazine and ametryn (kg).

Region	Basin	Diuron (kg)			Atrazine (kg)			Ametryn (kg)		
		Baseline	Current	Confidence	Baseline	Current	Confidence	Baseline	Current	Confidence
Wet Tropics	Daintree	0	20	Low	0	21	Low	0	1	Low
	Mossman	0	44	Low	0	46	Low	0	3	Low
	Barron	0	13	Low	0	14	Low	0	1	Low
	Russell Mulgrave	0	236	Low	0	248	Low	0	17	Low
	Johnstone	0	216	Low	0	226	Low	0	16	Low
	Tully-Murray	0	116	Low	0	122	Low	0	9	Low
	Herbert	0	443	Low	0	467	Low	0	33	Low
Burdekin	Haughton	0	293	Low	0	309	Low	0	22	Low
	Burdekin	0	109	Low	0	115	Low	0	8	Low
Mackay Whitsunday	Proserpine	0	30	Low	0	32	Low	0	2	Low
	O'Connell	0	115	Low	0	122	Low	0	9	Low
	Pioneer	0	183	Low	0	194	Low	0	14	Low
	Plane	0	239	Low	0	253	Low	0	18	Low

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8 APPENDIX

Appendix 1. Total nitrogen fertiliser applied (t) in the Wet Tropics Region (from Pulsford, 1996)

Year	Daintree	Mossman	Barron	Russell Mulgrave	Johnstone	Tully-Murray	Herbert
1910							10
1915				50			50
1920		10		100	10		100
1925		20		250	50		200
1930	10	30	10	430	200	50	350
1935	20	60	20	450	600	100	400
1940	30	90	100	675	1100	200	490
1945	40	120	80	1000	900	230	500
1950	55	260	100	1155	1130	400	1100
1955	75	350	140	1590	1550	545	1500
1960	95	450	180	2040	1990	695	1930
1961	110	525	210	2380	2325	810	2255
1962	115	550	222	2480	2430	845	2355
1963	155	740	260	3010	3230	1085	2950
1964	155	775	490	3150	3370	1170	3270
1965	180	860	605	3525	3790	1158	3580
1966	200	870	620	3550	3830	1169	3590
1967	210	875	645	3680	3640	1350	3600
1968	200	820	650	3600	3760	1340	3630
1969	205	825	650	3600	3720	1330	3670
1970	210	840	700	3910	4020	1100	4200
1971	225	860	750	4120	4600	1220	4225
1972	240	885	800	3860	4980	1440	4905
1973	220	810	760	3850	4840	1390	4870
1974	230	840	800	3965	5225	1530	5090
1975	240	850	900	4020	5250	1500	5240
1976	255	900	1050	4375	5800	1660	5800
1977	305	1015	1200	4940	6540	1870	6555
1978	245	850	1160	4020	5220	1520	5085
1979	300	980	1390	4810	6230	1820	6100
1980	365	1195	1690	5850	7580	2210	7370
1981	365	1160	1540	5700	7230	2130	7120
1982	335	1130	1485	5550	7050	2040	6745
1983	337	1140	1480	5665	7000	2040	6800
1984	338	1140	1450	5665	7015	2060	6762
1985	400	1050	1445	5660	7005	2055	6800
1986	400	1050	1440	5050	7000	1420	7125
1987	420	1055	1610	4695	7260	2790	7570
1988	450	1130	1650	4660	6970	2650	9190
1989	440	945	1640	4660	6950	3680	9685
1990	340	820	1680	4720	7300	3950	9800

Appendix 1. Total nitrogen fertiliser applied (t) in the Burdekin and Mackay Whitsunday Regions (from Pulsford, 1996)

Year	Haughton	Burdekin	Proserpine	O'Connell	Pioneer	Plane
1910						10
1915	10			50	60	90
1920	50			120	180	195
1925	75		50	170	240	250
1930	150	5	100	240	365	390
1935	160	20	150	350	450	400
1940	200	50	200	400	615	675
1945	220	40	260	400	600	650
1950	600	210	310	420	655	720
1955	650	220	360	510	795	930
1960	785	270	680	720	1075	1305
1961	1020	350	760	930	1390	1685
1962	1105	380	820	1045	1560	1890
1963	1715	590	1045	1415	2015	2495
1964	1940	665	1205	1330	2120	2490
1965	2045	705	1245	1535	2260	2785
1966	2360	810	1005	1595	2380	2985
1967	2575	885	920	1665	2450	3015
1968	2725	940	1170	1785	2475	3070
1969	3240	1115	1170	2085	2990	3735
1970	2890	1000	1100	1990	2805	3555
1971	4150	1425	1200	2290	3235	4100
1972	4535	1560	1400	2325	3290	4180
1973	4865	1670	1550	2535	3580	4545
1974	5260	1815	1575	2575	3640	4615
1975	5980	2075	1640	2680	3790	4805
1976	6815	2365	1810	3405	4435	6160
1977	7115	2475	1850	3670	4780	6835
1978	5450	1905	1750	3085	3925	6210
1979	5870	2060	1770	3115	4025	5625
1980	8860	3115	2650	4545	5860	8190
1981	8015	2840	2390	4245	5480	7665
1982	8215	2915	2500	4190	5360	7565
1983	8940	3180	2640	4285	5325	7510
1984	7400	2640	2120	4015	4985	6930
1985	7050	2520	1780	4010	4985	6905
1986	6760	2425	2020	3670	4555	6315
1987	6875	2475	2015	3745	4670	6570
1988	7115	2565	2060	3750	4695	6555
1989	7880	2840	2500	4125	5160	7215
1990	8805	3180	3040	4390	5490	7685

Appendix 2. Total phosphorus fertiliser applied (t) in the Wet Tropics Region (from Pulsford, 1996)

Year	Daintree	Mossman	Barron	Russell Mulgrave	Johnstone	Tully-Murray	Herbert
1920				10	10		10
1925		10		30	30	10	20
1930		15		75	70	25	44
1935		30	10	120	108	40	78
1940	5	45	30	185	175	60	136
1945	10	50	30	220	225	85	150
1950	15	65	25	300	290	105	200
1955	15	65	25	315	310	105	265
1960	17	82	34	375	360	127	350
1961	22	105	40	480	470	175	446
1962	20	100	38	460	450	166	424
1963	30	160	60	740	735	265	680
1964	30	167	160	740	730	258	705
1965	35	175	180	780	800	286	710
1966	35	175	190	780	770	290	700
1967	40	180	230	800	800	306	720
1968	45	190	240	810	780	390	720
1969	60	215	300	840	1048	460	720
1970	70	236	330	870	1296	565	720
1971	72	240	403	880	1300	790	565
1972	80	250	436	880	1400	910	646
1973	80	245	445	880	1300	790	600
1974	85	250	490	870	1400	780	525
1975	80	260	485	865	1300	610	600
1976	85	280	460	900	1450	625	700
1977	85	300	465	920	1400	640	750
1978	80	280	455	900	1300	625	700
1979	90	300	563	950	1650	650	720
1980	100	350	600	1220	1950	1780	1000
1981	120	245	660	1215	1890	675	950
1982	100	200	660	865	1700	635	970
1983	110	225	670	865	1650	670	950
1984	120	220	630	820	1600	660	1020
1985	110	220	580	770	1550	690	980
1986	100	220	540	700	1500	670	1000
1987	115	220	510	625	1450	727	1070
1988	110	210	546	600	1400	730	1100
1989	100	220	580	600	1600	735	1200
1990	100	240	625	605	1700	750	1330

Appendix 2. Total phosphorus fertiliser applied (t) in the Burdekin and Mackay Whitsunday Regions (from Pulsford, 1996)

Year	Haughton	Burdekin	Proserpine	O'Connell	Pioneer	Plane
1920					5	10
1925	10				10	20
1930	30	10	10	10	17	30
1935	55	10	20	20	35	60
1940	100	20	35	50	70	120
1945	120	35	50	70	100	160
1950	160	50	70	100	125	215
1955	175	53	107	148	180	315
1960	200	56	130	180	220	370
1961	245	72	145	208	253	426
1962	284	83	170	250	305	511
1963	307	87	240	366	445	749
1964	348	100	300	459	557	936
1965	387	111	285	435	527	888
1966	317	86	258	397	482	811
1967	370	105	235	365	444	746
1968	350	101	220	343	417	700
1969	304	86	267	410	496	837
1970	339	92	290	484	576	953
1971	236	65	196	449	533	882
1972	256	72	308	447	530	878
1973	333	80	290	446	530	877
1974	271	73	282	492	584	965
1975	254	73	290	512	609	1007
1976	266	73	330	546	648	1071
1977	303	83	320	524	622	1028
1978	259	76	229	477	566	936
1979	341	101	240	500	593	982
1980	484	147	360	576	684	1130
1981	532	164	377	609	732	1125
1982	679	217	350	578	695	1046
1983	485	157	360	593	713	1094
1984	450	146	267	524	632	965
1985	432	136	205	443	533	819
1986	404	136	270	428	518	789
1987	342	143	307	433	524	798
1988	434	181	300	458	550	846
1989	529	221	330	494	594	912
1990	613	256	459	539	648	995

Appendix 3. Rates of nitrogen and phosphorus (kg/Ha) in the sugar industry 1996 to 2011 (Incitec Pivot 2011)

Year	N rate Wet Tropics	P rate Wet Tropics	N rate Herbert	P rate Herbert	N rate Burdekin	P rate Burdekin	N rate Mackay Whitsunday	P rate Mackay Whitsunday
1996	169	28	213	28	272	26	225	28
1997	151	25	198	26	246	23	232	30
1998	138	22	209	25	247	23	214	26
1999	144	19	204	21	269	22	233	24
2000	151	23	183	21	233	21	176	18
2001	149	24	201	30	229	19	175	20
2002	147	20	205	26	234	17	166	14
2003	137	21	191	24	219	19	171	15
2004	145	20	155	16	223	21	174	14
2005	142	21	153	16	213	22	172	13
2006	143	24	149	18	218	18	176	19
2007	145	20	151	17	212	16	165	19
2008	127	11	138	10	198	10	153	11
2009	132	18	153	24	231	16	177	24
2010	120	16	132	20	227	19	138	15
2011	143	18	151	18	215	15	153	15

Appendix 4. Average rates of nitrogen and phosphorus (kg/Ha) in the banana industry 1995 to 2011 (Daniells (1995), DPI&F (2007) and J. Armour (personal communication, 2013))

Year	N rate Bananas	P rate Wet Tropics
1995	520	70
2007	298	70

Appendix 5. Total amount of herbicide used in the Hebert Region (Johnson and Ebert 2000)

Year	2,4-D (kg ai)	Diuron (kg ai)	Atrazine (kg ai)	Ametryn (kg ai)
1949	13746			
1950	13405			
1951	14146			
1952	18642			
1953	17934			
1954	14305			
1955	14379			
1956	14822			
1957	14478			
1958	17606			
1959	13765			
1960	14307	11057	17513	
1961	16804	10586	16768	
1962	17293	10532	16683	
1963	19386	10279	16282	
1964	19900	10234	16211	
1965	20129	12533	19852	
1966	19552	15279	24201	1519
1967	21197	15316	24261	1546
1968	20094	15888	25167	1576
1969	21316	15758	24960	1584
1970	20652	16024	25382	1595
1971	20599	15956	25274	1589
1972	21199	15901	25188	1593
1973	20338	16173	25617	1602
1974	20714	16099	25501	1602
1975	23931	14166	22439	1602
1976	25898	17564	27821	1813
1977	24889	19073	30212	1903
1978	24054	19459	30823	1921
1979	23210	20196	31991	1924
1980	25344	19231	30461	1922
1981	23308	20365	32258	1982
1982	21467	21791	34516	2069
1983	22008	22046	34921	2097
1984	21589	22142	35073	2098
1985	21856	22105	38014	2100
1986	21463	22177	42128	2099
1987	22965	21883	49326	2099
1988	25060	18651	64087	2165
1989	24654	19722	62479	2209
1990	25866	21413	67837	2269
1991	26832	20892	66185	2384
1992	29423	21347	67627	2497
1993	29532	22396	70951	2584
1994	32310	25051	79362	2703
1995	34841	24773	78481	2750