Herbert Water Quality Monitoring Program (HWQMP) Sugarcane specific monitoring 2014-2016 (Project NEMO) Final Report 2015-2016 to EHP.

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Sugarcane specific monitoring 2014-2016 (Project NEMO)

Final Report 2015-2016

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Executive summary

The **Herbert Water Quality Monitoring Program** (HWQMP) commenced in July 2011 and operated for 3 years to monitor water quality for the whole Herbert Catchment area. This project was initiated and funded by Herbert Cane Productivity Services Ltd (HCPSL) with support from Terrain NRM, the Department of Science, Industry, Technology and Innovation (DSITI), TropWATER (James Cook University), and two Local Governments (Hinchinbrook Shire Council (HSC) and Tablelands Regional Council (TRC). The HWQMP (2011 -2014) identified that the sugarcane industry is a major contributor to reef pollutants in some sub-catchments in the Herbert basin; and as a result monitoring was extended in known hotspots to gauge the effectiveness of targeted extension programs delivered by industry. The Department of Environment and Heritage Protection (DEHP) has invested in the water quality monitoring component of the extended project which is referred to as RP122C - the "HWQMP – Extension" from 2014 - 2016.

This project monitored sediment, nutrient and pesticide concentrations in surface waters collected from various sub-catchments, including cane dominated, rainforest reference and mixed land use sites on major tributaries to monitor any changes from that measured previously under the HWQMP. Insights were also gained into the temporal and seasonal effects of land use on water quality (WQ), which contribute to the end of catchment loads.

The initial HWQMP program was highly successful by providing industry with meaningful data at a scale which enabled them to develop appropriate extension and farm management strategies to address issues as they arose (Di Bella *et.al*. 2015). With funding secured until June 2018, Projects NEMO and the HWQMP-extension initiatives will build industry knowledge on extension strategies and generate data on practice change adoption and WQ outcomes in known pollutant hotspots within the Herbert sugarcane growing district. This information is likely to be highly applicable to other rain fed sugarcane growing districts of the GBR.

In 2014 -16, surface water event and ambient samples were collected from 5 sites including 2 dedicated sugarcane sub-catchments, which are the focus of a targeted extension program (Project NEMO) looking at Nitrogen and Pesticides loss pathways within the sugar growing district.

These results indicate that although there has been a sizeable shift in the way that sugarcane farmers have applied their fertilizer in the past 24 months as a result of a concerted extension effort by the project managers, seasonal drivers such as rainfall still have the greatest effect on loss pathways and ongoing extension efforts may need to focus on further refinement of application rates in accordance with best practice (6 Easy Steps) and the WQ risk framework.

In relation to chemical use, there has been some improvements in the use of some chemical constituents, but the off label use of other chemicals has also been identified and subsequently addressed by the HCPSL, demonstrating the value of consistent WQ monitoring at high risk sites.

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1.0 Introduction

1.1 Water quality in the Great Barrier Reef catchment area

The impact of terrestrially derived pollution on coastal and marine ecosystems is a universal issue and the focus of land management activities worldwide (Doney, 2010). The effect of terrestrial pollution runoff into the Great Barrier Reef (GBR) has been the subject of much research and review (Devlin and Brodie, 2005; Mitchell *et al.*, 2005; Bainbridge *et al.*, 2009; Lewis *et al.*, 2009; Brodie *et al.*, 2012a; Brodie *et al.*, 2012b; Kennedy *et al.*, 2012; Kroon *et al.*, 2012; Lewis *et al.*, 2012; Waterhouse *et al.*, 2012). Despite the protected status of the Great Barrier Reef (GBR), there has been a recognised decrease in the overall health of the coral reefs (Bellwood *et al.*, 2004; Bruno and Selig, 2007; Osborne *et al.*, 2011; Sweatman *et al.*, 2011; Sweatman and Syms, 2011) as well as localised impacts on seagrass meadows (McKenzie et al., 2010) and mangrove forests (Schaffelke et al., 2005) throughout the GBR.

The Reef Water Quality Protection Plan (Reef Plan) was established in 2003 with the long-term goal that “the quality of water entering the reef from broad scale land use will have no detrimental impact on the health and resilience of the GBR”. Reef Plan has since been audited and reviewed a number of times to evaluate progress and to revise the current state of knowledge regarding the health of the GBR ecosystem and degradation due to terrestrial pollution runoff; in the form of scientific consensus statements prepared for the Queensland Government in 2008 (Brodie *et al.*, 2008a; Brodie *et al.*, 2008b) and 2013 (Brodie *et al.*, 2013). Conclusions from the 2008 Consensus Statement included:

1. River water discharging into the GBR is of poor quality in many locations.
2. Concentrations of land derived contaminants (suspended sediments, nutrients and pesticides) present in the GBR are likely to cause environmental harm.
3. The causal relationship between water quality and coastal and marine ecosystem health is being supported by an increasing body of evidence.

These conclusions were supported in the 2013 Consensus Statement that went on to clarify:

1. A major cause of the current poor state of many key marine ecosystems within the GBR is associated severe weather events and terrestrial runoff from adjacent catchments that are continuing to cause a decline in marine water quality.
2. The greatest risks to the GBR are linked to A) nitrogen discharge and associated crown-of-thorns starfish outbreaks; B) fine sediment discharge effecting the light availability for inshore seagrass ecosystems and coral reefs; and C) pesticide movement within freshwater and some inshore and coastal habitats.

Both the 2008 and 2013 Consensus Statements concluded that anthropogenic activities, in particular diffuse source pollution from agricultural land use is the main source of excess sediments, nutrients and pesticides transported to the GBR. Furthermore, as part of Reef Plan there is a requirement to reduce the quantity of terrestrial pollutants to the GBR lagoon. This has led to the development of a number of management programs (such as the Reef Rescue Reef Water Quality Grants, the Paddock to Reef Integrated Monitoring, Modelling and Reporting program (P2R), Reef Rescue R&D and now Reef Trust) that are aimed at both quantifying the volume of pollutants exported from the GBR catchments and at introducing improved land management practices that will lead to a reduction in export volumes (QLD DPC, 2015). These programs have focused on assessing the impact of land use on both fresh and marine water quality (WQ) (Devlin and Brodie, 2005; Mitchell *et al.*, 2005; Bainbridge *et* *al.*, 2009; Lewis *et al.*, 2009; Brodie *et al.*, 2012a; Brodie *et al.*, 2012b; Kennedy *et al.*, 2012; Lewis *et al.*, 2012; Waterhouse *et al.*, 2012), annual load assessment (Kroon *et al.*, 2012; Smith *et al.*, 2012; Turner *et al.*, 2012; Turner. R *et al.*, 2013) and engagement with industry to encourage the voluntary adoption of best management practices (see for example the sugarcane best practice presented by Schroeder *et al.* (2008)). This work was informed by research undertaken across all the GBR catchments however prior to the implementation of Reef Plan, most monitoring programs were undertaken by government or research organisations in regions where there is a known or conceivable threat to ecosystem health as part of ecosystem assessment and compliance monitoring, or during opportunistic investigations. This has led to incomplete record on the overall ecosystem health with regard to WQ in some catchments and across the whole GBR. More detailed research into WQ and the effect of land use practices has been undertaken for the Pioneer, Burdekin, Johnstone and Tully/Murray basins (Hunter, 1993; Brodie *et al.*, 2004; Mitchell *et al.*, 2005; Bainbridge *et al.*, 2007a; Bainbridge *et al.*, 2007b; Bainbridge *et al.*, 2007c; Faithful *et al.*, 2007; Rohde *et al.*, 2008; Bainbridge *et al.*, 2009; Bainbridge *et al.*, 2012) compared to the limited extent within the Barron, Daintree and Russell Mulgrave, (Davies and Eyre, 2005; Lewis and Brodie, 2006; Mitchell *et al.*, 2006). Previous studies into WQ within the Herbert catchment have been undertaken (Bramley and Muller, 1999; Bramley and Roth, 2002b; Bartley *et al.*, 2003) however at the time of the inception of this monitoring program no detailed long term studies into the effects of land use across the greater Herbert basin have been undertaken.

1.2 Initiation of the Herbert Water Quality Monitoring Program (HWQMP)

The HWQMP was initiated by stakeholders in the Herbert River Catchment who were concerned with the lack of local data available to validate the proposed Paddock to Reef (P2R) Monitoring and Modelling Program. The Queensland Government's original intention was to use more recent and comprehensive monitoring data generated from other catchments (Tully) in the Wet Tropics to validate catchment model scenarios for the Herbert Catchment (Faithful *et al.*, 2007; Bainbridge *et al.*, 2009). Stakeholders felt that new local (Herbert specific) data that captured recent changes/improvements in management practices should be applied in the quantification of loads discharging from the Herbert Catchment. This new data, in combination with the data collected in previous monitoring programs within the Herbert catchment (Bramley and Muller, 1999; Johnson and Ebert, 2000; Bramley and Roth, 2002a; Bartley *et al.*, 2003) would then be used in the validation of load estimations being calculated as part of the assessment of catchment pollutant contributions to the Great Barrier Reef (GBR). This program was established with an aim to provide additional local water quality (WQ) data to ease stakeholder concerns regarding the use of alternative data to estimate loads on a catchment scale for the validation of models. In addition, the information collected as part of this monitoring program will provide insight into relative concentrations of reef pollutants on a sub-catchment and paddock scale for use by extension staff and catchment managers to improve sustainable land management practices which will lead to improved WQ to the GBR. This program also functioned to help with addressing knowledge gaps on water quality issues in the region identified in the Herbert Healthy Waters Management Plan (draft) such as land use specific contributions and pollution hot spots within the catchment. The HWQMP provided the necessary catalyst for managers and industry to engage and assist landholders in the Herbert in future decision making by identifying specific issues that contribute to WQ degradation and provide tailored advice to improved land management practices (BMPs) which will deliver the greatest gains in water quality flowing to the Great Barrier Reef Lagoon.

1.3 The Herbert River Catchment

The Herbert River Catchment is situated at the southern end of the Wet Tropics Region of Far North Queensland and covers approximately 10,000 square kilometres. Unlike many other coastal catchments in the wet tropics, the Herbert River has a significant inland component dominated by areas of relatively low rainfall (< 1000mm per annum). The Upper Herbert River Catchment covers a large geographic area (~6000km^2) and consists of 3 major tributaries; the Wild River; The Millstream and Rudd Creek (see: Figure 1) which culminate in the Herbert River above Cashmere Crossing. Results from the initial HWQMP suggest that the Upper Herbert Catchment is not a significant contributor to reef related contaminants, but is continued to be monitored at Nash's Crossing, which provides not only a measure of upper catchment contributions, but also provides a benchmark for the sugar industry in the lower catchment.

The Lower Catchment of the Herbert River alluvial floodplain is dominated by sugar cane farms (approximately 63000 Ha) and National Park; with some forestry industries and the major township of Ingham. In order to provide greater confidence and insight into the relative contributions from cane and other land use to the end of catchment loads being measured by DSITI under the Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP: Turner *et al.* (2012)); DNRM, DEEDI, Terrain NRM and industry groups have undertaken a number of complementary projects to collect paddock scale data within the Herbert Catchment, which can be found in ***O'Brien et al, 2014***.

The Herbert River discharges into an extensive estuarine system contained by the Hinchinbrook Channel (part of the GBRWHA) before discharging into the GBR lagoon through two estuarine mouths; the northern mouth discharging into coastal waters at Cardwell and the southern mouth discharging at Lucinda. As such the HWQMP has also provided a basis to better inform the offshore monitoring and modelling being coordinated by GBRMPA/JCU. Through partnership building and good communications, JCU has agreed to continue their offshore monitoring effort adjacent to the Herbert River outfalls within the Hinchinbrook channel in response to the integrated nature, obvious linkages and additional value this program provides. The HWQMP offers a rare and comprehensive Range to Reef sampling scenario in the Wet Tropics region on which both source catchments and offshore modelling can be manipulated and other contributing factors to WQ on the GBR lagoon can be better assessed.

2.0 Program Rationale

2.1 Paddock to Reef (P2R) Objective

The **Herbert Water Quality Monitoring Program** (HWQMP) aimed to:

- Identify reef pollutant sources from various sub-catchments and land use practices which contribute to the Herbert River, End of Catchment Loads
- Provide estimates of annual and daily loads for the Paddock to Reef (P2R) modellers to help validate Source Catchments Model.
- Provide event mean concentrations (EMC) data on specific land uses within the Herbert Catchment to validate source catchments modelling.
- Inform and guide future extension and research activities in the Herbert Catchment to meet Water Quality (WQ) objectives under Reef Plan 2013 and the Reef 2050 Long Term Sustainability Plan (LTSP).

2.2 Extension and Education Objectives

The **Herbert Water Quality Monitoring Program** (HWQMP) aimed to:

- Identify reef pollutant sources for various sub-catchments and land use practices which contribute to the Herbert River, End of Catchment Loads
- Identify remedial actions that will reduce the effects of degraded water quality and the subsequent impact on Great Barrier Reef (GBR) Lagoon.
- Provide specific local data for the Herbert Catchment to be used by modellers in the Paddock to Reef program.
- Inform and guide investment in future extension and research activities in the Herbert Catchment to meet Water Quality (WQ) objectives under Reef Plan 2013 and Reef LTSP.

3.0 Monitoring program outline

3.1 Sampling locations

The HWQMP collected samples from various locations across much of the Herbert Catchment. Given its large footprint several sites were selected so that the influence of sugarcane farming practices on water quality within the lower catchment area could be assessed. The HWQMP also included sites located above the area influenced by sugarcane production at Nash's Crossing (start of the lower catchment area), and a rainforest reference site at Waterfall Creek as a comparison for non-agricultural impact. Data from the end of catchment water monitoring site at John Row Bridge was also provided by DSITI (Department of Science, Information Technology and Innovation) as part of this program for comparison with data collected as part of this study.

A description of each sampling site is outlined below and a summary of the land uses captured as each sampling site is given in Table 1.

Table 1: WQ Monitoring Sites sampled during 2014-2015

Site	Dominant Land Use	Sampling undertaken					Gauged
		TSS	PSA	Nutrients	Metals	Pesticides	
Nash's Crossing	Start of Lower Catchment	✓	✓	✓		✓	Yes[1]
Waterfall Ck (A)	Rainforest	✓	✓	✓		✓	No
Boundary Creek	Sugarcane	✓	✓	✓		✓	No
Hawkins Creek	Sugarcane	✓	✓	✓		✓	No
Stone River	Sugarcane/Grazing (introduced in 2013/2014 sampling year)	✓		✓		✓	Yes
John Row Bridge	End of Catchment (lower)	✓	✓	✓		✓	Yes

1 – Height gauge present but needs rating curve developed by DNRM hydrological services.

Table 2: Additional sampling sites that were included in the 2011-2014 HWQMP, but now discontinued.

Site	Land Use	Sampling undertaken					Gauged
		TSS	PSA	Nutrients	Metals	Pesticides	
Blunder Creek	Rainforest	✓	✓	✓		✓	Yes
Mill Creek	Mixed cropping (peanuts, potatoes, maize, and grazing)	✓	✓	✓		✓	No
Millstream	Mixed (cropping, urban, grazing, ex-mining)	✓	✓	✓	✓	✓	Yes
Wild River	Mixed (including grazing, dairy, urban and some tree crops)	✓	✓	✓	✓	✓	Yes
Nettle Creek	Ex-tin mining	✓	✓	✓	✓	✓	No
Rudd Creek	Grazing	✓	✓	✓	✓	✓	Yes
Cashmere Crossing	End of Catchment (upper)	✓	✓	✓	✓	✓	Yes
Waterfall Ck (B)	Sugarcane (only sampled between July 2011 and July 2013)	✓	✓	✓		✓	No
Foresthome Drain	Urban	✓	✓	✓		✓	No
Waterview Creek	Cane	✓		✓		✓	No
Seymour River	Overland flow	✓	✓	✓	✓	✓	Yes[2]

2 – Height gauges (x2) were installed by Terrain for use by WBM Model to calculate flows

Figure 1(a) -

The area highlighted in red is the Herbert Catchment area.

The area highlighted in pink is the Terrain NRM region, which includes the Herbert Catchment area.

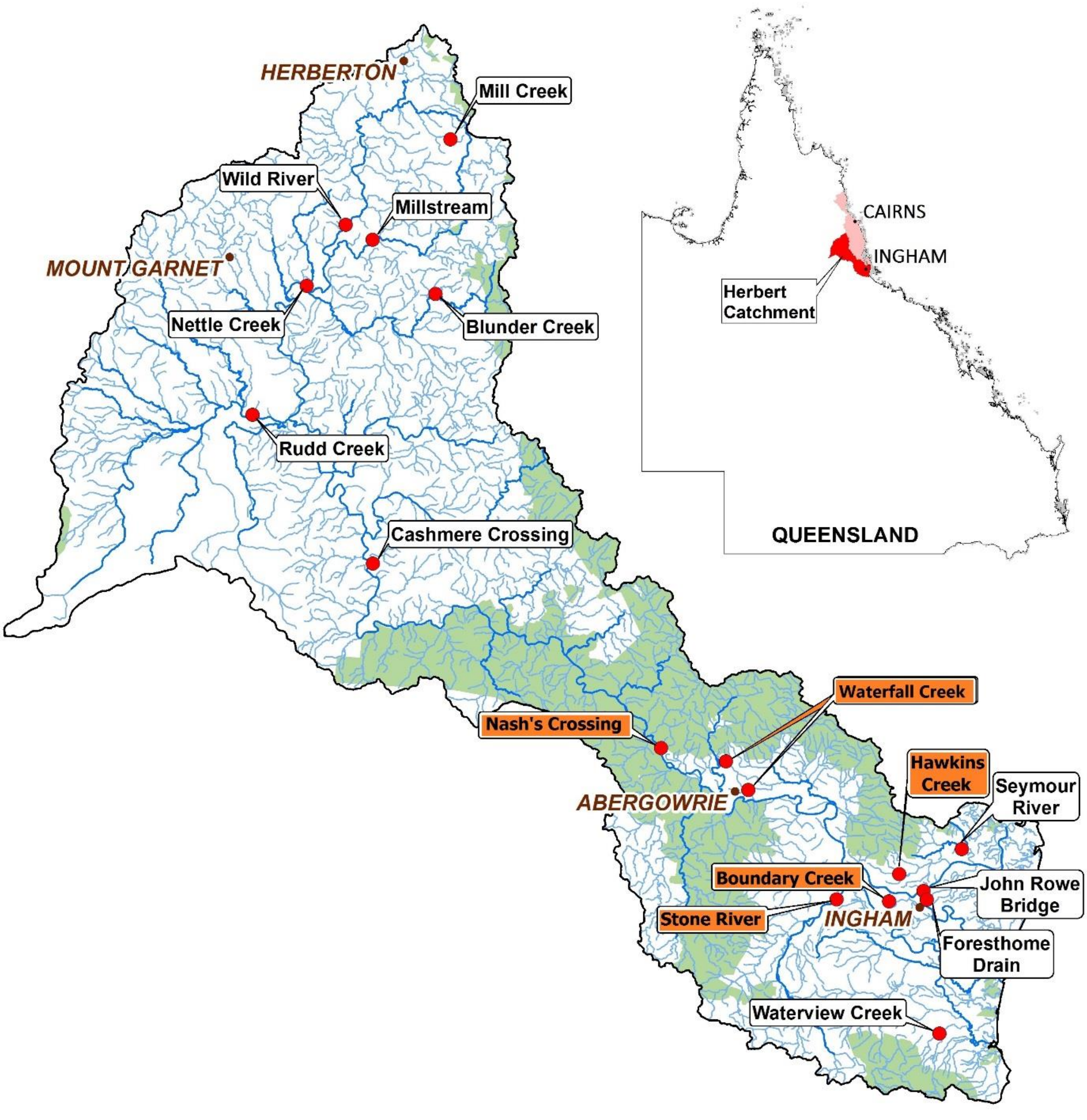


Figure 1(b) - Locations of the Herbert Water Quality Monitoring Program monitoring sites 2011-2016. Sampling sites funded by this project that were monitored during the 2014-2016 sampling years are highlighted in orange. Data from the John Row Bridge site which is funded by DSITI GBRCLMP is also included.

3.2 Lower Herbert Catchment:

Nash's Crossing plays an important role in the HWQMP as it provides a point of reference to separate Upper and Lower Catchment contributions of various pollutants. This site also provided insight into the relative contribution of large sections of Protected Area Estate (National Park) on WQ between this site and Cashmere Crossing further upstream. Nash's Crossing possesses a height gauge managed by Hinchinbrook Shire Council (HSC). Sampling at this point occurred as often as possible before water from upper catchment events reached; or immediately rainfall was detected in the area, and sampled daily over the hydrograph which often lasted a week or more.

Boundary Ck @ Guazzo's provided cane related WQ data from relatively heavy clay soils indicative of large areas of the Herbert cane growing areas. The average rainfall at this site is approx. 2200mm pa.

The DEEDI (now DAF) Demo Farm also resided in this area and provided paddock scale data which was used to demonstrate comparisons between farming systems. Concentrations of pesticides, nutrients and sediments were measured at this site. Manual grab sampling was undertaken 1-2 times a day, which proved sufficient to achieve adequate coverage over an event.

Gangemi's Road Drain @ Hawkins Creek was an important site as this is one of the highest rainfall areas (average approx. 3500mm pa) in the Herbert Catchment. This is also a cane industry specific site and represents an area of primarily alluvial soils which drain away from the Herbert River's system of levies and drains to the coast via Ripple Ck and Seymour River. Although also on the floodplain, most of this area only floods in moderate or major flooding events and provides good representation of pesticide, nutrient and sediment contribution during first flush and minor flood events. Testing for pesticides, nutrients and sediments required regular manual grab sampling, to provide EMC data for Source Catchments modelling.

John Row Bridge @ Herbert River is the current sampling site for DSITI GBRCLMP (formerly GBR-I5) program and provides the longest continuous data set that exists for the Herbert River. As the major conduit for water from the Herbert Valley to the ocean, this site provides valuable data for the caluculation of total annual loads of pollutants to the GBR Lagoon, but does not provide much information as to the origin of these pollutants. Historical hydrograph data indicates changes are slow to occur, hence sampling once daily (perhaps twice during major events) is sufficient. Sampling would occur for extended periods up to a week or two to ensure sufficient coverage for changes in concentration data and use in Annual and Daily Loads calculations.

If the objectives of ReefPlan (2009; 2013) and LTSP 2050 are likely to be achieved, then identification of major sources (both industry specific and geographically) need to be identified in order to target WQ improvement extension programs. Flows at John Row Bridge are measured at the Ingham Pump Station Gauge (116001), since access to the pump station site is problematic during floods. DNRM hydrographers are satisfied that there are no major inflows or outflows in the system between these sites to jeopardise the assumptions made in this case.

Manual grab samples for pesticides, nutrients and sediments have been taken from this site for a number of years (with SD <+or- 10%). Passive pesticide sampling methods have also been deployed in recent years to improve the level of confidence and accuracy of sampling regimes.

Stone River @ Venables Crossing was employed as a new WQ Monitoring site in Year 3 of the HWQMP as a replacement for Waterfall Ck @Vella's. The Waterfall Ck site suffered from a lack of flow in the second year and much of the intended paddock scale work and engagment with farmers around this site had already occurred by the end of Year 2. Moving forward, Stone River is a major tributary of the Herbert and was thought to be a good long term monitoring site because it receives significant drainage from surrounding intensive agricultural land. An understanding of the loads from Stone River can also assist in the calculation of load estimates at the end of catchment site at John Row Bridge.

3.3 Sampling approach

Concentrations of pollutants were measured by manual sampling at all sites as often as practical (ideally 5-10 samples collected) across the hydrograph of first flush and major rain events during the wet season. Samples representing ambient concentrations were collected bi-monthly to provide baseline data and to potentially assess contributions from other sources, like groundwater.

Water quality concentration data for nutrients, sediment and pesticides was collected on all non-gauged sites, with an estimate of relative height taken and if known whether the water is rising or falling. This was done in case a sub-catchment registered unusually high levels of pollutants. This site information could then be used retrospectively to help determine why anomalies occurred or why pollutant hotspots exist due to natural variation or contributing land use practices.

3.4 Sampling Personnel, Quality Assurance/Quality Control

Project Staff are all accredited by DSITI in collecting samples in accordance with QA/QC protocols and provided with sampling equipment, including gloves and detailed instructions of the procedures to ensure results are consistent and defensible.

Table 3: Sampling Personnel

Site	Primary	Location Stored
Nash's crossing	Michael	Ingham
Waterfall Ck	Michael	Ingham
Boundary Ck	Michael	Ingham
Hawkins Ck	Michael	Ingham
John Row	Michael	Ingham/Brisbane
Stone River	Michael	Ingham

3.5 Sampling methods

Water samples were collected at each site by project staff from the water surface (top 0.5 m) at each sampling site and were collected unfiltered into pre-rinsed 1 L polypropylene bottles (obtained from TropWATER analytical laboratory) for total suspended sediment (TSS); 60 ml Sarstedt sterile polypropylene vials for total nutrient (TN and TP) analysis and into 1 L amber glass bottles for pesticide analysis. Filtered samples were collected onsite into six 10 ml Sarstedt polypropylene vials using pre-rinsed filter modules (Sartorius MiniStart 0.45 µm cellulose acetate). All samples were immediately placed on ice following collection. Nutrient samples were frozen as soon as possible (within 6-12 hours) and TSS and pesticide samples were stored at 4°C prior to analysis.

3.6 Parameters measured

Table 4: Water quality parameters measured by the HWQMP.

Parameter	Manual
Total Nitrogen (TN)[1]	✓
Total Dissolved Nitrogen (TDN)[2]	✓
Oxidised Nitrogen (NOx)[2,4]	✓
Ammonium	✓
Dissolved Organic Nitrogen (DOC)[2]	✓
Urea	✓
Total Phosphorus (TP)[1]	✓
Total Dissolved Phosphorus (TDP)[2]	✓
Dissolved Organic Phosphorus (DOP) [2]	✓
Filterable Reactive Phosphorus (FRP) [3]	✓
Total Suspended Solids (TSS)[1]	✓
Pesticides[5]	✓

1. TP, TN and TSS are the only parameters that can be measured, if there was an inability to refrigerate samples.

2. Samples must be refrigerated immediately and preserved within 48 hours of collection.

3. Samples must be filtered and frozen on day of collection.

4. Reliability to be confirmed by comparison with results from samples filtered immediately

5. Samples must be refrigerated on the day of collection.

3.7 Sample analysis

Nutrient analysis was undertaken by TropWATER analytical services (James Cook University, Townsville).

Pesticide analysis was undertaken by the Queensland Health Forensic and Scientific Services (Coopers Plains, Queensland).

4.0 Results

4.1 Rainfall summary

Rainfall recorded within the vicinity of the sites sampled during the 2014-2015 and 2015-2016 water years were obtained and are outlined in the tables below (Commonwealth of Australia 2014). Annual rainfall across the sampling region ranged between 626 and 1570 mm and between 1138 and 2149 mm during the 2014-2015 and 2015-2016 water years respectively.

The average annual rainfall (June-July) recorded during the HWQMP operation period varied between 1103 and 2382 mm. The rainfall during the sampling year (2015-2016) was considered low to average compared to the long term average rainfall data (Commonwealth of Australia 2014) for the district.

Table 5: Rainfall (mm) statistics recorded at Ingham Composite gauging site during the sampling period.

		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual (JAN-DEC)	Annual (JUL-JUN)
Sampling year:	2011-2012	13	34.8	4	73.7	151.1	254.3	322.1	629.5	939.4	100.5	148.4	74.9	2717.9	2745.7
	2012-2013	113.2	22.4	14	53.2	14.9	285.4	625.7	433.3	207.6	101	117	23.7	1727.3	2011.4
	2013-2014	32.9	7.4	9.3	14.6	144.6	10.2	192.1	367.5	411.1	350.9	63.5	77.5	1628.7	1681.6
	2014-2015	0	45.7	31.3	7.1	32.8	49.2	227.3	135	126.3	181.2	53.2	73.6	1051.9	962.7
	2015-2016	22.5	8	10.3	73	17.5	124	119	168.1	828.2	195.4	120.5	71.7	--	1758.2
Statistic	**Mean**	**380.1**	**470.4**	**390.3**	**202.8**	**107.8**	**46.8**	**37.9**	**37.6**	**39**	**51.1**	**121.1**	**197.6**	**2141.6**	**1831.92**
	Lowest	**30**	**0**	**29**	**33.4**	**5.4**	**3**	**0**	**0.3**	**0**	**0**	**3**	**10.2**	**1051.9**	**962.7**
	5th %ile	**72.1**	**102.5**	**91.1**	**52.8**	**28.2**	**7.1**	**3.4**	**1.4**	**2.2**	**1.6**	**9.6**	**38.4**	**1118.7**	**--**
	10th %ile	**79.5**	**147**	**109.4**	**67.9**	**33**	**9.8**	**3.7**	**2.2**	**3.8**	**10.5**	**14.2**	**47.5**	**1319.7**	**--**
	Median	**321.3**	**433.3**	**320.5**	**158.8**	**83**	**35**	**33.2**	**32**	**14**	**37.8**	**82.4**	**124**	**2103**	**1758.2**
	90th %ile	**791.5**	**817.6**	**780.6**	**421.8**	**229.6**	**85.8**	**77.7**	**76**	**83.8**	**95.4**	**203.5**	**433.8**	**3255.4**	**--**
	95th %ile	**978.6**	**1127.9**	**902.9**	**478.1**	**247.2**	**122.6**	**106.8**	**113.1**	**169.5**	**156.8**	**454.1**	**609.2**	**3385.4**	**--**
	Highest	**1712**	**1400.6**	**1278.4**	**528**	**270**	**200.6**	**138**	**168.8**	**231.2**	**233.1**	**782.6**	**792.6**	**3484.1**	**2745.7**

Table 6: Rainfall (mm) statistics recorded at Ingham Pump Station gauging site during the sampling period.

		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual (JAN-DEC)	Annual (JUL-JUN)
Sampling year:	2011-2012	6	30	3	62	214	163	227	560	764	88	136	44	2251	2297
	2012-2013	103	21	2	38	8	260	686	351	163	102	93	22	1620	1849
	2013-2014	51	1	5	3	132	11	136	0	343	292	57	54	1018	1085
	2014-2015	13	42	30	2	13	36	180	0	144	172	46	79	823	757
	2015-2016	16	18	14	60	11	83	108	96	947	153	127	69	--	1702
Statistic	**Mean**	**303.6**	**450.4**	**302.3**	**173.7**	**61.7**	**46**	**34.5**	**23.4**	**34**	**39.6**	**75.4**	**136.9**	**1704.2**	**1538**
	Lowest	**72**	**0**	**20**	**50**	**3**	**14**	**0**	**0**	**0**	**0**	**0**	**11**	**610**	**757**
	5th %ile	**81.8**	**62.4**	**68.3**	**55.6**	**6.5**	**14.7**	**3.5**	**0**	**0.8**	**0**	**3**	**29.8**	**766.8**	**--**
	10th %ile	**92**	**126**	**92.2**	**60**	**8.4**	**16.2**	**5.4**	**0**	**1.5**	**0.8**	**5.5**	**41**	**907.6**	**--**
	Median	**194**	**461.5**	**219**	**138**	**57**	**44**	**16**	**19**	**10.5**	**31**	**25**	**86**	**1526.5**	**1702**
	90th %ile	**636.5**	**749**	**660**	**349**	**119.4**	**75**	**86.2**	**57**	**98**	**61.2**	**174.5**	**314.5**	**2919.7**	**--**
	95th %ile	**787.5**	**987.2**	**818.9**	**416.4**	**129.7**	**90.4**	**109**	**76**	**178.8**	**109.4**	**245.8**	**383.2**	**3044.9**	**--**
	Highest	**1092**	**1279**	**947**	**485**	**136**	**117**	**123**	**88**	**229**	**220**	**341**	**426**	**3107**	**2297**

Table 7: Rainfall (mm) statistics recorded at Hawkins Creek gauging site during the sampling period.

		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual (JAN-DEC)	Annual (JUL-JUN)
Sampling year:	2011-2012	18	7.5	23.8	130.4	245.6	345.6	294.4	786	803.6	97	251.6	80.6	2857	3084.1
	2012-2013	182.8	45.6	5.8	71.6	24	214	836	336.6	173.8	233.8	126.6	54.4	2077.8	2305
	2013-2014	143.6	3	7.4	12.4	127	23.2	188	597.2	389.8	464.4	113.6	123.2	2144.2	2192.8
	2014-2015	54.2	55.2	80	11	22	45.6	272.4	236	238.4	168.2	100.4	151.8	1481.4	1435.2
	2015-2016	63.8	0	12	81.4	11	146	69.4	122.2	977.7	238.5	194.4	141	--	2057.4
Statistic	**Mean**	**419.2**	**556.4**	**454.9**	**243.6**	**143.1**	**80.5**	**78.1**	**57.5**	**52**	**69.1**	**112.9**	**205.6**	**2479.1**	**2214.9**
	Lowest	**11.1**	**60**	**44**	**22**	**3**	**0**	**1**	**0**	**0**	**0**	**0**	**8.6**	**1264**	**1435.2**
	5th %ile	**64.8**	**132.3**	**94.4**	**53.6**	**33.2**	**12.8**	**8.3**	**3**	**0.6**	**0.7**	**4**	**30.4**	**1469.5**	**--**
	10th %ile	**88.9**	**179.4**	**150.8**	**91.7**	**46.5**	**20.6**	**10.9**	**6.1**	**3.8**	**9.1**	**10**	**45.9**	**1661**	**--**
	Median	**283.4**	**485**	**388.8**	**198.9**	**125.8**	**64.5**	**62.4**	**41.2**	**23.9**	**46.2**	**74.2**	**146**	**2339.8**	**2192.8**
	90th %ile	**852.7**	**1009.4**	**842.1**	**465.2**	**286.1**	**142.8**	**163.8**	**126.4**	**126.1**	**147.7**	**238.3**	**404.1**	**3549.5**	**--**
	95th %ile	**1250**	**1171.9**	**1006**	**543.8**	**303.8**	**183.1**	**208.1**	**181.2**	**201.7**	**207**	**428.9**	**615.4**	**3902.2**	**--**
	Highest	**1820.1**	**1689.2**	**1288.8**	**637**	**321**	**250.4**	**230.8**	**221.5**	**291**	**294**	**642**	**715**	**4151.9**	**3084.1**

Table 8: Rainfall (mm) statistics recorded at Peacock Siding Alert gauging site during the sampling period.

		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual (JAN-DEC)	Annual (JUL-JUN)
Sampling year:	2011-2012	8	7	0	31	233	207	201	437	457	36	80	38	1452	1735
	2012-2013	65	17	0	0	12	109	381	237	125	101	34	9	1024	1090
	2013-2014	16	0	1	8	97	15	136	370	196	0	32	59	883	930
	2014-2015	9	25	11	2	12	31	203	86	154	72	21	0	592	626
	2015-2016	7	12	8	15	14	0	76	194	605	103	42	62	--	1138
Statistic	**Mean**	**247.1**	**364.4**	**265.4**	**106.9**	**36.4**	**31.5**	**28.6**	**16.9**	**42.2**	**35.1**	**73.2**	**133.3**	**1445.4**	**1103.8**
	Lowest	**72**	**32**	**111**	**14**	**0**	**5**	**0**	**0**	**0**	**0**	**0**	**15**	**806**	**626**
	5th %ile	**75**	**65**	**111**	**25.9**	**9.8**	**7.1**	**0.8**	**0**	**0**	**1.4**	**1.5**	**16.4**	**856**	**--**
	10th %ile	**98.5**	**81**	**118**	**33**	**14**	**8.4**	**1.5**	**0.5**	**0.5**	**4.4**	**6**	**22.6**	**902.9**	**--**
	Median	**212.5**	**365**	**171.5**	**100**	**33**	**24**	**18.5**	**12**	**10.5**	**31**	**27**	**79**	**1281**	**1090**
	90th %ile	**392.5**	**565**	**531**	**224.8**	**74**	**60.8**	**79.5**	**40.5**	**92**	**57.6**	**189**	**244.6**	**2289.4**	**--**
	95th %ile	**464.2**	**708.5**	**694.5**	**278.4**	**77.8**	**72.5**	**95.8**	**58.8**	**181.8**	**83.9**	**240.2**	**332.5**	**2338.3**	**--**
	Highest	**645**	**1022**	**963**	**340**	**80**	**97**	**101**	**67**	**367**	**135**	**262**	**532**	**2390**	**1735**

Table 9: Rainfall (mm) statistics recorded at Ingham Cardwell Range gauging site during the sampling period.

		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual (JAN-DEC)	Annual (JUL-JUN)
Sampling year:	2011-2012	18.4	26.4	14	152.8	286	317.4	274.2	945.6	1157.6	109.4	291.2	85	3456.6	3678
	2012-2013	199.6	35.2	16	40	38.8	264	730.4	369	214	187.2	191.8	47	2025.8	2333
	2013-2014	89.4	0	4.8	34.8	134.8	22.6	176.2	657.4	422.6	412.4	125.2	101.8	2142	2182
	2014-2015	47.8	44.6	84	8.4	15.4	46.2	359.4	304	155.8	230.8	88.8	185	1614.8	1570.2
	2015-2016	43	33.6	22.8	66.4	7.2	118	109.2	97.4	1176.9	199.4	158.8	116.6	--	2149.3
Statistic	**Mean**	**388.4**	**540.7**	**444.8**	**253.2**	**142.2**	**76.5**	**60.4**	**55.7**	**56.6**	**62.9**	**105.5**	**213.2**	**2458.8**	**2382.5**
	Lowest	**21**	**60**	**49**	**30**	**6.5**	**0**	**0**	**0**	**0**	**0**	**0**	**22.6**	**1208**	**1570.2**
	5th %ile	**51.2**	**122.8**	**99.7**	**50.5**	**32.7**	**8.9**	**4.4**	**1.6**	**0**	**0**	**7.6**	**51.3**	**1586.1**	**--**
	10th %ile	**71.2**	**193.5**	**126**	**103.4**	**53.4**	**23**	**10.7**	**6**	**2.5**	**8**	**9**	**62.5**	**1716.2**	**--**
	Median	**327.6**	**452**	**379**	**220.1**	**125.2**	**62.2**	**46**	**42.5**	**22.8**	**41.8**	**70.2**	**138.4**	**2271.6**	**2182**
	90th %ile	**926**	**968.8**	**834.5**	**528.4**	**265**	**153.9**	**125.2**	**105.5**	**137**	**155.7**	**233.4**	**457.8**	**3593.7**	**--**
	95th %ile	**1021.5**	**1169.2**	**1063.2**	**579.6**	**297.7**	**177.3**	**163.8**	**141.8**	**208.7**	**184.5**	**330.5**	**630.1**	**3739.1**	**--**
	Highest	**1267.4**	**1477.2**	**1176.9**	**664**	**379**	**250.2**	**220.4**	**222**	**488.5**	**284.8**	**601.4**	**946.1**	**4055**	**3678**

Table 10: Nutrient and TSS sampling summary 2014-2015 (highlighted cells indicate where Qld. WQ Guidelines (QWQG 2009) for wet tropics lowland streams have been exceeded).

		TSS (mg/L)	TN (µg/L)	DN (µg/L)	PN (µg/L)	DIN (µg/L)	DON (µg/L)	NH4 (µg/L)	Urea (µg/L)	NOx (µg/L)	TP (µg/L)	DIP (µg/L)	DOP (µg/L)	PP (µg/L)
Wet Tropics WQ guideline		9	240				200	10		30	10	4		
Rainforest	n	11	11	11	11	11	11	10	11	11	11	11	11	11
	min	0.12	174	55	2	42	20	1	4	34	6	2	1	0
	max	1.5	460	214	312	145.819	100	3	15.250	138	33	3	13	29
	average	0.592	259.727	138.545	121.182	92.327	53.636	1.300	7.509	83.636	10.727	2.636	3.909	4.182
Nash's Crossing	n	13	13	13	13	13	13	13	13	13	13	13	13	13
	min	0.54	232	100	38	10.342	46	2	3.342	2	7	1	0	1
	max	71	948	509	503	281.174	323	22	22.742	249	85	5	8	74
	average	18.158	510.462	268.692	241.769	97.994	182.846	9.231	12.148	76.615	32.615	3.154	4.846	24.615
Boundary Ck	n	18	18	18	18	18	18	18	18	18	18	18	18	18
	min	0	410	328	16	38.868	12	3	1.726	1	24	3	1	3
	max	51	9301	7733	1568	7705.052	1304	551	39.298	7132	961	909	77	178
	average	12.261	3464.167	2815.667	648.500	2285.024	551.333	110.000	20.691	2154.333	293.944	187.000	31.556	75.389
Gangemi's Rd	n	20	20	20	20	20	20	20	20	20	20	20	20	20
	min	1.7	0	0	0	0	0	0	0	0	0	0	0	0
	max	130	7595	7144	1308	7122.719	915	2165	50.604	4920	527	246	73	487
	average	32.385	1635.500	1258.900	376.600	822.574	457.300	138.900	20.974	662.700	140.300	24.100	32.600	83.600
Stone R	n	21	21	21	21	21	21	21	21	21	21	21	21	21
	min	0.78	219	189	2	41.052	71	8	6.429	18	13	3	2	1
	max	30	1051	621	515	487.538	258	31	31.524	459	58	14	10	40
	average	3.891	472.190	342.667	129.524	192.054	163.333	19.571	12.720	159.762	23.714	6.905	5.810	11.000
John Row Bridge	n	38	39	Not measured	31	Not measured	38	39	Not measured	39	18	34	Not measured	13
	min	1	180		30		70	3		10	20	1		20
	max	132	910		290		280	36		319	90	7		80
	average	24.684	387.692		122.258		157.632	15.077		115.205	42.222	2.882		40.769

Table 11: Nutrient and TSS sampling summary 2015-2016 (highlighted cells indicate measurements that exceed Qld. WQ Guidelines for the QWQG (2009) wet tropics lowland streams).

		TSS (mg/L)	TN (µg/L)	DN (µg/L)	PN (µg/L)	DIN (µg/L)	DON (µg/L)	NH4 (µg/L)	Urea (µg/L)	NOx (µg/L)	TP (µg/L)	DIP (µg/L)	DOP (µg/L)	PP (µg/L)
Wet Tropics guideline		9	240				200	10		30	10	4		
Rainforest	n	18	18	18	18	18	18	18	18	18	18	18	18	18
	min	0	32	69	0	29	0	74	0	21	2	2	2	0
	max	6.4	178	290	26	159	26	337	69	131	15	12	3	9
	average	1.481	90.111	126.44	4.500	53.556	5.278	143.66	17.222	68.389	5.111	3.444	2.667	0.778
Nash's Crossing	n	17	17	17	17	17	17	17	17	17	17	17	17	17
	min	0	167	142	0	7	2	176	3	119	5	3	3	-1
	max	35	501	428	27	140	43	641	265	331	51	15	12	4
	average	8.900	303.17	281.17	6.882	56.118	11.059	359.29	78.118	218.17	18.412	6.588	5.176	1.412
Boundary Ck	n	27	27	27	27	27	27	27	27	27	27	27	27	27
	min	0.67	52	96	0	7	4	102	6	46	6	3	3	0
	max	170	2907	7001	626	5939	53	7952	1641	1481	784	647	646	124
	average	23.31	1287.7	2075.4	144.704	1158.6	30.85	2446	370.92	772.1	387.0	279.2	237.07	42.14
Gangemi'sRd	n	28	28	28	28	28	28	28	28	28	28	28	28	28
	min	0	192	184	8	29	3	250	3	110	21	12	6	0
	max	180	2265	9878	662	8043	45	10308	1076	1173	765	571	571	155
	average	46.72	917.32	2167.0	116.60	1500.8	21.35	2418	251.14	549.5	228.82	145.28	115.89	29.39
Stone R	n	30	30	30	30	30	30	30	30	30	30	30	30	30
	min	0	80	218	0	12	3	222	1	24	10	8	3	0
	max	230	6826	1058	51	637	56	6899	6487	509	147	40	32	18
	average	23.21	629.47	578.8	12.600	307.70	13.400	937.16	358.37	258.5	31.933	15.933	10.967	4.967
John Row Bridge	n	52	58	47	47	58	57	56	58	Not measured	32	49	2	23
	min	1	130	80	30	5	50	1	4		20	1	20	20
	max	218	2280	2000	690	1398	600	1290	108		190	45	20	150
	average	31.450	494.180	419.77	142.73	169.09	210.93	159.64	15.25		63.75	8.32	20.00	57.83

4.2 TSS

Previous evidence from the particle size analysis (PSA) undertaken through the original HWQMP concluded that fine sediments, which provide a transport mechanism to the reef for other pollutants such as nutrients and pesticides; as well as reduce light in inshore coastal ecosystems; are generally a minor issue in the Herbert Catchment compared to the Burdekin as the data indicates (O'Brien et. al; 2014). Concentrations of sediments from the upper catchment at Nash's can be heavily influence by rainfall, and in 2014-15 maximum and average concentrations were considerably higher, than in the subsequent (2015-16) year despite it being a relatively dry year. It would be reasonable to expect that after the 2014-15 dry year that TSS in the second year would be higher given the same conditions due to increased latent periods and reduced ground cover in the upper catchment, but clearly less intense rainfall events and more regular rain spread out over the water year has resulted in significantly less sediment movement, supported by the increased number of samples taken in the second year.

Coordinated extension by QDAF involved in the original HWQMP program around rangeland grazing in the upper Herbert has also continued since the end of the 2014 project; which has resulted in better groundcover management in many areas (B. English pers comm, 2016). This is also likely to have contributed to the improved results despite the less than average rainfall in the upper catchment.

In the lower Herbert it appears from the rainforest site that the intensity of rainfall was greater in the 2015-16 water year. With no changes to the land condition other than that imposed by the previous dry (2014-15) weather conditions, TSS at the rainforest reference (control) site increased 3 fold, even though it was still below the Queensland WQ Guideline value for lowland streams in the Wet Tropics. This demonstrates the variability of pollutant potential due to climatic factors in the Wet Tropics. This pattern is also consistent with other sites in the lower catchment regardless of the land-use composition or relative position in the landscape.

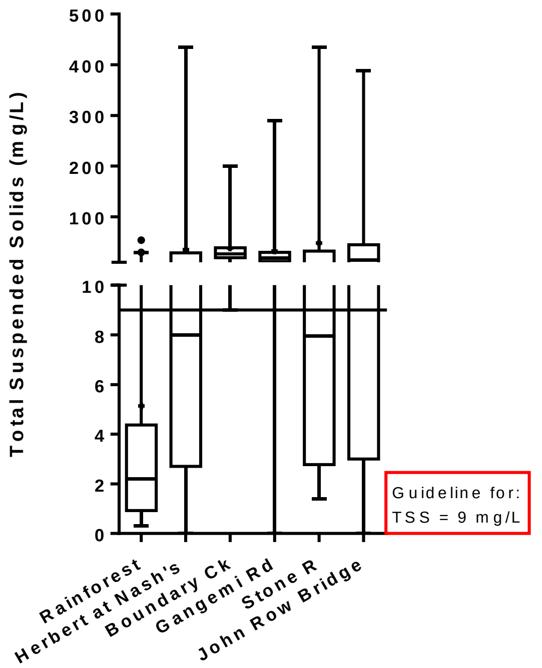
The two Herbert WQ sugarcane sites (Gangemi's Rd and Boundary Ck) are both very similar and characterised by heavy clay soils (fine particles) and reside low in the landscape. Dryer weather and longer latency periods between rainfall events has likely increased the average concentration of TSS at these sites in recent years, but without an adequate measure of flow, it is reasonable to assume there is still a reduction in TSS load from these respective sites, due to the reduced volume of water leaving the landscape as supported by the End of Catchment Loads taken at the John Road Bridge. (GBRCLMP, 2016)

The location of these sampling sites are also highly modified ephemeral systems (ie. drains) and whether the above WQ guidelines are even appropriate to these sites is perhaps a point for further discussion. Where these systems discharge into High Environmental Value (HEV) or permanent aquatic habitats is worth investigating, but these locations are even lower in the landscape and highly susceptible to flooding, which would make event sampling highly problematic for access and safety.

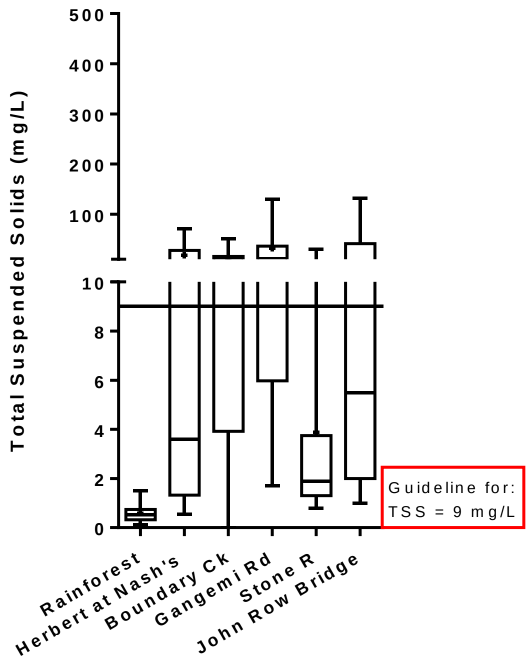
The pre-wet season condition of the Upper Stone Catchment would have significantly contributed to the high TSS loads in the 2015-16 water year. Unlike much of the upper Herbert, this catchment is characterised by steep areas of forestry, grazing and conservation land use, but more importantly is comprised of granite (not basalt), which provides little buffering of water delivery within the catchment. Decomposed granite soils are also highly transmissive, erodible and on relatively steep grades, therefore any significant event, especially following extended periods of dry weather (and poor groundcover) as was the case in late 2015, will deliver disproportionate amounts of sediment in high intensity rainfall events like those experienced in March/April 2016.

Similarly, the GBRCLMP site at John Row Bridge demonstrated the same trend as other lower catchment sites by having higher TSS concentration in 2015-16 than the previous (2014-15) water year, suggesting the relative contribution from the upper Herbert which bucked this trend at Nash's Crossing in 2015-16, made a relatively small contribution to the end of catchment load. Although the John Row Bridge results were above Qld. WQ Guideline values for max and average TSS concentrations; and this is likely to have implications for instream biota; the Total loads for 2014-15 and 2015-16 were relatively low (59,240 Tonnes and 58,203 Tonnes respectively). This was only 1/6th of the average TSS discharge of ~383,000 Tonnes during the period 2012- 2014 water years; and therefore has provided a potential window for recovery for marine habitats such as seagrass and coral reefs in the inshore and estuarine systems within the receiving marine environment of the Herbert River, including the World Heritage Area of the Hinchinbrook Channel over the past 2 years (M.Nash, pers comm 2017).

2011-2014



2014-2015



2015-2016

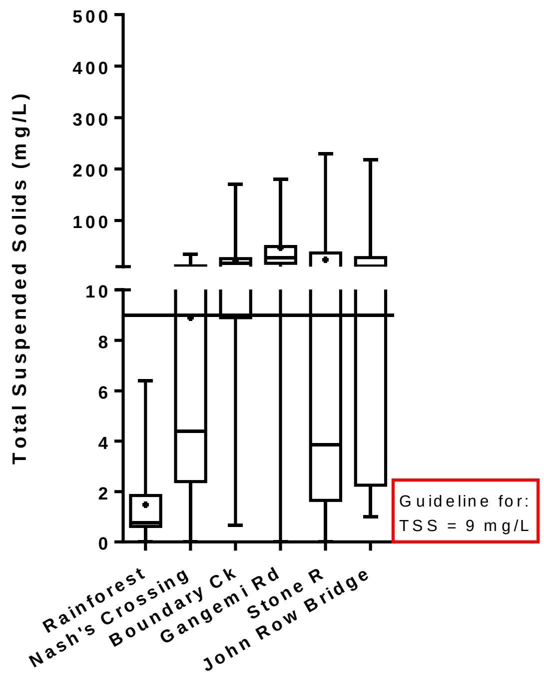


Figure 2: TSS measured across the sampling sites during the 2014-2015 and 2015-2016 water years compared to the concentrations measured during previous monitoring program (2011-2014).

Herbert at Nash' s Crossing

Rainforest reference site.

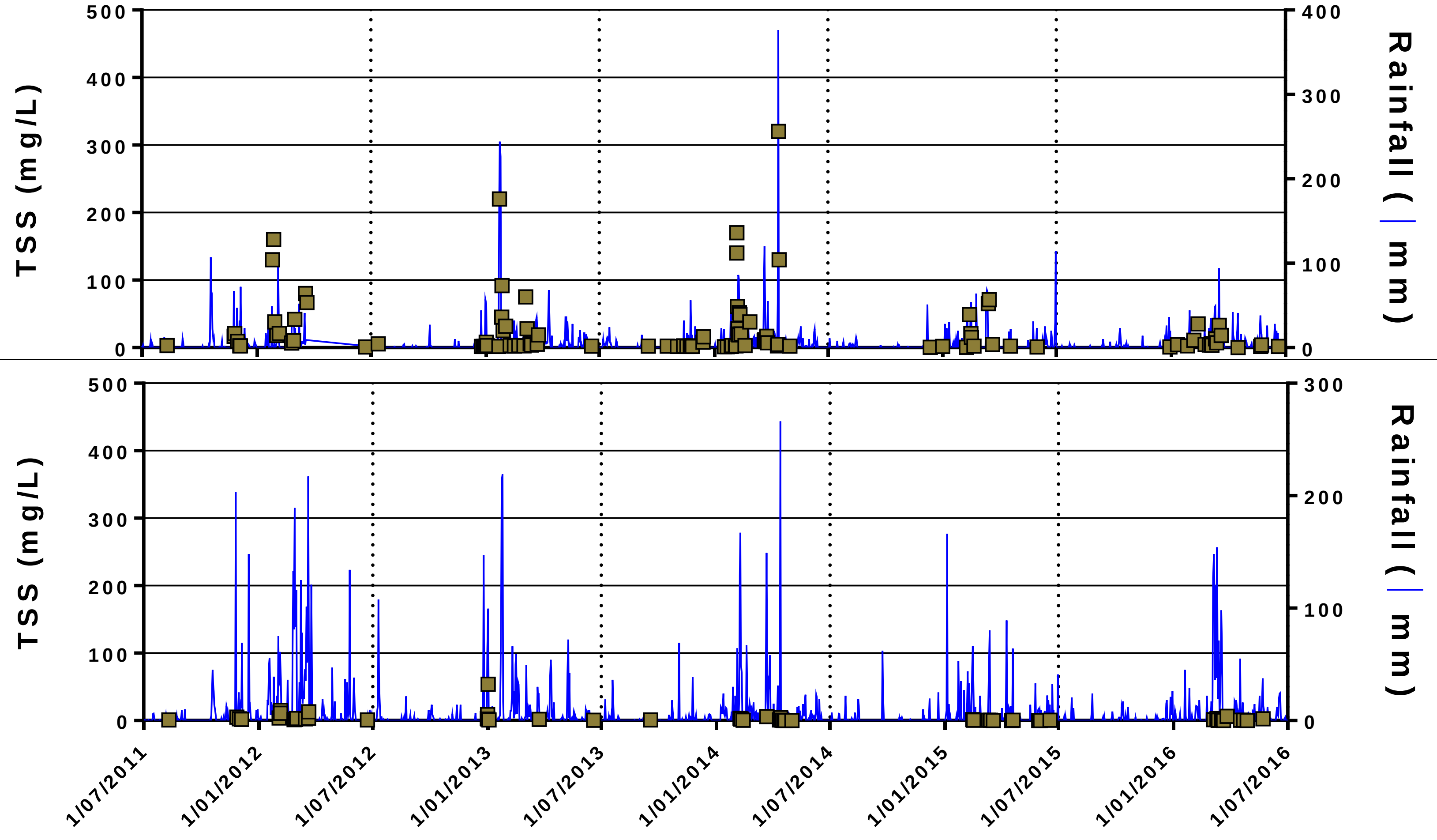


Figure 3: Site specific point in time TSS concentrations in waters exiting the Upper Herbert Catchment (Herbert at Nash's Crossing) and at the rainforest reference site.

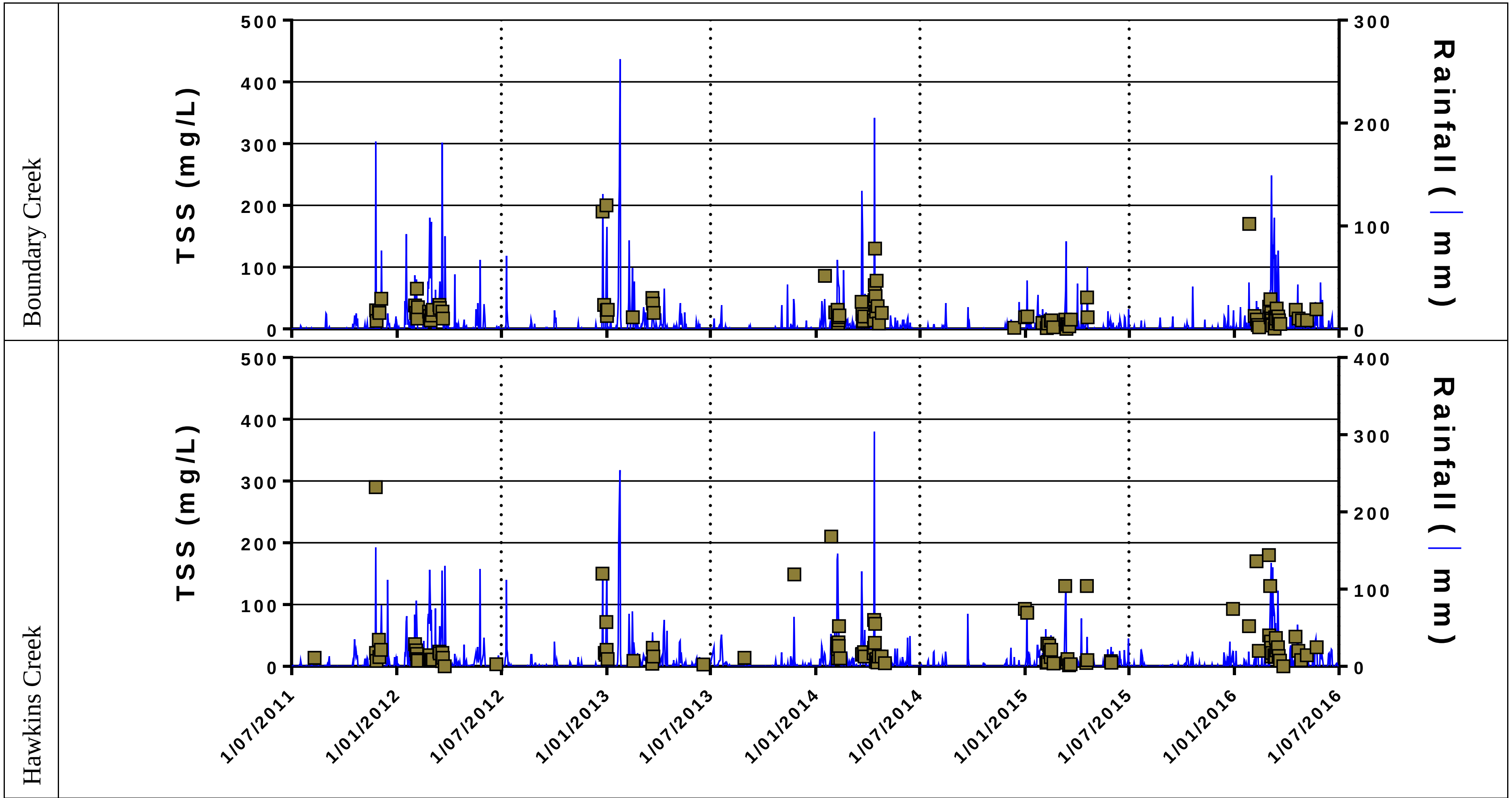


Figure 4: Site specific point in time TSS concentrations in waters exiting the Upper Herbert Catchment (Herbert at Nash's Crossing) and at the rainforest reference site.

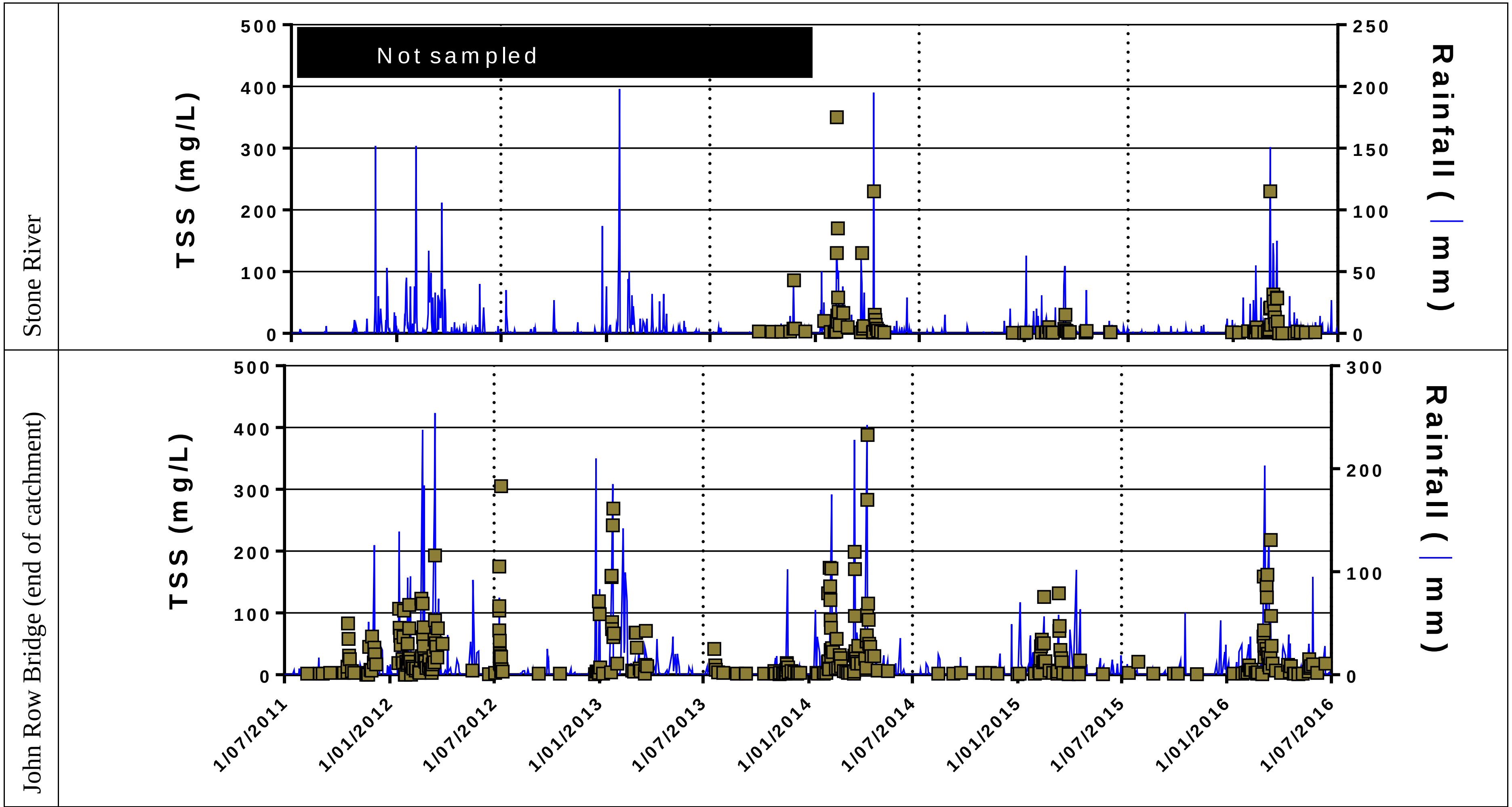


Figure 5: Site specific point in time TSS concentrations in waters exiting the Upper Herbert Catchment (Herbert at Nash's Crossing) and at the rainforest reference site.

4.3 Nutrients

Nutrient losses from intensive Herbert WQ Sugarcane sites dominate the comparative Figures (6-10) and support the general scientific consensus that intensive agriculture is the major contributor per unit area of nutrients (particularly dissolved nutrients) from terrestrial sources to the Great Barrier Reef. (SCS, 2013)

Nutrient concentrations recorded across the other sampling sites are all comparable in range and mean to the concentrations recorded during previous monitoring years, for example, the additional inputs of DIN, DIP, PN and PP between Nash's crossing and JRB where we see a moderate input of DIN and small inputs of (others) were similar across the sampling years.

4.3.1 Nitrogen:

During this 2015-16 sampling year the concentrations of TN, NOx, and ammonium were all above Qld. WQ Guidelines for lowland streams in the Wet Tropics at almost all sites including the Rainforest control. But unlike 2014-2015, DON concentrations were all below guideline values with the exception of JRB, which had a max of 600µg/L and an average of 210 µg/L, just above the 200µg/L DON guideline for the Wet Tropics.

As with previous years the concentration of all nitrogen species recorded, suggest that during wet years waterlogging may lead to higher levels of ammonium in surface water runoff. Further, while the increase in the rainfall during this current sampling year (2015-2016) did see an increase in urea concentrations compared to the concentrations measured during the previous sampling year (2014-2015), the increase did not reflect the magnitude of concentrations measured in samples collected between 2011 and 2014, except perhaps at the two sugar dominated sites.

Both Boundary Creek and Gangemi's Rd sites continue to experience high nitrogen losses. This is likely due to poor rainfall infiltration during events (combination of soil type and potentially land management) delivering relatively high runoff and almost the entire catchment area of these sites is dominated by intensive sugarcane production. The topography in these areas is also relatively flat and subject to water logging in larger events. Although Work undertaken by Cowie, *et.al* (2013) indicates that a change in fertiliser placement from surface to sub-surface application of nitrogenous fertiliser would lead to significant differences in nitrogen runoff in surface waters at the Waterfall Creek site in the Herbert, this is not apparent in concentrations collected at Boundary Creek and Gangemi's Rd to date.

Local extension efforts to change management practices at Boundary Creek from surface applied to subsurface application of granular fertilisers in an attempt to address losses previously noted from this site appear to be limited in terms of Total Nitrogen (TN) abatement (Figure 7). From 2014-2016 data indicates a reduction in ammonium, which may have significant localized ecological impacts (Figure 8); while the concentration of all other nitrogen species analysed are still comparable (in range and mean concentrations) to the data recorded during 2011-2014 sampling period (Figures 6,7&8). The improvements witnessed during the 2014-15 year were most likely due to the lack of substantial early wet season rain that year. It was observed from the data that significant losses of urea and ammonium (as nitrified urea) occurred when the wet season arrived soon after harvest and the crops ability to take up available nitrogen was limited. It was concluded that the surface applications of fertiliser applied by cane farmers was the primary source of urea and ammonia (as nitrified urea) being detected in water samples, while the early onset of the wet season, with heavy rainfall events occurring during these periods (2011-14 & 2016) appears to be the primary reason for the elevated urea and ammonia levels found within water samples.

Meanwhile, in contrast, during the 2014-2015 period, increases in the concentrations of NOx can be attributed to the later onset of the wet season which also coincides with a reduction in Ammonium and Urea losses in that same year (Figure 7). This suggests that the concentrations of Inorganic Nitrogen (including Urea) as a whole have not decreased in the Boundary Creek area despite the improvement in management practice as a result of targeted extension; and that climatic conditions have a greater influence over the nitrogen loss pathway than placement itself. Longer periods between rainfall events in drier years (like 2014-15) is also likely to result in higher sampling concentrations due to the increased accumulation of pollutants over time; and reduced dilution effects of these between relatively minor/moderate events when compared to the major rainfall and flooding which have occurred in previous (2011-14) sampling years.

But it is important to note, that although concentrations of Nitrogen (e.g. Guideline Values) are important in terms of freshwater ecology, it is its bioavailability at the End of System that is most important for the health of the GBR. Since this project has not been able to determine flow at many sites other than at the John Row Bridge; the true impacts of improved management practice in Boundary Creek for GBR-WQ outcomes cannot be accurately assessed. Anecdotally, from the rainfall data; it is reasonable to assume that although the concentrations have not changed significantly in recent years, the reduced rainfall (and therefore runoff) will have resulted in a reduced Nitrogen load to the confluence @ Herbert River. This is strongly supported by data from DISITI - GBRCLMP, 2016 at John Row Bridge (JRB), which estimates that the two-year average (2014-16) as discharging 212 tonnes of DIN per annum compared to the 2011-14 (3-year) period average of 1882 tonnes; approximately $1/9^{th}$ (or 11%) of the load entering the GBR lagoon per annum over the past two years, when compared to the 3-year (2011-14) average preceding it. When compared with TN and PN which are still contributing 23% and 18% of their annual averages respectively; it suggests perhaps that DIN has improved disproportionately (for the better) than other sources of nitrogen, despite the more favourable climatic conditions all round in recent years.

As observed during previous years PN, while reduced across all sites compared to the previous sampling year, continues to be higher in the Boundary Creek area compared to the concentrations recorded at other sampling sites. The higher concentrations of PN at Boundary Creek is attributed to the predominance of clay soils in the area with a high percentage of fine particles present and subject to erosion. These soils are highly erodible following prolonged dry periods were there is little ground cover to prevent soil movement across a landscape. A similar pattern exists for Gangemi's Rd as well (presumably for the same reasons), but 2015-16 has seen a slight reduction in PN despite the increased average TSS and stable PP at this site over a number of years. Both Boundary Creek and Gangemi's Road in particular tended toward oxidised nitrogen (NO_x) dominated losses in 2014-15, but ammonium (NH_4)-dominated losses in 2015-16. These losses are likely associated with different patterns of rainfall occurrence in relation to fertiliser application.

When we compare Nash's Crossing nutrient species to John Rowe Bridge, it is clear that for species such as NO_x there is large increases in concentration between the two sites. For example median NO_x concentrations increase by at least twofold reflecting input from sugarcane cultivation areas. While NO_x exceedances do occur at Nash's Crossing, peak values of NO_x exceeding 1000 µg/L (far in excess of guidelines) are found at John Rowe Bridge. Increasing concentrations of some phosphorus species also occur moving downstream from Nash's

Crossing to John Rowe Bridge (as do exceedances), but the scale of change is not as pronounced.

4.3.1.1 Extension response to nitrogen losses.

In response to the elevated levels of nitrogen in water quality samples collected by the HWQMP and research undertaken by associated projects like the Herbert Demonstration Farm and Rainfall Simulation project, the Herbert industry is now investigating ways to better manage nitrogen losses associated with sugarcane production through Project NEMO.

Project NEMO (funded by DNRM) allows growers to evaluate on-farm practices to better manage nitrogen that could lead to improvements in N use efficiency and water quality outcomes. In 2016, Project NEMO influenced growers managing 28,065 ha of the area under cane production, in the Herbert. The project has given growers the opportunity to assess different nitrogen rates, gain confidence in industry using nutrient management guidelines developed as a part of the Six Easy Steps (6ES) program, assess enhanced efficiency nitrogen fertilizers (like nitrification inhibitors and controlled release urea) and adopt farming systems that improve soil health and nutrient recycling and better manage water quality issues and maintain industry viability. Project NEMO has also established numerous farm demonstration trials (like mound planting of cane, controlled traffic and better practices to manage legumes) which has allowed growers to assess various farming systems to improve nitrogen use efficiencies and improve water quality outcomes.

The 2016 Project NEMO report- Extension and Practice Change Report compared grower practices in relation to nitrogen application rates between 2012 and 2015, for growers engaged in the project. Of the 18 growers engaged in the project in 2015, the results showed that 10 out of the 18 growers had reduced their nitrogen rates. From the 18 growers, 8 growers reduced rates to below the 6ES district average and in line with 6ES recommendations. Only one grower was still applying over the maximum district average compared to five growers in 2011-12. The biggest reduction by a single grower was 58kg of N/ha (180kgN/ha to 122kgN/ha). Overall the average reduction of nitrogen applied per hectare by the 18 growers engaged through Project NEMO was 14kgN/ha.

The Rainfall Simulation project validated that sub-surface application fertiliser in sugarcane crops had the lowest nitrogen runoff losses when compared to other application methods available to the industry (Cowie *et al.*, 2013). Since the inception of the Australian Government's Reef Rescue grants program, HWQMP, and reporting of the Rainfall Simulation trial results, there has been a significant shift from surface fertiliser application to sub-surface application in the Herbert cane growing region. Surface application of fertilisers reduced from 78% of area treated in 2008 to 38 % of area treated in 2013, for the Herbert sugarcane growing region (Di Bella *et al.*, 2016).

There was an improvement in the adoption of improved legume management practices whereby there was a sixth fold increase from 2.4% to 14.2% increase, in the number of growers planting legumes their fallow. This increase can be attributed to growers planting legumes on mounds, which reduces the potential nitrogen losses from the fallow legume green manure crop.

A four-year water quality study conducted in the Mackay region by the DNRM found an average reduction in runoff of 17% on a 1.8m controlled traffic system, compared to a 1.5m system (Billing; 2016). The Herbert data compared 2011 and 2015 the area planted to dual row and single pass mound planting systems increased by 100% and 210% respectively; therefore, making up almost 25% of total area planted in 2015. Due to limited data, it was difficult to evaluate the extent of uptake of controlled traffic systems; where row spacing is 1.8m or greater. While trends are believed to be similar to the increases in planting systems, an assessment of row spacing will again be attempted at the end of 2017.

4.3.2 Phosphorus:

The phosphorus concentrations recorded during the 2014-2016 sampling years (Table 10 &11) reflect a similar pattern as with nitrogen (i.e. higher mean concentrations and less low concentrations that are attributed to the low flow year). Overall, the concentrations of phosphorus nutrient species recorded reflected the average and range of concentrations recorded during the sampling undertaken during 2011-2014, with TP and DIP consistently above Qld WQ Guidelines for lowland streams in the Wet Tropics (Figure 9). However, despite exceedance levels being discharged at almost all sites including the Rainforest control and Nash's Crossing in 2015-16 for both TP and DIP; extremely high (100+ times) levels of TP, DIP & DOP were observed at Boundary Creek and Gangemi's Rd when compared to areas with less intensive land use catchments (Table 11).

The most notable point of interest is that in 2014-15, Gangemi's Rd had much lower levels of DIP than previous years, the level rose again dramatically in 2016, while TP and DOP remained fairly consistent (Figure 10). Perhaps this suggests that although the source of DOP and TP may be somewhat consistent with current land management, the distinct reduction in DIP in 2014-15 maybe as a result of different land management in adjacent fields. Investigation to identify the cause may be worth following up on.

4.3.2.1 Extension response to phosphorus losses.

In response to the elevated levels of phosphorus in water quality samples collected by the HWQMP, the Herbert industry is now investigating ways to better manage phosphorus losses associated with sugarcane production through HCPSL and Wilmar extension strategies.

Since 2011, HCPSL extension staff are also working with growers, mills and the mill mud contractors to improve the use of mill mud and mill ash to improve soil structure, which will lead to improvements in nitrogen use efficiencies (HCPSL unpublished data, 2014). The practices being applied to improve the use of mill mud and mill ash, are through: the reduction in application rates (from 200+ t/ha wet weight to below 100t/ha wet weight of product and improved placement of the products within the field and subsoil. Between 2011 and 2016, approximately 70% of growers in the Victoria Mill area have converted to application of mill mud in ratoons at rates below 100 t/ha wet weight on the cane row, instead of in the wheel track (where it is more prone to nutrient losses associated with water runoff).

Wilmar also commissioned a series of trials in 2015 and 2016, to assess water quality impacts associated with mill mud applications and different farming systems. These trials will investigate which farming systems minimise phosphorus losses associated with mill mud and mill mud ash use. Some of these trials are equipped with water quality monitoring equipment to assess the differences between farming systems. The results of these trials will be communicated through the HCPSL extension program and likely be applicable to other rain fed sugarcane growing districts.

2011-2014	2014-2015	2015-2016

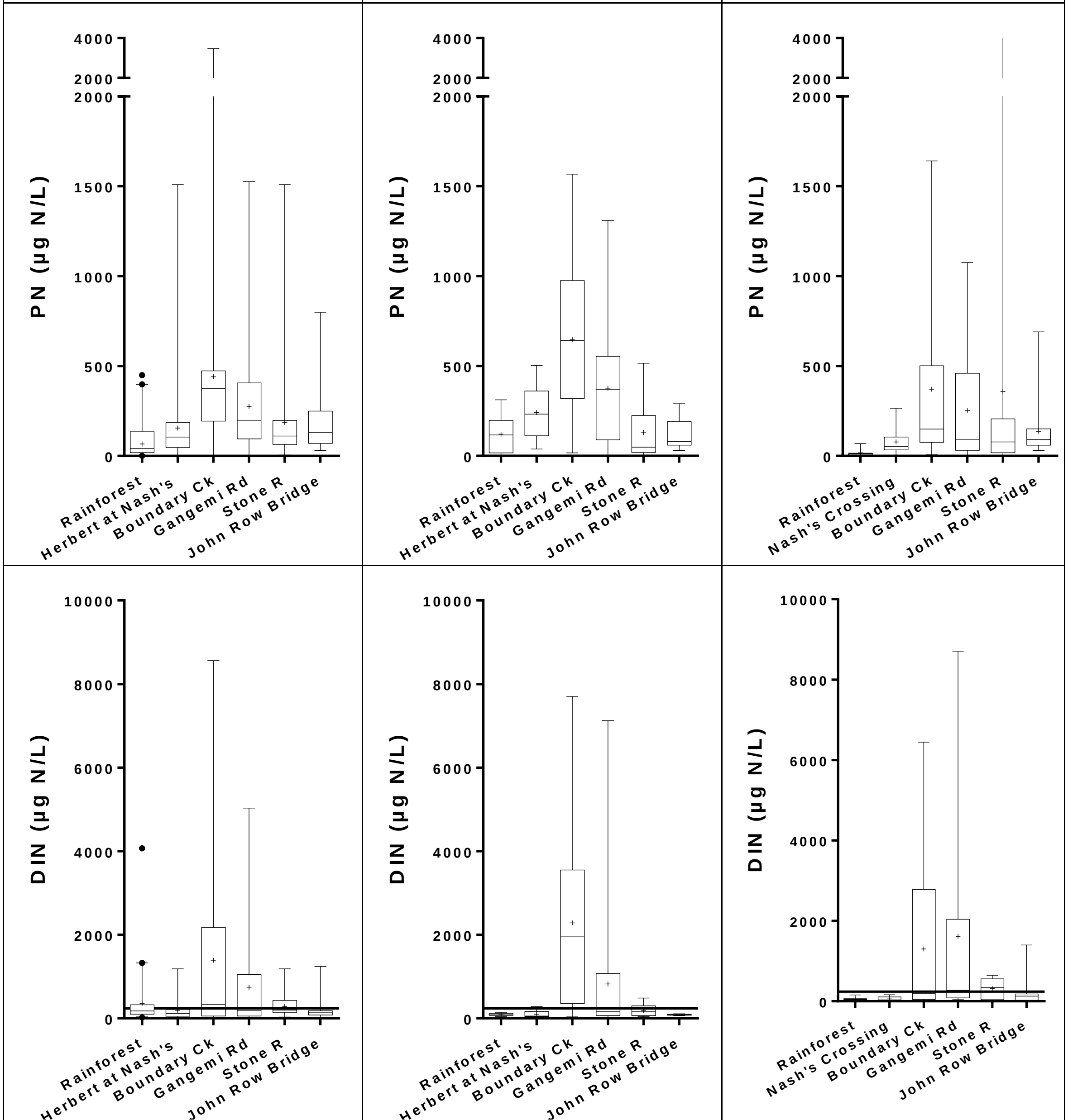


Figure 6: Concentration of particulate and dissolved inorganic nitrogen measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

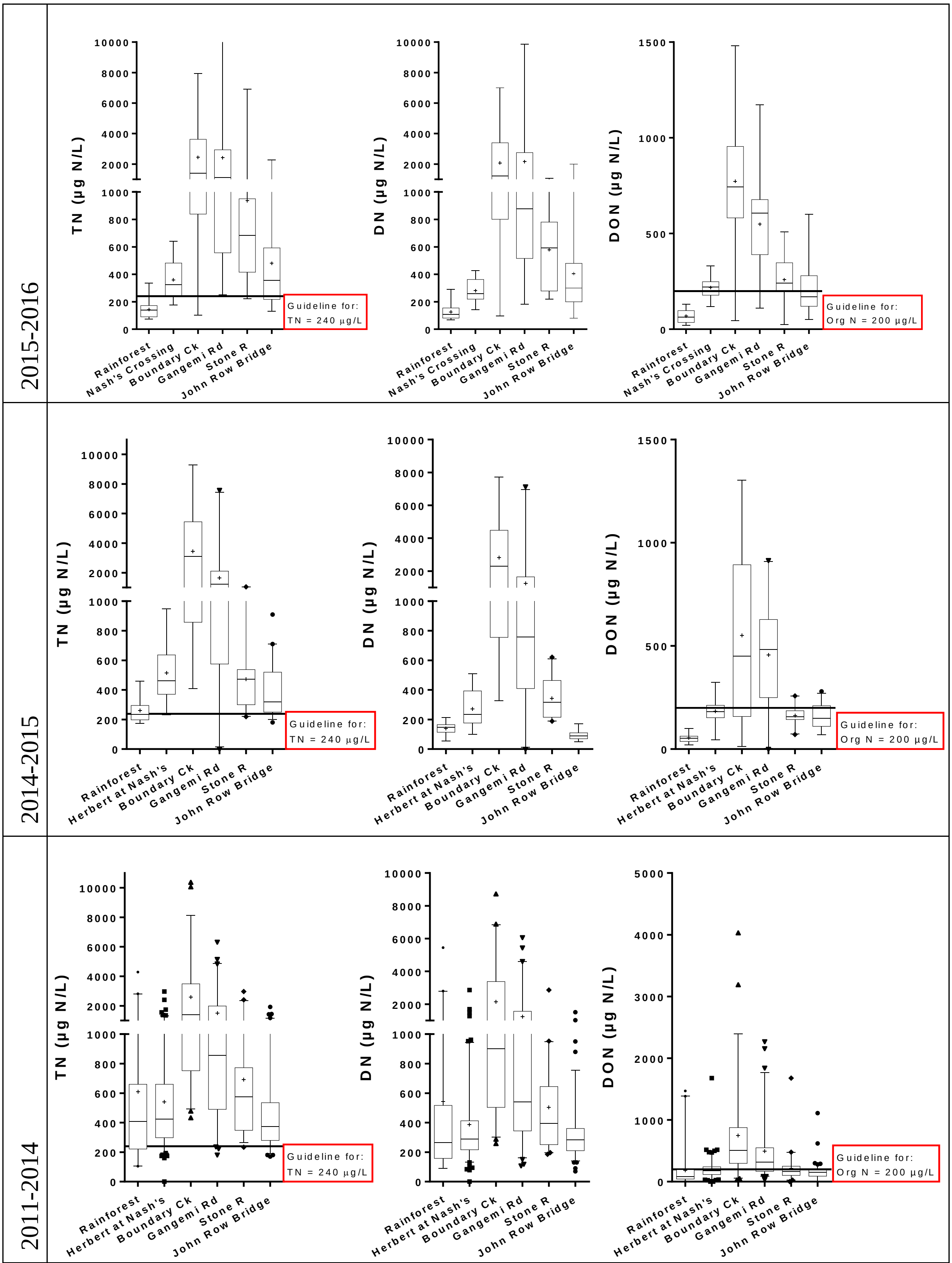


Figure 7: Concentrations of total nitrogen (TN), total dissolved nitrogen (DN) and dissolved organic nitrogen (DON) measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

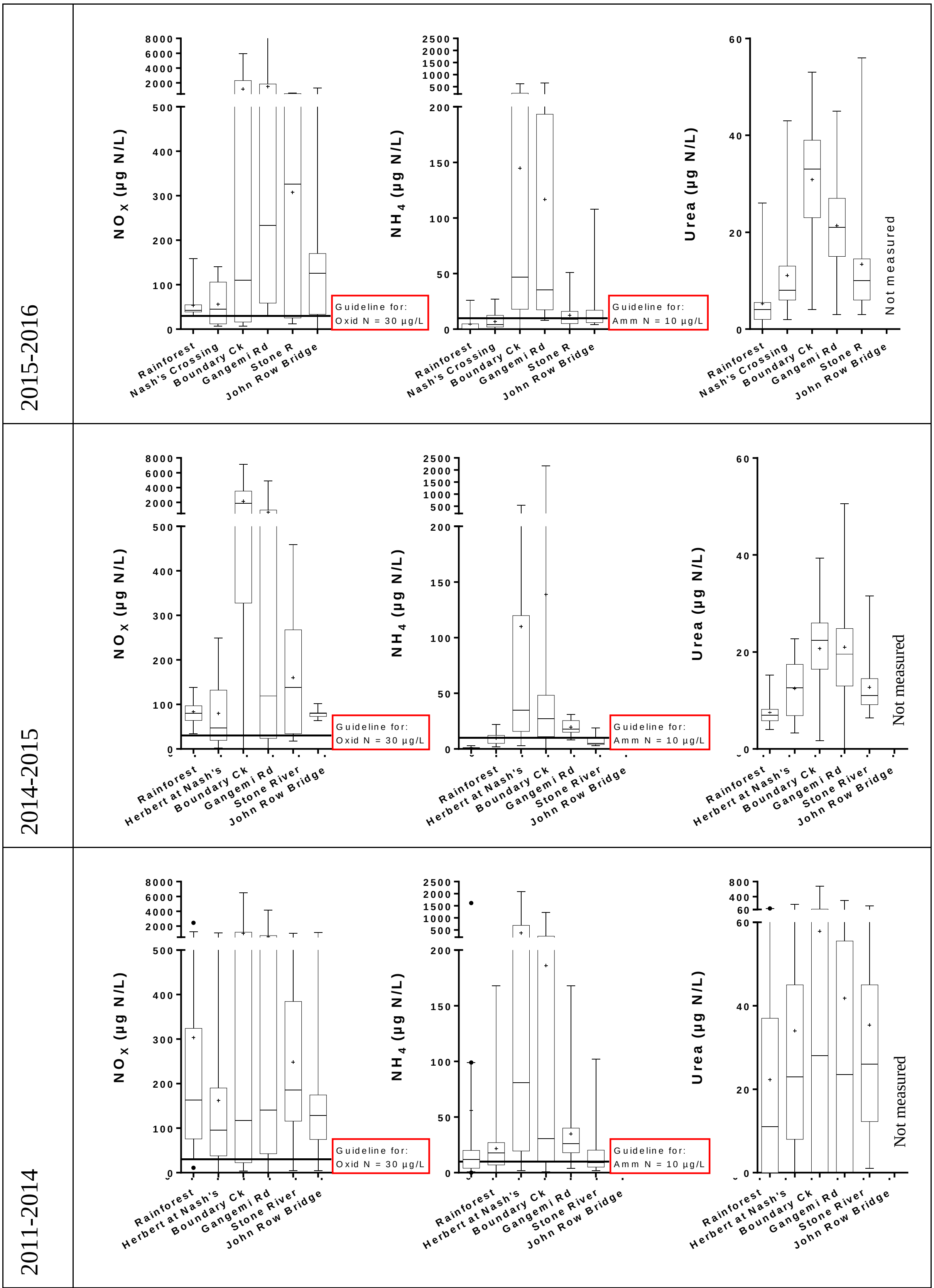


Figure 8: Concentrations of total nitrogen (TN), total dissolved nitrogen (DN) and dissolved organic nitrogen (DON) measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

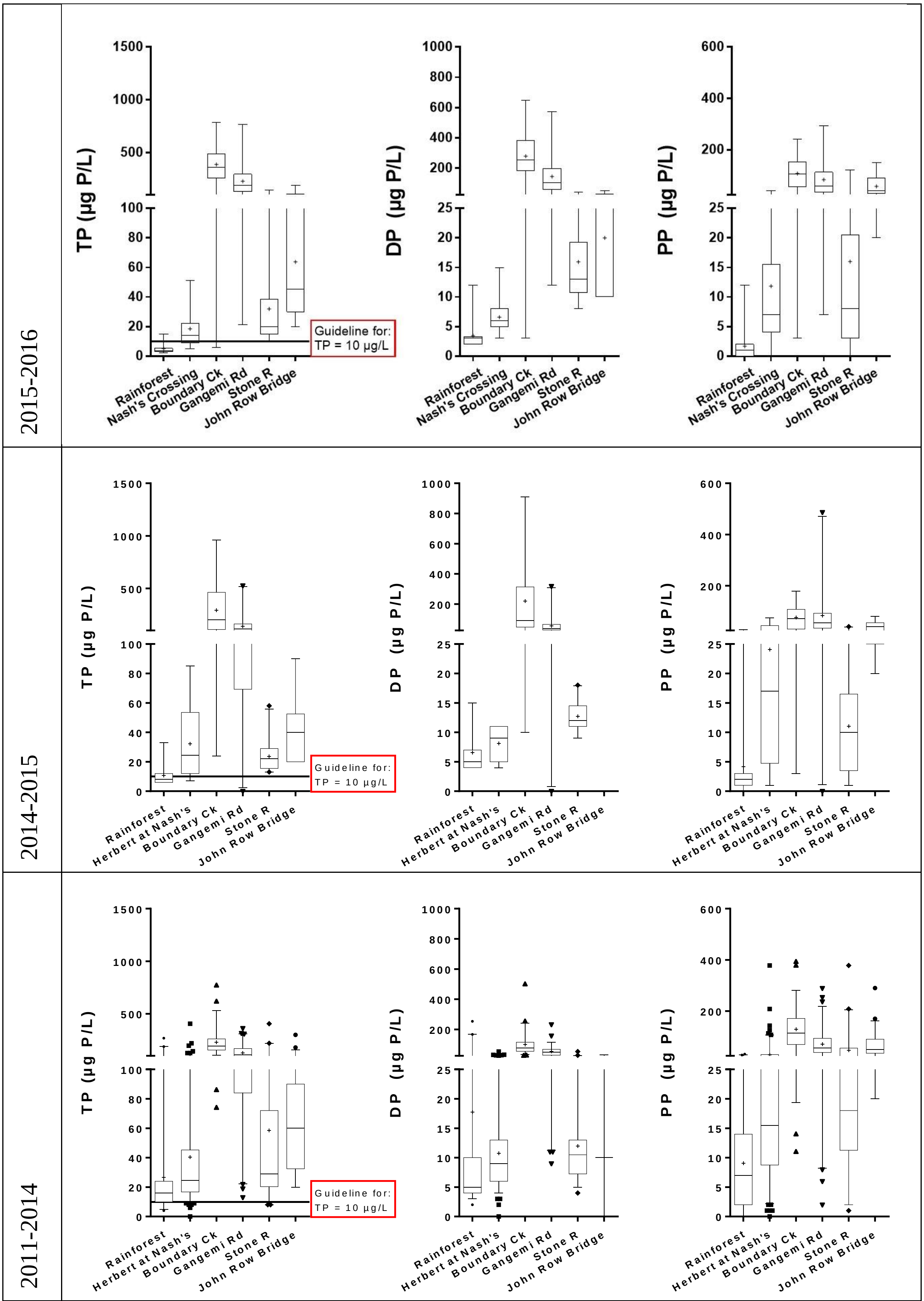


Figure 9: Concentrations of total phosphorus (TP), total dissolved phosphorus (DP) and particulate phosphorus (PP) measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

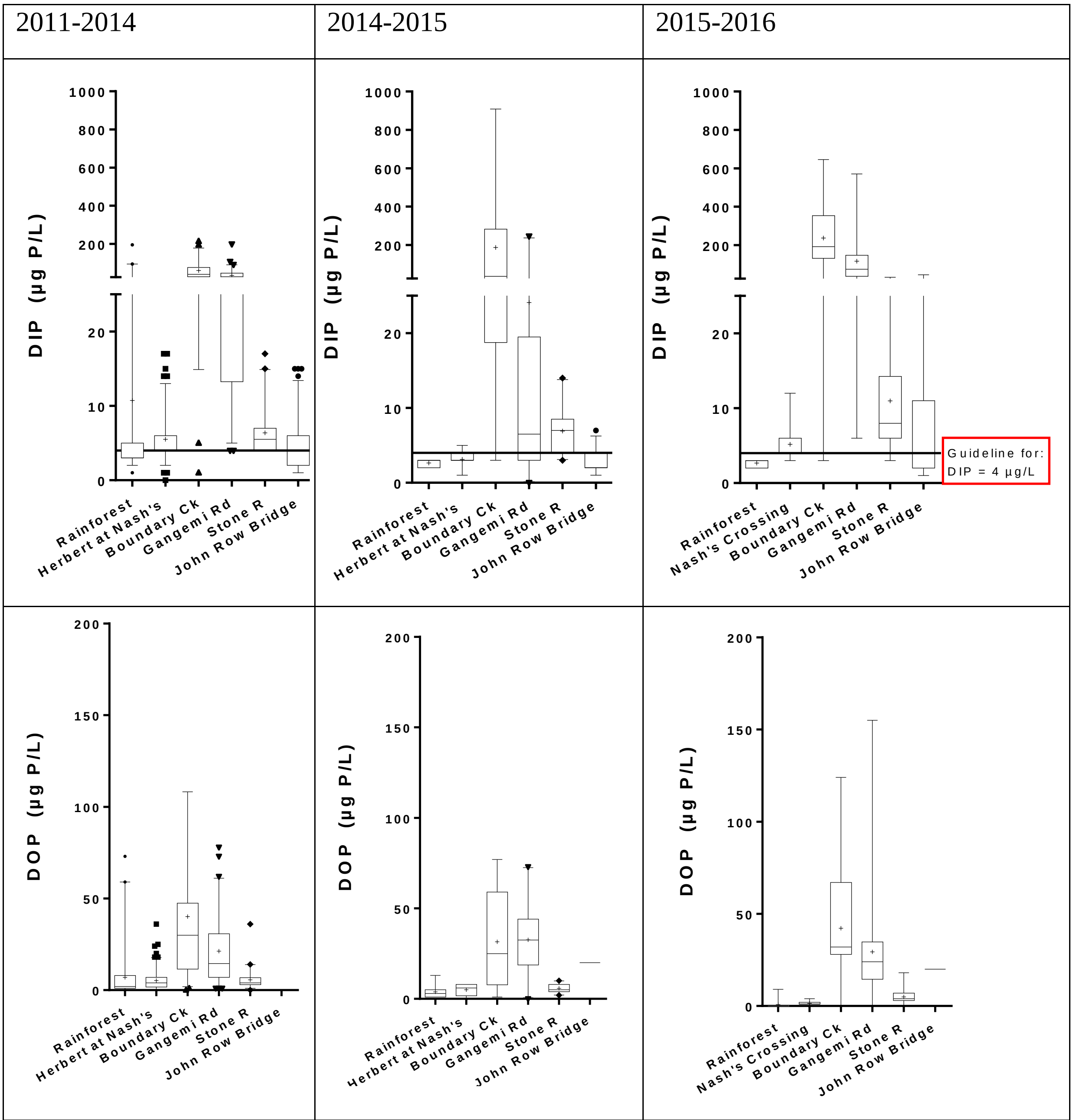
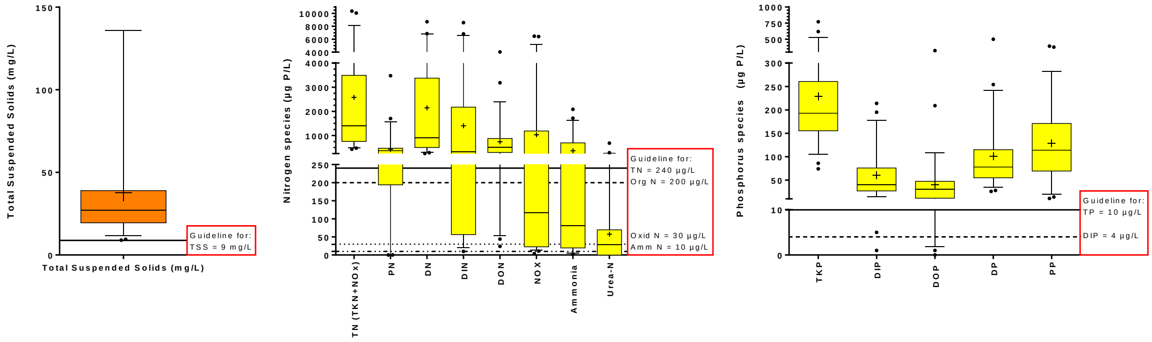
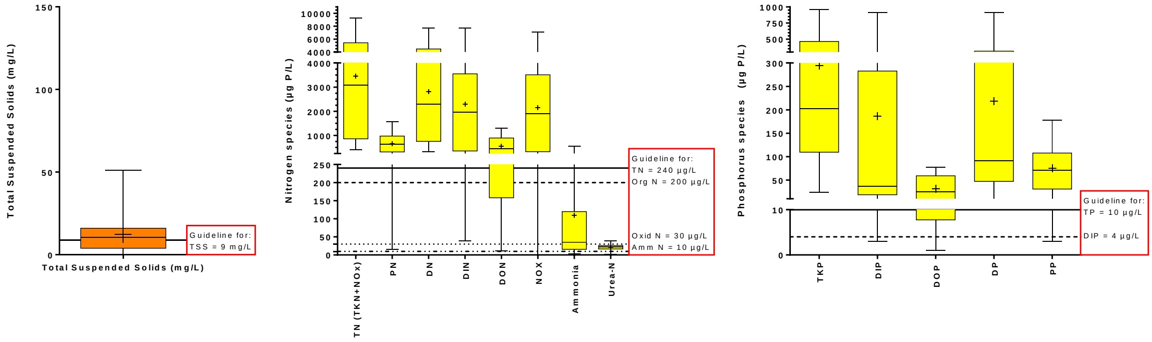


Figure 10: Concentrations of total dissolved inorganic phosphorus (DIP) and dissolved organic phosphorus (DOP) measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

2011-2014



2014-2015



2015-2016

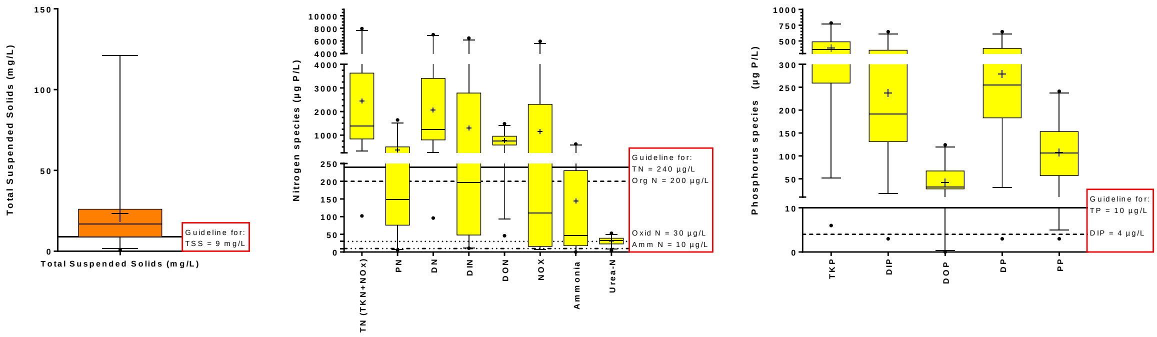
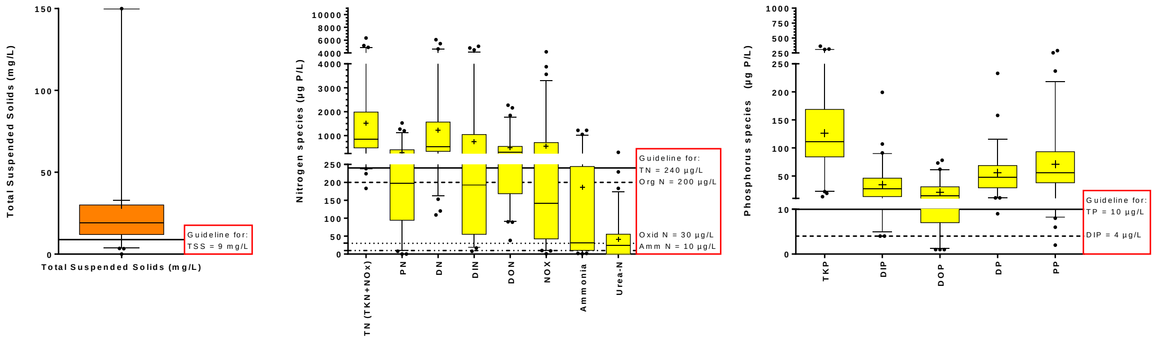
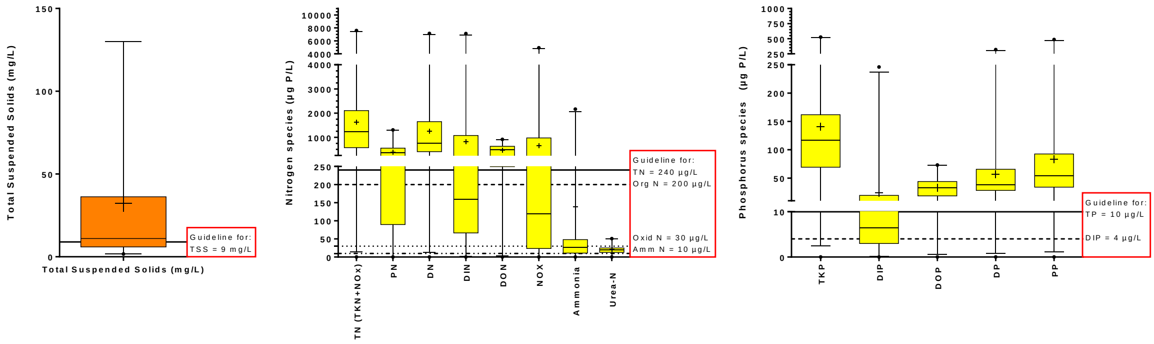


Figure 11: Concentrations of nutrient species measured at Boundary Creek per water year (2014-2015 and 2015-2016) and between 2011 and 2014.

2011-2014



2014-2015



2015-2016

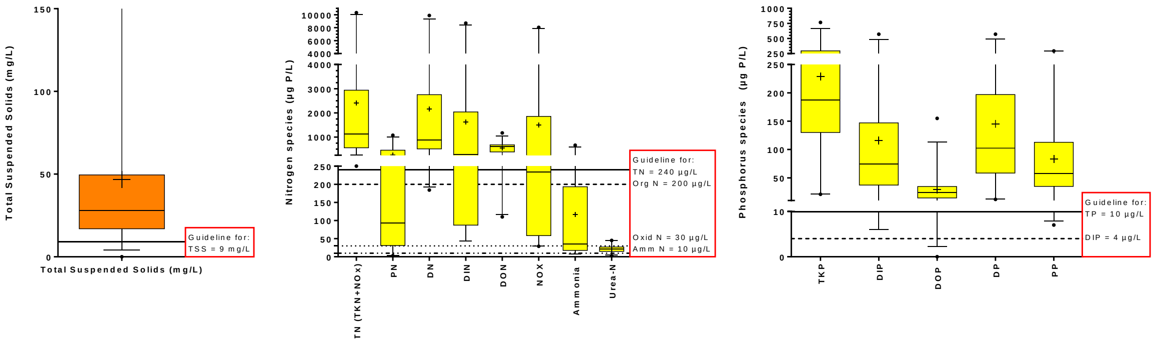
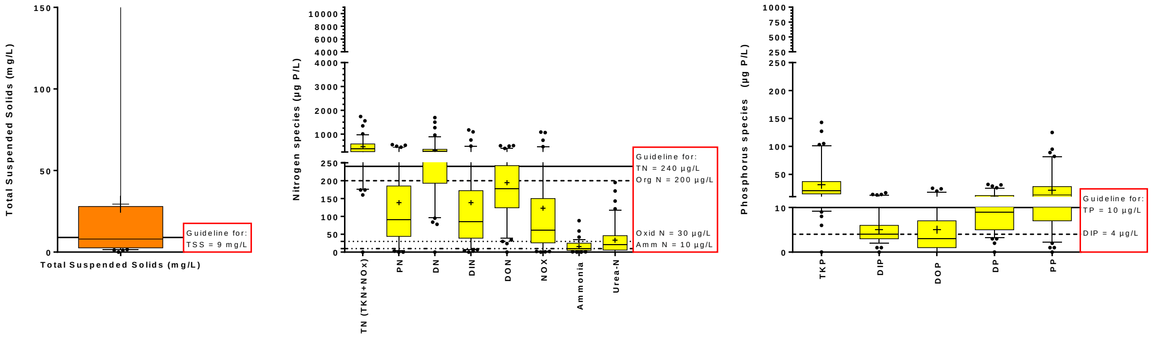
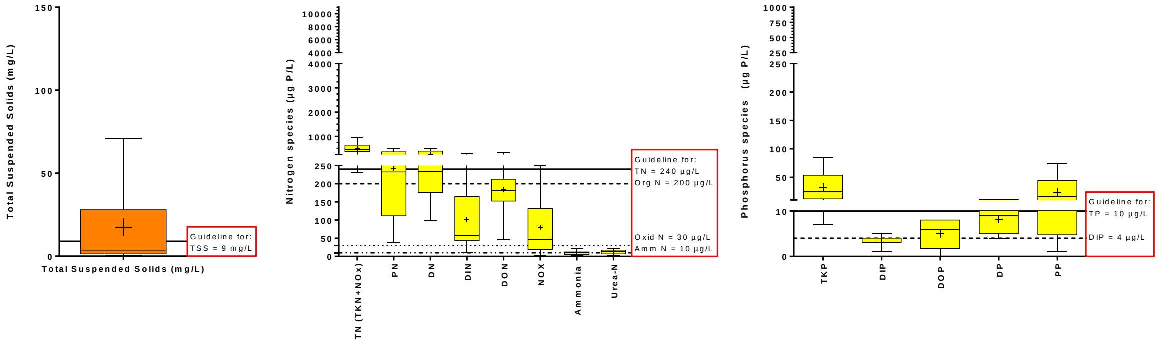


Figure 12: Concentrations of nutrient species measured at Gangemi Rd per water year (2014-2015 and 2015-2016) and between 2011 and 2014.

2011-2014



2014-2015



2015-2016

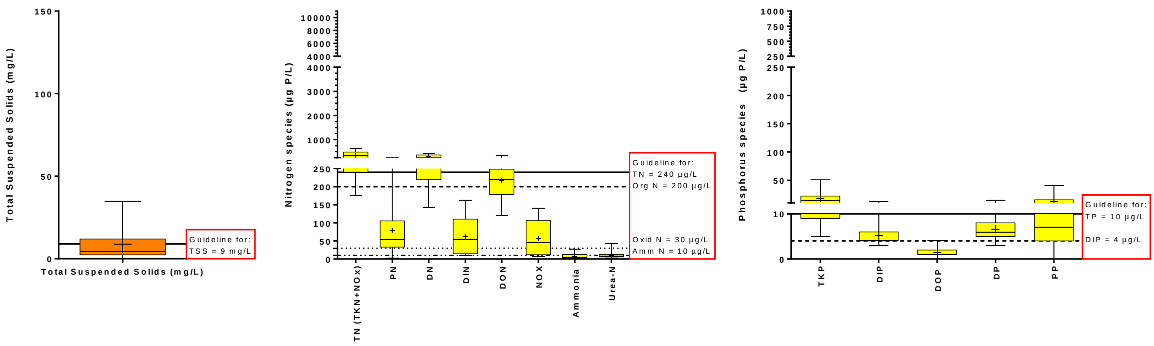
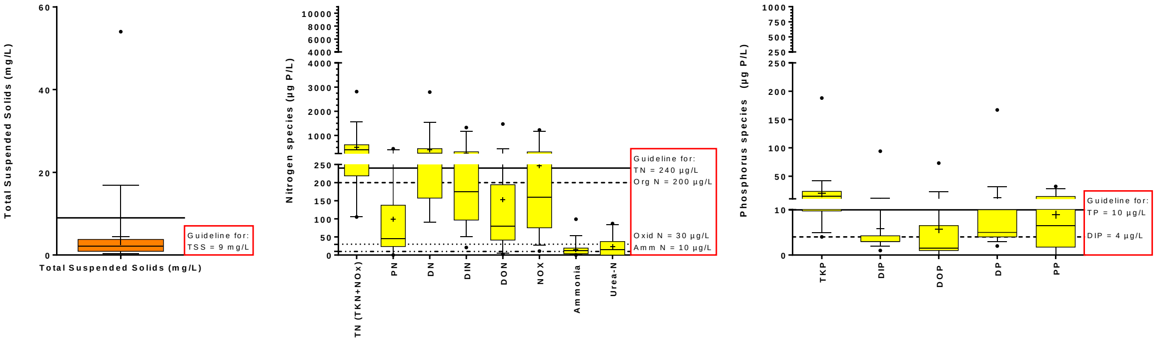
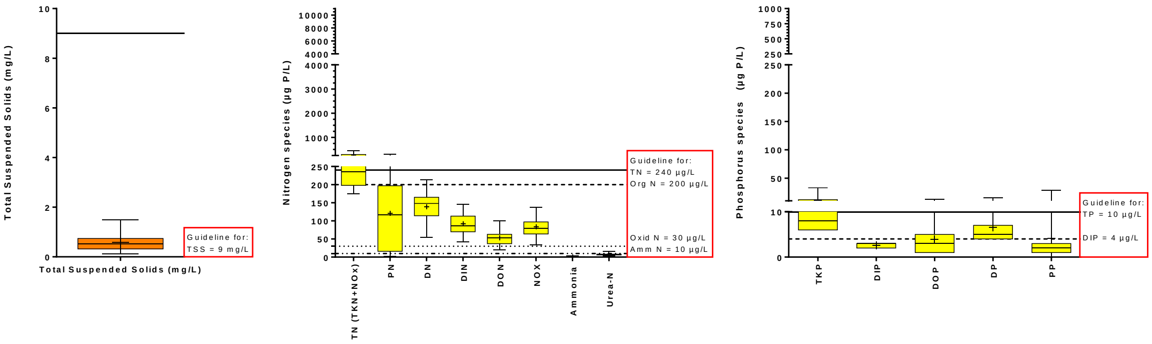


Figure 13: Concentrations of nutrient species measured in the Herbert R at Nash's Crossing per water year (2014-2015 and 2015-2016) and between 2011 and 2014.

2011-2014



2014-2015



2015-2016

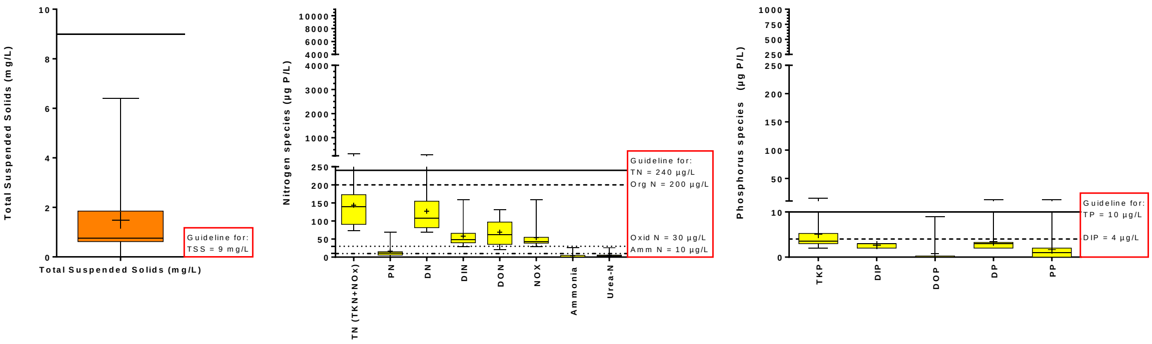
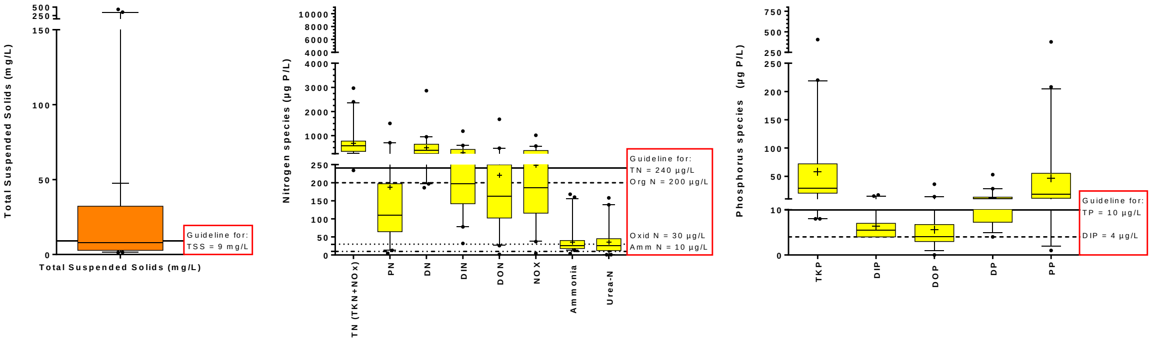
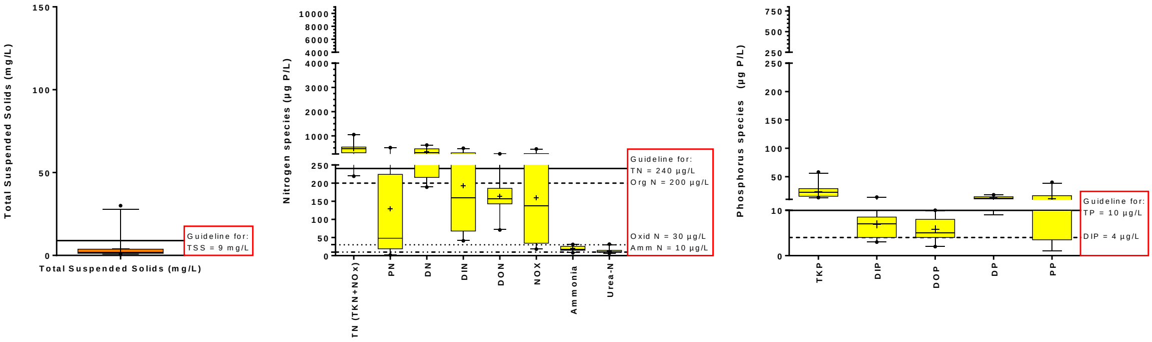


Figure 14: Concentrations of nutrient species measured in the rainforest reference site per water year (2014-2015 and 2015-2016) and between 2011 and 2014.

2011-2014



2014-2015



2015-2016

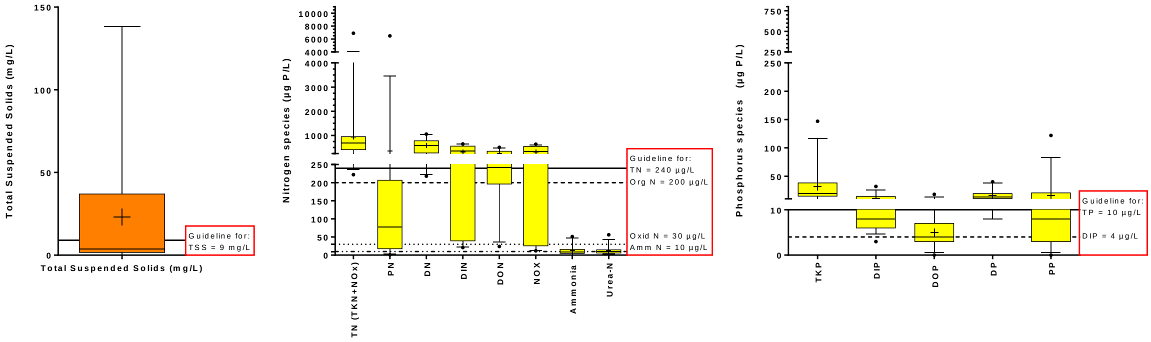
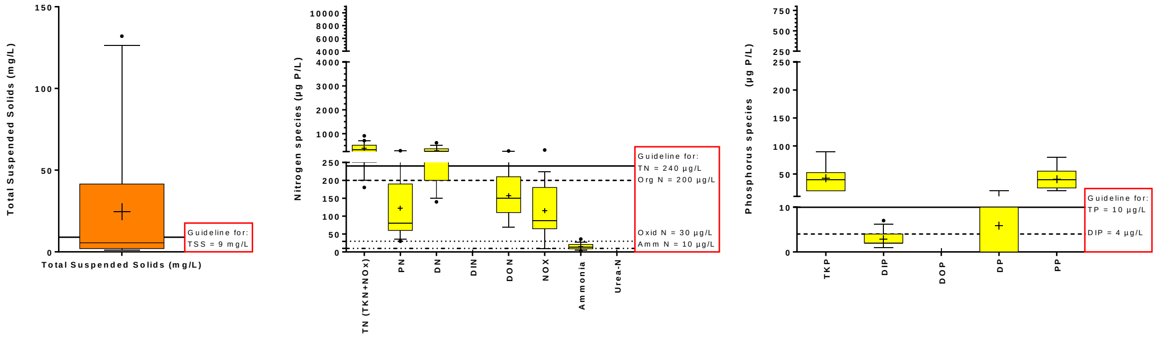


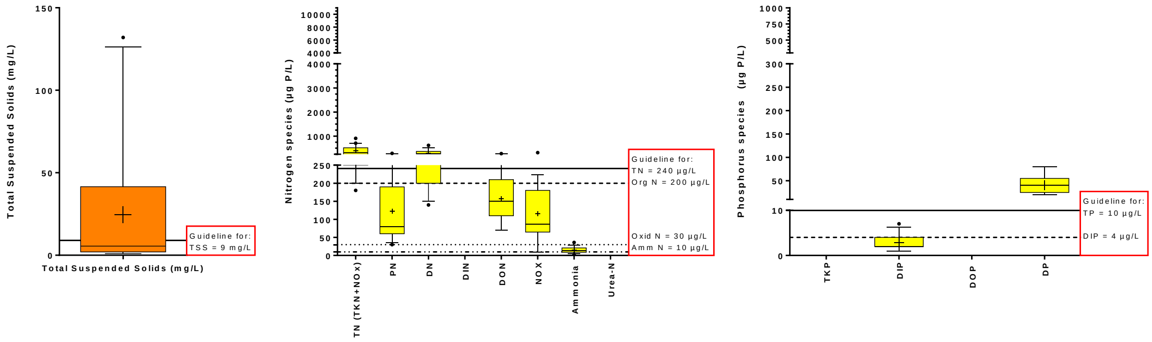
Figure 15: Concentrations of nutrient species measured in Stone R per water year (2014-2015 and 2015-2016) and between 2011 and 2014.

John Row Bridge

2011-2014



2014-2015



2015-2016

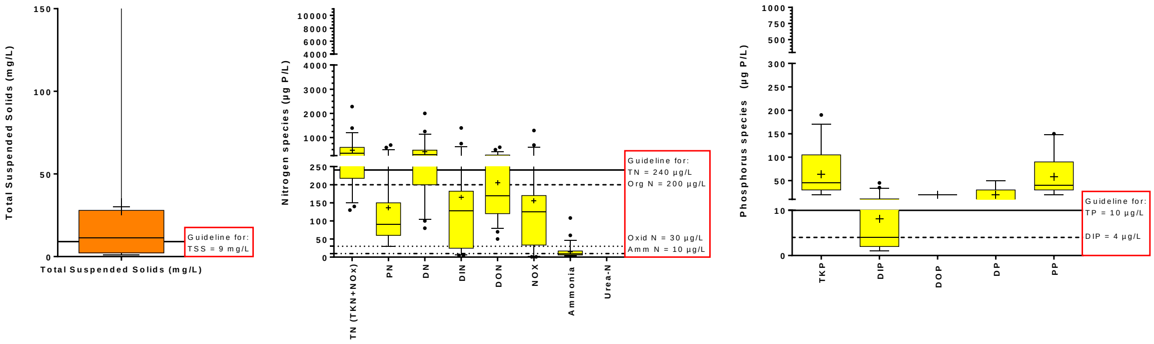


Figure 16: Concentrations of nutrient species measured in the Herbert R at John Row Bridge per water year (2014-2015 and 2015-2016) and between 2011 and 2014.

4.4 Pesticides sampling

Atrazine: The 2015-2016 results continue to indicate that there has been a shift away from atrazine use within the Herbert Catchment that was observed during monitoring in the 2014-2015 water year. This is reflected in the sustained recording of atrazine concentrations across all sampling sites below 0.7 µg/L.

Diuron: Given the change in regulation application rates we anticipated that there would be an associated decrease in diuron concentration observed by approximately ½ during our ongoing monitoring. However, no change in the concentration range was recorded and an increase in the mean concentrations measured at Gangemi/Hawkins Creek was recorded during the 2014-2015 water year. The observation during the 2014-2015 water year may have been due to the low number of ambient samples taken where no flow (no sample) has contributed to the higher mean. However, diuron concentrations recorded during the 2015-2016 water year continued to report concentrations comparable to those measured during 2011-2014 (prior to the change in regulation application rates).

Targeted extension/ grower workshops are ongoing in the Herbert to further reduce the impact of Diuron on WQ. HCPSL are also continuing to work with agri-chemical companies to seek alternative herbicides to Diuron.

Hexazinone: As with diuron we anticipated that the concentrations of hexazinone should have decreased with because of the change in use regulation however there has been no shift in concentration range during the 2014-2015 and 2015-2016 sampling years. Concentrations of hexazinone parallel those of diuron with an increase in mean concentrations recorded at Boundary Ck and Gangemi's/Hawkins Ck during the 2014-2015 sampling year that reflected the lack of ambient/low flow samples that generally contribute lower concentrations within the sampling pool. Hexazinone concentrations recorded during the 2015-2016 water year were comparable (in mean and range) to the concentrations recorded between 2011 and 2014.

Imidacloprid: Concentrations of Imidacloprid in surface waters monitored within the Herbert Catchment, particularly in the Boundary Creek and Stone River growing areas, are an ongoing concern.

Boundary Creek has no known issues with cane grubs, for which this product is permitted. Anecdotal evidence suggests that there was some link between the use of Imidacloprid and reduced expression of Yellow Canopy Syndrome (YCS), yet since this product is not registered for such use, there is no reason why farmers in this area should be applying Imidacloprid. Previous monitoring did not identify Imidacloprid as an issue at this site and thus the previous targeted extension that was undertaken to manage Imidacloprid use in the Herbert did not include farmers from this sub catchment.

Extension response to imidacloprid issues 2011 - 2014.

In response to early detections from the HWQMP (2011-2014), Herbert Cane Productivity Services Limited (HCPSL) conducted several growers shed meetings throughout the district in late August- early September 2012 to inform growers of the impeding risks associated with the improper use of Imidacloprid, its impact on water quality and recommendations for effective grub control with minimal runoff. Over 150 growers attended the meetings. The targeted extension program also focussed on issues associated with placement and timing of the product. Due to the project, it was found that placement in field was inadequate, hence numerous applicators have been redesigned and since modified.

Since the targeted extension approach in late 2012, associated with product timing and placement, there has been a considerable reduction in Imidacloprid levels detected in water samples in the sugarcane sub-catchments monitored by the HWQMP. Imidacloprid levels detected in water decreased while the area treated by the product in the Herbert has increased substantially over the three-year period during the HWQMP (Murphy, personal communication, 2014). This change could be attributed to the large extension effort and improved practices adopted by the Herbert industry to manage the use of Imidacloprid; Figure 18 shows the changes over time due the extension strategy implemented.

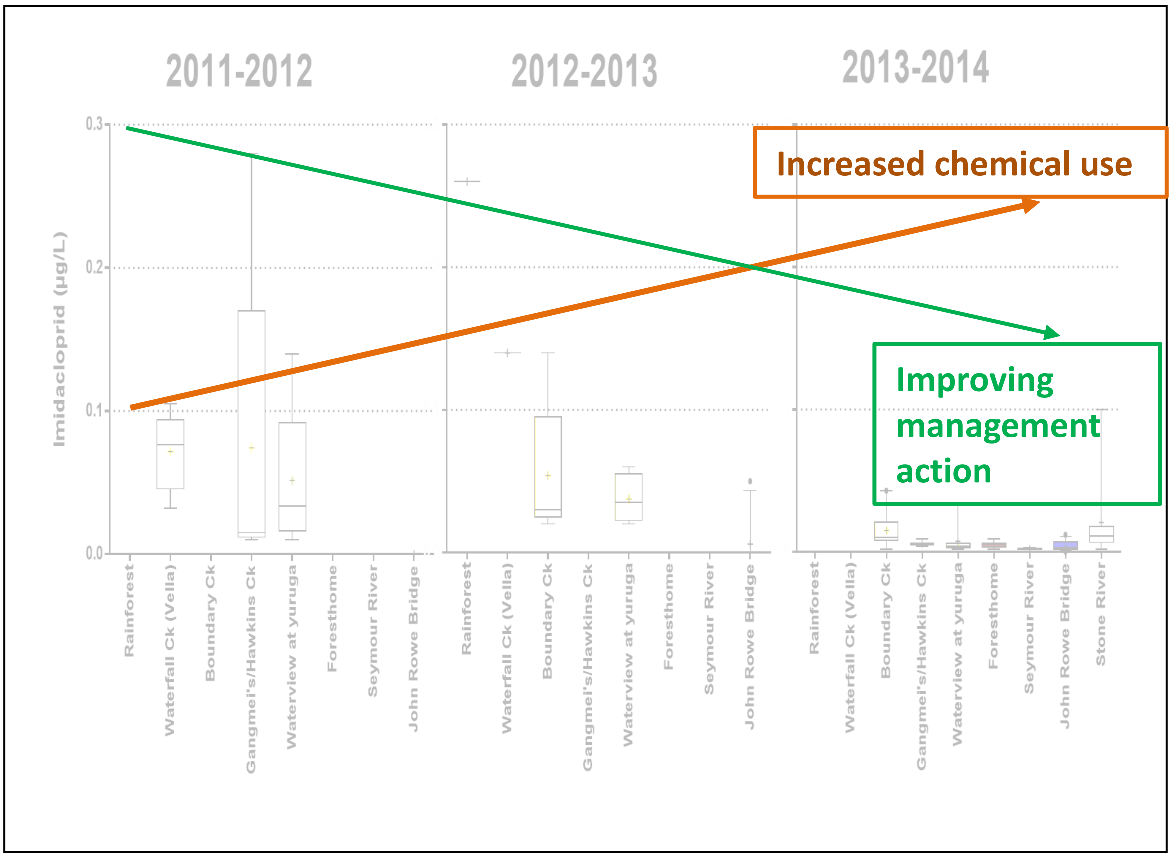


Figure 18: Comparing years for Imidacloprid levels found in water quality samples taken as a part of the HWQMP.

Managing Imidacloprid over the long term.

While engagement with farmers appeared to lead to effective management of Imidacloprid use within most sugar growing areas within the Herbert catchment (i.e. decrease in concentrations at all sites between 2012-2013 and 2014-2015 sampling years), there is ongoing cause for concern about the concentrations of Imidacloprid in surface waters monitored within the Herbert Catchment, particularly in the Boundary Creek and Stone River growing areas.

HCPSL has investigated these latest WQ findings and issued growers in the Boundary Creek sub-catchments with formal letters advising them of the registered label use and the latest facts concerning YCS. Ongoing extension activities to maintain the importance of effectively managing the use Imidacloprid to ensure that the use of this insecticide will remain available within the cane industry.

Metolachlor: Detections were all within the range of detection recorded during previous years.

Ametryn: Ametryn is only used in wet years or as a knockdown herbicide at lower rates; the results reflect low usage of this product during the 2014-2015 sampling year. While the 2015-2016 was a wetter year, Ametryn was not detected in any samples collected.

Revised guidelines have been established for Ametryn. During the 2014-2015 water year~50% of detections from both Boundary and Hawkins Creeks exceed the 99% species protection guideline. Concentrations do not exceed the 95% SP guidelines which are more applicable given the impacted condition of the Herbert Catchment agricultural area.

<u>Other pesticides of note</u>

Triclopyr: Triclopyr is not registered for use in sugarcane. During 2014-2015 nine detections (3 at Boundary Creek and 5 at Gangemi's Rd/Hawkins Ck) were recorded with concentrations of up to 0.67 µg/L. Registered use is for pasture and woody weeds. Uncertainty with regard to the source of these detections lead to concerns that off label use may have been occurring within the catchment area. As such, HCPSL met with Herbert agricultural resellers in 2015 to discuss the issue concerning Triclopyr use in sugarcane.

No detections of Triclopyr were recorded during the 2015-2016 water year.

Metsulfuron Methyl: Metsulfuron Methyl is not registered for use in sugarcane (trading as Brush-off®). It is a sulfonylurea herbicide that is registered for use in urban, industrial, commercial, pasture, and grain crops on broadleaf weeds and some annual grasses. Following the detection of Metsulfuron methyl in 15 samples (concentrations ranging between 0.01 and 0.48 µg/L, with the majority of detections recorded in samples collected at Boundary and Hawkins Creeks) during the 2014-2015 water year. HCPSL has met with Herbert agricultural resellers in 2016 to discuss issues concerning issues concerning Metsulfuron Methyl use. HCPSL sent a letter to all growers in early 2015 to discontinue the use of Metsulfuron methyl in sugarcane crops and on fallow blocks to be planted back into cane. The products use has been linked to poor germination of plant cane crops in the Herbert region.

During the 2015-2016 water year 11 samples collected at Boundary and Hawkins Creeks returned detection of metsulfuron methyl at concentrations between 0.02 and 1.2 µg/L.

Table 12: Pesticide sampling summary for the 2014-2015 sampling year (data includes number of detections (n), number of non-detects (ND) and minimum (min), maximum (max), median and the 95th percentile concentrations recorded across the sampling period).

		All sites						Nash's Crossing					
				Concentration (µg/L)						Concentration (µg/L)			
Pesticide	LOD	n	ND	min	max	median	95th	n	ND	min	Max	median	95th
Diuron	0.01	43	15	0.02	15	1.7	8.44	0	9	0	0	--	--
Hexazinone	0.01	40	18	0.01	2.9	0.54	2.79	0	9	0	0	--	--
2,4-D	0.01	40	18	0.01	21	0.34	17.215	0	9	0	0	--	--
Atrazine	0.01	39	19	0.01	0.68	0.05	0.6	3	6	0.04	0.15	0.09	--
Fluroxypyr	0.01	38	20	0.01	20	0.47	4.23	0	9	0	0	--	--
Total Diuron	0.1	35	23	0.12	15	2.2	9.88	0	9	0	0	--	--
Imidacloprid	0.01	31	27	0.01	1.9	0.07	1.6	0	9	0	0	--	--
Metolachlor	0.01	22	36	0.01	0.55	0.05	0.4915	0	9	0	0	--	--
Metribuzin	0.01	20	38	0.01	0.29	0.045	0.2865	0	9	0	0	--	--
Total Isoxaflutole	0.01	20	38	0.01	0.35	0.04	0.346	0	9	0	0	--	--
Desethyl Atrazine	0.01	18	40	0.01	0.05	0.02	--	0	9	0	0	--	--
Total Imidacloprid	0.03	17	41	0.07	1.9	0.43	--	0	9	0	0	--	--
Metsulfuron methyl	0.01	15	43	0.01	0.48	0.03	--	0	9	0	0	--	--
Ametryn	0.01	10	48	0.01	0.07	0.01	--	0	9	0	0	--	--
Desisopropyl Atrazine	0.01	8	50	0.01	0.06	0.01	--	0	9	0	0	--	--
Imidacloprid metabolites	0.01	7	51	0.01	0.03	0.02	--	0	9	0	0	--	--
Triclopyr	0.01	8	48	0	0.67	0.075	--	0	8	0	0	--	--
Imazapic	0.01	2	56	0.02	0.02	0.02	--	0	9	0	0	--	--
Propazin-2-hydroxy	0.02	1	57	0.02	0.02	0.02	--	0	9	0	0	--	--
Haloxyfop (acid)	0.01	1	57	0.02	0.02	0.02	--	0	9	0	0	--	--
MCPA	0.01	1	57	0.01	0.01	0.01	--	0	9	0	0	--	--

Table 13: Pesticide sampling summary for the 2015-2016 sampling year (data includes number of detections (n), number of non-detects (ND) and minimum (min), maximum (max), median and the 95th percentile concentrations recorded across the sampling period).

		All sites						Nash's Crossing					
				Concentration (µg/L)						Concentration (µg/L)			
Pesticide	LOD	n	ND	min	max	median	95th	n	ND	min	Max	median	95th
Diuron	0.01	64	17	0.02	7	0.515	3.275	0	10	0	0	--	--
Hexazinone	0.01	64	17	0.01	6.2	0.295	1.8	0	10	0	0	--	--
2,4-D	0.01	47	34	0.14	25	0.48	15.32	0	10	0	0	--	--
Atrazine	0.01	20	61	0.04	0.52	0.11	0.513	0	10	0	0	--	--
Fluroxypyr	0.01	51	30	0.05	11	0.6	8.84	0	10	0	0	--	--
Total Diuron	0.1	59	22	0.06	7	0.64	3.3	0	10	0	0	--	--
Imidacloprid	0.01	57	24	0.02	1.9	0.18	1.71	0	10	0	0	--	--
Metolachlor	0.01	12	69	0.01	0.29	0.125	--	0	10	0	0	--	--
Metribuzin	0.01	14	67	0.02	0.48	0.03	--	0	10	0	0	--	--
Total Isoxaflutole	0.01	29	52	0.01	1.1	0.03	0.655	0	10	0	0	--	--
Desethyl Atrazine	0.01	10	71	0.02	0.07	0.035	--	0	10	0	0	--	--
Total Imidacloprid	0.03	50	31	0.04	1.9	0.275	1.745	0	10	0	0	--	--
Metsulfuron methyl	0.01	11	70	0.02	1.4	0.06	--	0	10	0	0	--	--
Ametryn	0.01	0	81	0	0	--	--	0	10	0	0	--	--
Desisopropyl Atrazine	0.01	5	76	0.02	0.05	0.03	--	0	10	0	0	--	--
Imidacloprid metabolites	0.01	4	77	0.02	0.05	0.035	--	0	10	0	0	--	--
Triclopyr	0.01	0	81	0	0	--	--	0	10	0	0	--	--
Imazapic	0.01	18	63	0.01	1.1	0.02	--	0	10	0	0	--	--
Propazin-2-hydroxy	0.02	0	81	0	0	--	--	0	10	0	0	--	--
Haloxyfop (acid)	0.01	8	73	0.02	0.15	0.04	--	0	10	0	0	--	--
MCPA	0.01	1	80	0.16	0.16	0.16	--	0	10	0	0	--	--

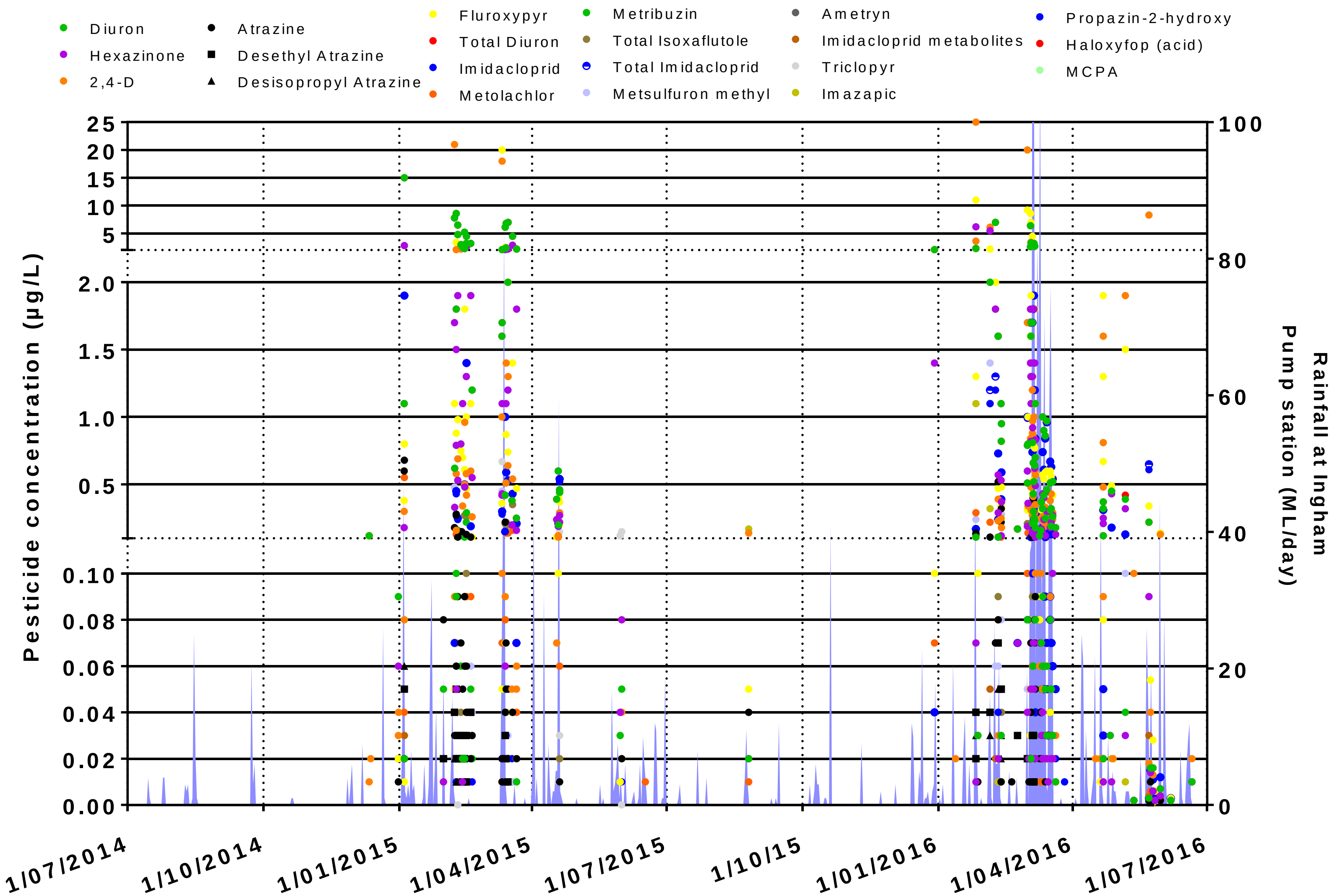


Figure 17: Pesticide detections across all sampling sites during the 2014-2016.

Table 14: Sugarcane site specific pesticide sampling summary for the 2014-2015 sampling year. (data includes sample number (n), number of non-detects (ND) and minimum (min), maximum (max), median and the 95th percentile concentrations recorded across the sampling period).

		Boundary Ck							Gangemi Rd						Stone R					
				Concentration (µg/L)						Concentration (µg/L)						Concentration (µg/L)			
Pesticide	LOD	n	ND	min	max	median	95th	n	ND	min	max	Median	95th	n	ND	min	max	median	95th
Diuron	0.01	15	3	0.2	15	4.5	--	20	0	0.03	8.6	1.45	8.56	8	3	0.02	1.6	0.07	--
Hexazinone	0.01	15	3	0.22	2.9	1.9	--	20	0	0.04	1.7	0.455	1.69	5	6	0.01	0.42	0.05	--
2,4-D	0.01	16	2	0.02	18	0.46	--	19	1	0.03	21	0.34	21	5	6	0.01	1	0.09	--
Atrazine	0.01	14	4	0.02	0.68	0.05	--	15	5	0.01	0.6	0.06	--	7	4	0.01	0.28	0.03	--
Fluroxypyr	0.01	14	4	0.05	20	0.84	--	20	0	0.01	3.4	0.375	3.32	4	7	0.01	0.36	0.05	--
Total Diuron	0.1	15	3	0.2	15	4.5	--	17	3	0.25	8.6	2	--	3	8	0.12	1.6	0.42	--
Imidacloprid	0.01	15	3	0.07	1.9	0.43	--	13	7	0.01	0.07	0.02	--	3	8	0.01	0.15	0.02	--
Metolachlor	0.01	13	5	0.03	0.55	0.09	--	7	13	0.01	0.04	0.02	--	2	9	0.01	0.01	0.01	--
Metribuzin	0.01	11	7	0.01	0.29	0.05	--	9	11	0.01	0.22	0.03	--	0	11	0	0	--	--
Total Isoxaflutole	0.01	11	7	0.02	0.35	0.2	--	9	11	0.01	0.1	0.02	--	0	11	0	0	--	--
Desethyl Atrazine	0.01	6	12	0.01	0.05	0.02	--	9	11	0.01	0.05	0.02	--	3	8	0.02	0.03	0.02	--
Total Imidacloprid	0.03	15	3	0.07	1.9	0.45	--	1	19	0.07	0.07	0.07	--	1	10	0.15	0.15	0.15	--
Metsulfuron methyl	0.01	7	11	0.01	0.45	0.02	--	7	13	0.01	0.48	0.03	--	1	10	0.01	0.01	0.01	--
Ametryn	0.01	4	14	0.01	0.02	0.01	--	6	14	0.01	0.07	0.015	--	0	11	0	0	--	--
Desisopropyl Atrazine	0.01	3	15	0.01	0.06	0.01	--	4	16	0.01	0.02	0.015	--	1	10	0.01	0.01	0.01	--
Imidacloprid metabolites	0.01	7	11	0.01	0.03	0.02	--	0	20	0	0	--	--	0	11	0	0	--	--
Triclopyr	0.01	3	14	0	0.67	0.135	--	5	15	0.01	0.15	0.03	--	0	11	0	0	--	--
Imazapic	0.01	2	16	0.02	0.02	0.02	--	0	20	0	0	--	--	0	11	0	0	--	--
Propazin-2-hydroxy	0.02	1	17	0.02	0.02	0.02	--	0	20	0	0	--	--	0	11	0	0	--	--
Haloxyfop (acid)	0.01	1	17	0.02	0.02	0.02	--	0	20	0	0	--	--	0	11	0	0	--	--
MCPA	0.01	1	17	0.01	0.01	0.01	--	0	20	0	0	--	--	0	11	0	0	--	--

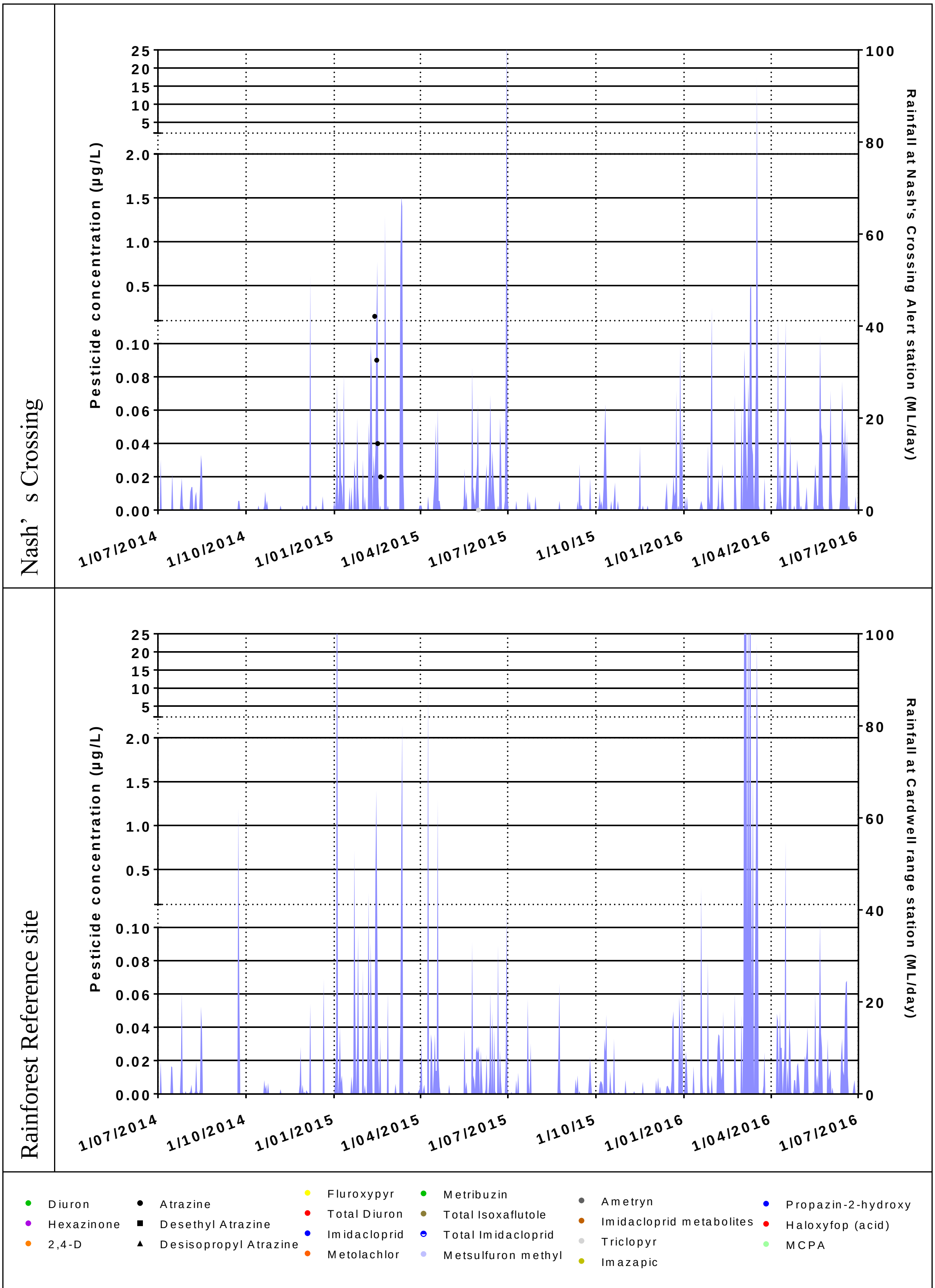


Figure 18: Pesticide detections in waters exiting the upper Herbert Catchment (Nash’s Crossing) and at the rainforest reference site in the lower catchment.

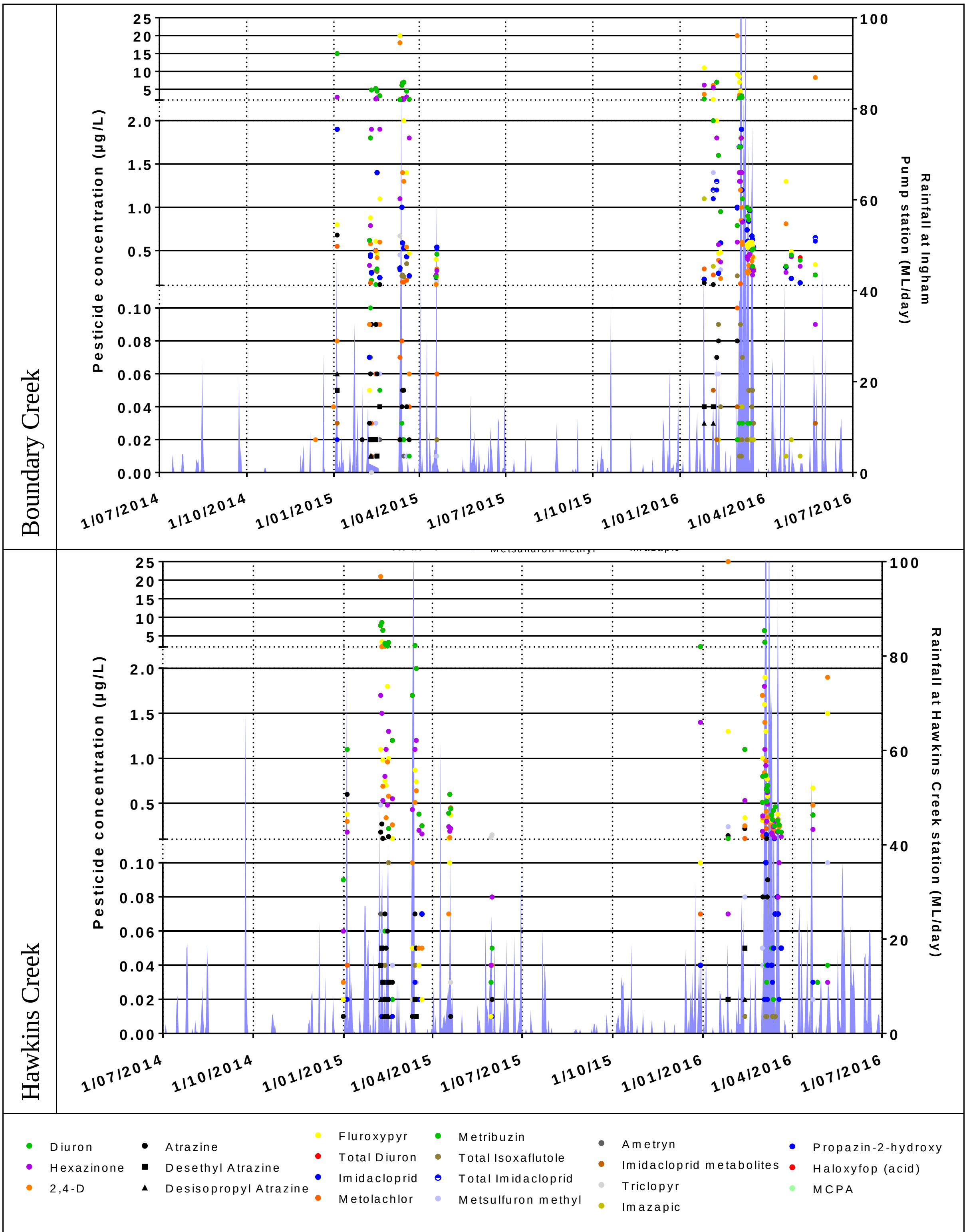


Figure 19: Pesticide detections in water sampled at Boundary Creek and Hawkins Creek in the Lower Herbert Catchment.

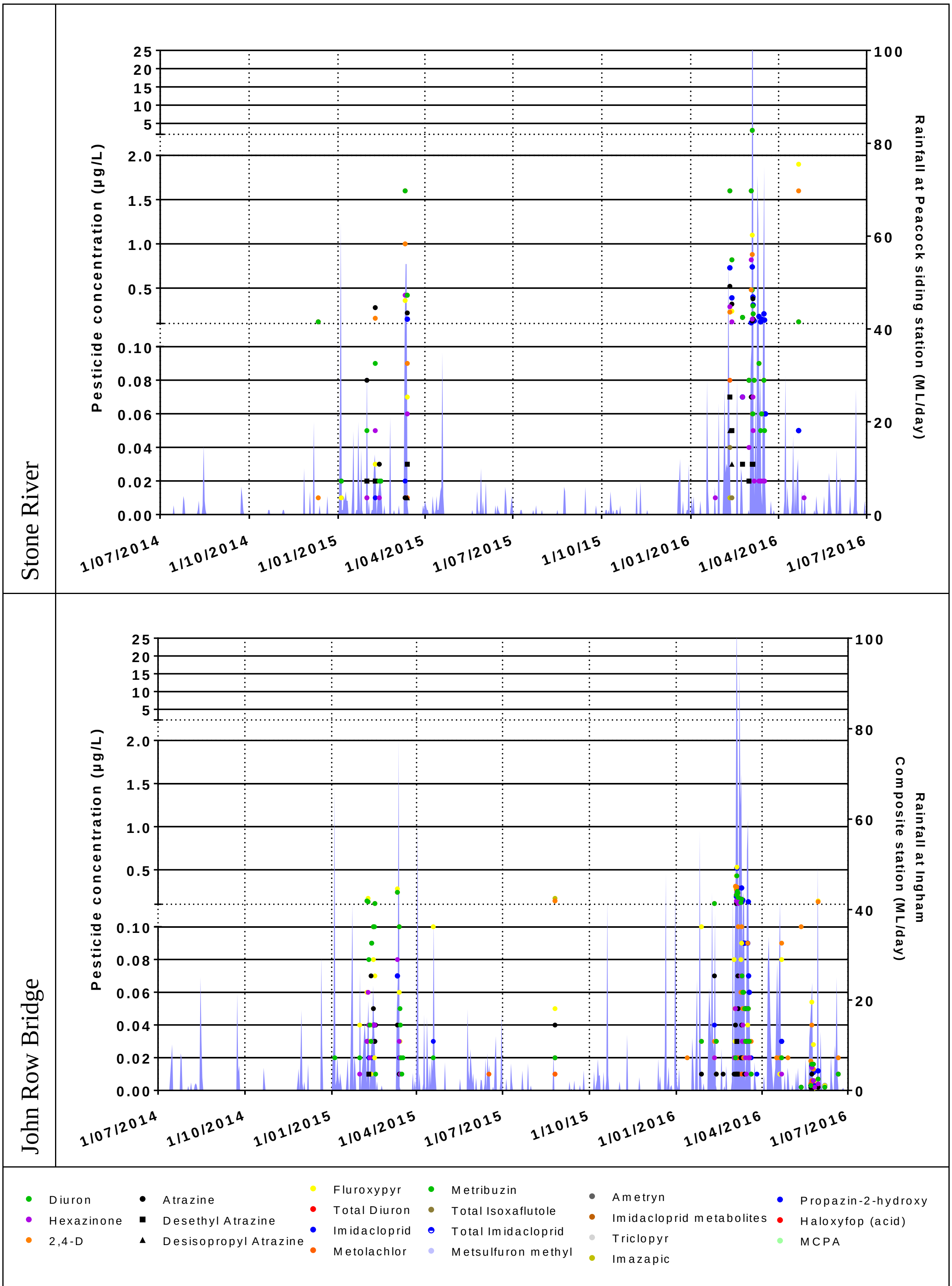


Figure 20: Pesticide detections in water sampled at Stone River and Herbert River at John Row Bridge in the Lower Herbert Catchment.

4.4.1 Atrazine

Nash's Crossing

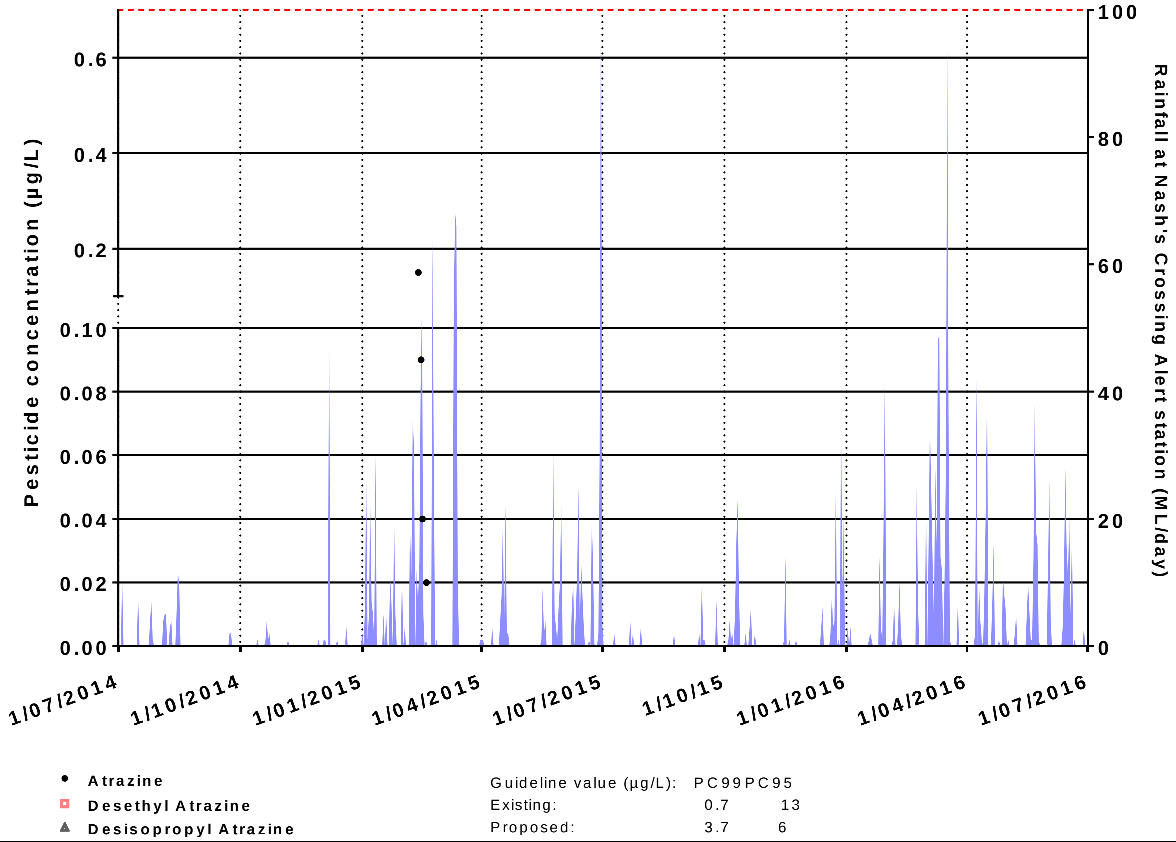


Figure 21: Atrazine detections in waters exiting the upper Herbert Catchment (Nash's Crossing).

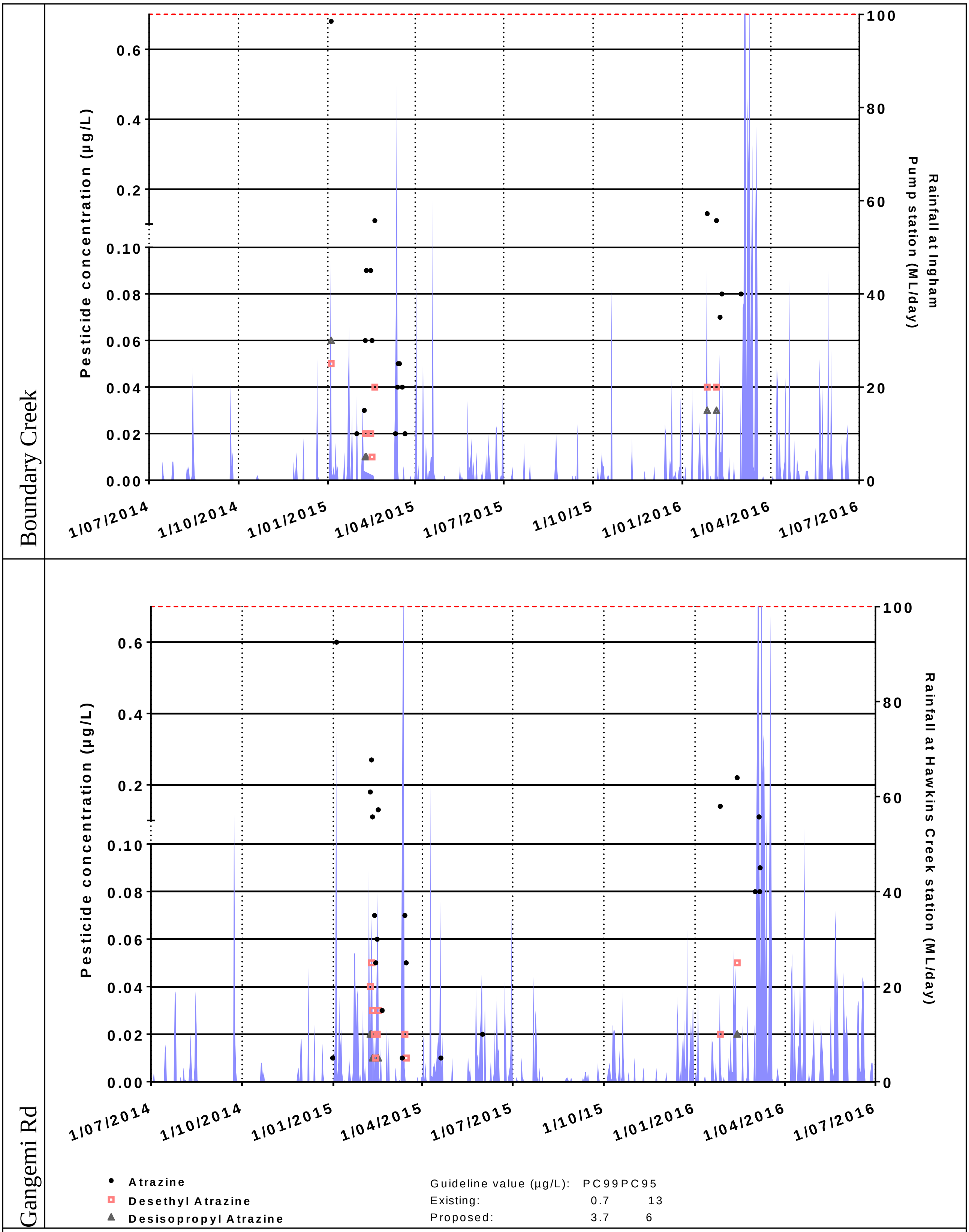


Figure 22: Atrazine detections in water sampled at Boundary Creek and Hawkins Creek in the Lower Herbert Catchment.

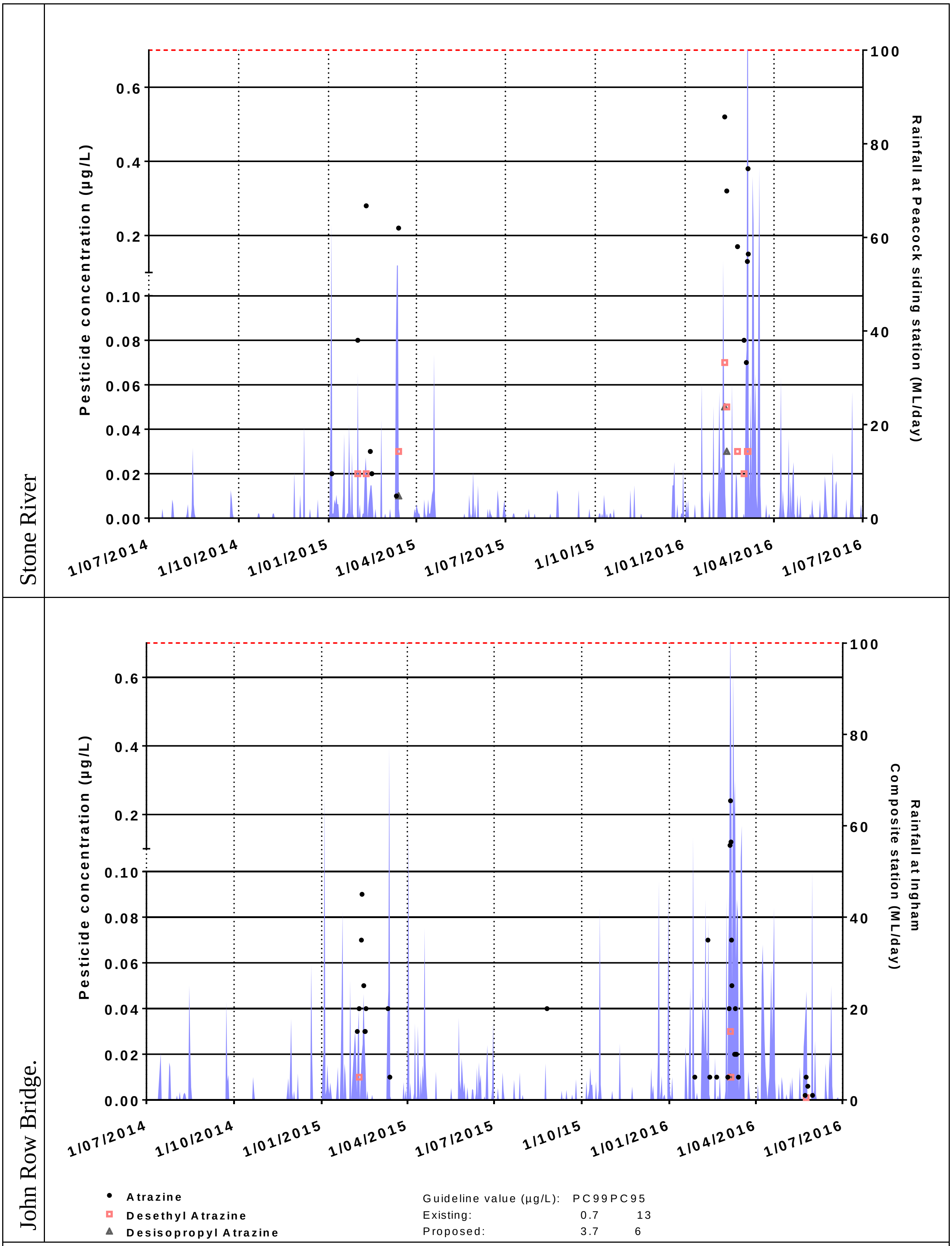


Figure 23: Atrazine detections in water sampled at Stone River and Herbert River at John Row Bridge in the Lower Herbert Catchment.

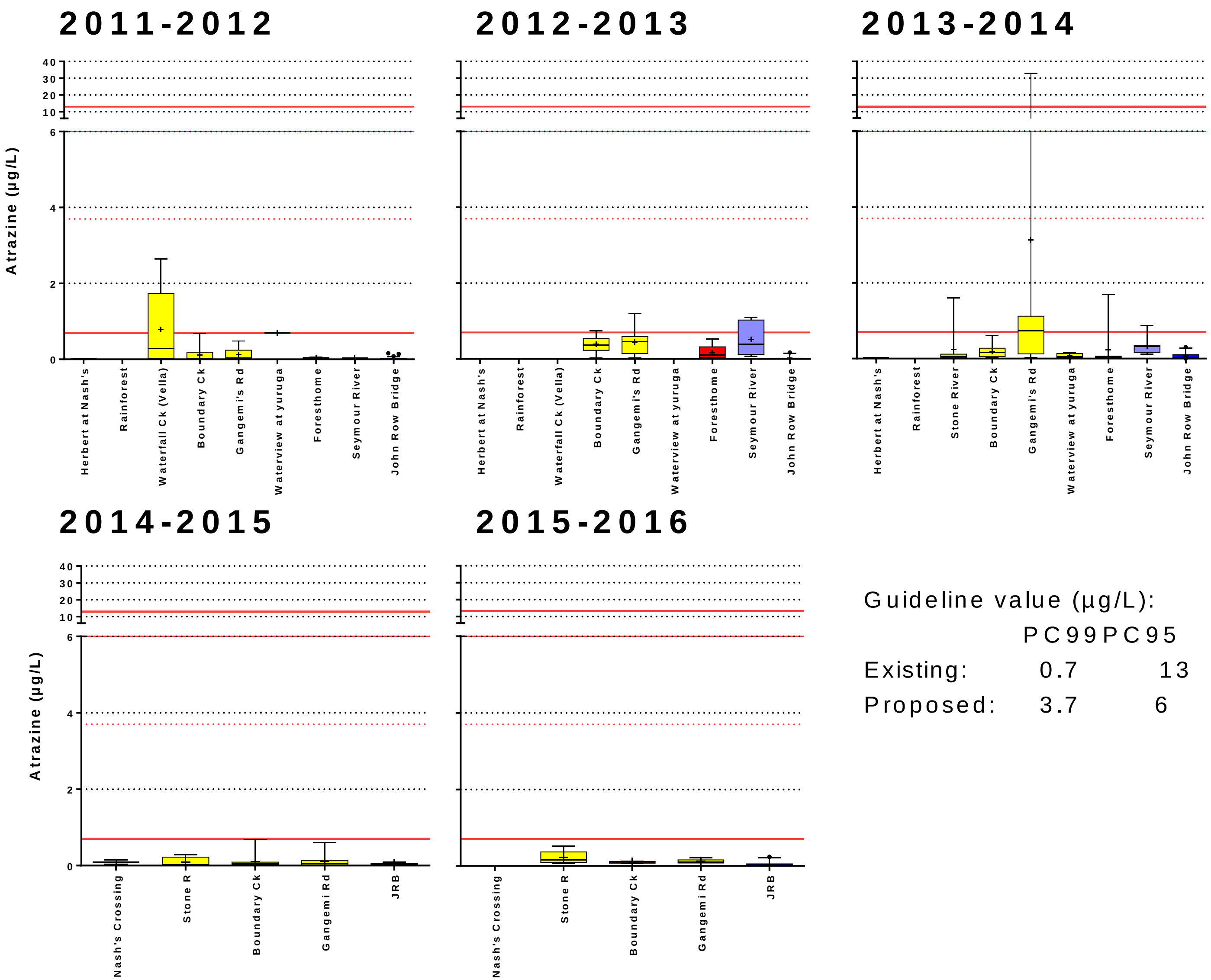


Figure 24: Concentration atrazine measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

4.4.2 Diuron and Hexazinone

Nash' s Crossing	No Detections

Figure 25: Diuron and hexazinone detections in waters exiting the upper Herbert Catchment (Nash's Crossing).

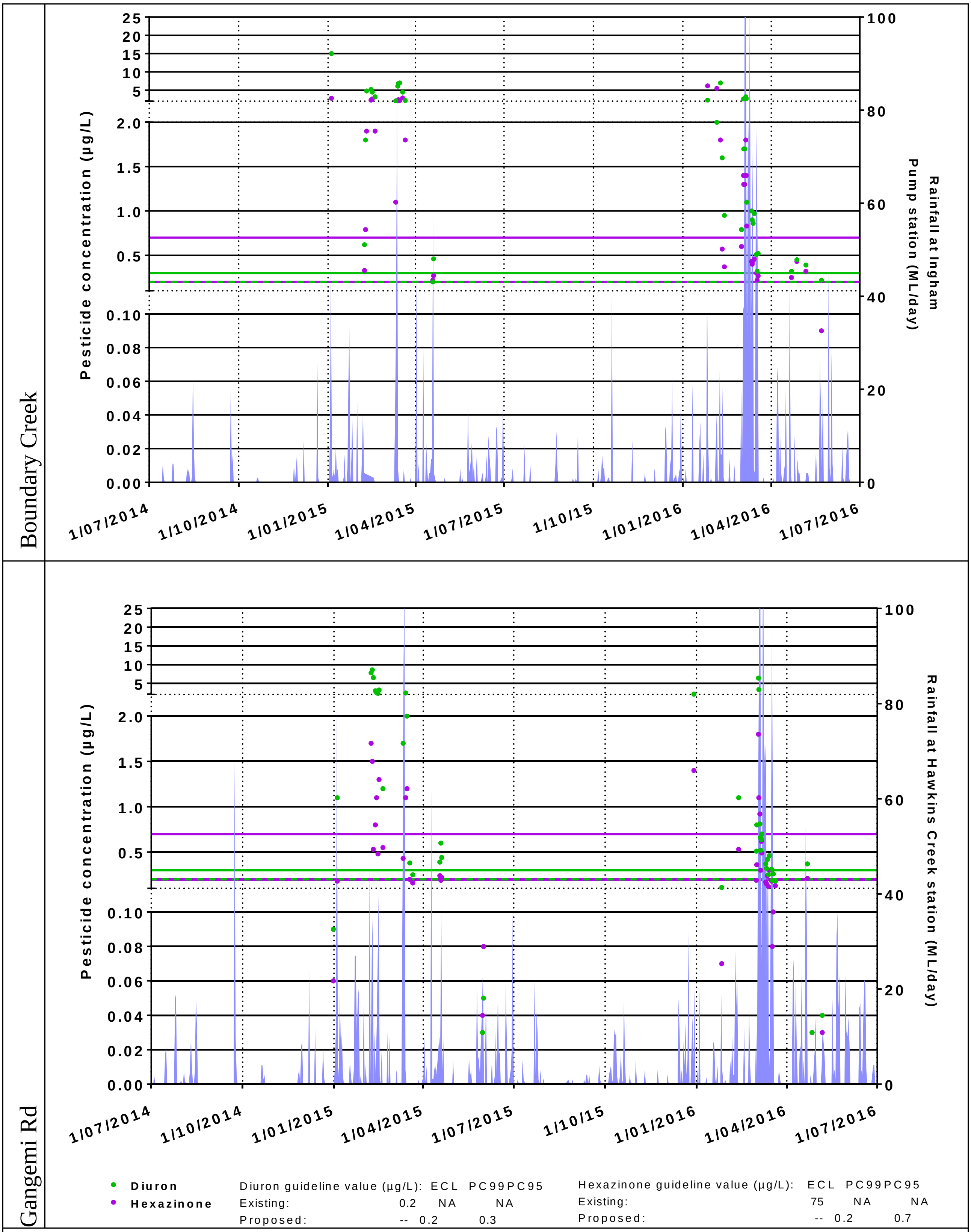


Figure 26: Diuron and Hexazinone detections in water sampled at Boundary Creek and Hawkins Creek in the Lower Herbert Catchment.

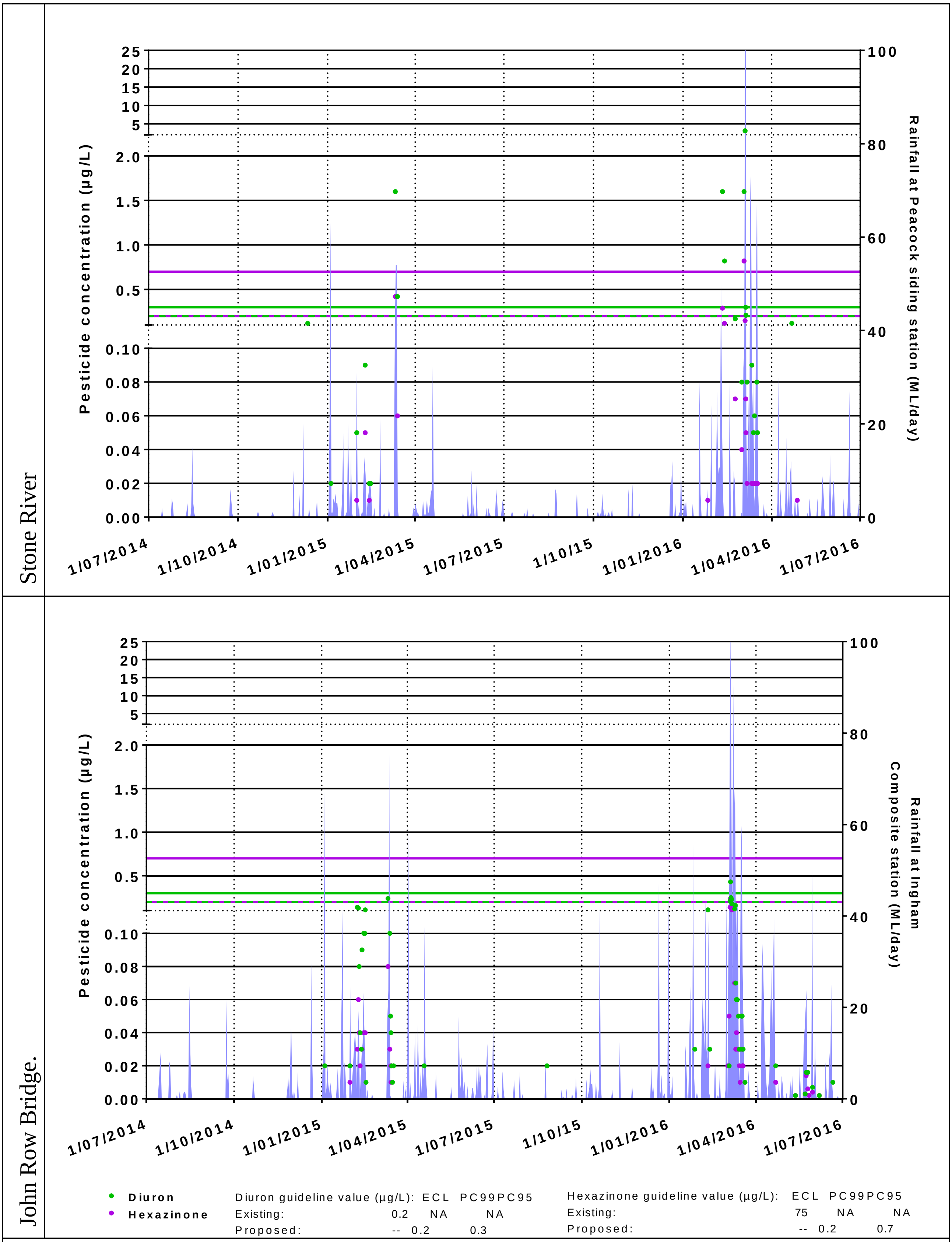


Figure 27: Diuron and Hexazinone detections in water sampled at Stone River and Herbert River at John Row Bridge in the Lower Herbert Catchment.

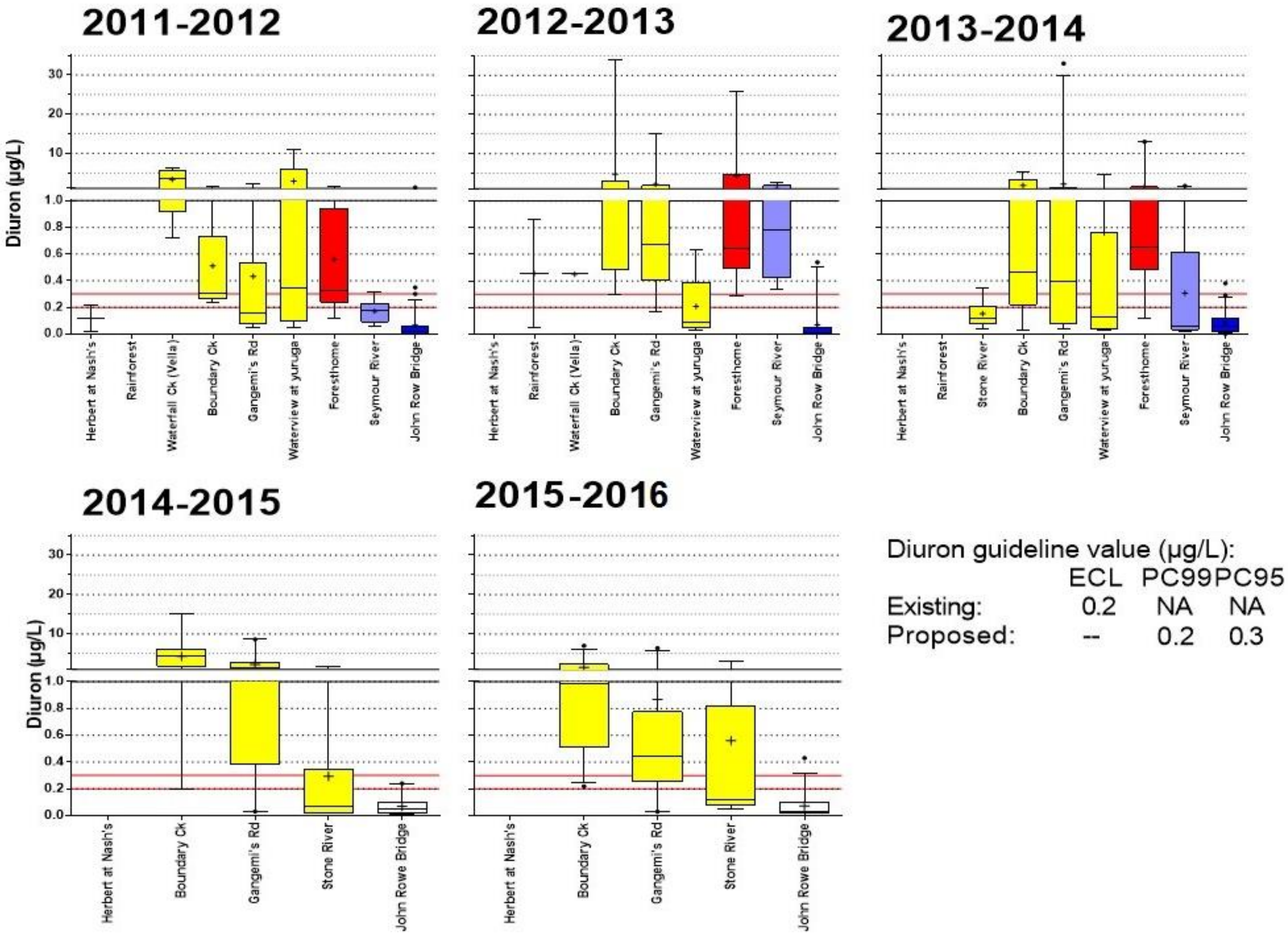


Figure 28: Concentration diuron measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

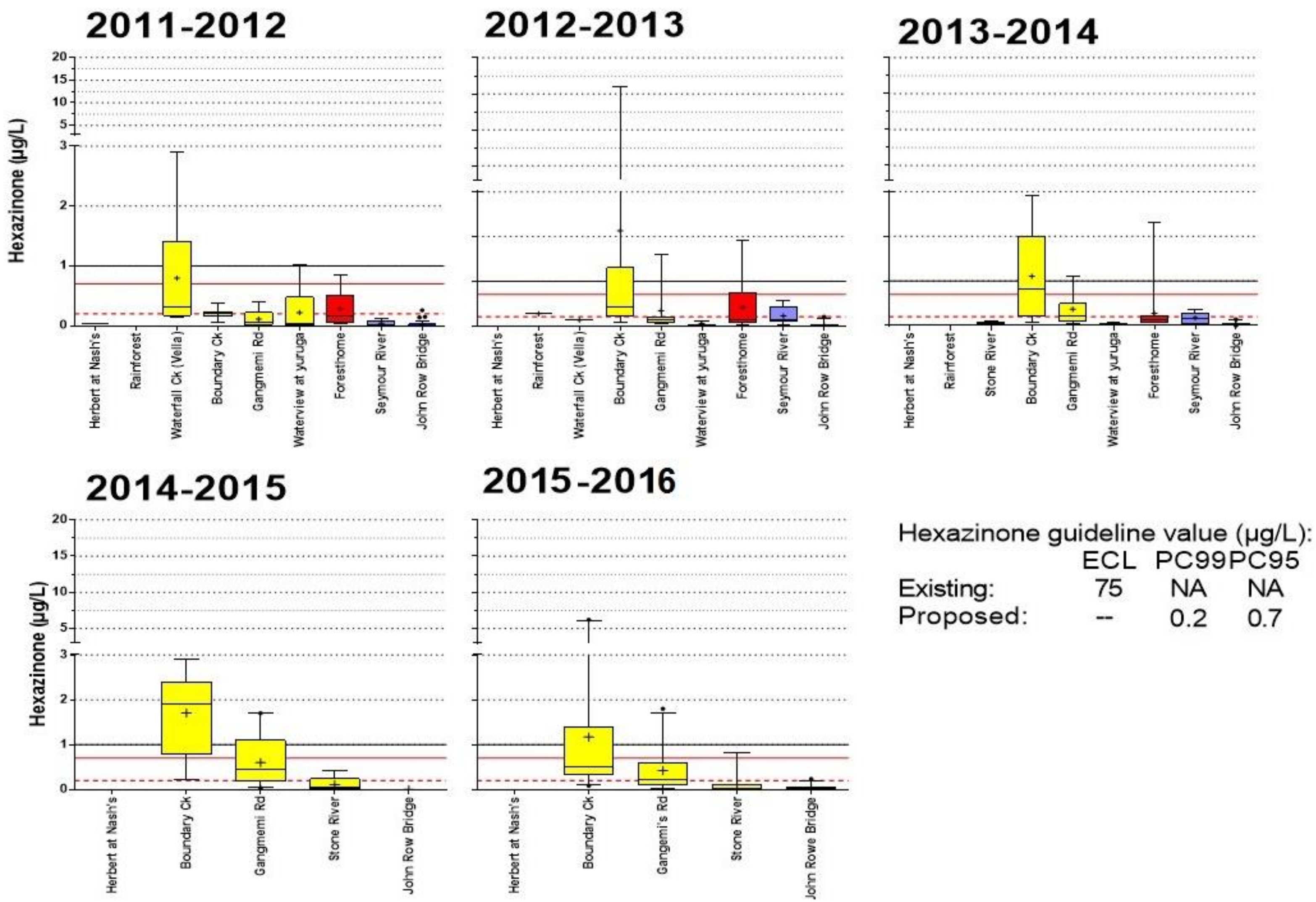


Figure 29: Concentration hexazinone measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

4.4.3 Imidacloprid

Nash's Crossing	No Detections

Figure 30: Imidacloprid detections in waters exiting the upper Herbert Catchment (Nash's Crossing).

Boundary Creek

Gangemi Rd

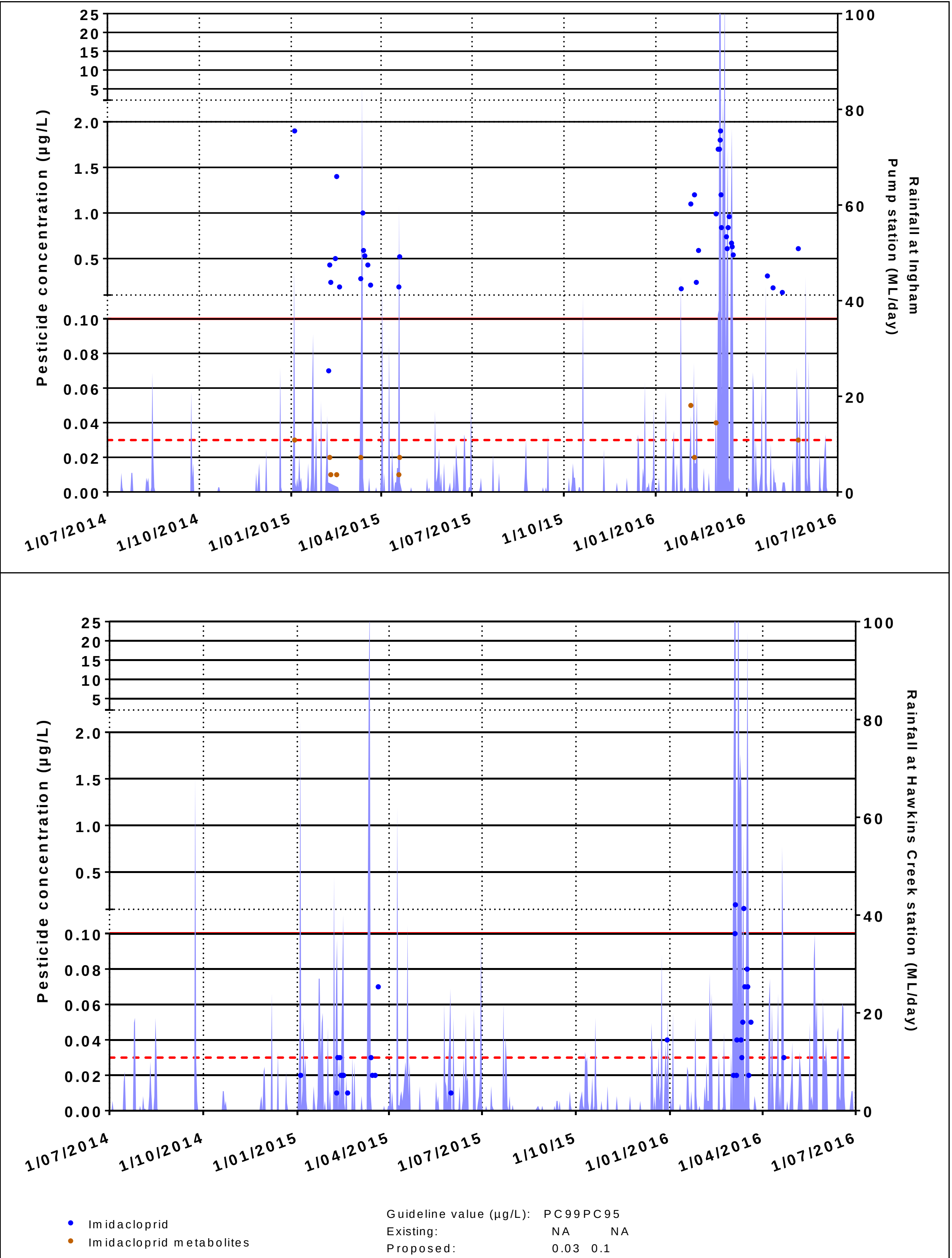
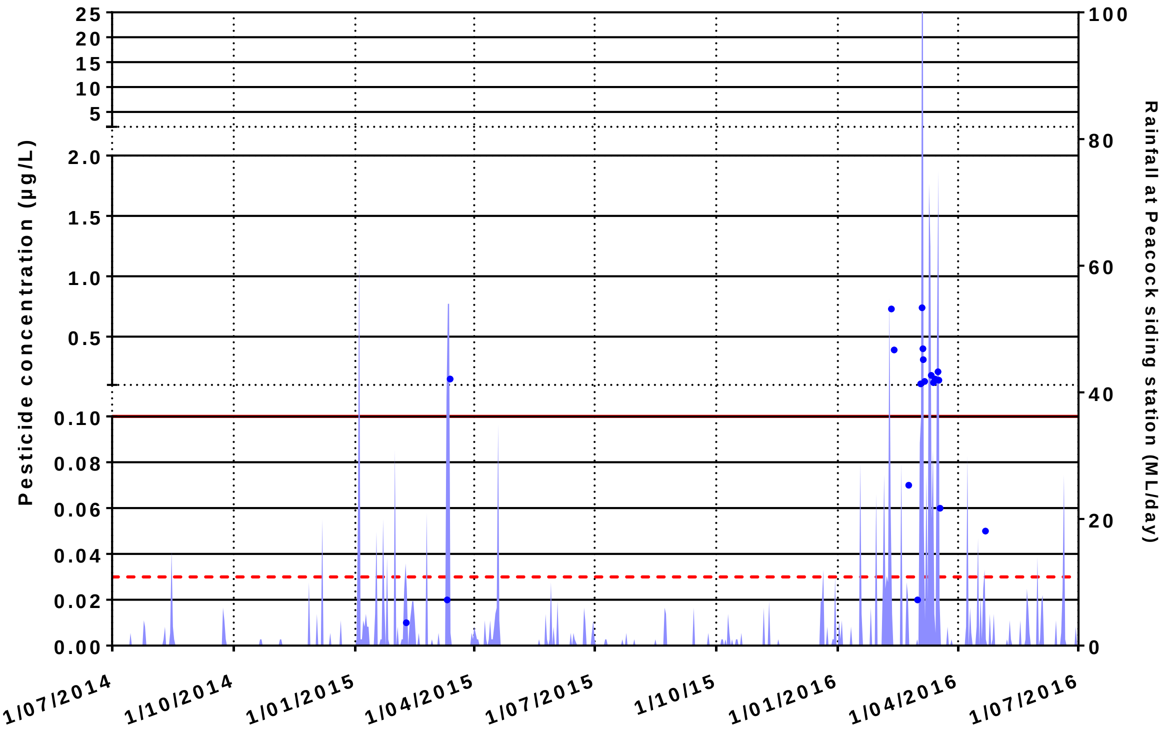


Figure 31: Imidacloprid detections in water sampled at Boundary Creek and Hawkins Creek in the Lower Herbert Catchment.

Stone River



John Row Bridge.

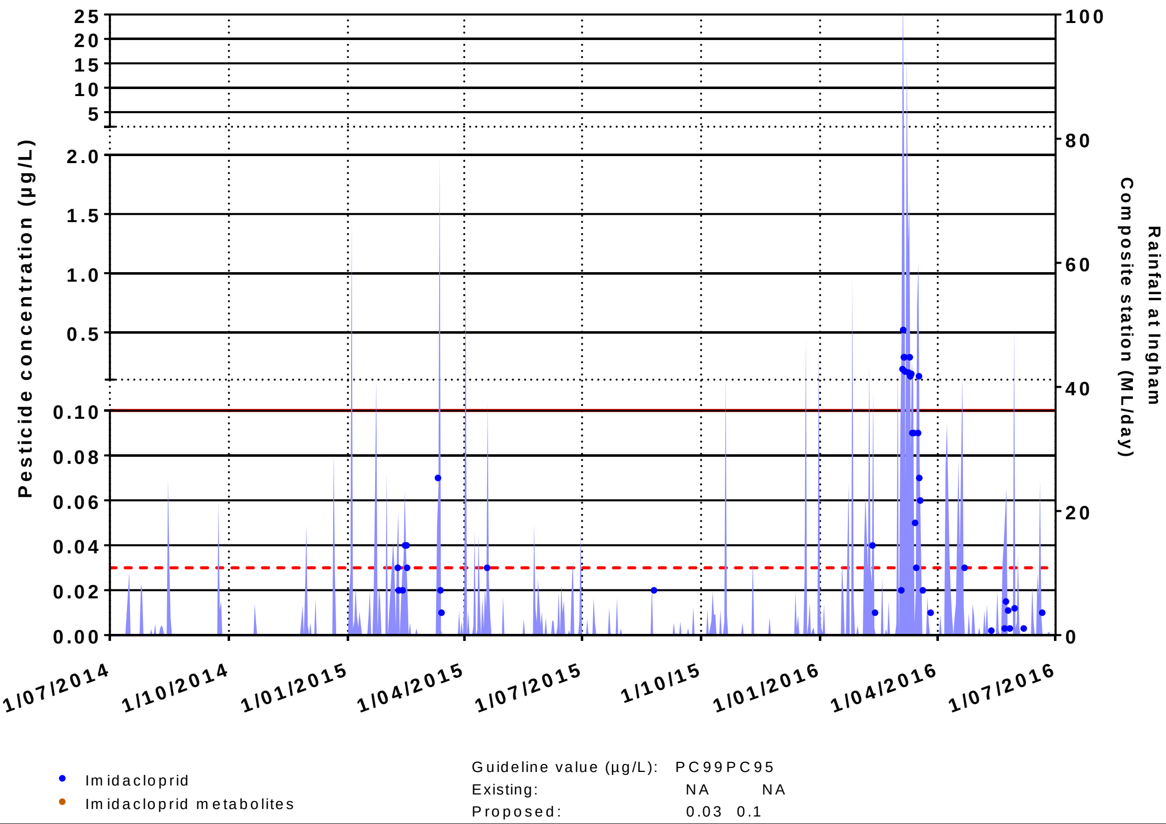


Figure 32: Imidacloprid detections in water sampled at Stone River and Herbert River at John Row Bridge in the Lower Herbert Catchment.

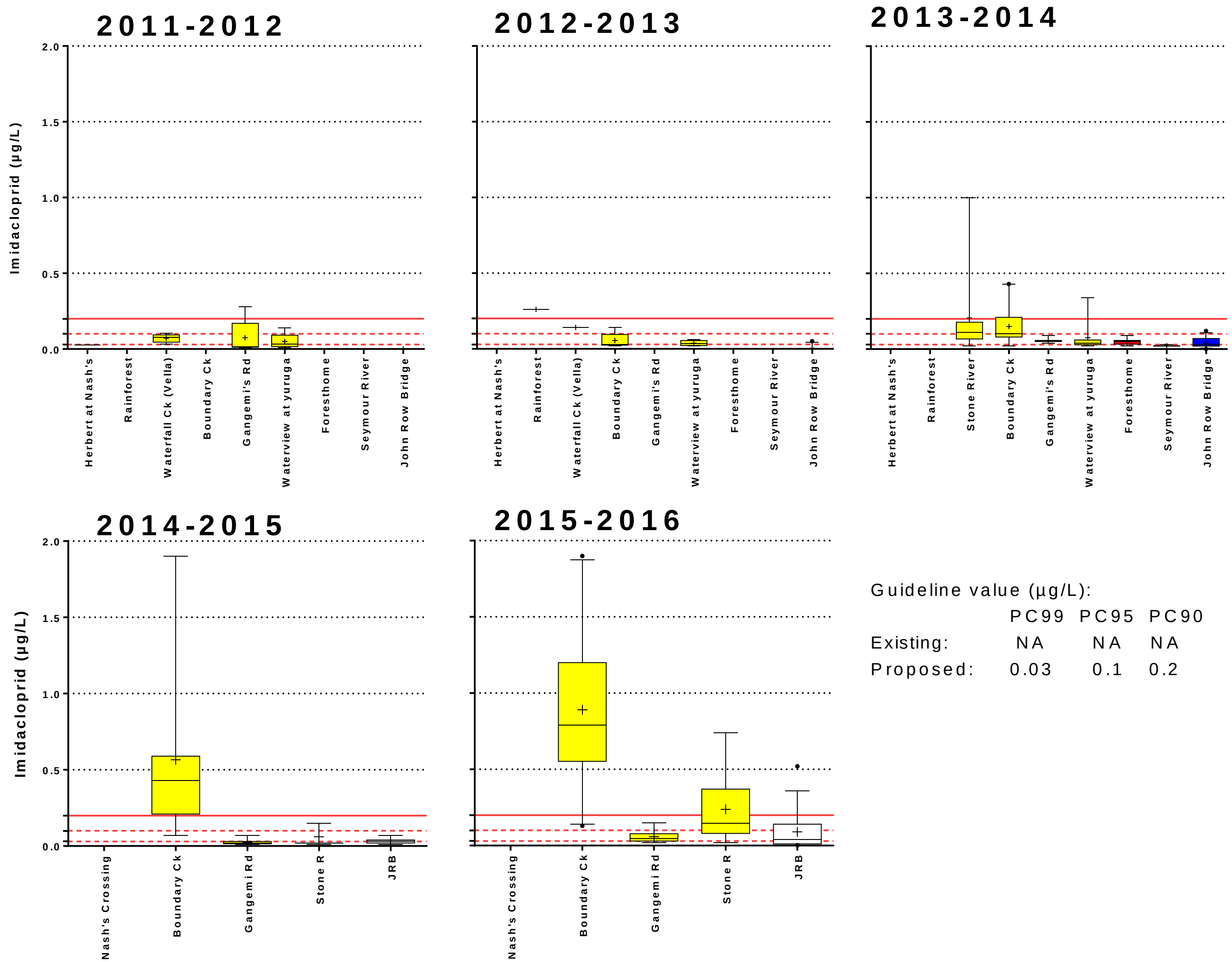


Figure 33: Concentration imidacloprid measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

4.4.4 Other pesticide detections

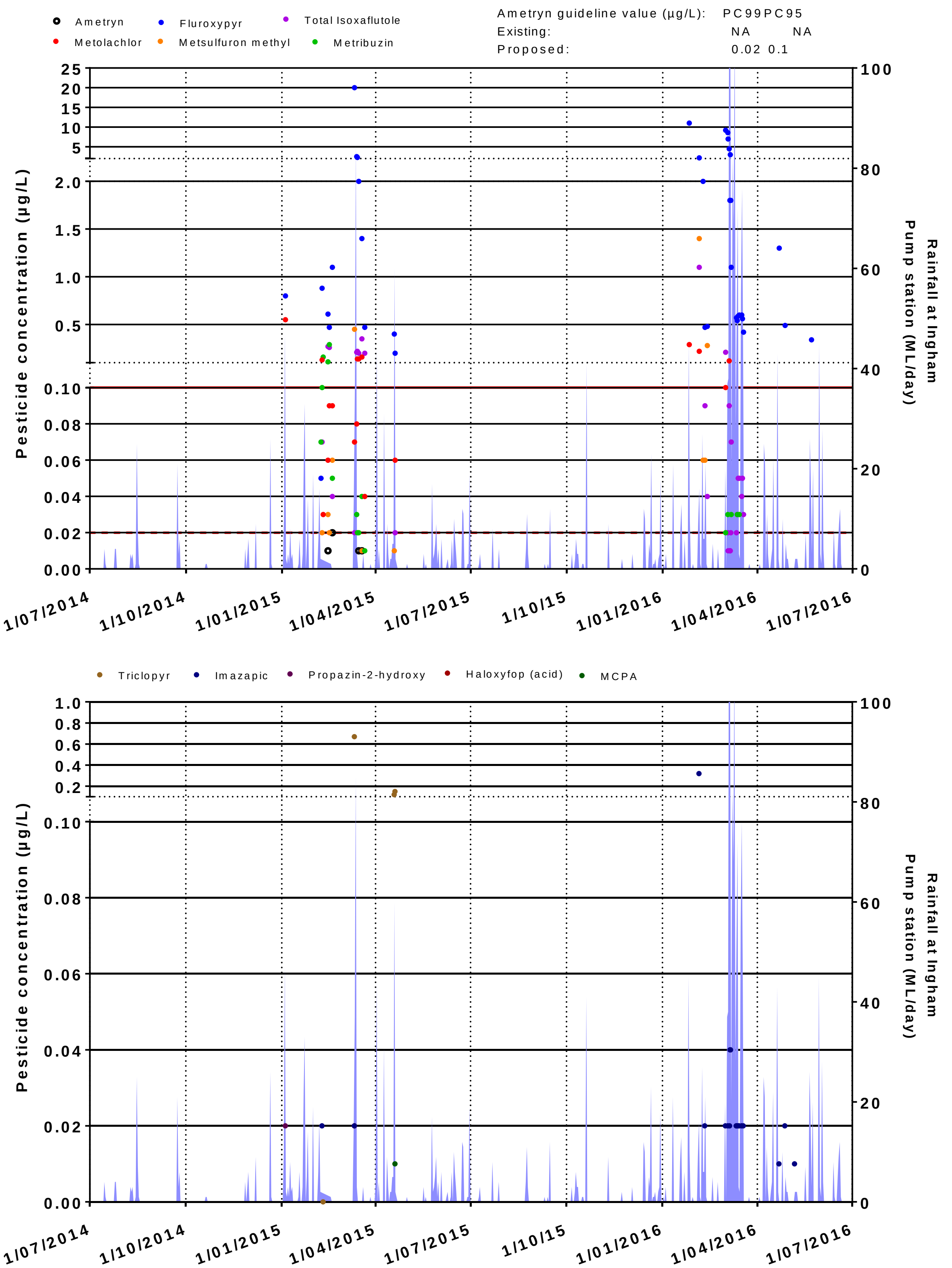


Figure 34: Other pesticides detected in water sampled at Boundary Creek in the Lower Herbert Catchment.

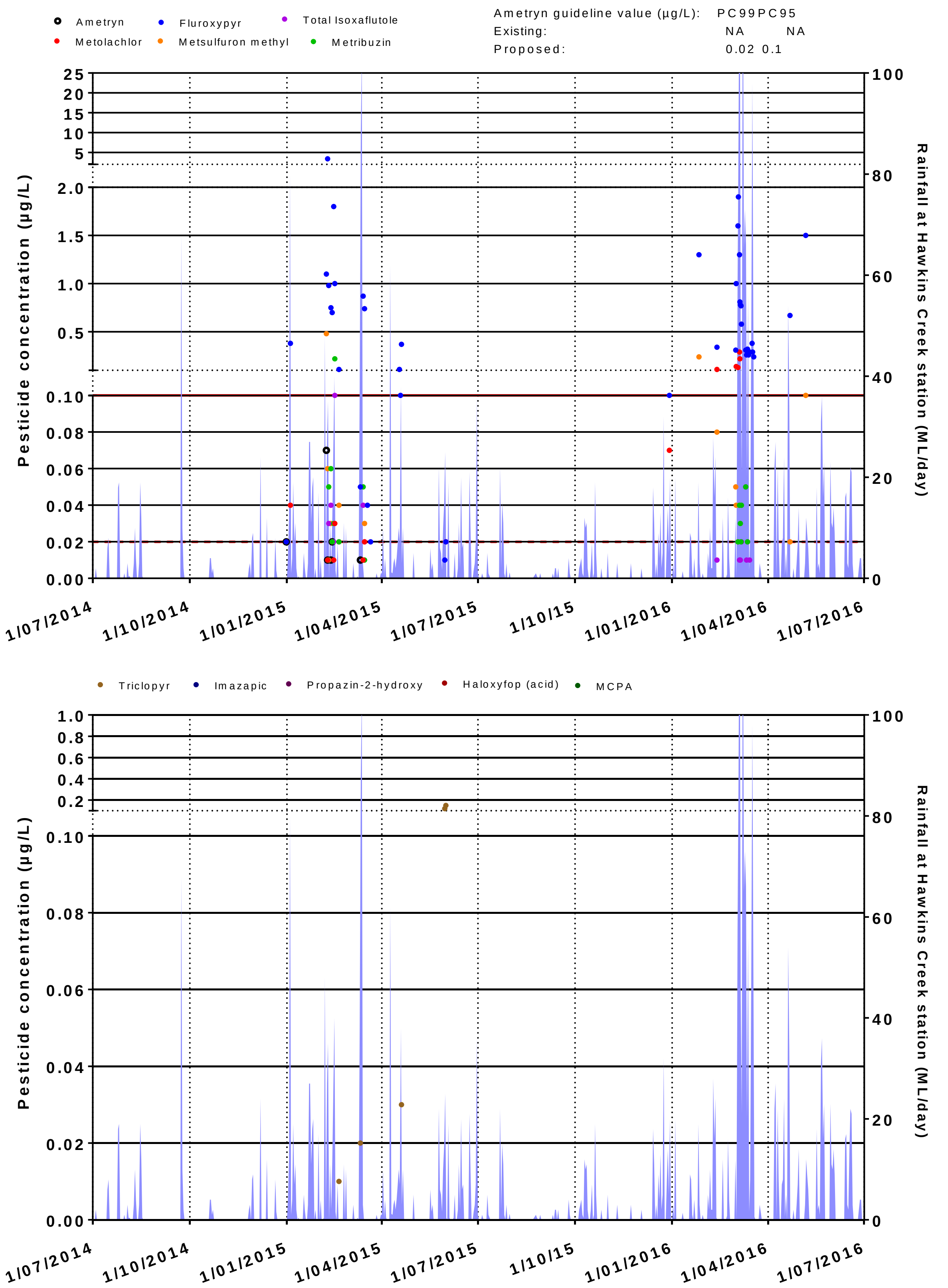


Figure 35: Other pesticides detected in water sampled at Hawkins Creek in the Lower Herbert Catchment.

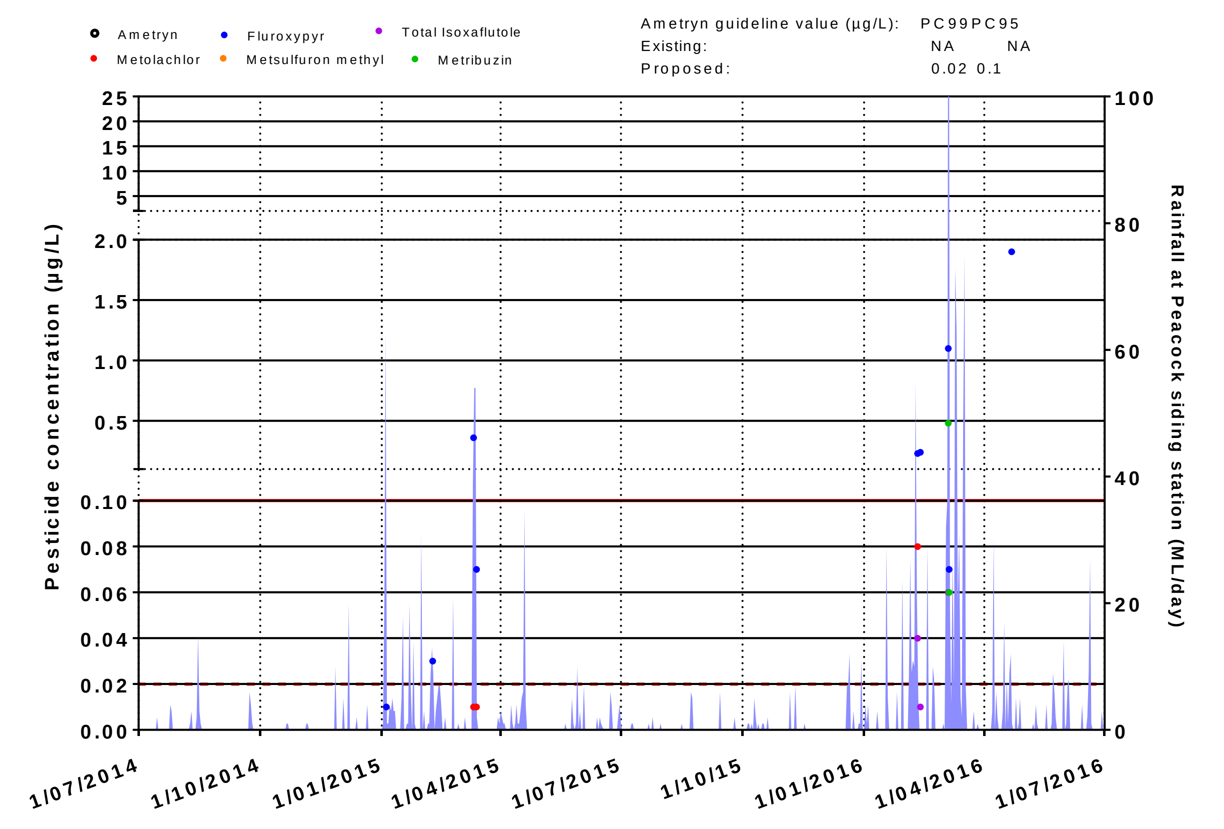


Figure 36: Other pesticides detected in water sampled at Stone in the Lower Herbert Catchment.

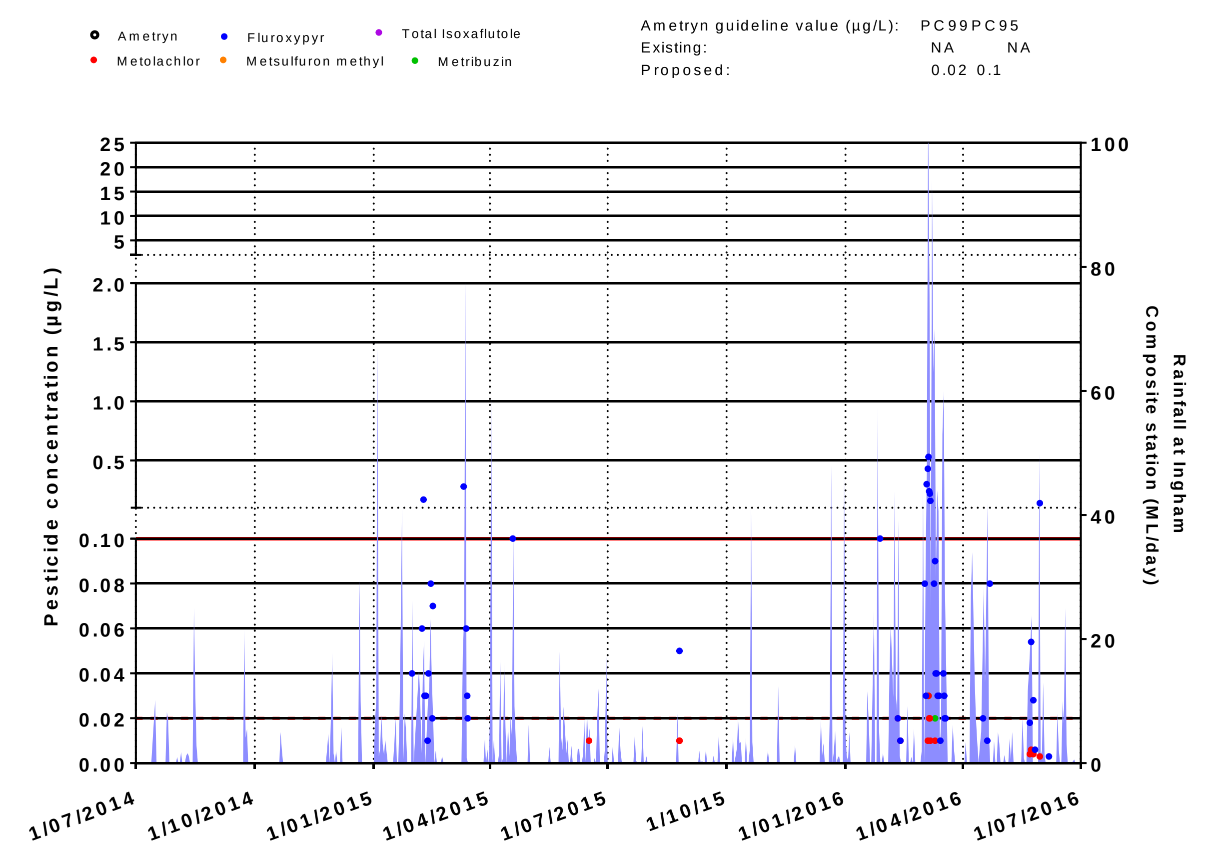


Figure 37: Other pesticides detected in water sampled at Herbert river at John Row Bridge in the Lower Herbert Catchment.

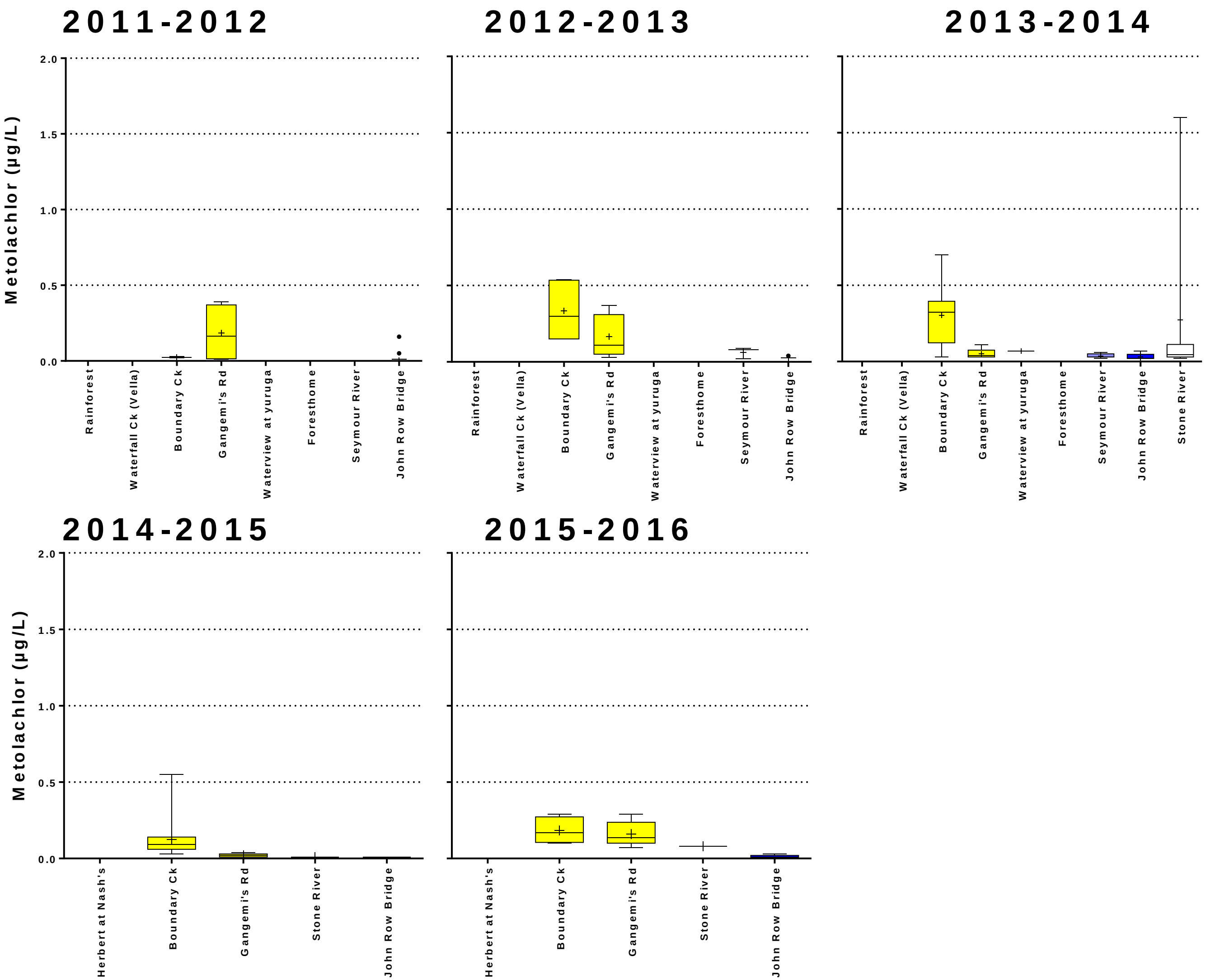


Figure 38: Concentration Metolachlor measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

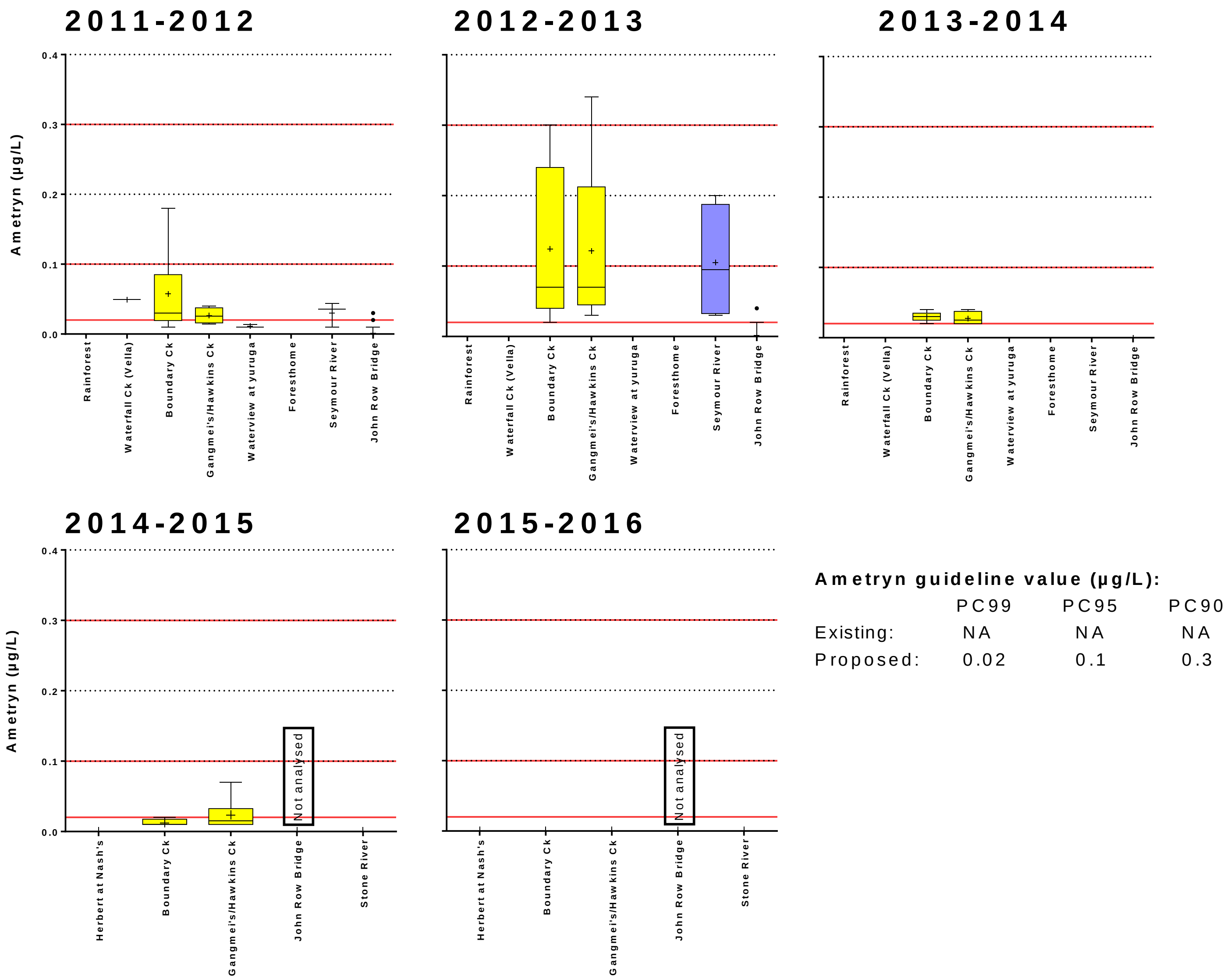


Figure 39: Concentration ametryn measured at each sampling site per water year (2014-2015 and 2015-2016) compared to the concentrations recorded at each site between 2011 and 2014.

5.0 Conclusion

The HWQMP is one of the longest monitoring programs of its kind and has produced a significant dataset that represents a valuable resource for the management of environmental impacts within the sugarcane industry. The dataset has assisted managers, modellers, investors and landholders to better understand the impacts of various land uses in relation to water quality and to effect changes in industry practice. Issues associated with fertiliser placement, and off label use of chemicals such as Diuron and Imidacloprid in sugarcane are good examples where-by data generated by the HWQMP has been used to target extension efforts around specific issues as they have arisen.

Access to good quality data has led to meaningful engagement with growers around the connection between WQ and on farm practices. There has been a very extensive extension program (through the HCPSL extension program and Project NEMO), in the Herbert cane industry (as well as grazing) since the inception of water quality monitoring in the region which has also improved regional (and cross regional) capacity in extension.

There are still some ongoing challenges with WQ in the Herbert Catchment, however, the managers of the program have established a good foundation for future work to improve water quality outcomes. The program has achieved regional, GBR-wide and international recognition for what has been achieved to date in establishing solid grower engagement and practice change. The project team are well poised to take this 'flagship of industry engagement' forward to achieve the ultimate goal of best practice in agriculture in the Herbert catchment and improved local water quality contributing to the resilience of the Great Barrier Reef.

6.0 Future directions

Based on the findings/learnings of the HWQMP the program of water quality monitoring within the Herbert Catchment would benefit should consideration be given to the following recommendations:

The recently developed Landscape Prioritisation Decision Support Tool for the Wet Tropics Region (Reef –DST) which uses a combination of P2R modelling and other analytical and contextual data sets has identified likely hot-spots that include the Macknade, Foresthome and Toobanna sub-district areas. As such, it is recommended that future project work should include scoping to establish suitable sampling sites that will facilitate an assessment of the impact of agricultural practice on the local surface water quality in these hotspot areas.

Data collected as part of this ongoing monitoring program has the potential to contribute to the evaluation of the loads of nutrients, sediments and pesticides delivered to the local ecosystem as a result of sugarcane land use within the Herbert Catchment. Lack of loads data is an identified limitation of the HWQMP to date that has made the assessment of temporal data sets difficult. Further progress with regard to loads assessment, however, will require the implementation of hydrological instrumentation and the development flow ratings at established sampling sites within the lower Herbert catchment in order to calculate these accurately.

Actual and proposed changes in material land use within the Herbert catchment indicate that there will likely be expansion of current crops or introduction of additional cropping types. Future monitoring work will benefit by including assessment of the impact of alternative or rotational cropping with sugarcane on surface water quality within the Herbert Catchment to insure that an adequate assessment of the risks to local water quality associated with the agriculture industry within the Herbert Catchment is maintained.

Appendix 1: Discontinued sampling sites

Upper Herbert Catchment:

Blunder Creek @ Blunder Park Crossing was selected as representative of Rainforest or pre-european condition to assess pollutant loads as a control site for other Upper Catchment sites. Given the relatively low rainfall, differences in soil composition and the spatial differences between Upper and Lower Catchments, it was deemed inappropriate not to have a representative control site in the Upper Catchment as well as the Lower Catchment for the scientific integrity and industry acceptance of the HWQMP. Samples from this site were manually collected by a suitablity trained local volunteer living adjacent to the site and was sampled as intensively as possible (3-5samples) per event and analysed for TSS, Nutrients and Pesticides. Given its close proximity to DNRM Gauge (116015A) loads were able to be calculated from here to validate loads and EMC's for modelling uncleared catchments in the Upper Herbert.

Mill Creek @ Jossan's, Wondecla holds water most of the year round and represents runoff from mixed cropping (peanuts, potatos, maize, and grazing) activities commonly grown in rotation in this area. Mixed cropping is highly intensive with N application rates as high as 1000Kg/ Ha for some crops, and although is still a relatively small industry in terms of the area it occupies, it is expanding in the Herbert to meet the demand for food domestically and provides an alternative for some leaving other industries such as dairy. A better understanding of losses in these systems can improve WQ in the Upper Herbert and with support from extension and research, may make significant improvements, not only to WQ, but the viability of farmers involved in this industry. Being only a relatively small area, this non gauged sub-catchment was sampled intensely (3-5 times) during events in order to capture concentration gradients for TSS, Nutrient and Pesticide, which are likely to change quickly with rain intensity. Sampling occurred at this site by manual grab sampling by DEEDI staff and/or trained volunteers when necessary to provide EMC data for mixed cropping land use.

Wild River @ Silver Valley is one of 3 major tributaries of the Upper Herbert Catchment and although mixed in terms of its landuse contributions (cropping, urban, grazing, ex-mining), the HWQMP is looking to identify which tributaries (areas) are contributing the most in terms of End of Catchment Loads to Cashmere Crossing. The sampling location for this site is at the Wild River Gauging Station (116014), therefore Daily and Annual Loads calculations for TSS, Nutrients and Pesticides were calculated using standard DNRM methods and used by P2R modellers for Source catchments validation. PSA will also be measured at this site to help determine the origin of sediments in this system. Ambient and event monitoring is will be performed by manual grab samples (5-10 per event) taken by a suitably trained volunteer that lives in the area. Being a larger catchment, sampling once or twice a day either during, between and even after intense rain was adequate to cover the hydrograph.

The Millstream @ Archers Ck is the second major tribuary of the Herbert River in the Upper Catchment. It too has a number of contributing factors to WQ, including grazing, dairy, urban and some tree crops. TSS, PSA, Nutrient and Pestcide samples were collected using manual grab samples at this site. Being a major tributary of the Herbert and covering much of the northern part of the catchment, sampling once or twice a day over monsoonal events wassufficient to cover changes in concentration over the hydrograph. Some more intense sampling was required during first flush events when associated with localised storms (3-5 samples over 1-2 days) is desirable.

Nettle Ck @ Herbert River Road has specifically been chosen to help assess the relative concentrations of sediment contributions of ex-tin mining activities in the Upper Herbert. Many of these tailings (or slime) dams used during dredging operations up until the mid 1980s to extract Tin, still hold large amounts of Kaoline (very fine clay) which contribute negatively to WQ and may even provide a transport mechanism for other pollutants such as pesticides and nutrients to the outer Great Barrier Reef due to their reluctance to settle out of the water column. Both TSS and PSA will be measured at this site to assess the relative importance of these sediments downstream , but more importantly what proportion of the very fine clay particles originate at these sites and whether slime dams are a significant cause for concern and should be included for targeted remedial action under ReefPlan to improve WQ reaching the GBR Lagoon. Once again, intensive sampling (3-5) during and immediately after rainfall events provided the best measure of peak and relative concentrations for this site. If the modelled load calculations for sediments generated from this site are considered worthy of more detailed investigation. The TWG and Terrain will seek additional funding to gauge this site if need be, or develop other projects to specifically target this this issue. Due to the occurance of a single dairy operation on this system, Queensland Dairyfarmers Organisation (QDO), did not support the monitoring of nutrients and pesticides as part of the broader DEEDI E&E program in this system.

Rudd Creek @ Gunnawarra is the third major tributary of the Upper Herbert and is almost exclusively grazing in terms of its landuse. This site is also gauged (116016a) and manually sampled by DEEDI staff for relative concentrations of Nutrients, Sediments and Pesticides. This provided details of its relative importance in terms of End of Catchment loads contributions at Cashmere Crossing and allowed for some extrapolation of measure of the contribution of sediments (and perhaps other pollutants) per unit area for extensive grazing activities which is the most common landuse in the Upper Catchment. Given the extensive catchment area of this system, sampling intensity of 1-2 times a day during wet seasonal events was adequate over a number of days/week, but more intense sampling was desirable during early storm (first flush) events, especially if the rain was localised.

Cashmere Crossing @ Gleneagle provided End of Catchment Load calculations on sediments, nutrients and pesticides for the Upper Catchment before water entered the significant section of National Park between this site and Nash’s Crossing (Lower Catchment). By providing Daily and Annual Load information through grab sampling at this guaged site (116004), a total budget for all pollutants being measured was achieved. Coupled with the relative contributions from other sub-catchments and with the assistance of P2R modelling, DEEDI extension staff were able to target their activities in adjacent areas and around the activities where the greatest gains in WQ improvement could be made. This feedback provided the basis for DEEDI investment in the upper catchment which covers almost 6000 square kilometres and with limited people and resources across this vast area, providing direction on where activities should be focussed is paramount in engaging the right landholders around the necessary activities to meet WQ improvements objectives under ReefPlan 2009.

Lower Herbert Catchment:

Waterfall Creek @ Vella's was been chosen as a cane specific site and represents a comparison to water shed from Tomba's (Rainforest) site, plus contributions exclusively from cane production systems in this area. Relative concentrations (EMC) of pesticides, nutrients and sediments per unit area of cane production systems were measured at this site in years one and two. Testing for pesticide, nutrients and sediments were taken by use of manual grab sampling, with first flush requiring intensive sampling (3-5 times a day) while wet season sampling of 1-2 times day when flowing was suffice.

Seymour River @ QR Bridge was included to provide some quantative insight into the relative contributions of overland flow to the relative loads of pollutants in floodwater. From modelling developed by WBM, it appears that in flooding events, that much of the water in the Herbert River at John Row Bridge, breaks out around this point and flows across the floodplain (canelands) and finds its way to the coastline via a number of distributary channels. From the modelling provided on a 1:10 year event, the Seymour River is the second largest conveor of water to the GBR Lagoon after the Herbert River Channel itself. It is for this reason concentrations of pesticide, nutrients and sediments and relative heights were measured at this point to determine the contribution of pollutant loads between the Seymour River outfall and that of the Herbert River main channel (measured at the John Row Bridge site).

During non-overland flooding events in the first year, samples for this site were taken upstream @ the Highway Bridge to avoid dilution by tidal influence experienced at the QR site. Channel flows from the Gangemi Rd site @ Hawkins Creek flow past this point and provided some valuable correlations between nutrients concentrations and WQ in Hinchinbrook Channel which was being measured by JCU under the P2R Marine Monitoring Program. In years 2&3, ambient samples were consistantly collected at the QR bridge despite the dilution effect of tidal influence for consistancy.

Forresthome (Urban) Drain @ Darymple Street was included in the HWQMP to gauge the relative concentration (EMC) of stormwater runoff from the township of Ingham to WQ in the Herbert District. The Herbert River has a number of small towns and hamlets along its length and scattered throughout the district, and many of the industries involved in this program were interested to see what pollutants maybe coming from this non-agricultural sector. Testing for Pesticide, Nutrients and Sediments was undertaken from this site by use of manual grab sampling. Well defined drainage lines from approximately half of Ingham provided concentration data to modellers in order to account and predict broader community impacts on WQ and may also provide insight into population growth scenerios for GBR catchments across the Wet Tropics which were being considered under ReefPlan 3.

Waterveiw Creek @ Yuruga Road provides floodplain representation to the south of Ingham (Ingham Line) and although runoff does not flow directly into the Herbert River itself, it was believed to be a significant contributer to WQ in the GBR Lagoon, due to the large area of sugarcane under cultivation, its lighter soil structure, steep foothills and very different rainfall regime. Many farmers along the Ingham Line also employ supplementry irrigation and traditionally apply higher rates of nitrogen, than other areas in the district. The sub-catchment of Waterview is predominately cane with a small area of grazing and National Park contributing to WQ at this site. Testing for Pesticide, Nutrients and Sediments were undertaken from this site by use of manual grab sampling and given its steep catchment and spasmotic rainfall, needed to be sampled intesively during events (2-3 times daily) in order to capture the necessary concentration gradients to inform P2R modelling through EMC's.

Appendix 2: Metal monitoring results obtained as part of the 2011-2014 HWQMP (extracted from 2015 HWQMP report, p86 - 91)

4.5 Water Quality: Metals

A total of 35 samples from 6 upper catchment sites (Mill Ck, Millstream, Nettle Ck, Wild R, Rudd Ck and Cashmere Crossing) were collected for analysis targeting 12 metals. Two additional samples were collected from the ex-tin mine tailings dam within the Nettle Ck catchment. While training was provided to samplers regarding the collection of samples for metal analysis there were issues regarding sample handling and missed sampling such that only 4 samples could be used to quantify dissolved metal concentrations and no field blanks were included.

The twelve metals included in the analytical suit were arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, tin and zinc. All metals but cadmium were detected. As the upper Herbert Catchment is a slightly to moderately disturbed system the Water quality trigger values for 95% species protection and the Australian drinking water guidelines (where they have been established) have been applied in the assessment of risk with regard to the metal concentrations detected (ANZECC and ARMCANZ, 2000; NHMRC and NRMMC, 2011).

Iron was detected in 100% of samples. The only guideline established for iron is an aesthetic drinking water guideline; this guideline was exceeded in all but four samples, two detections at both Millstream and Wild R. Highest concentrations were recorded in the tailings dam samples collected. Lead was detected in 85% of samples. Levels exceeded environmental and drinking water guidelines in all of the upper catchment sites except Mill Ck. The iron environmental trigger value was exceeded in 75% of samples regardless of land use which suggests that it may be a natural property of the upper Herbert. Chromium and zinc were detected across all sampling sites at a frequency of 55% and concentrations exceeded the environmental trigger guideline in 48%, 45% and 13% of all samples. Copper was detected in 52% of samples across all sites except Rudd Ck and 90% of detections exceeded the environmental trigger. Arsenic and nickel concentrations were below guidelines across all sampling sites however concentrations measured in the samples collected from the tailings dam did exceeded the fresh water trigger values in the tailings dam samples collected in at least one sample. Manganese was detected at Millstream and Wild R. at concentrations that do not pose a health or environmental risk. Mercury concentrations did not exceed established guidelines. Tin and cobalt were detected across all sites however no guidelines are established for these metals.

A similar metal profile was obtained when comparing the detections across the whole upper catchment with the detections in the samples collected from the ex-tin mine tailings dam, with the exception of manganese which was recorded at lower concentrations in the tailings dam samples.

These results indicate that there may be cause for further investigation with regard to lead chromium, copper and zinc concentrations within the Herbert upper catchment. It is advised that should this be a priority in future extra care in the collection of samples and the inclusion of duplicates and field blanks will be needed.

Table 14: Metal detections and concentration range for sampling undertaken in the upper catchment

	Detection frequency (%)	Total Metals (mg/L)		Water Guidelines (freshwater)	
		min	max	Environmental Trigger (95% Species protection)	Drinking (health)
Arsenic	62	0.001	0.01	0.013	0.01
Chromium	56	0.001	0.014	0.001	0.05
Cobalt	68	0.001	0.07	-	-
Copper	53	0.001	0.012	0.0014	2
Iron	100	0.2	7.86	-	-
Lead	85	0.001	2.06	0.0034	0.01
Manganese	35	0.012	0.114	1.9	0.5
Mercury	6	0.0001	0.0002	0.06	0.001
Nickel	65	0.001	0.01	0.011	0.02
Tin	50	0.006	0.028	-	-
Zinc	56	0.001	0.018	0.008	-

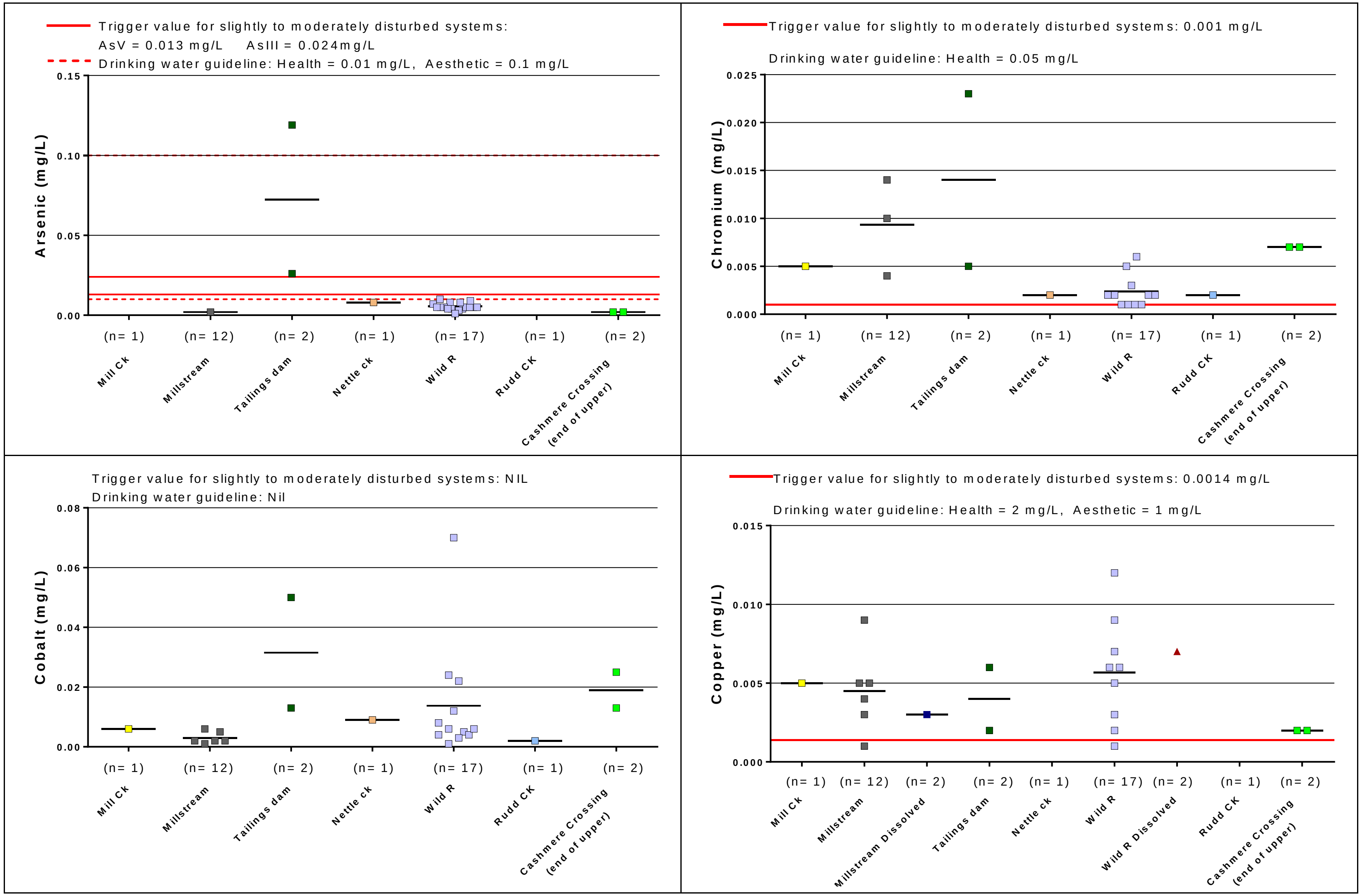


Figure 37 Metal concentrations measured in the Upper Catchment. Where guidelines have been established they are outlined on the graphs for each individual metal.

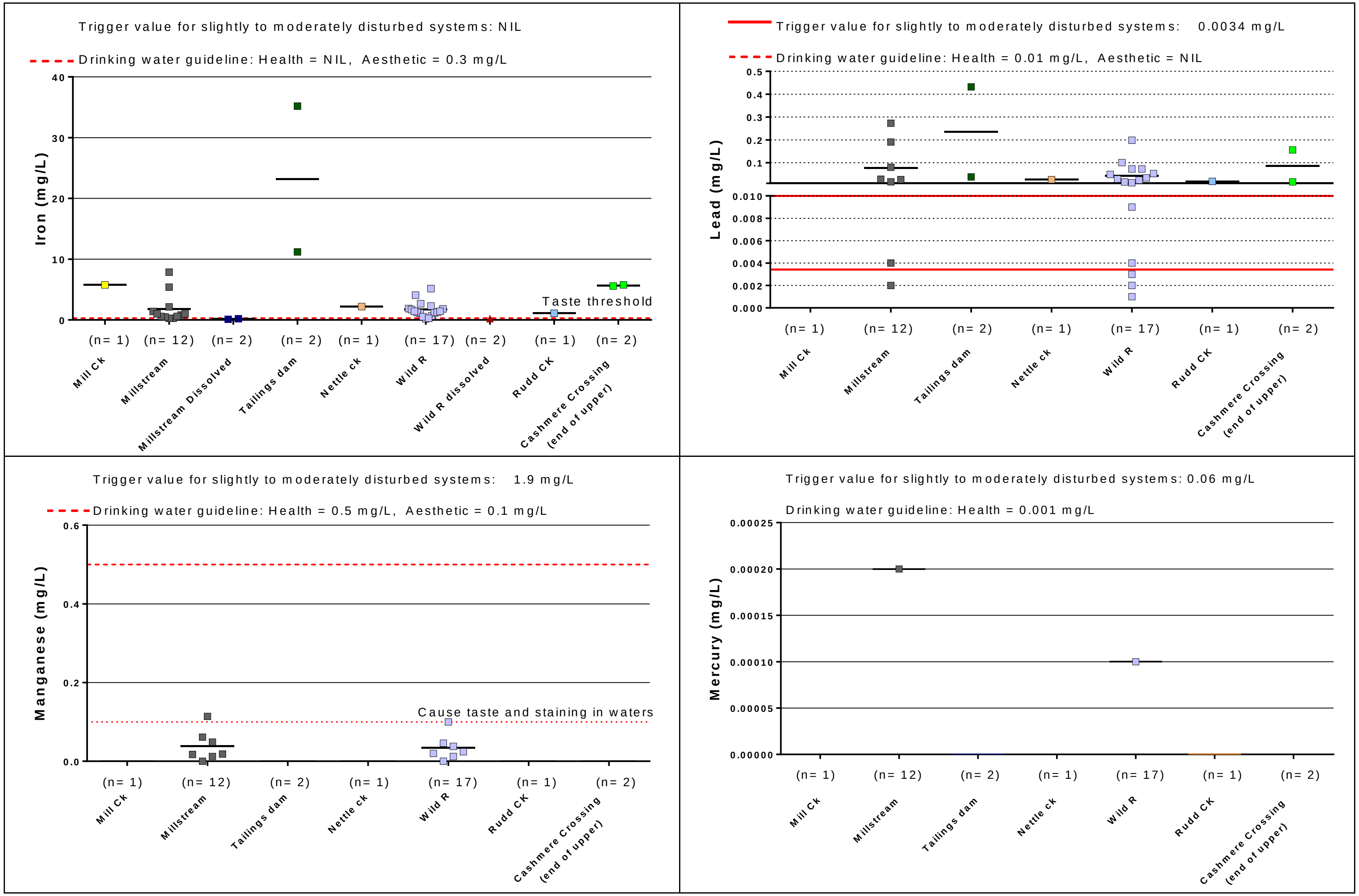


Figure 37 (cont.) Metal concentrations measured in the Upper Catchment. Where guidelines have been established they are outlined on the graphs for each individual metal.

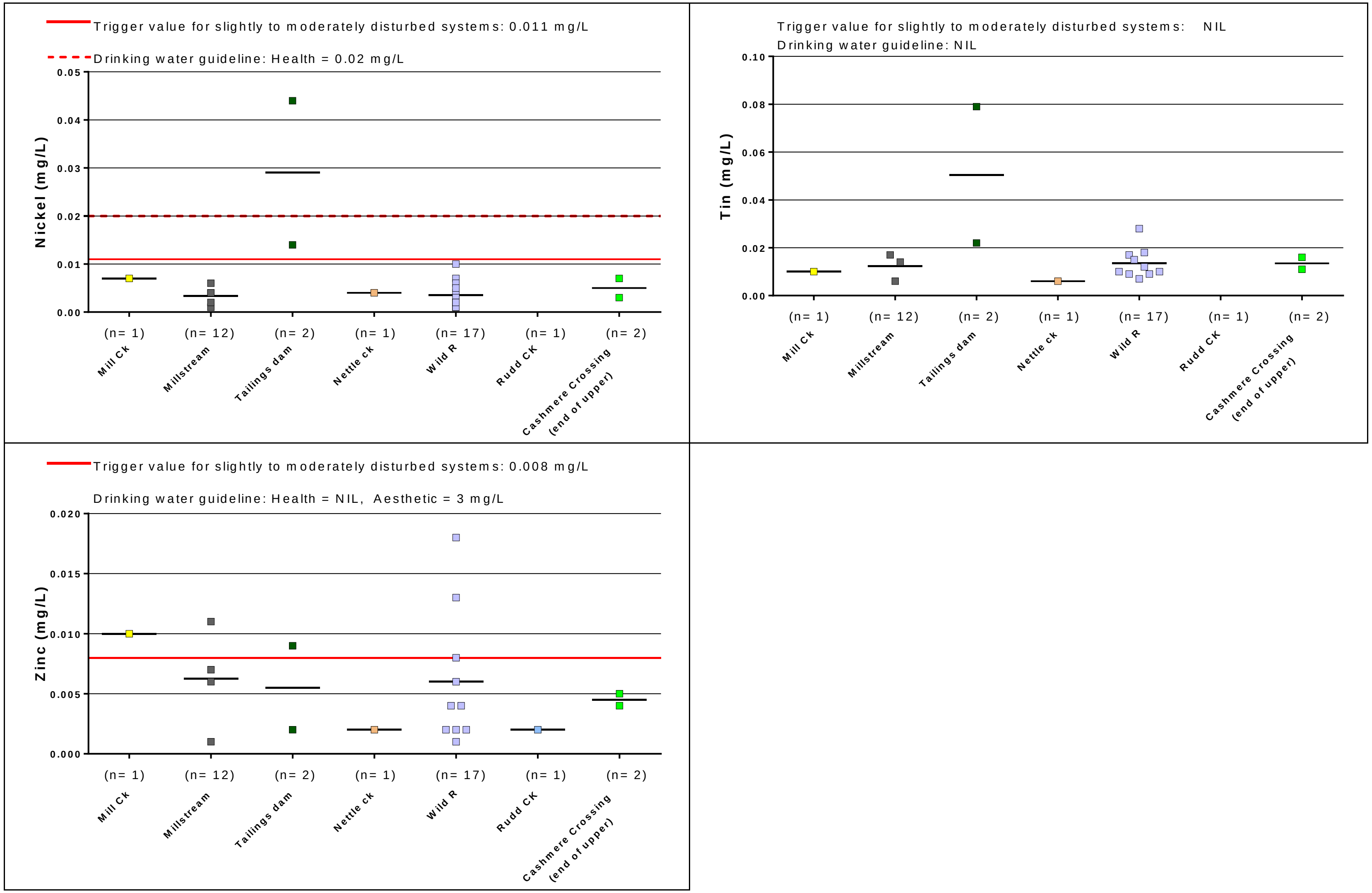


Figure 37 (cont.) Metal concentrations measured in the Upper Catchment. Where guidelines have been established they are outlined on the graphs for each individual metal.

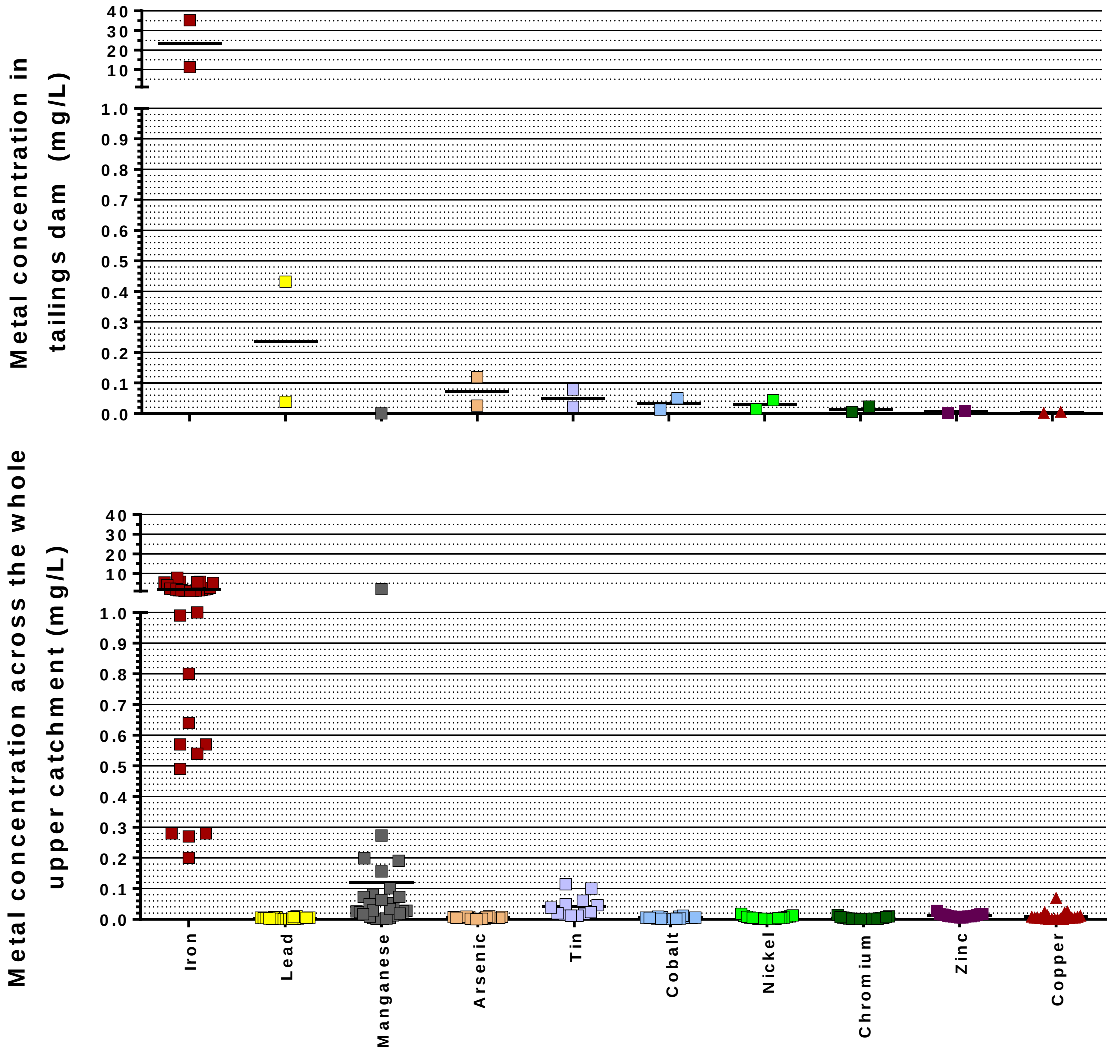


Figure 38: Metal profile across the upper catchment sites compared to the metal profile of the ex-tin mine tailings dam.

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