Department of **Natural Resources and Mines**

Paddock to Sub-catchment Scale Water Quality Monitoring of Sugarcane Management Practices

Interim Report
2011/2012 Wet Season

Mackay Whitsunday Region

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Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

The Australian and Queensland Governments are committed to improving the water quality in the Great Barrier Reef (GBR) lagoon to ensure the continued survival of the GBR as a healthy functional reef ecosystem. The *Reef Water Quality Protection Plan* (Reef Plan) was released by the Australian and Queensland Government's in 2003, subsequently reviewed and updated in 2009, and released as the Reef Plan (The State of Queensland and Commonwealth of Australia 2009). The Reef Plan has two goals; to halt and reverse the decline in water quality entering the reef by 2013, and to ensure that by 2020, the quality of water entering the reef from adjacent catchments has no detrimental impact on the health and resilience of the reef.

To achieve the water quality targets in the plan, investments are made through Reef Rescue, industry organisations and voluntarily by sugarcane growers and other landholders to improve management practices at a farm scale. Thus, it is important to study the effectiveness of the management practices in improving water quality at the paddock scale. In conjunction with this plan, the *Paddock to Reef Integrated Monitoring, Modelling and Reporting (P2R) Program* is using multiple lines of evidence to report on the effectiveness of these investments and whether targets are being met (Carroll *et al.* 2012). One of these lines of evidence is practice effectiveness in improving water quality at the paddock (edge-of-field) scale.

Under the P2R program, paddock scale monitoring of water quality from various levels of management practices was implemented in selected GBR catchments and agricultural industries (Carroll *et al.* 2012). As part of this program and in conjunction with *Project Catalyst*, two sugarcane blocks in the Mackay Whitsunday region are being used to measure levels of herbicides, nutrients and sediments in runoff. Different sugarcane management strategies are being investigated, with the emphasis on improving water quality with improved management practices. All treatments this season (second ratoon crop) were farmed with green cane trash blanket and no tillage.

The Victoria Plains site (uniform cracking clay) was divided into two treatments of soil, nutrient and herbicide management practices. The Marian site (duplex soil) was divided into five treatments of soil, nutrient and herbicide management practices.

	ABCD Classification	**Soil Management**	**Nutrient Management**	**Herbicide Management**
Victoria Plains site – uniform cracking clay				
Treatment 1	CCC[1]	1.5 m current practice	Generalised recommendation	Regulated[3]
Treatment 2	BBB	1.8 m controlled traffic	Six Easy Steps[2]	Non-regulated[4]
Marian site – duplex soil				
Treatment 1	CCC	1.5 m current practice	Generalised recommendation	Regulated
Treatment 2	BCC	1.8 m controlled traffic	Generalised recommendation	Regulated
Treatment 3	BBB	1.8 m controlled traffic	Six Easy Steps	Non-regulated
Treatment 4	BAB	1.8 m controlled traffic	Nutrient replacement	Non-regulated
Treatment 5	ABB	1.8 m controlled traffic, skip row	Six Easy Steps	Non-regulated

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES
[3] – Herbicides identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999
[4] – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

Two additional sites (Multi-block and Multi-farm) were used to measure the effects of changes in management strategies at larger scales. Each treatment and site was instrumented to measure runoff and collect samples for water quality analyses (total suspended solids, total and filtered nutrients, and herbicides).

Results from the third year of monitoring (2011/12 season) are outlined for each site below.

At the Victoria Plains site (cracking clay), controlled traffic on wider row spacings resulted in a reduction in runoff. Specifically:

- Total runoff from individual runoff events from Treatment 2 (1.8 m row spacing) averaged 13.7% less than Treatment 1 (1.5 m row spacing) (816 mm and 946 mm, respectively from 2213 mm rainfall). Runoff from Treatment 2 was delayed on average by ~9 minutes compared with Treatment 1, and the peak runoff rate was ~23% lower, all contributing to reduced runoff. These findings are similar to previous seasons.
- Total suspended solids (TSS) concentrations were low (14-61 mg/L) and consistent throughout the season. The wet season flow-weighted TSS concentrations were similar between treatments: 22 mg/L and 24 mg/L for Treatments 1 and 2, respectively.
- Total estimated wet season soil loss for Treatment 1 was 217 kg/ha, lower than that of Treatment 2 (298 kg/ha). These sediment loads are much lower than measured in previous seasons due to the low sediment concentrations, the reduced runoff compared to the 2010/11 season, and the green cane trash blanket.
- Initial nitrogen concentrations in runoff (first runoff event 75 days after application) were dominated by NO_x-N, with concentrations highest in Treatment 1 (higher application rate). In contrast to the previous season, urea-N concentrations were low, presumably due to the longer period between application and first runoff this season. The total wet season loss of NO_x-N and urea-N was 1.8 kg/ha and 1.6 kg/ha for Treatments 1 and 2, respectively. This represents ~1% of the nitrogen applied to each treatment, much lower than the ~10% measured in previous seasons.
- The filterable reactive phosphorus (FRP) flow-weighted wet season concentration was similar between treatments: 48 and 47 µg P/L for Treatments 1 and 2 respectively, lower than that measured last season.
- The calculated half-lives of diuron, hexazinone and imazapic were 74, 39 and 47 days, respectively from surface soil field dissipation measured 10-203 days after application. For cane trash, the calculated half-lives were 30, 22 and 33 days for diuron, hexazinone and imazapic, respectively.
- Herbicide residues of diuron and hexazinone were detected in runoff in low concentrations (compared to previous seasons) from Treatment 1 (Bobcat applied 128 days prior to the first runoff event, compared to Velpar K4 applied 7-8 days prior to the first runoff event in previous seasons). Less than 0.4% of the applied product was lost in the season’s runoff, with 50% of that lost in the initial 10-15% of the season’s runoff.
- Imazapic was only detected in one runoff sample at 1 µg/L.
- Low concentrations (<0.01-0.05 µg/L) of atrazine were detected in runoff from Treatment 1, despite no application this season. It is thought that the source of

this atrazine may be from the source water used in the spray tank mixture, rather than persistence in the environment.

- Only two drainage water samples were collected from each treatment for the season. As a result, no meaningful conclusions can be made, but concentrations of nutrients and herbicides were much lower than in the previous season.
- Machine harvest yield results of the second ratoon cane crop were very similar – 90.4 t/ha for Treatment 1 and 90.6 t/ha for Treatment 2, despite Treatment 2 receiving 61 kg/ha less nitrogen than Treatment 1.

At the Marian site (duplex soil), total runoff was confounded by the site flooding several times. Therefore, it is not possible to derive accurate runoff figures or water quality loads.

- Total suspended solid concentrations were generally low (13-140 mg/L), but slightly higher than the Victoria Plains site. The treatment average concentrations (26-77 mg/L) were less than one third of those measured in the previous season, which appears to be due to the green cane trash blanket and lack of cultivation.
- Nitrogen concentrations in rainfall runoff were low compared to the previous season, and dominated by NO_x-N. For the events sampled, average NO_x-N concentrations did not follow the rate of nitrogen application, presumably due to the variability in the number of events sampled. In contrast to rainfall runoff, the samples collected from the irrigation runoff event had relatively high NO_x-N concentrations, presumably due to the high nitrate content of the irrigation water.
- Average FRP concentrations (355-499 µg P/L) were ~10-fold more than those detected at the Victoria Plains site, following a similar trend to the surface soil phosphorus concentrations.
- Using the surface soil field dissipation data of 25-105 days after application, the calculated half-lives of diuron and hexazinone were 45 and 31 days, respectively (Treatment 1 only) and 34 days for paraquat (average of Treatments 3-5). For cane trash, the calculated half-lives were 12 and 11 days for diuron and hexazinone, respectively. Concentrations of paraquat on cane trash were very variable over time, and no clear trend in dissipation could be detected.
- Herbicide residues of diuron and hexazinone detected in runoff this season were low ($\leq$ 0.5 µg/L) (Treatments 1 and 2; first runoff samples collected 30 and 67 days after application, respectively) and isoxaflutole (Treatments 3 and 5) was not detected in any runoff samples (<1 µg/L).
- Machine harvest yield results of the second ratoon cane crop showed that cane yield (59-103 t/ha) trended with the amount of nitrogen applied. The skip row treatment (Treatment 5) yielded 71% of Treatment 3 (solid plant, same nitrogen rate), despite only having 56% of the area planted to cane.

At the Multi-block and Multi-farm sites:

- Total seasonal runoff from the Multi-farm site was estimated to be 649 mm from 2241 mm of rainfall. Determining accurate volumes of runoff (and therefore water quality loads) at the Multi-block site are not possible due to flooding issues.
- Total suspended solid concentrations at the Multi-block site (26-46 mg/L) were generally lower than the Multi-farm site (9-180 mg/L). These concentrations are lower than those detected in the previous season, and may be attributed to the variance in ground cover levels on paddocks within each of the monitoring catchments.

- Total estimated wet season sediment yield for the Multi-farm catchment was 779 kg/ha, with a flow-weighted seasonal mean concentration of 120 mg/L.
- At both sites, NO_x-N concentrations were highest in the initial sampled event, with the seasonal average and range of concentrations being higher than the previous season. This may reflect the timing of nitrogen application prior to the initial runoff event. The total estimated wet season loss of NO_x-N in runoff from the Multi-farm site was 1.8 kg/ha (flow-weighted seasonal average concentration of 283 µg N/L).
- Filterable reactive phosphorus concentrations at the Multi-block site were consistently higher than those of the Multi-farm site. Similar to the paddock data, this may reflect the variable phosphorus levels in the surface soil.
- Maximum herbicide residue concentrations were generally higher at the Multi-farm site than the Multi-block site. This may be a reflection of the different periods of application (and the products applied) between the two catchments.

In summary, results from the 2011/12 season showed similar trends between treatments and sites as those observed in previous seasons, although concentrations were generally lower this season due to the delay in commencement of runoff (compared to when treatment applications were applied). Green cane trash blanket results in an approximate ten-fold decrease in suspended sediment losses compared to previous seasons (plant cane) with bare soil. Differences between sites highlights the importance of soil characteristics, input application rates, and the duration between application and the first runoff event on nutrient and herbicide losses in runoff water. Higher nitrogen inputs and high background soil phosphorus levels can lead to larger runoff losses. Matching row spacing to machinery track width can reduce runoff and therefore reduce off-site transport of nutrients and herbicides.

1 INTRODUCTION

Several water quality studies in the past decade have focussed on quantifying the pollutants generated by the major land uses within the Great Barrier Reef (GBR) catchments. Sugarcane has been found to export high concentrations (compared to "natural" sites) of dissolved inorganic nitrogen (DIN or NO_x-N, consisting primarily of nitrate) (Bainbridge *et al.* 2009; Bramley and Roth 2002; Hunter and Walton 2008; Rohde *et al.* 2008). The herbicide residues most commonly found in surface waters in the GBR region where sugarcane is grown (ametryn, atrazine, diuron and hexazinone) are largely derived from sugarcane landuse (Bainbridge *et al.* 2009; Faithful *et al.* 2006; Lewis *et al.* 2009; Rohde *et al.* 2008). In recent years, sediment fluxes from sugarcane landuse has been shown to be relatively low (Prove *et al.* 1995), which is a result of the industry adopting improved management practices (e.g. green cane trash blanketing) over the past twenty years. However, there is little paddock-scale data available to assess the water quality benefits of adopting practices considered to be "best practice".

1.1 Reef Plan

To address the issue of declining water quality entering the GBR lagoon, the *Reef Water Quality Protection Plan* (Reef Plan) was endorsed by the Prime Minister and Premier in October 2003. It was primarily developed from existing government programs and community initiatives to encourage a more coordinated and cooperative approach to improving water quality.

An independent audit and report to the Prime Minister and the Premier of Queensland on the implementation of the Reef Plan was undertaken in 2005. Whilst the positive outcomes that were achieved over the period from 2003 to 2005 have been recognised, input from stakeholders and new scientific evidence confirmed the need to renew and reinvigorate the Reef Plan to ensure the goals and objectives will be met.

This updated Reef Plan (The State of Queensland and Commonwealth of Australia 2009) builds on the 2003 plan by targeting priority outcomes, integrating industry and community initiatives and incorporating new policy and regulatory frameworks. Reef Plan is now underpinned by clear and measurable targets, improved accountability and more comprehensive and coordinated monitoring and evaluation.

Reef Plan has two primary goals. The immediate goal is to halt and reverse the decline in water quality entering the reef by 2013. The long term goal is to ensure that by 2020 the quality of water entering the reef from adjacent catchments has no detrimental impact on the health and resilience of the reef. Achievement of these goals will be assessed against quantitative targets established for land management and water quality outcomes.

To help achieve the Reef Plan goals and objectives, three priority work areas (Focusing the Activity, Responding to the Challenge, Measuring Success) have been identified and specific actions and deliverables have been outlined for completion by 2013.

The plan will be reviewed again in 2013 to ensure that it is delivering the intended outcomes. Throughout the course of Reef Plan there will also be regular reviews and improvements of the plan to ensure its relevance and effectiveness.

1.2 Reef Rescue

Reef Rescue is a key component of *Caring for our Country*, the Australian Government's $2.25 billion initiative to restore the health of Australia's environment and to improve land management practices. Reef Rescue's objective is to improve the water quality of the GBR lagoon by increasing the adoption of land management practices that reduce the runoff of nutrients, pesticides and sediment from agricultural land. The Reef Rescue component of Caring for our Country is comprised of five integrated components (http://www.nrm.gov.au/funding/reef-rescue/index.html):

- Water Quality Grants ($146 million over five years)
- Reef Partnerships ($12 million over five years)
- Land and Sea Country Indigenous Partnerships ($10 million over five years)
- Reef Water Quality Research and Development ($10 million over five years)
- Water Quality Monitoring and Reporting, including the publication of an annual Great Barrier Reef Water Quality Report Card ($22 million over five years)

1.3 Water Quality Improvement Plans

The Mackay Whitsunday *Reef Rescue* delivery process is focused on the increased adoption of "A" and "B" class (cutting-edge and current best practice, respectively) land management practices (DPI&F 2009) across agricultural commodities in the region. These practices were identified in the *Mackay Whitsunday Water Quality Improvement Plan* (Drewry *et al.* 2008) and are based on the best available science and information with regards to improving on-farm economic and environmental sustainability. The objective of these practices is to improve the water quality of the GBR lagoon by reducing nutrient, pesticide and sediment loads whilst helping to improve farm productivity and profitability. The validation of new innovative practices and the monitoring of practice adoption rates will help determine natural resource condition (including water quality) improvements at a farm, sub-catchment, catchment and region-wide scale.

1.4 Project Catalyst

Project Catalyst aims to quantify the water quality, productivity, social and economic benefits of adopting "cutting-edge" (A class) management practices in the sugar industry. The foundation partners of *Project Catalyst* are The Coca Cola Company, World Wildlife Fund and Reef Catchments (Mackay Whitsunday Isaac) Limited.

In 2009, *Project Catalyst* worked with 15 cane growers adopting A class management practices in the Mackay Whitsunday region. Now, in 2012, Project Catalyst has 27 cane growers adopting A class management practices in the Mackay Whitsunday region (http://projectcatalyst.net.au/) and 73 cane growers in total throughout the GBR catchment (http://reefcatchments.com.au/land/project-catalyst/). In the future, *Project Catalyst* aims to translate the experience gained from the GBR catchment to the global sugar industry.

1.5 Paddock to Reef Integrated Monitoring, Modelling and Reporting Program

The *Paddock to Reef Integrated Monitoring, Modelling and Reporting (P2R) Program* was implemented to determine the success of the Reef Plan in reducing anthropogenic contaminants entering the GBR lagoon (The State of Queensland 2009). The P2R Program is using multiple lines of evidence to report on the effectiveness of investments and whether targets are being met (Carroll *et al.* 2012). One of these lines of evidence is practice effectiveness in improving water quality at the paddock (edge-of-field) scale. It combines on-ground end of paddock runoff, sub-catchment and catchment scale water quality monitoring within the GBR catchments with modelling at both paddock and catchment scales. At the catchment scale, water quality samples are to be collected for a three year period prior to and following the Reef Plan regulations coming into effect to determine any change in water quality. At the paddock scale, plots were established utilising differing levels of soil management, pesticide and herbicide application on sugarcane, horticulture crops and grazing lands. These plots are used to determine how the different land management practices (A, B, C and D classes) affect water quality. Collected water quality data are used to validate and calibrate the models at each scale. Annual reporting is undertaken to assess progress towards the goals and objectives of the Reef Plan based on collected water quality data (The State of Queensland 2009).

1.6 Project Intent

The purpose of the current Mackay Whitsunday region project is to reduce the amounts of herbicides, nutrients and sediments leaving sugarcane farms and entering the GBR lagoon. The reduction will be achieved by providing growers that are involved in the delivery of the Australian Government's *Reef Rescue* program with detailed information on how their management practices affect water quality. This will enable growers to refine their practices and further reduce the amounts of contaminants leaving the farm. Supporting farmers in this manner will allow for adaptive management of practice implementation to deliver the highest possible water quality benefits for the GBR. Practice refinements developed through this process will become a core part of future industry extension efforts. The project involves collaboration between the Department of Natural Resources and Mines, Mackay Area Productivity Services (MAPS), Reef Catchments (Mackay Whitsunday Isaac) Limited and individual cane farmers.

This report outlines the third year (2011/2012 wet season) of implementation and the results of paddock to sub-catchment scale water quality monitoring within the Sandy Creek catchment near Mackay in central Queensland.

2 METHODOLOGY

There are three monitoring scales from the plot (paddock) to sub-catchment (multi-farm) scale. These include management treatment plots at the paddock scale; a multi-block scale site and a multi-farm scale site (Figure 1). There are seven treatments at the paddock scale – two treatments at the Victoria Plains site and five at the Marian site. All sites are located within the Sandy Creek catchment.

2.1 Paddock-scale

2.1.1 Victoria Plains site

The selected block (Farm 3434A, Block 14-1; Figure 1) is located near Mount Vince, west of Mackay (21^{o} 11’ 3”S 148^{o} 58’ 7”E). The block has a slope of 1.1%, draining to the south. The soil has previously been mapped (1:100,000) on the change between a Victoria Plains (“Vc”) and Wollingford (“Wo”) soil (Holz and Shields 1984). A Victoria Plains soil is a uniform clay derived from quaternary alluvium, and a Wollingford soil is a soil of uplands derived from acid to volcanic rocks on 2-8% slopes.

Uniform clay soils of the alluvial plains represent 16% of the sugarcane growing area in the Mackay district, with Victoria Plains soils occupying 7% of the growing area. Soils of uplands derived from acid to intermediate volcanics on 2-8% slopes represent a further 7%, with Wollingford soils occupying 3% of the growing area (Holz and Shields 1985).

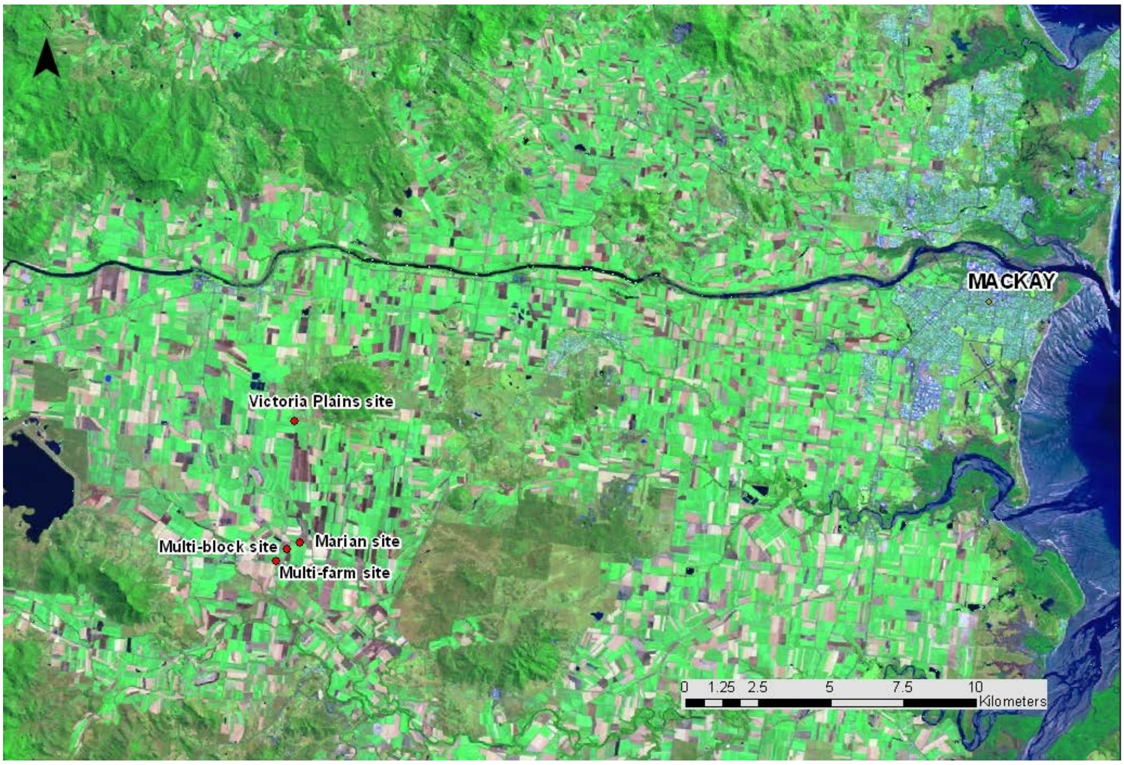

Figure 1 Locality map of monitoring sites

The soil across the monitoring site can be generally described as a deep (>1.6 m) black to dark grey self-mulching medium clay. Details of soil properties can be found in the 2009/10 report (Rohde and Bush 2011). Prior to planting this trial in August 2009 (when row spacing treatments were established), soybeans were grown and sprayed out using glyphosate. Trash from the previous cane crop was not burnt and was worked into the soil. The block was divided into two treatments of 30 rows (Table 1). Row length across the entire block ranges from approximately 225-300 m.

Table 1 Summary of treatments applied at the Victoria Plains site

	ABCD Classification	Soil Management	Nutrient Management	Herbicide Management
Treatment 1	CCC[1]	1.5 m current practice	Generalised recommendation	Regulated[3]
Treatment 2	BBB	1.8 m controlled traffic	Six Easy Steps[2]	Non-regulated[4]

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES
[3] – Herbicides identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999
[4] – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

2.1.1.1 *Harvest, nutrient and herbicide applications*

Both treatments were machine harvested on 10th August 2011 (first ratoon). The cane was harvested green, the trash blanket was left on the soil surface and no cultivation was undertaken. Herbicide treatments were applied as a boom spray to the entire area on 22nd August 2011 (Table 2). Nutrient treatments were applied on 14th October 2011 as a liquid mix to the cane stool using a contractor tractor and boom (Table 3).

Table 2 Application of herbicide treatments to the Victoria Plains site

Treatment	Date	Product (amount applied)	Active ingredients (amount applied)
1	22nd August 2011	Bobcat (3.8 kg/ha) and Gramoxone 250 (0.5 L/ha)	diuron (1778 g a.i./ha) hexazinone (502 g a.i./ha) paraquat (125 g a.i./ha)
2	22nd August 2011	Flame (0.4 L/ha) and Gramoxone 250 (0.5 L/ha)	imazapic (96 g a.i./ha) paraquat (125 g a.i./ha)

Table 3 Application of nutrient treatments to the Victoria Plains site

Treatment	Product (amount applied)	Nutrient analysis (%)				Nutrient applied (kg/ha)			
		N	P	K	S	N	P	K	S
1	BKN200 (3800 kg/ha)	5.28	0.79	2.6	0.94	200	30	99	36
2	PMR2 (3800 kg/ha)	3.66	0.68	2.69	1.16	139	26	102	44

(Note – Products applied are from the Sucrogen AgServices BioDunder™ Liquid Fertiliser range of products)

The second ratoon cane crop was harvested on 17th October 2012. The cane was harvested green, the trash blanket was left on the soil surface and no cultivation was undertaken.

2.1.2 Marian site

The selected block (Farm 3120, Block 2-2; Figure 1) is located near North Eton, SW of Mackay (21° 13’ 37”S 148° 58’ 17”E). Slope is 0.4%, draining to the north. The soil is a duplex derived from quaternary alluvium and has been previously mapped as mapping unit “Ma1” (Marian, yellow B horizon variant) (Holz and Shields 1984), which is a Brown Chromosol (Great Soil Group) (Isbell 1996).

Duplex soils (of the alluvial plains) represent 28% of the sugarcane growing area in the Mackay district, with Marian soils (Ma and Ma1) occupying 6% (Holz and Shields 1985).

The soil across the monitoring site can be generally described as a 0.3 m deep, very dark brown (sometimes greyish) to black sandy or silty clay loam A horizon; there is a sharp change to a dark to yellowish or black medium clay B horizon with a generally strong prismatic structure. The surface of the soil is hard setting, imperfectly drained and slowly permeable. Details of soil properties can be found in the 2009/10 report (Rohde and Bush 2011).

Prior to cane being planted in August 2009 (when row spacing treatments were established), this block was in its final ratoon from a previous cane rotation which was subsequently ploughed out and replanted, with no fallow. Trash from the previous cane crop was burnt before replanting for ease of cultivation. This is not representative of current cane practice in the Mackay region with most growers choosing to undertake a fallow period or a nitrogen fixing crop rotation prior to planting; however suitable sites for this study were limited. The block was divided into five treatments (Table 4) of 18 rows each with an approximate row length of 260 m.

Table 4 Summary of treatments applied at the Marian site

	ABCD Classification	Soil Management	Nutrient Management	Herbicide Management
Treatment 1	CCC[1]	1.5 m current practice	Generalised recommendation	Regulated[3]
Treatment 2	BCC	1.8 m controlled traffic	Generalised recommendation	Regulated
Treatment 3	BBB	1.8 m controlled traffic	Six Easy Steps[2]	Non-regulated[4]
Treatment 4	BAB	1.8 m controlled traffic	Nutrient replacement	Non-regulated
Treatment 5	ABB	1.8 m controlled traffic, skip row	Six Easy Steps	Non-regulated

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES
[3] – Herbicides identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999
[4] – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

2.1.2.1 Harvest, nutrient and herbicide applications

All treatments were machine harvested on 30th August 2011 (first ratoon). The cane was harvested green, the trash blanket left on the soil surface and no cultivation was undertaken. Nutrient treatments were applied on 14th September 2011 as a liquid mix to the cane stool using a contractor tractor and boom (Table 5).

Herbicides were applied on 13th October and 28th November 2011 (Table 6).

The second ratoon crop was harvested on 18th September 2012. The cane was harvested green, the trash blanket was left on the soil surface and no cultivation was undertaken.

Table 5 Application of nutrient treatments to the Marian site

Treatment	Product (amount applied)	Nutrient analysis (%)				Nutrient applied (kg/ha)			
		N	P	K	S	N	P	K	S
1	LOS+P (4200 kg/ha)	4.7	0.48	2.66	0.73	197	20	112	31
2	LOS+P (4200 kg/ha)	4.7	0.48	2.66	0.73	197	20	112	31
3	MKY170 (4200 kg/ha)	3.78	0	2.74	0.41	159	0	115	17
4	MKY70 (3300 kg/ha)	1.61	0	2.84	0.34	53	0	94	11
5	MKY170 (4200 kg/ha)	3.78	0	2.74	0.41	159	0	115	17

(Note – Products applied are from the Sucrogen AgServices BioDunder™ Liquid Fertiliser range of products)

Table 6 Application of herbicide treatments to the Marian site

Treatment(s)	Date	Product (amount applied)	Active ingredients (amount applied)
1-5	13th October 2011	Gramoxone 250 (0.5 L/ha) [1]	paraquat (125 g a.i./ha)
1-5	28th November 2011	Gramoxone 250 (1 L/ha) [2] Amicide 625 (1 L/ha) [3]	paraquat (250 g a.i./ha) 2,4-D amicide (625 g a.i./ha)
1-2	28th November 2011	Velpar K4 (2 kg/ha) [2]	diuron (936 g a.i./ha) hexazinone (264 g a.i./ha)
3	28th November 2011	Balance (0.12 kg/ha) [2]	isoxaflutole (90 g a.i./ha)
5	28th November 2011	Spinnaker (0.14 kg/ha) [4] Verdict (0.15 L/ha) [4]	imazethapyr (98 g a.i./ha) haloxyfop (78 mL a.i./ha)

Notes: [1] – applied to the interspace using a shielded sprayer; [2] – applied to the interspace using a ground rig; [3] – applied to all zones using a ground rig; [4] – applied to the skip area only using a ground rig

2.1.3 Soil and cane trash sampling

2.1.3.1 Soil nutrients

Soil profile samples were collected to 1.5 m depth from four locations (row and interspace, top and bottom of paddock) in each treatment. Post-harvest, pre-nutrient application samples were collected from the Victoria Plains site on 24th August 2011 and from the Marian site on 7th September 2011. After the application of the nutrient treatments, sampling was repeated at both sites on 16th November 2011 (33 and 38 days after nutrient application for Victoria Plains and Marian sites, respectively). Depth increments for all samplings were at 0.1 m depth intervals to 0.3 m, and then 0.3 m intervals to 1.5 m.

Samples were chilled to 4ºC and sent to the laboratory for prompt analysis of mineral nitrogen (N and P, ammonium-N and nitrate-N) in the field wet samples. The results were adjusted to air dry values. All other analyses were undertaken on samples that had been air dried and ground <2 mm with analytical methods described elsewhere (Rayment and Lyons 2011).

2.1.3.2 Soil and cane trash herbicides

Samples of soil (0-2.5 cm) and cane trash were collected prior to herbicide application, and 0.3-203 days after application for the Victoria Plains site and 0.9-105 days for the Marian site. Three cane trash samples (using 8x12 cm quadrats) were taken from beside the cane stool, and three from the interspace (bottom of furrow).

The six samples were bulked, and placed into alfoil lined bags. Samples were immediately stored on ice, and then refrigerated before being transported to the laboratory on ice.

The soil samples were collected from immediately below where the cane trash samples were taken, using a 10 cm diameter bulk density ring. The samples were mixed and bulked to produce one composite sample for each treatment. The bulk sample was then sub-sampled into 500 mL solvent rinsed glass jars with teflon lined lids. As with the cane trash samples, soil samples were immediately stored on ice then refrigerated before being transported to the laboratory overnight on ice.

2.1.3.3 Soil moisture

Continuous soil moisture monitoring is undertaken directly below the stool within treatments that were expected to have different runoff/infiltration (Treatments 1, 2 and 5 at the Marian site, and both treatments at the Victoria Plains site). Moisture content is recorded at one hourly intervals (using EnviroSCAN systems) and logged using the CR800 data loggers. Six sensors are used at each monitoring site, distributed at 20 cm intervals to 1 m, with the final sensor at 1.5 m.

EnviroSCAN sensors consist of two brass rings (50.5 mm diameter and 25 mm high) mounted on a plastic body and separated by a 12 mm plastic ring. The sensors are designed to operate inside a PVC access tube. The frequency of oscillation depends on the permittivity of the media surrounding the tube. Sensitivity studies show that 90% of the sensor’s response is obtained from a zone that stretches from about 3 cm above and below the centre of the plastic ring to about 3 cm in radial direction, starting from the access tube (Kelleners *et al.* 2004).

2.1.4 Rainfall, runoff and water quality

Sampling at each treatment monitoring site is controlled using a Campbell Scientific CR800 data logger housed in a weatherproof container. The logger is programmed to read all sensors every 60 seconds. When runoff water begins to flow through the San Dimas flumes (see following), the station will begin the pre-programmed sampling routine.

Rainfall is measured at each site using a Hydrological Services TB4 tipping bucket rain gauge, with 0.2 mm bucket. Bucket tips are recorded by the data logger allowing for measurements of rainfall volume and intensity. A volumetric rain gauge (250 mm) is also installed at each site as a backup, but these overtopped periodically.

San Dimas flumes (300 mm; Figure 2) are used to measure the runoff discharge from each treatment. The galvanised steel flumes were manufactured to standard specifications as outlined by Walkowiak (2006). The flumes are installed approximately five metres beyond the end of the sugarcane rows (outside of the actual cropped area), and rubber belting is used as bunding to collect runoff from four furrows (commencing eight rows in from the edge of the treatment) and direct the runoff water into the flume for discharge measurement and sample collection. The standard discharge calibration equation (Walkowiak 2006) for converting water depth into discharge is:

$$Q\ (\mathrm{L/s}) = 0.110925 \times \mathrm{depth}\ (\mathrm{mm})^{1.285788}$$

Water depth is measured using a Campbell Scientific CS450 stainless steel SDI-12 pressure transducer, installed in a stilling well at the side of the San Dimas flume, with a connection to the main chamber. The pressure transducer has an accuracy of approximately 0.1% at full scale. Standard equations programmed into the logger automatically convert pressure into water height.

Event integrated water samples are collected using an ISCO Avalanche refrigerated auto-sampler containing four 1.8 L glass bottles. The refrigeration system is activated after collection of the first sample. The sampler is triggered by the CR800 logger. Using the flume discharge equation above, the logger is programmed to take a sub-sample (~160 mL) every 3 mm of runoff, filling each bottle consecutively and allowing for 120 mm of runoff to be sampled. The integrated “bulked” samples are sub-sampled and analysed for total suspended solids (TSS; Section 2.5.2.1), nutrients (total and filtered; Section 2.5.2.3), and herbicides (Section 2.5.2.4) where possible (depending on volume collected). Following smaller rainfall events with limited volume of sample collected, priority is given to analysis in the order of nutrients, herbicides and then TSS.

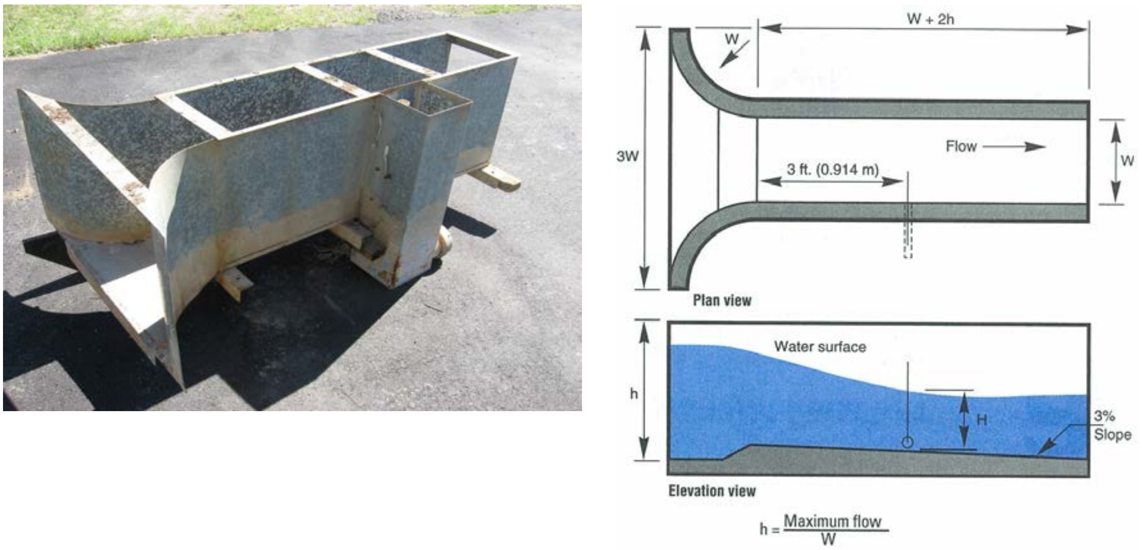

Figure 2 A 300 mm San Dimas flume (left) and critical design dimensions (right)

A radio telemetry network was established between sites that are “within line of sight” (e.g. paddock treatments at the Marian site, and the Multi-block (Section 2.2) and Multi-farm sites (Section 2.3)). Next G modems were located at the Multi-block site and treatment two of the Victoria Plains site to enable communication and download/upload of information from offsite.

Separate power supply systems were installed for the data logger and instrumentation, and for the auto-sampler. The logger power and charging system consists of an 18 A/hr deep cycle battery, a 10 W solar panel with a power regulator, while the auto-sampler power system is two 100 A/hr sealed, deep cycle batteries, a 40 W solar panel and a power regulator.

Water quality monitoring equipment was removed from the site on 2nd July 2012.

2.1.5 Drainage water quality

Drainage water quality below rooting depth (0.9 m) was sampled between mid-February and early March (two or three occasions, depending on each treatment sample volume) using soil solution samplers ("suction cups"). Two soil solution samplers were installed in each treatment (in close proximity to the subsurface EnviroSCAN's) after the cane was planted. A soil solution sampler at the Marian site (Treatment 5) was destroyed during soil preparation (plant cane phase) prior to any sampling taking place and was not replaced. Samples are bulked from each treatment, and analysed for nutrients (total and filtered) and herbicides.

2.1.6 Agronomic sampling

Prior to cane harvesting at both sites, plant samples (stalk and tops) were collected and analysed for nitrogen and phosphorus content at the Bureau of Sugar Experimental stations laboratory, Indooroopilly. At the time of reporting, results were not available.

Cane was mechanically harvested at the Marian site on 18th September 2012 and at the Victoria Plains site on 17th October 2012. All bin numbers were recorded and treatments remained in separate bins to allow for yield and PRS (percent recoverable sugar) measurements to be collected for each treatment during cane processing.

2.2 Multi-block scale

At the Multi-block scale (21° 13' 36"S 148° 57' 57"E; Figure 1), runoff is measured within a farm drain (catchment area approximately 53.5 ha) using a 1 in 40 flat vee crest weir, with depth of flow again being recorded by a pressure transducer at one minute intervals.

The standard discharge calibration equations (Cooney *et al.* 1992) for converting water depth into discharge are shown in Table 7.

Table 7 Discharge equations used at the Multi-block site

Water Depth (m)	Discharge equation	Notes
0 – 0.125 m	Q (cumecs) = 1.557 x 40 x depth (m)$^{2.5}$	Within vee
0.126 – 0.250 m	Q (cumecs) = 1.557 x 40 x [depth$^{2.5}$ – (depth – 0.125)$^{2.5}$]	Within wing walls
0.251 – 0.350 m	Subject to final gauging measurements	Within drain

As with the paddock sites, rainfall (amount and intensity) is measured using a Hydrological Services TB4 tipping bucket rain gauge. A Campbell Scientific CR800 data logger collects outputs from sensors and triggers the ISCO Avalanche refrigerated auto-sampler (with four 1.8 L glass bottle configuration). While submerged, an Analite NEP9510 turbidity probe continuously measures turbidity (data not reported), and water depth is measured via a Campbell Scientific CS450 SDI-12 pressure transducer to calculate flow.

Using the weir discharge equations above, an attempt was made to program the logger to sub-sample (~160 mL) every 3 mm of runoff through the weir. At present, the accuracy of flow calculations is uncertain as water would back-up in the channel after a downstream storage dam filled, affecting flow rates over the weir. Additionally, as the channel overtopped water spread out across the paddocks making measuring water heights and flow rates somewhat problematic. Again bulked samples were analysed (Section 2.5.2) for nutrients (total and filtered), herbicides and TSS, with priority being given to nutrients, herbicides and then TSS depending on the volume of sample collected.

Water quality monitoring equipment was removed from the site on 2nd June 2012.

2.3 Multi-farm scale

At the Multi-farm scale (21° 13' 49"S 148° 57' 45"E; Figure 1), runoff is measured within a natural drain (catchment area approximately 2965 ha) using a 1 in 20 flat vee crest weir, with depth of flow again being recorded by a pressure transducer at one minute intervals. With the exception of the weir, sampling equipment at the Multi-farm scale is identical to that of the Multi-block scale.

The standard discharge calibration equations (Cooney *et al.* 1992) for converting water depth into discharge are shown in Table 8.

Table 8 Discharge equations used at the Multi-farm site

Water Depth (m)	Discharge equation	Notes
0 – 0.250 m	Q (cumecs) = 1.557 x 20 x depth$^{2.5}$	Within vee
0.251 – 0.500 m	Q (cumecs) = 1.557 x 20 x [depth$^{2.5}$ – (depth – 0.250)$^{2.5}$]	Within wing walls
0.501 – 2.000 m	Q (cumecs) = (1.3085 x depth^{2}) + (5.726 x depth) + 1.3114	Within drain

Using the weir discharge equation above, the logger was programmed to sub-sample (~160 mL) every 3 mm of runoff allowing for a total of 120 mm of runoff to be sampled. The bulked sample was sub-sampled and analysed for nutrients (total and filtered), herbicides and sediments (Section 2.5.2).

At the time of reporting, details of specific management practices undertaken with the Multi-farm catchment were not known.

2.4 Water quality load calculations

To estimate the total water quality loads for the wet season, constituent concentrations are required for every runoff event. This was not possible due to occasional equipment failure, insufficient sample volume or samplers being turned off during extreme weather events. Therefore, water quality concentrations need to be estimated for those events that were not sampled.

For the Victoria Plain site, approximately 50-60% of the total seasonal runoff was sampled. As a result, the estimated seasonal loads (particularly Treatment 2, where the initial runoff events were not sampled) are uncertain. In contrast, >95% of the total seasonal runoff at the Multi-farm site was sampled; therefore we have confidence in the calculated seasonal loads. Due to flooding issues with the Marian and Multi-block sites, no load calculations have been undertaken for these sites.

2.4.1 Total suspended solids and nutrients

For Victoria Plains Treatment 1, a regression curve was fitted to known concentrations of TSS and nutrients with time after first runoff (or maximum rainfall intensity for TSS) to estimate concentrations in non-sampled runoff events (Table 9). Due to the initial runoff events from Treatment 2 not being sampled, it was difficult to calculate at accurate estimation of concentrations. For the majority of parameters, a linear relationship was fitted with known concentrations from Treatment 1, and for others a regression curve was fitted to known concentrations with time after first runoff (Table 9), which ever suited the data set best. Event water quality loads were calculated by multiplying the total event discharge by the concentration.

Table 9 Regression equations used to estimate missing water quality concentrations, Victoria Plains and Multi-farm sites

Parameter	Victoria Plains Treatment 1	Victoria Plains Treatment 2	Notes
TSS (mg/L)	$y=0.0718x+15.472$ ($R^2=0.37$)	$y=0.4189x-9$ ($R^2=0.68$)	x = maximum rainfall intensity (mm/hr)
TKN (µg N/L)	$y=2997.5e^{-0.033x}$ ($R^2=0.87$)	$y=2840.1e^{-0.0301x}$ ($R^2=0.82$)	x = days after first runoff
Urea-N (µg N/L)	$y=186.29e^{-0.0186x}$ ($R^2=0.57$)	$y=569.27e^{-0.0401x}$ ($R^2=0.72$)	x = days after first runoff
NO_x-N (µg N/L)	$y=2489e^{-0.0675x}$ ($R^2=0.67$)	$y =0.424x+65.248$ ($R^2=0.98$)	T1: x = days after first runoff T2: x = concentration of T1
TKP (µg P/L)	$y=252.27x^{-0.1834}$ ($R^2=0.74$)	$y =2.4309x-159.15$ ($R^2=0.70$)	T1: x = days after first runoff T2: x = concentration of T1
FRP (µg P/L)	$y=155.51x^{-0.2868}$ ($R^2=0.45$)	$y =0.4778x+30.223$ ($R^2=0.46$)	T1: x = days after first runoff T2: x = concentration of T1

Parameter	Multi-farm site	Notes
TSS (mg/L)	$y=8.9133x$ ($R^2=0.97$)	x=maximum discharge (cumecs)

(Note - Refer to section 2.5.2.3 for nutrient parameter acronyms. Regression plots are shown in Sections 7.1 and 7.2)

2.4.2 Herbicides

At Victoria Plains (Treatment 1), the concentrations of unsampled events were estimated using the average concentration of those sampled events either side of the unsampled event. No herbicide loads were calculated from Treatment 2, as the applied herbicide was only detected in one sample.

At the Multi-farm site, the concentration of Event 1 (not sampled; <0.1% of the seasonal flow) was estimated to be the same as that sampled in Event 2 (22 days later; 4.5% of the seasonal flow). For all other unsampled events, the approach used at Victoria Plains (Treatment 1) was applied.

2.5 Laboratory methodologies

2.5.1 Soil nutrients

Air-dried soil samples (10 g) are weighed into a 250 mL plastic extracting bottle and 100 mL of 1M KCl extracting solution is added. The plastic extracting bottle is securely stoppered and mechanically shaken (end-over-end) at ~25ºC for one hour. The soil extracts are then allowed to clear for around 30 minutes or centrifuged before a known aliquot (e.g. 20 mL) is extracted. Mineral-N fractions in the clarified soil extract are then determined by automated colorimetric procedures (Rayment and Lyons 2011).

2.5.2 Water analyses

Analysis of TSS, turbidity, electrical conductivity, and nutrients (filtered and unfiltered) are conducted by the Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) laboratory, James Cook University, Townsville. Unfiltered herbicide samples are analysed by the Queensland Health Forensic and Scientific Services (QHFSS) laboratory, Brisbane and ACS Laboratories (Australia), Kensington.

2.5.2.1 Total suspended solids and turbidity

To determine the mass per volume of TSS, a known volume of sample is filtered through a pre-weighed standard glass fibre filter. The filter is then oven dried at 103-105^{o}C, and the difference in weight determined between the initial filter weight and the filter and sample weight. The sample is dried until this difference becomes constant or weight change is less than 4% of the previous weight change (or less than 0.5 mg), whichever is less (APHA 1998).

Laboratory turbidity measurements (APHA 2130B) are based on a comparison between the intensity of light scattered by the water sample under defined conditions, and the intensity of light scattered by a standard reference suspension under the same defined conditions. A formazin polymer is used as the primary standard reference suspension (turbidity of 4000 NTU).

2.5.2.2 Electrical conductivity

Electrical conductivity is measured directly using a calibrated conductivity cell rinsed with sample at a known temperature. The conductivity cell is calibrated with known standards of potassium chloride solution prior to analysis (APHA 1998).

2.5.2.3 Nutrients

Nutrient samples from surface water runoff and drainage soil solution are analysed for ammonium-N, urea-N, oxidised nitrogen (NO_x-N, consisting of nitrate and nitrite), total filterable nitrogen (TFN), total Kjeldahl nitrogen (TKN), total filterable phosphorous (TFP), filterable reactive phosphorous (FRP) and total Kjeldahl phosphorous (TKP). Samples for TFN and TFP are digested in an autoclave using an alkaline persulphate technique (modified from Hosomi & Sudo, 1986) and the resulting solution simultaneously analysed for NO_x-N and FRP using an ALPKEM (Texas, USA) Flow Solution II. The analyses of NO_x-N, ammonium-N and FRP are also conducted using segmented flow auto-analysis techniques following standard methods (APHA 2005).

For TKN and TKP, the sample is digested prior to analysis in the presence of sulphuric acid, potassium sulphate and a mercury catalyst. Total Kjeldahl nitrogen is then determined using the indophenol reaction (Searle 1984) on an OI Analytical Flow Solution IV segmented flow analyzer. Total Kjeldahl phosphorus is determined using the phosphomolybdic blue reaction (Murphy and Riley 1962) on an OI Analytical Flow Solution IV segmented flow analyser.

2.5.2.4 Herbicides

Water samples are analysed by liquid chromatography mass spectrometry (LCMS) at the QHFSS laboratory. Urea and triazine herbicides and polychlorinated biphenyls are extracted from the sample with dichloromethane. The dichloromethane extract is concentrated prior to instrumentation quantification by LCMS (QHFSS method number 16315). Phenoxy acid herbicide water samples, which are collected in separate 750 mL glass bottles, are acidified and extracted with diethyl-ether. After evaporation and methylation (methanol, concentrated sulphuric acid and heat) the samples are extracted with petroleum ether and analysed by LCMS (QHFSS method number 16631).

Imazapic and isoxaflutole analysis are conducted by ACS Laboratories (Australia). Samples are filtered through a 0.45 µm nylon filter to remove particulate matter before being extracted through a solid phase extraction (SPE) cartridge which is eluted using acetonitrile. The extracted sample is analysed by LCMS using standard blanks, matrix spikes and duplicates for quality control.

2.5.3 Soil and cane trash analysis

Analysis of samples for atrazine, diuron and hexazinone are conducted at QHFSS. Samples are extracted using routine procedures and analysed by LCMS.

Paraquat analysis is conducted by ACS Laboratories. Homogenous 10 g samples of soil are acid digested on a hot block for four hours. The soil is then extracted with aqueous acid to release highly bound paraquat and diquat from the soil. Extracts are neutralized using KOH and analysed by LCMS using standard blanks, matrix spikes and duplicates for quality control.

Imazapic and isoxaflutole analysis are conducted by ACS Laboratories. Samples are homogenized by freezing with dry ice and blending to a fine powder. Five grams of homogenized sample is extracted with acetonitrile and passed through an SPE cartridge which is eluted using acetonitrile. The extracted sample is analysed by LCMS using standard blanks, matrix spikes and duplicates for quality control.

3 RESULTS

3.1 Overview of runoff events

3.1.1 Paddock scale

In excess of 12 runoff events were recorded at each of the paddock scale monitoring sites, with the first runoff event occurring on 28th December 2011. The final runoff event at the Victoria Plains site occurred on 10th July 2012, by which time all equipment had been removed from the Marian site (last monitored event occurred on 2nd June 2012). Due to the magnitude of the wet season (particularly late March), the automatic samplers were turned off and on throughout the wet season to limit the number of events being sampled; hence not all runoff events have associated water quality data.

Irrigation was not applied to the Victoria Plains site during the reporting period, but the Marian site was irrigated six times (22nd September 2011, 3rd October 2011, 7th November 2011, 7th January 2012, 25th April 2012, and 14th May 2012), with 40 mm being applied on each occasion.

3.1.2 Multi-block and Multi-farm scale

More than 13 runoff events were measured at the Multi-block and Multi-farm scale sites. The first runoff event at the Multi-block site on 9th October 2011 was a result of irrigation, with the first rainfall runoff event occurring 28th December 2011. Runoff first commenced at the Multi-farm site on 6th December 2012. It was difficult to define individual runoff events at the sites, as flows were still being recorded when the next rainfall event occurred. The final runoff event at the Multi-farm site commenced on 10th July 2012, by which time all monitoring equipment had been removed from the Multi-block site (last monitored event commenced on 2nd June 2012, but no water quality samples were collected).

3.2 Victoria Plains site

3.2.1 Soil nutrients

Soil nitrate-N concentrations (KCl extraction) after harvest and prior to nutrient application (24th August 2011) were ≤ 1 mg/kg in both treatments (row and interspace) at all depths. Ammonium-N concentrations were variable, with up to 4 mg/kg (air dry) detected in Treatment 1, and 2 mg/kg (air dry) in Treatment 2.

On 16th November (33 days after nutrient application; 34 mm of rain), soil nitrate-N concentrations were much higher in the surface 0-0.3 m of the row area of Treatment 1 (200 kg N/ha applied) than Treatment 2 (139 kg N/ha applied) (Figure 3). In the interspace, concentrations were much lower (≤ 3 mg/kg) due to the nutrients being applied to the row area only.

Soil phosphorus (KCl extraction) concentrations were similar (generally 80-120 µg/kg) between treatments after harvest and prior to nutrient application. As with nitrate-N, phosphorus concentrations (33 days after nutrient application) were much higher in the surface 0-0.3 m of the row area of Treatment 1 (113-328 µg/kg; 30 kg

P/ha applied) than Treatment 2 (77-117 µg/kg; 26 kg P/ha applied). Concentrations were much lower in the interspace (67-89 µg/kg) due to the nutrients being applied to the row area only.

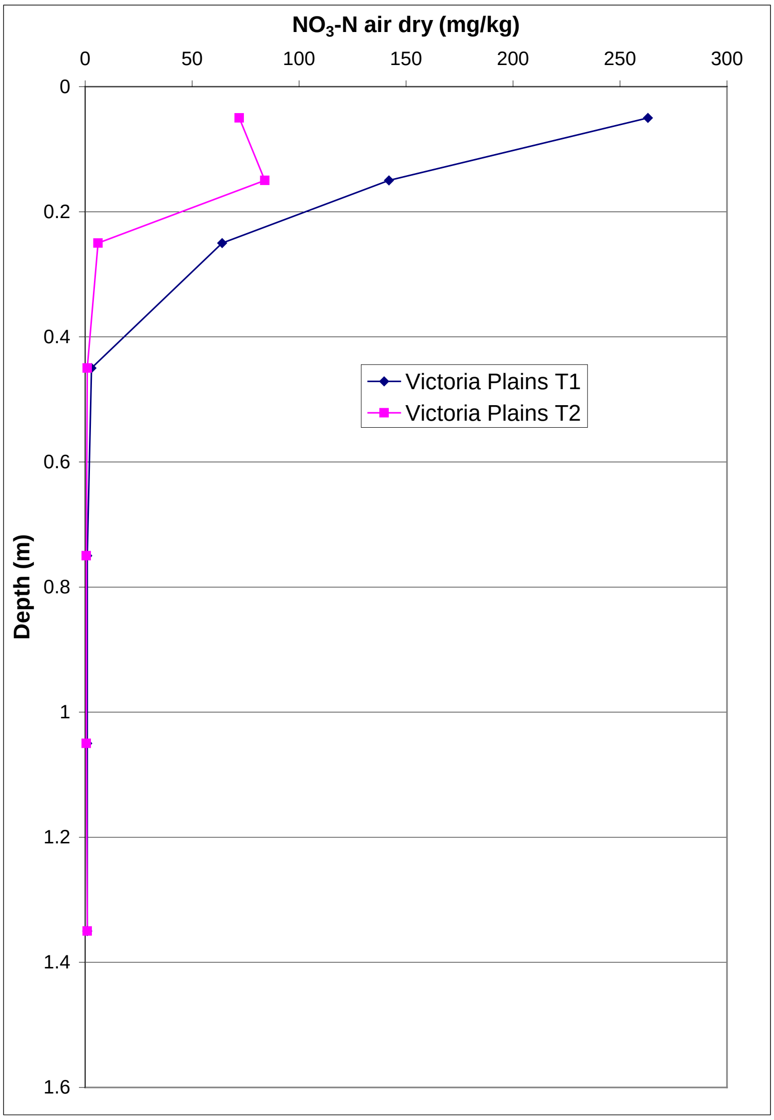

Figure 3 Soil nitrate-N concentrations (KCl extraction; air dry) in the soil profile 33 days after application (row only), Victoria Plains site

3.2.2 Soil and cane trash herbicides

Surface soil (0-2.5 cm) and cane trash samples were collected for herbicide analysis prior to herbicide application, and on nine occasions (0.3-203 days) after application. During this sampling period, 1093 mm of rainfall was recorded.

Concentrations of diuron and hexazinone were detected in the surface soil prior to application this season (0.27 and 0.012 mg/kg, respectively; 343 days after previous application), however imazapic was not detected (<0.01 mg/kg). After application, peak concentrations were not recorded in the surface soil until ~10 days after application (Figure 4), as the herbicide was applied to the cane trash blanket. During this 10 day period, 22.8 mm of rain was recorded (first rain was recorded four days after application). Using the field dissipation data of 10-203 days after application, the calculated half-lives of diuron, hexazinone and imazapic were 74, 39 and 47 days, respectively.

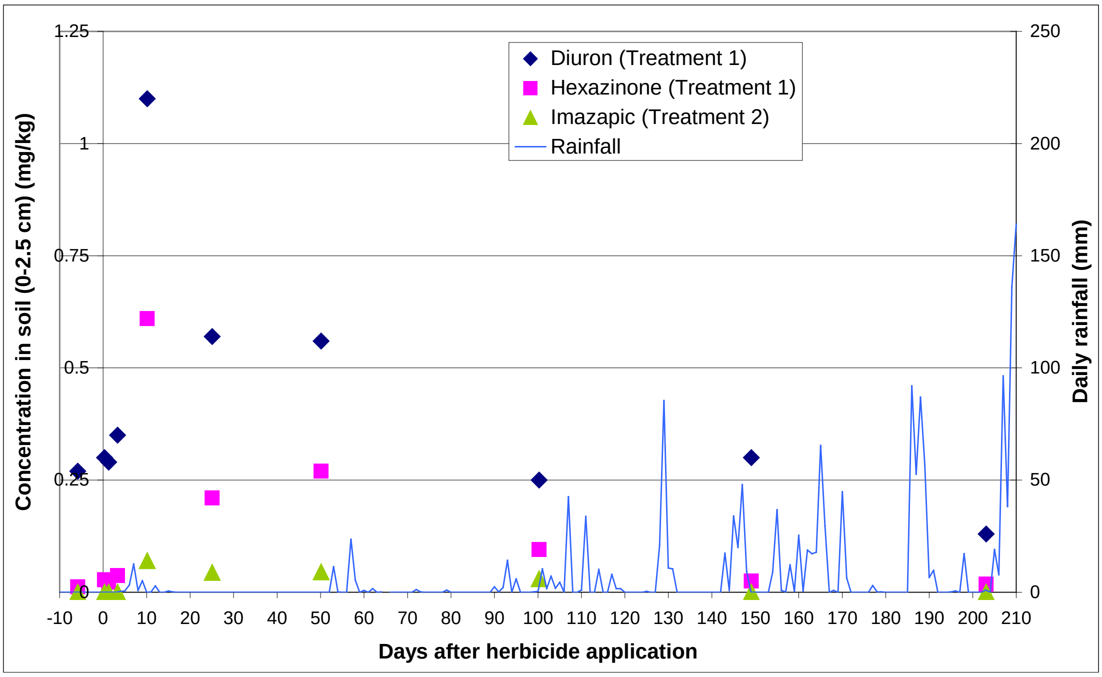

Figure 4 Field dissipation of diuron, hexazinone and imazapic in the surface soil (0-2.5 cm), Victoria Plains site
(Note - Herbicides applied on 22nd August 2011)

Unlike the surface soil, herbicides were not detected (<0.05 mg/kg for diuron and hexazinone, and <0.01 mg/kg for imazapic) on the cane trash blanket prior to application this season. Peak concentrations of all herbicides were detected one day after application (these concentrations were higher than those detected at 0.3 days), and rapidly declined within 25 days of application (Figure 5). Hexazinone and imazapic were not detected on the cane trash blanket 150 days after application, but diuron was (0.83 mg/kg, reducing to 0.33 mg/kg at 203 days). Using this field dissipation data, the calculated half-lives for diuron, hexazinone and imazapic on the cane trash blanket were 30, 22 and 33 days, respectively.

3.2.3 Soil moisture

Soil water extraction was evident throughout the season, with short periods of saturation evident in February and March (Figure 6). It is uncertain whether the differences in total moisture are likely to be related to the treatments or the soil cracking patterns under dry conditions (between harvest and first runoff).

Data from the individual depth sensors shows water extraction at 150 cm in Treatment 1 was evident from mid-November to mid-January, and there was no clear evidence of a shallow water table (Section 7.3.1). Water extraction at 150 cm in Treatment 2 was evident from mid-November to late December. A water table was evident at 150 cm from late January to late April and again from early June. It rose to 100 cm for a short period (mid-March to early April), and was not evident at 80 cm (Section 7.3.2).

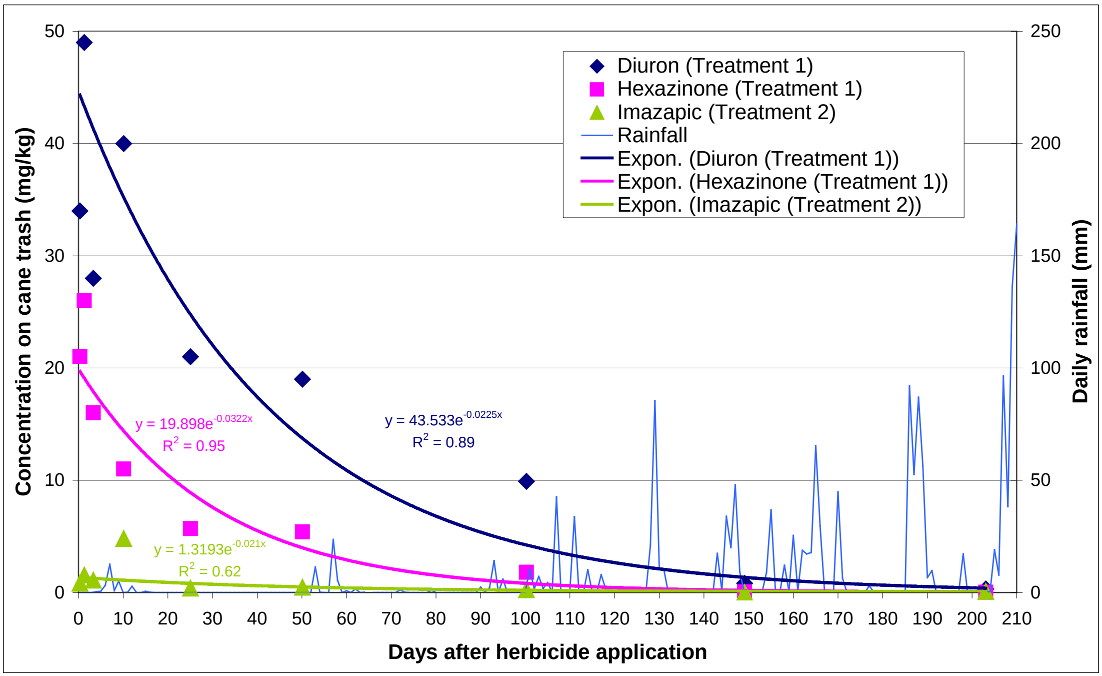

Figure 5 Field dissipation of diuron, hexazinone and imazapic on the cane trash blanket, Victoria Plains site
(Note - Herbicides applied on 22nd August 2011)

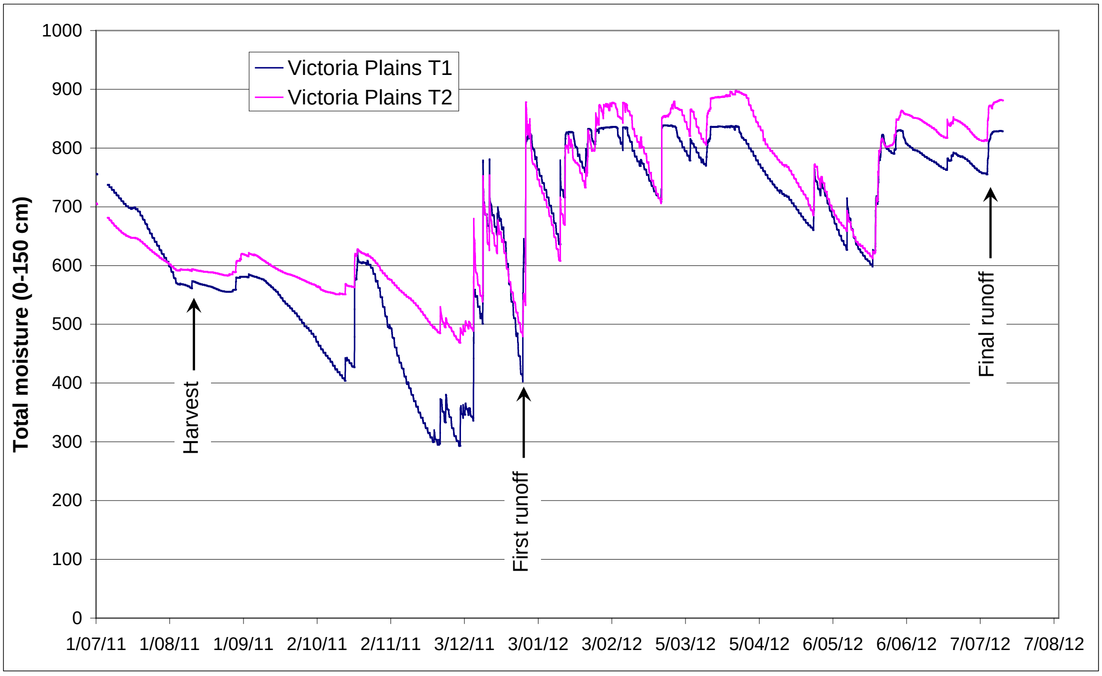

Figure 6 Total moisture in the soil profile (0-150 cm), Victoria Plains site

3.2.4 Rainfall and runoff

A total of 2213 mm of rainfall was recorded at the Victoria Plains site between 1st December 2011 and 31st July 2012, which was above the long-term average of 1498 mm (Te Kowai Research Station, records since 1889). The highest daily total of 270 mm was recorded on 21st March 2012.

Total wet season runoff (Table 10) from Treatment 2 (1.8 m row spacing) averaged 13.7% less than Treatment 1 (1.5 m row spacing) (816 mm and 946 mm, respectively;

or 37% and 43% of rainfall). Runoff from Treatment 2 was delayed by ~9 minutes on average compared with Treatment 1, and the peak runoff was 23% lower.

Table 10 Event rainfall and runoff during the 2011/12 wet season, Victoria Plains site

Event	Start Date	Rainfall		Treatment 1 Runoff		Treatment 2 Runoff	
		Total (mm)	Max. intensity (mm/hr)	Total (mm)	Maximum (mm/hr)	Total (mm)	Maximum (mm/hr)
1	28/12/11	82.2	156	8.7	4.9	4.3	3.3
2	15/01/12	48.0	84	20.4	18.3	13.9	13.2
3	23/01/12	36.8	84	1.7	2.4	0.1	0.4
4	28/01/12	25.0	96	0.8	0.8	0.4	0.5
5	30/01/12	14.4	84	0.8	1.2	0.4	0.6
6	31/01/12	19.0	72	3.8	1.7	1.9	1.3
7	02/02/12	17.6	36	2.2	1.4	1.5	1.0
8	03/02/12	92.4	144	50.2	21.0	44.8	17.7
9	07/02/12	44.8	144	12.6	13.7	13.0	12.6
10	24/02/12	55.6**	72**	61.8	14.2	44.1	15.1
11	25/02/12	86.2	120	67.6	28.1	63.6	24.0
12	26/02/12	56.4	108	34.7	12.1	31.0	11.7
13	15/03/12	421.8	120	280	48.7	250	35.1
14*	19/03/12	502.4	120	337	64.7	309	41.5
15	01/06/12	34.4	18	12.4	3.2	5.2	1.3
16	10/07/12	134.0	24	51.5	4.3	32.6	4.0
Total				**946**		**816**	

(Note - * represented periods of time when automatic samplers were turned off, and therefore classified as a single event. ** - partially blocked pluviometer, may not reflect correct rainfall total or intensity)

3.2.5 Runoff water quality

3.2.5.1 Total suspended solids, turbidity and electrical conductivity

Concentrations of TSS across all of the samples collected were low (<70 mg/L) and generally consistent throughout the season (Figure 7). Concentrations ranged from 14-29 mg/L for Treatment 1 and 26-61 mg/L for Treatment 2. The total estimated sediment load for the wet season from Treatment 2 was 298 kg/ha, higher than that from Treatment 1 (217 kg/ha) (Table 11). These sediment loads are much lower than measured in previous seasons due to the reduced runoff compared to the 2010/11 season, and the low sediment concentrations. The estimated flow-weighted TSS concentration for both treatments was similar: 22 mg/L and 24 mg/L for Treatments 1 and 2, respectively.

Similar to TSS concentrations, runoff turbidity was low and consistent between treatments (11-135 NTU). When samples for each treatment were combined, there was a poor relationship (R^2=0.40) between TSS concentration and turbidity (data not shown). This is thought to be due to the low range in TSS concentrations.

Electrical conductivity (EC) values were very low and similar between treatments (31-73 µS/cm), except for the first sample collected from Treatment 1 (313 µS/cm on 28th December 2011; no sample collected from Treatment 2). Values tended to decline through the season.

Table 11 Calculated loads of sediment and nutrients from runoff, Victoria Plains site

Event	**Start**	**TSS (kg/ha**		**TKN (kg/ha)**		**NO$_x$–N (kg/ha)**		**Urea-N (kg/ha)**		**TKP (kg/ha)**		**FRP (kg/ha)**	
	Date	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
1	28/12/11	2.5	*2.4*	0.301	*0.121*	0.504	0.108	0.011	*0.024*	0.032	0.032	0.024	*0.007*
2	15/01/12	3.7	*3.6*	0.372	*0.232*	0.447	0.137	0.021	0.056	0.037	0.038	0.031	0.012
3	23/01/12	*0.4*	*0.0*	*0.021*	*0.002*	*0.007*	*0.000*	*0.002*	*0.000*	*0.002*	0.000	*0.001*	*0.000*
4	28/01/12	*0.2*	*0.1*	*0.009*	*0.005*	*0.003*	*0.001*	*0.001*	*0.001*	*0.001*	0.001	*0.000*	*0.000*
5	30/01/12	*0.2*	*0.1*	0.009	*0.004*	0.005	*0.001*	0.001	*0.001*	0.001	0.001	0.001	*0.000*
6	31/01/12	*0.8*	*0.4*	0.048	*0.020*	0.003	*0.002*	0.006	*0.003*	0.004	0.002	0.001	*0.001*
7	02/02/12	*0.4*	*0.1*	0.021	*0.015*	0.002	*0.001*	0.003	*0.002*	0.002	0.001	0.001	*0.001*
8	03/02/12	13.6	27.3	0.340	0.306	0.029	0.045	0.043	0.032	0.061	0.063	0.027	0.034
9	07/02/12	*3.3*	*6.7*	0.052	0.139	0.018	0.030	0.014	0.010	0.022	0.040	0.013	0.016
10	24/02/12	8.7	11.5	0.308	0.252	0.051	0.028	0.061	0.054	0.087	0.045	0.057	0.025
11	25/02/12	14.9	21.6	0.258	0.344	0.017	0.019	0.042	0.041	0.061	0.064	0.011	0.018
12	26/02/12	*8.2*	*11.2*	*0.145*	*0.146*	*0.015*	*0.026*	*0.021*	*0.016*	*0.041*	0.040	*0.017*	*0.017*
13	15/03/12	75.6	85.1	0.854	0.588	0.134	0.135	0.064	0.048	0.288	0.190	0.137	0.093
14	19/03/12	*82.1*	*127*	*0.688*	*0.756*	*0.034*	*0.215*	*0.138*	*0.067*	*0.379*	0.354	*0.148*	*0.158*
15	01/06/12	*2.4*	*0.6*	0.255	*0.001*	0.043	*0.011*	0.031	*0.000*	0.040	0.032	0.012	*0.004*
16	10/07/12	12	*0.3*	0.609	*0.003*	0.008	0.450	0.042	0.076	0.072	0.059	0.030	0.185
Total load (kg/ha)		**217**	**298**	**4.3**	**2.9**	**1.3**	**1.2**	**0.50**	**0.43**	**1.1**	**0.96**	**0.51**	**0.57**
Flow weighted seasonal av. conc.		**22 mg/L**	**24 mg/L**	**406 µg N/L**	**239 µg N/L**	**125 µg N/L**	**99 µg N/L**	**47 µg N/L**	**35 µg N/L**	**107 µg P/L**	**79 µg P/L**	**48 µg P/L**	**47 µg P/L**

(Note – T1=Treatment 1 (1.5 m row spacing); T2=Treatment 2 (1.8 m row spacing, controlled traffic); figures in *italics* indicate loads estimated from regression curves (Table 9) where samples were not collected)

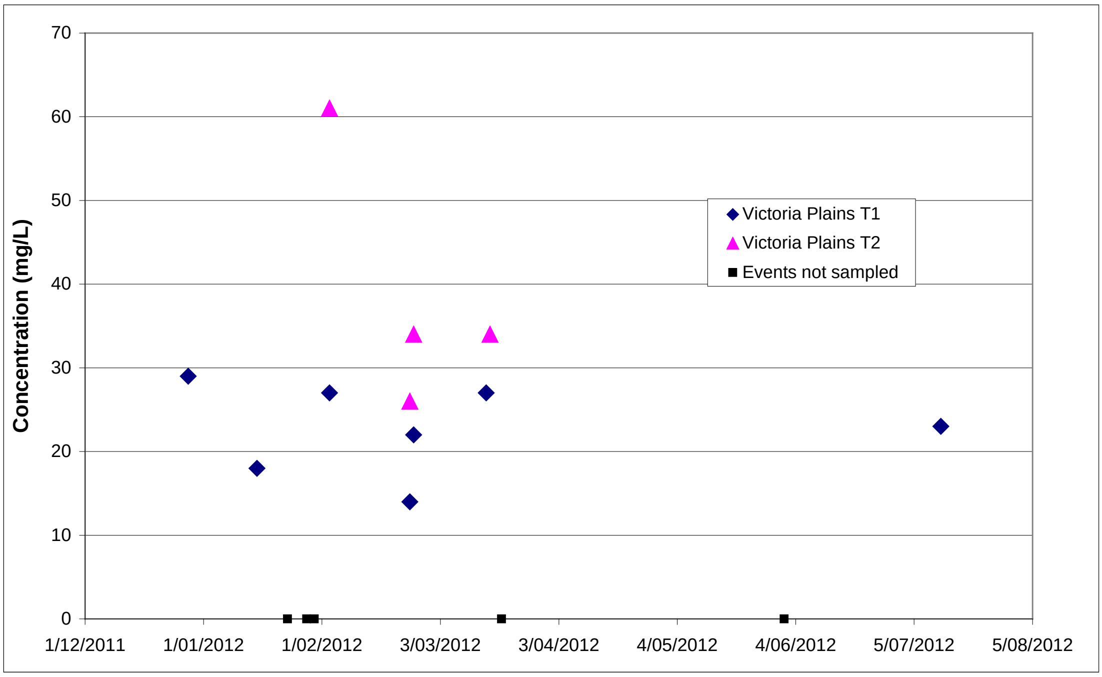

Figure 7 Concentrations of total suspended solids measured in runoff, Victoria Plains site

3.2.5.2 Nitrogen

Nitrogen concentrations in the first runoff event (Treatment 1 only) (28th December 2011, 75 days after application) were dominated by NO_x-N (Figure 8). Initial concentrations were highest in Treatment 1 (5795 µg N/L; Treatment 2 not sampled), then rapidly declined to <1000 µg N/L by the end of January, and averaged 71 µg N/L for the remainder of the season, although there was an increase in Treatment 2 on 10th July 2012.

In contrast to NO_x-N, urea-N concentrations were low throughout the season (<400 µg N/L), again with an increase in Treatment 2 in July. Ammonium-N concentrations were also low (<400 µg N/L), except for Treatment 2 in mid-January and again in July (1660 µg N/L and 1319 µg N/L, respectively) (Figure 8).

The total loss of NO_x-N was estimated to be 1.3 kg/ha and 1.2 kg/ha, and the seasonal flow weighted average concentration was 125 µg N/L and 99 µg N/L from Treatment 1 and 2, respectively (Table 11). The total loss of urea-N was estimated to be 0.50 kg/ha and 0.43 kg/ha, and the seasonal flow weighted average concentration was 47 µg N/L and 35 µg N/L from Treatment 1 and 2, respectively (Table 11). The loss of NO_x-N plus urea-N represents 0.9-1.2% of the applied nitrogen to each treatment, much lower than the ~10% measured in previous seasons.

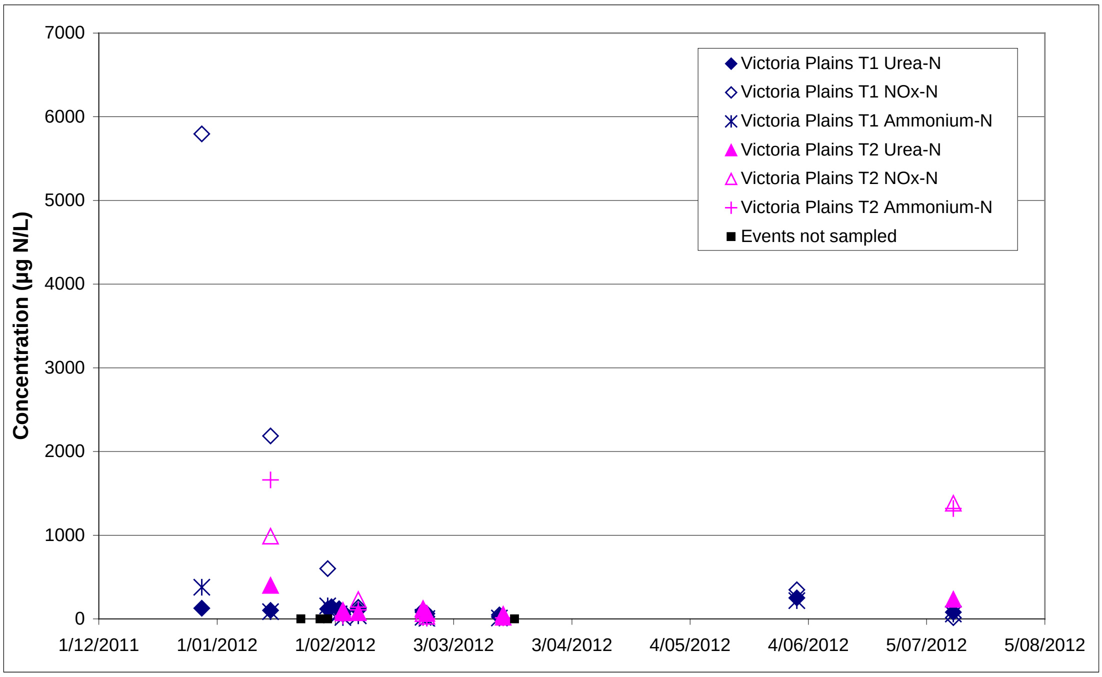

Figure 8 Urea-N, NO$_x$-N, and ammonium-N concentrations in runoff, Victoria Plains site
(Note - Nutrients applied on 14th October 2011)

3.2.5.3 Phosphorus

Phosphorus was applied to both treatments at similar rates (26-30 kg P/ha), resulting in similar concentrations in runoff (Figure 9). As with most other parameters, FRP concentrations were highest in the first runoff event after application (Treatment 2 not sampled), then declined throughout the season. The total FRP loss in runoff for the wet season was 0.51 kg/ha and 0.57 kg/ha for Treatments 1 and 2, respectively (Table 11). The seasonal flow weighted average concentration for each treatment was similar (48 µg P/L and 47 µg P/L for Treatment 1 and 2, respectively).

Across all of the samples collected, FRP comprised the majority (70%) of the TFP signature. Of those samples with both FRP and TP data, FRP was approximately half of TP.

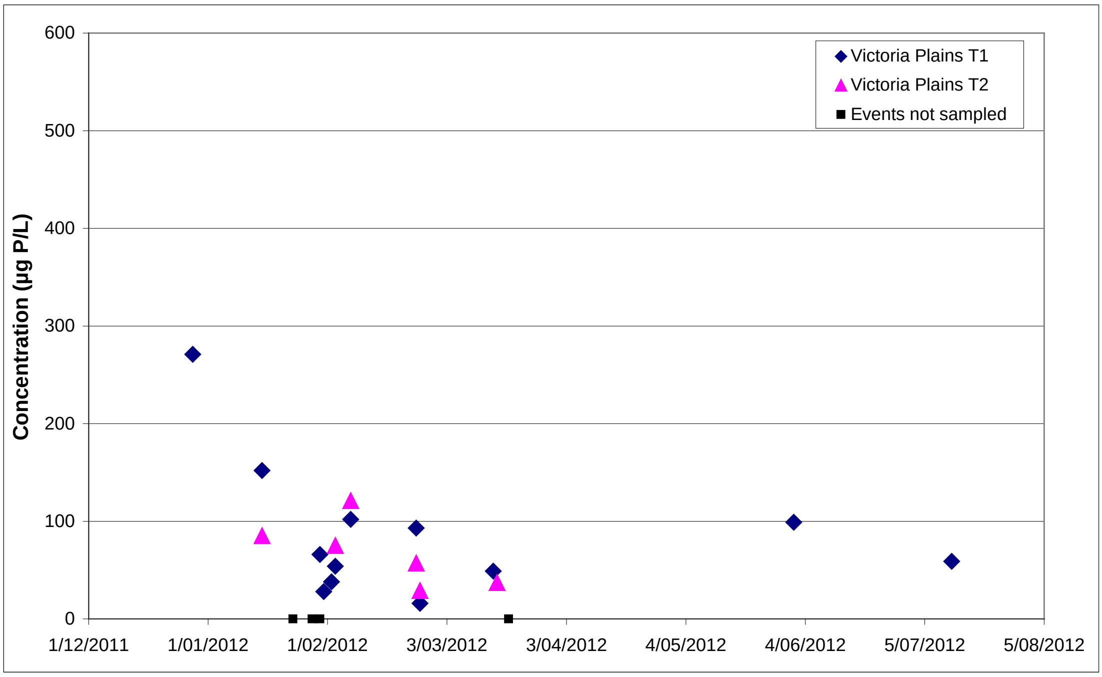

Figure 9 Filterable reactive phosphorus concentrations in runoff, Victoria Plains site
(Note - Nutrients applied on 14th October 2011)

3.2.5.4 Herbicides

Diuron and hexazinone were detected in low concentrations (compared to previous seasons) in runoff from Treatment 1 (Figure 10). Concentrations were highest in the first event, which was 128 days after application (compared to 7-8 days in previous seasons).

Limited sample volume meant that imazapic was not analysed in runoff samples from Treatment 2 until 3rd February 2012. It was detected at 1 µg/L in this event, and was not detected (<1 µg/L) in further events.

Although atrazine has not applied as part of our trial, it was detected at low concentrations (<0.01-0.05 µg/L) throughout the season (Treatment 1 only). These concentrations are lower than those detected in previous years (0.26-1.1 µg/L in 2009/10, 0.04-12 µg/L in 2010/11). It is thought that the source of this atrazine may be from the source water used in the spray tank mixture, rather than persistence in the environment.

The total seasonal calculated diuron and hexazinone loads from Treatment 1 were 3.0 g/ha (0.17% of applied) and 1.9 g/ha (0.37% of applied), with flow weighted seasonal average concentrations of 0.28 µg/L and 0.18 µg/L, respectively (Table 12). It is estimated that the first 50% of the total seasonal diuron and hexazinone load was delivered in the initial 10-15% of the seasonal runoff (Figure 11).

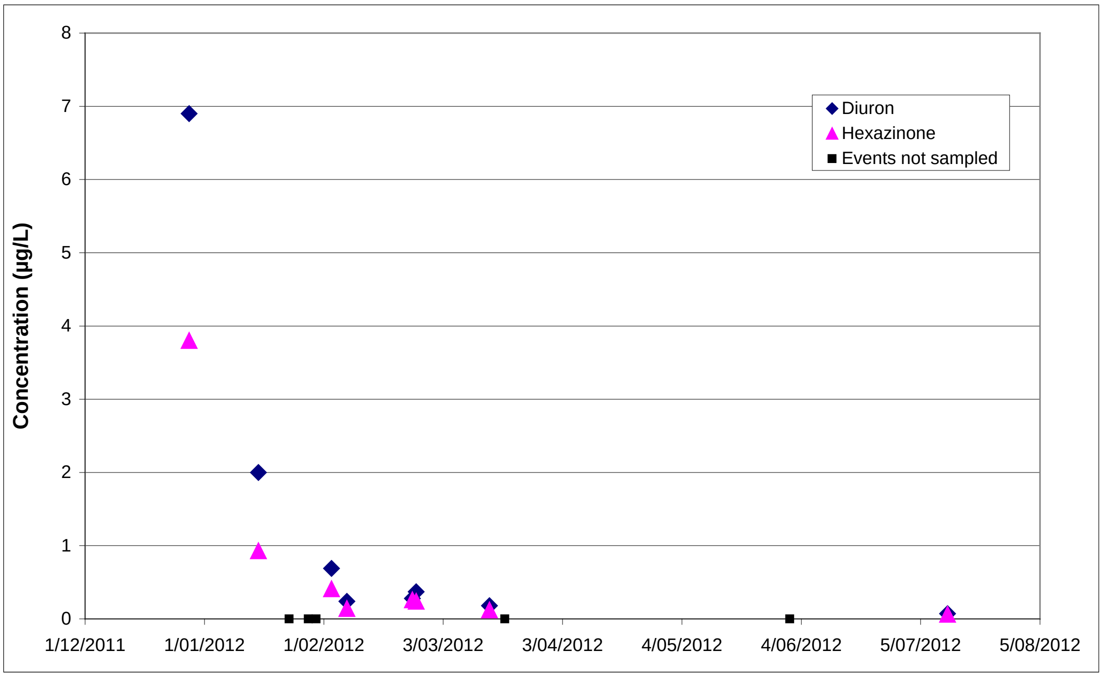

Figure 10 Diuron and hexazinone concentrations in runoff from Treatment 1, Victoria Plains site
(Note - Herbicides applied on 22nd August 2011)

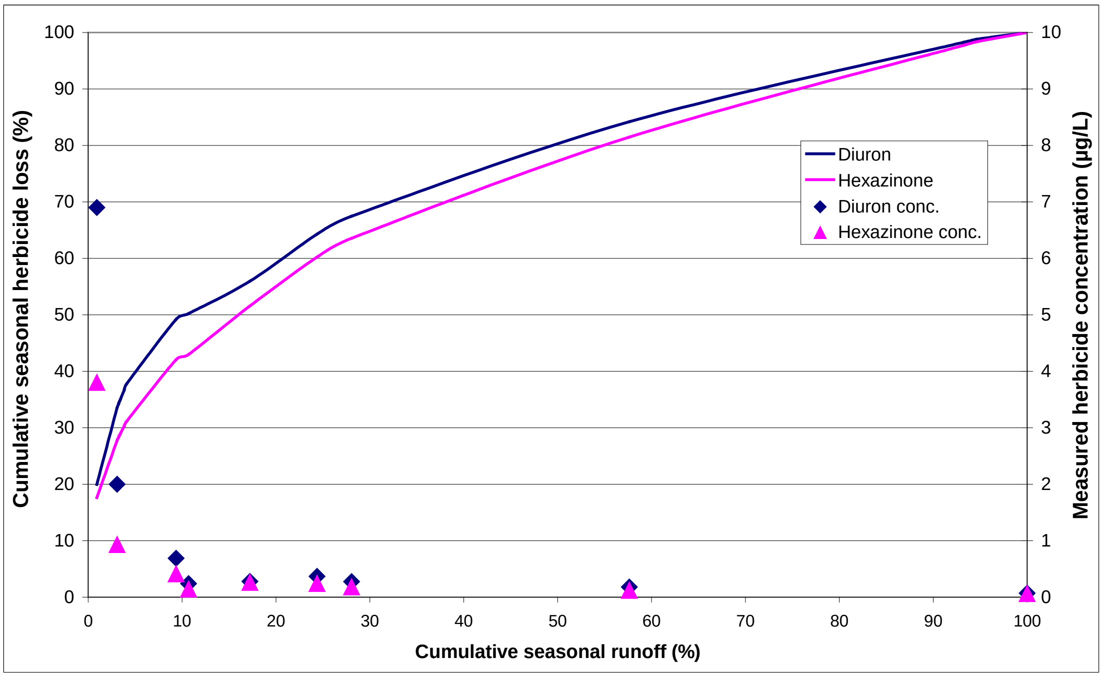

Figure 11 Cumulative seasonal runoff and herbicide loss from Treatment 1, Victoria Plains site

Table 12 Calculated loads of herbicides from Treatment 1 runoff, Victoria Plains site

Event	Start Date	Atrazine (g/ha)	Diuron (g/ha)	Hexazinone (g/ha)
1	28/12/11	0.004	0.600	0.331
2	15/01/12	0.006	0.408	0.190
3	23/01/12	*0.000*	*0.022*	*0.011*
4	28/01/12	*0.000*	*0.011*	*0.005*
5	30/01/12	*0.000*	*0.010*	*0.005*
6	31/01/12	*0.001*	*0.051*	*0.026*
7	02/02/12	*0.001*	*0.029*	*0.015*
8	03/02/12	0.015	0.347	0.206
9	07/02/12	0.003	0.030	0.018
10	24/02/12	0.019	0.173	0.161
11	25/02/12	0.020	0.250	0.162
12	26/02/12	*0.009*	*0.095*	*0.062*
13	15/03/12	0.056	0.504	0.336
14	19/03/12	*0.034*	*0.423*	*0.305*
15	01/06/12	*0.001*	*0.016*	*0.011*
16	10/07/12	0.000	0.037	0.031
Total load (g/ha)		**0.17**	**3.0**	**1.9**
Flow weighted seasonal av. conc. (µg/L)		**0.02**	**0.28**	**0.18**
Product transported in runoff (% of applied)		**not applied**	**0.17**	**0.37**

(Note – figures in *italics* indicate loads generated from estimated concentrations as described in Section 2.4.2)

3.2.6 Drainage water quality

Two water samples were collected from the soil solution samplers (0.9 m depth) of Treatment 1 (4th February and 5th March 2012) (insufficient sample volume meant herbicide analysis could not be undertaken on the second sample). Three samples were collected from Treatment 2 (16th January, 4th February and 5th March 2012). Again, insufficient sample volume meant herbicide analysis could not be undertaken on the last sample.

3.2.6.1 Nitrogen

Concentrations of NO_x-N, urea-N and ammonium-N were all low (12-126 µg N/L) for both treatments, with no obvious seasonal trend. Samples were collected 94-143 days after nutrient application, which may explain the low concentrations. In the 2010/11 season, samples were first collected six days after application, with a maximum NO_x-N concentration of 1780 µg N/L (Treatment 1).

3.2.6.2 Herbicides

From the single herbicide sampled collected from Treatment 1 (4th February 2012; 166 days after application), both diuron and hexazinone were detected at relatively low concentrations (0.06 and 0.34 µg/L, respectively).

In Treatment 2, imazapic was not detected (<1 µg/L) 147 days after application (16th January 2012), but was detected at 2 µg/L on 4th February 2012 (166 days after application).

3.2.7 Agronomic

Yield and percent recoverable sugar (PRS) information collected during machine harvest and processing showed very similar cane yield (and PRS) from both treatments (Table 13), despite Treatment 2 receiving 61 kg N/ha less than Treatment 1.

Table 13 Machine harvest yield results, Victoria Plains site

	Treatment 1	**Treatment 2**
N applied (kg/ha)	200	139
Cane (t/ha)	90.4	90.6
PRS	17.69	16.86
Sugar (t/ha)	16.0	15.3

3.3 Marian site

3.3.1 Soil nutrients

Soil nitrate-N concentrations (KCl extraction) after harvest and prior to nutrient applications (7th September 2011) were ≤ 1 mg/kg in the top 0.6 m of the soil profile, except for Treatment 1 row (4 mg/kg at 0-0.1 m) and Treatment 5 interspace (3 mg/kg at 0-0.1 m). Below 0.6 m, concentrations were variable (1-4 mg/kg), except Treatment 2 (<1 mg/kg).

On 16th November (33 days after application; following 38 mm of rainfall and 40 mm irrigation), surface soil nitrate-N concentrations were highest in Treatments 1 and 2 where application rates were highest (Figure 12). Nitrate-N was not detected (<1 mg/kg) at any depth in Treatment 4, except in the surface 0-0.2 m of the interspace (1-2 mg/kg).

Surface soil phosphorus concentrations (KCl extraction) after harvest and prior to nutrient application were variable across the treatments, but generally consistent between row and interspace, except for Treatment 5 (concentrations in the interspace were much higher than the row area). Concentrations then decreased to be consistent (61-134 µg/kg) below 0.6 m across all treatments (Figure 13).

Phosphorus was only applied to Treatments 1 and 2 (20 kg P/ha), and surface soil phosphorus concentrations increased in these treatments (particularly in Treatment 2; 4990 µg/kg at 0-0.1 m). Concentrations increased at depth (1.2-1.5 m) in Treatments 2, 3 and 5 (834-1190 µg/kg). The high concentrations detected in Treatment 5 (interspace) on 7th September 2011 were not evident in this sampling.

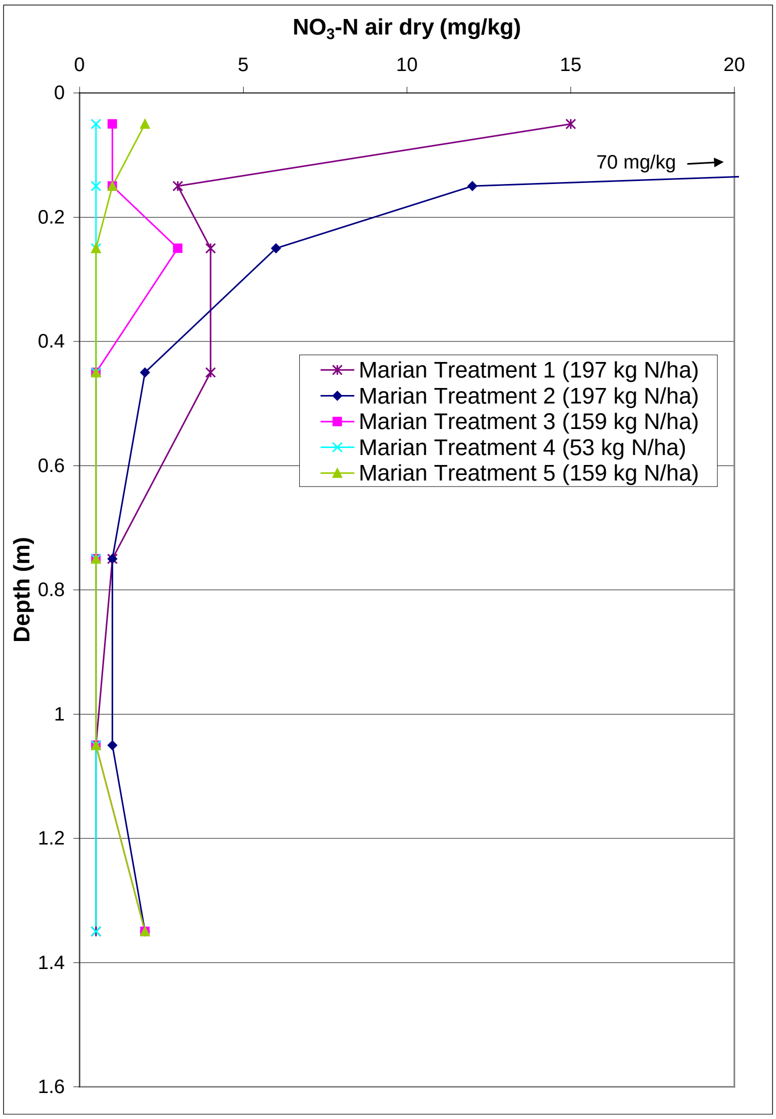

Figure 12 Soil nitrate-N concentrations (KCl extraction; air dry) in the soil profile 33 days after application (row only), Marian site

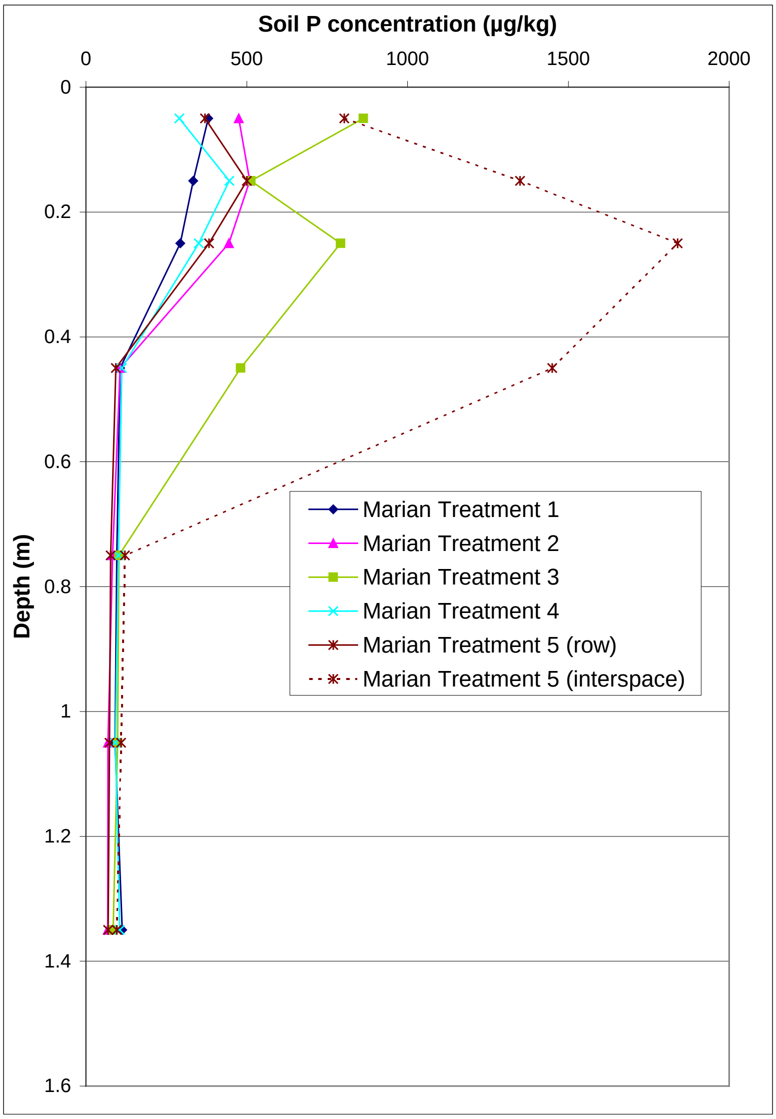

Figure 13 Soil phosphorus concentrations (KCl extraction; air dry) in the soil profile prior to nutrient application, Marian site
(Note - Treatments 1 to 4 have row and interspace concentrations combined)

3.3.2 Soil and cane trash herbicides

Surface soil (0-2.5 cm) and cane trash samples were collected for herbicide analysis (diuron and hexazinone only) prior to herbicide application, and on six occasions (0.9-104 days) after application. During this time, 982 mm of rainfall was recorded.

Diuron was detected in the surface soil prior to application (0.033 mg/kg and 0.002 mg/kg for Treatments 1 and 2, respectively), whereas hexazinone was not detected (<0.001 mg/kg). After application, peak concentrations were not detected in the surface soil until ~25 days after application (Figure 14), as the herbicide was applied to the cane trash blanket. During this 25 day period, 56 mm of rain was recorded. Using the field dissipation data of 25-105 days, the calculated half-lives of diuron and hexazinone were 45 and 31 days, respectively (Treatment 1 only; Treatment 2 data not presented due to low and variable concentrations) and 34 days for paraquat (average of Treatments 3-5).

Neither diuron nor hexazinone were detected (<0.08 mg/kg) on the cane trash blanket prior to application this season. Concentrations of paraquat were very variable over time, and no clear trend in dissipation could be detected (data not presented). Peak diuron and hexazinone concentrations were detected within two days of application, and then rapidly declined (Figure 15; Treatment 1 only). Despite the same application rate, concentrations detected in Treatment 2 were much lower than Treatment 1 (reason unknown), and therefore not presented. Using this field dissipation data, the calculated half-lives for diuron and hexazinone on cane trash were 12 and 11 days, respectively.

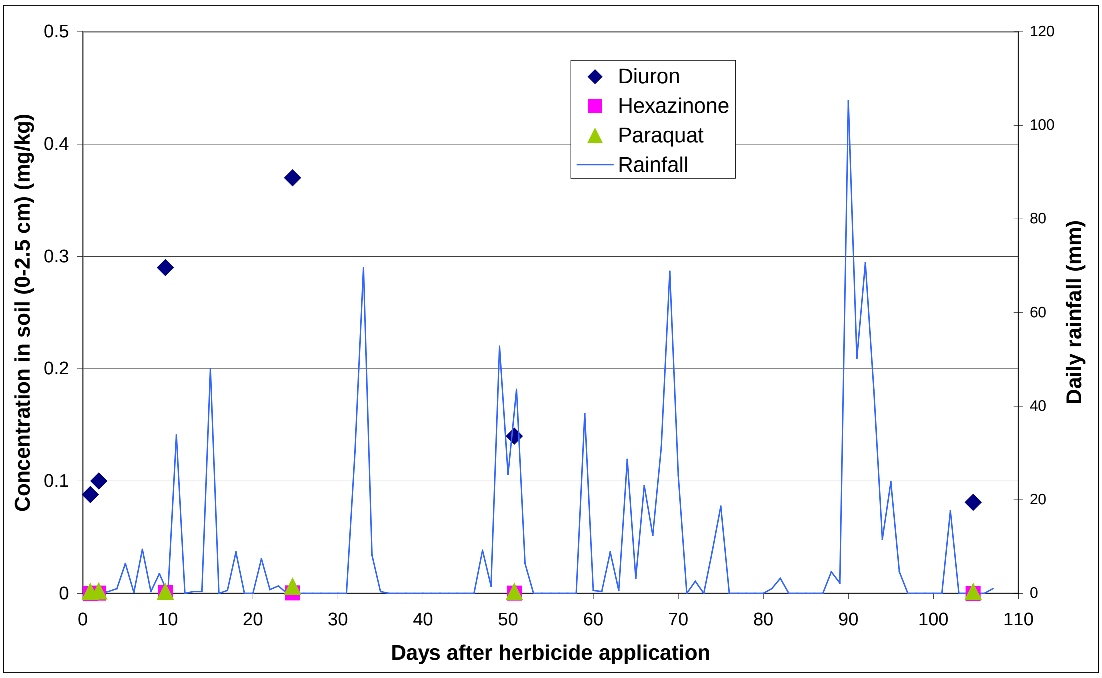

Figure 14 Field dissipation of diuron, hexazinone and paraquat in the surface soil (0-2.5 cm), Marian site

(Note - Herbicides applied on 28th November 2011)

3.3.3 Soil moisture

Soil water extraction was evident throughout the season, with short periods of saturation evident (late January/early February and late March) (Figure 16). Treatment differences in total moisture are likely to be related to the clay content differences across the treatments, rather than treatment differences. Treatment 1 has the highest clay content (35-46%) and higher soil moisture than Treatment 5 (17-46% clay content) and Treatment 2 (15-39% clay content).

Data from the individual depth sensors shows no water extraction at 150 cm in Treatment 1, and a shallow water table (80 cm) was evident from mid-January onwards (Section 7.3.3). Some extraction at 150 cm was evident in Treatment 5 from late October to mid-January, and a shallow water table (80 cm) was evident from late January (Section 7.3.5). The 150 cm sensor in Treatment 2 was not working for the season, but some extraction was evident at 100 cm from early November to mid-January, with a shallow water table (80 cm) evident from early February.

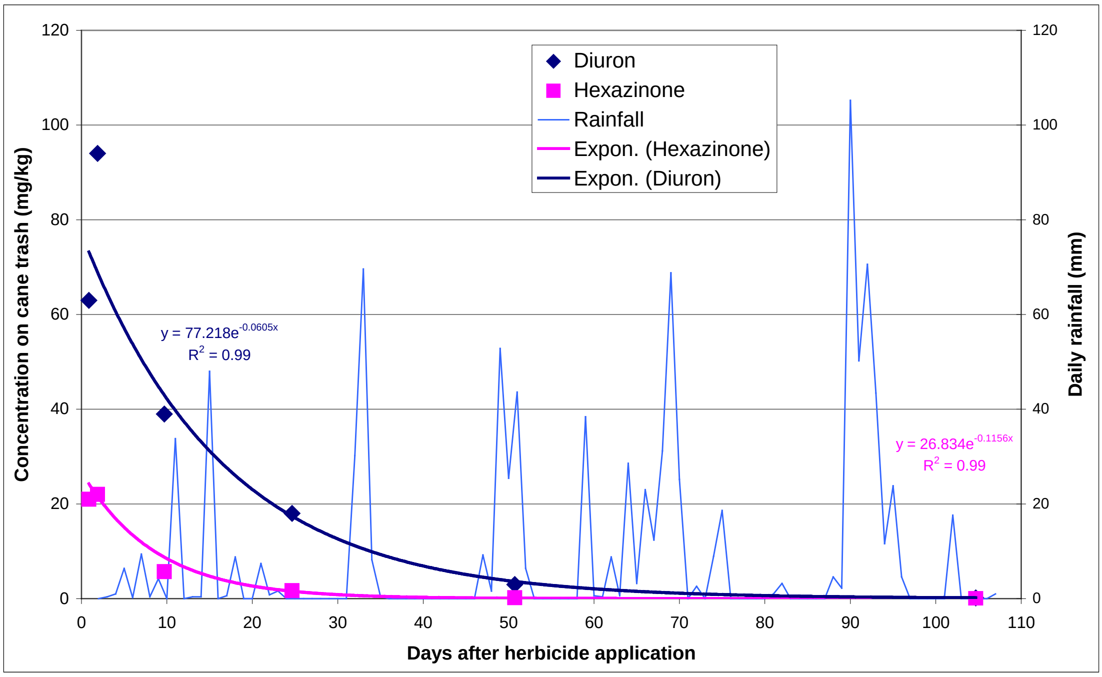

Figure 15 Field dissipation of diuron and hexazinone on the cane trash blanket, Marian site (Note - Herbicides applied on 28th November 2011)

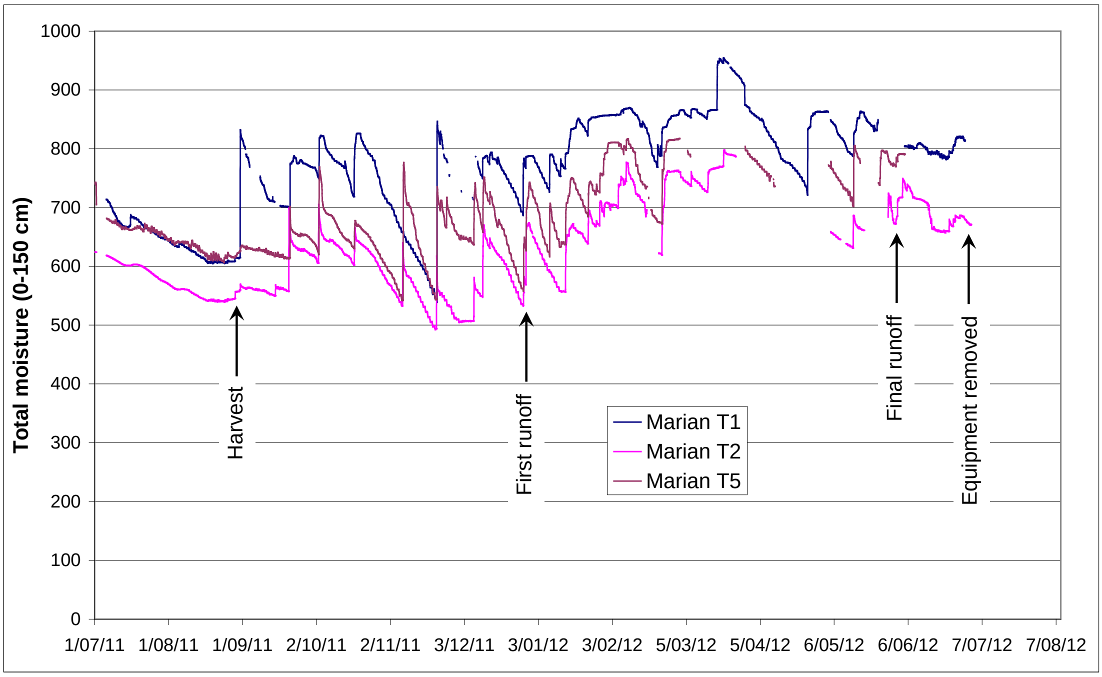

Figure 16 Total moisture in the soil profile (0-150 cm), Marian site

3.3.4 Rainfall and runoff

A total of 2160 mm of rainfall was recorded at the Marian site between 1st December 2011 and 30th June 2012, which was above the estimated long-term average of 1462 mm (Te Kowai Research Station, records since 1889). The highest daily total of 263 mm was recorded on 21st March 2012.

As with previous seasons, persistent flooding of the site impacted on the ability to accurately determine runoff rates and volumes, and the subsequent collection of water quality samples. Due to uncertainty in flow rates through the flumes, **no water quality loads have been calculated for this site.**

3.3.4.1 Total suspended solids, turbidity and electrical conductivity

Concentrations of TSS were generally low (13-140 mg/L) and declined throughout the season (Figure 17). Of the samples collected, Treatment 4 (1.8 m row spacing; N replacement) produced the highest mean TSS concentration (67 mg/L) and Treatment 3 (1.8 m row spacing; Six Easy Steps) had the lowest (26 mg/L). These average concentrations are less than one third of those measured in the previous year (due to the green cane trash blanket and lack of cultivation).

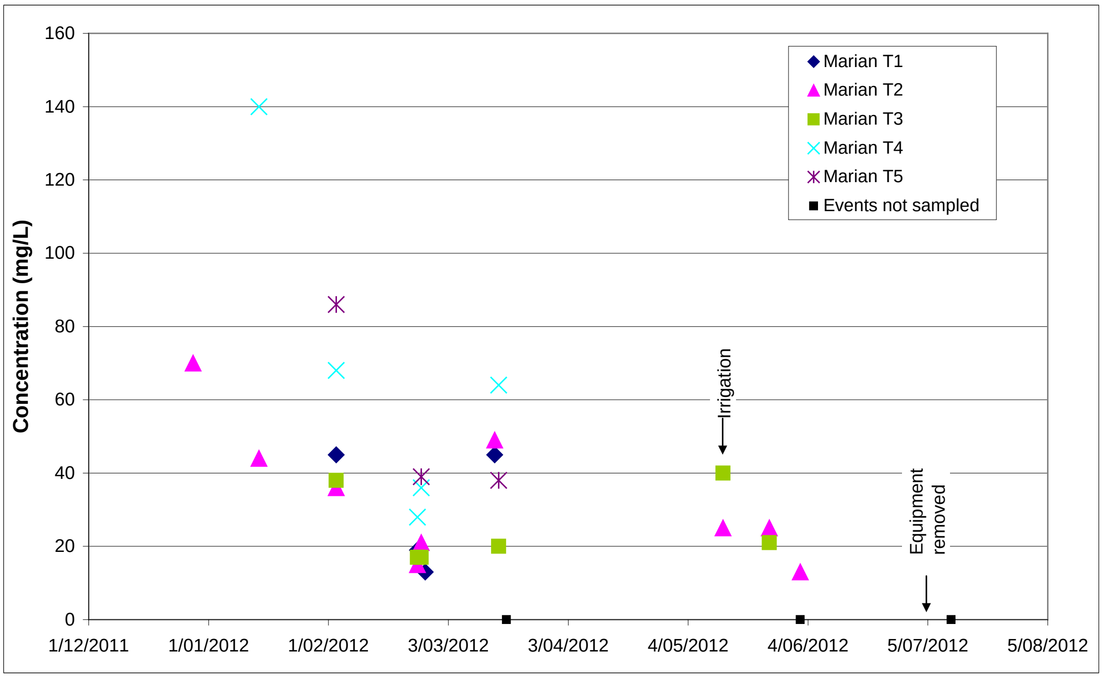

Figure 17 Concentrations of total suspended solids in runoff, Marian site

Similar to TSS concentrations, the lowest average turbidity level was observed in Treatment 3 (62 NTU). The range of average turbidity for the other treatments was 74 NTU (Treatment 2) to 124 NTU (Treatment 4). When samples from all treatments were combined, there was a poor relationship (R^2=0.41) between TSS concentration and turbidity (data not shown). This is thought to be due to the low range in TSS concentrations.

The EC of rainfall runoff water varied across the treatments; with an overall range of 50-153 µS/cm (2010/11 range was 26-255 µS/cm). The treatment averages were similar (72-78 µS/cm), except for Treatment 2 (95 µS/cm). These results are much lower than those samples collected from irrigation runoff water on 13th May 2012 (1171 µS/cm and 1308 µS/cm for Treatments 2 and 3, respectively), presumably due to groundwater being used for irrigation.

3.3.4.2 Nitrogen

The first rainfall runoff event occurred 75 days after nutrient application. As a result, NO_x-N concentrations in rainfall runoff were relatively low (Figure 18), and declined throughout the season. For the events sampled, average NO_x-N concentrations do not follow the trend of nitrogen application, presumably due to the variability in the number of events sampled. Concentrations were much lower than those detected in the 2010/11 season (maximum ~5000 µg N/L; treatment averages 365-724 µg N/L). In contrast to rainfall runoff, the samples collected from the irrigation runoff on 13th May 2012 had relatively high NO_x-N concentrations (4037-4505 µg N/L). Although the source water of this irrigation was not sampled, water quality results from a nearby bore (2 km) sampled in 2006/7 showed relatively high nitrate-N concentrations of 2260 µg N/L (Masters *et al.* 2008).

In comparison to the 2010/11 season, urea-N concentrations were low (16-194 µg N/L) (Figure 19). Similar to NO_x-N, the average urea-N concentrations do not follow the trend of nitrogen application, presumably due to the variability in the number of events sampled. In the irrigation runoff event, urea-N concentrations (16-94 µg N/L) were similar to that detected from rainfall runoff.

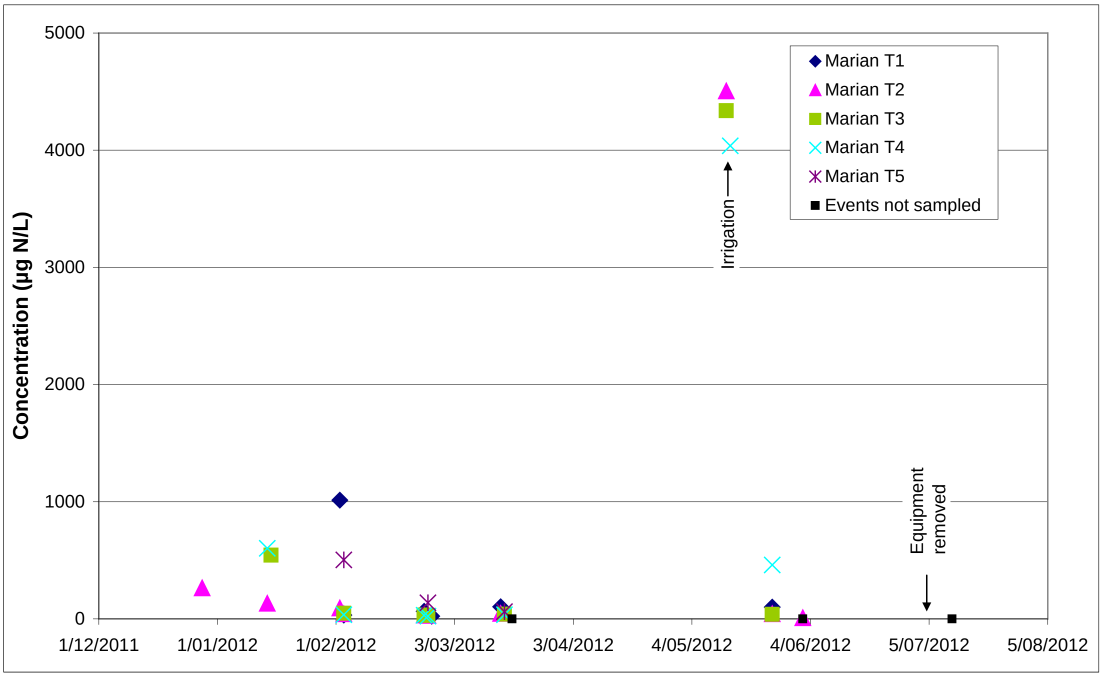

Figure 18 Concentrations of NO_x-N in runoff, Marian site
(Note - Nutrients applied on 14th September 2011)

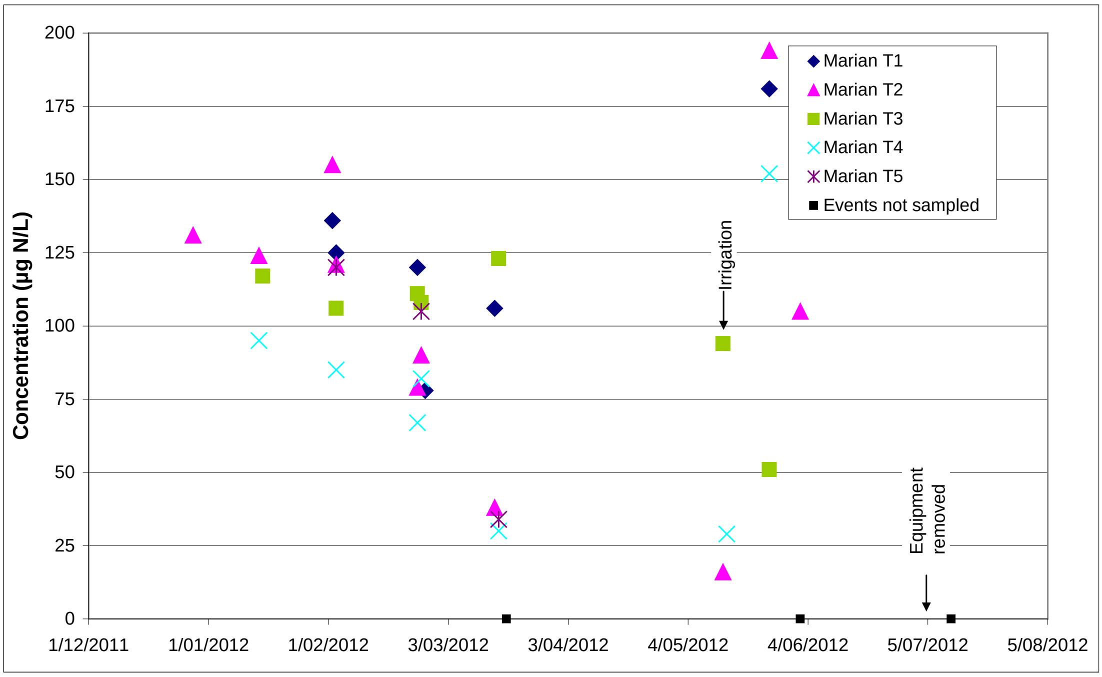

Figure 19 Urea-N concentrations in runoff, Marian site
(Note - Nutrients applied on 14th September 2011)

Ammonium-N concentrations in runoff were low (5-306 µg N/L) and tended to decline throughout the season (Figure 20). As with other nitrogen species, the range of concentrations (e.g. 4-1366 µg N/L in 2010/11) is much lower than those detected in the previous season.

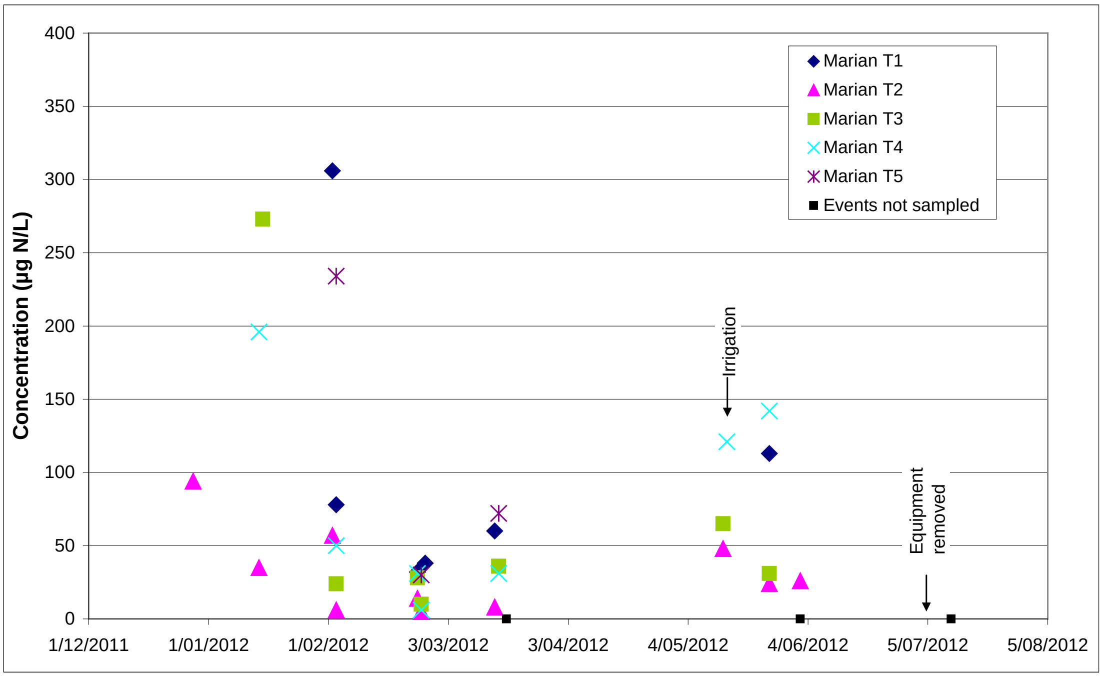

Figure 20 Ammonium-N concentrations in runoff, Marian site
(Note - Nutrients applied on 14th September 2011)

3.3.4.3 Phosphorus

Filterable reactive phosphorus concentrations generally declined throughout the season, although there were increases in concentrations at the end of May (Figure 21).

Overall, treatment averages were 355-499 µg P/L, except Treatment 2 (743 µg P/L). This supports the higher soil phosphorus concentrations detected in Treatment 2 after application (Section 3.3.1). These average concentrations in runoff are slightly lower than the 2010/11 season (403-628 µg P/L), when Treatment 2 also had the highest average concentration (835 µg P/L).

Across all of the samples collected, FRP comprised the majority (88%) of the TFP signature. Of those samples with both FRP and TP data, FRP averaged 77% of TP.

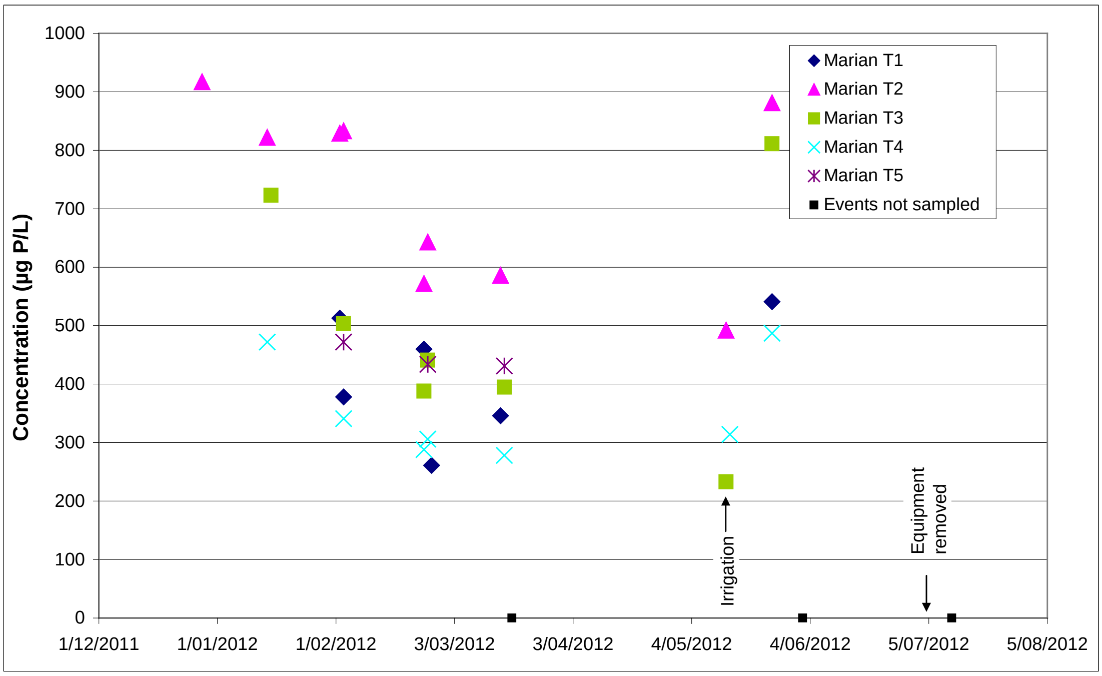

Figure 21 Filterable reactive phosphorus concentrations in runoff, Marian site
(Note - Nutrients applied on 14th September 2011)

3.3.4.4 Herbicides

The first herbicide runoff samples collected from Treatments 1 and 2 were 30 and 67 days after the application of diuron and hexazinone (Table 6), respectively. Diuron concentrations were low (≤ 0.5 µg/L), and decreased as the season progressed (Figure 22). Similar to the soil and cane trash concentration data, runoff concentrations were higher in Treatment 1 than Treatment 2. Similar results were found for hexazinone, with concentrations ≤ 0.3 µg/L (Figure 23).

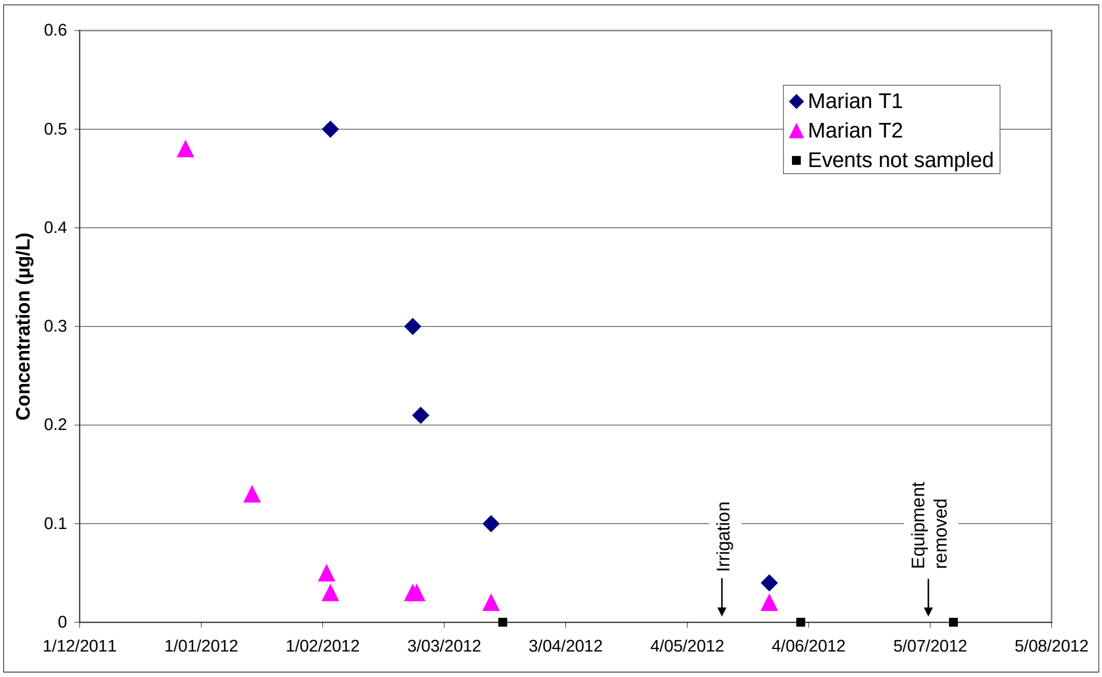

Figure 22 Diuron concentrations in runoff, Marian site
(Note - Herbicides applied on 28th November 2011)

Isoxaflutole (samples collected from Treatments 3 and 5) was not detected in any runoff samples (<1 µg/L), with samples first collected 48 days after application to Treatment 3. Runoff samples from 3rd February 2012 were analysed for 2,4-D (Treatments 1, 2 and 4), with concentrations in the range 0.14-0.96 µg/L. Two other samples collected for 2,4-D analysis from Treatment 4 on 25th February and 16th March 2012 had concentrations of <0.1 µg/L and 0.19 µg/L, respectively.

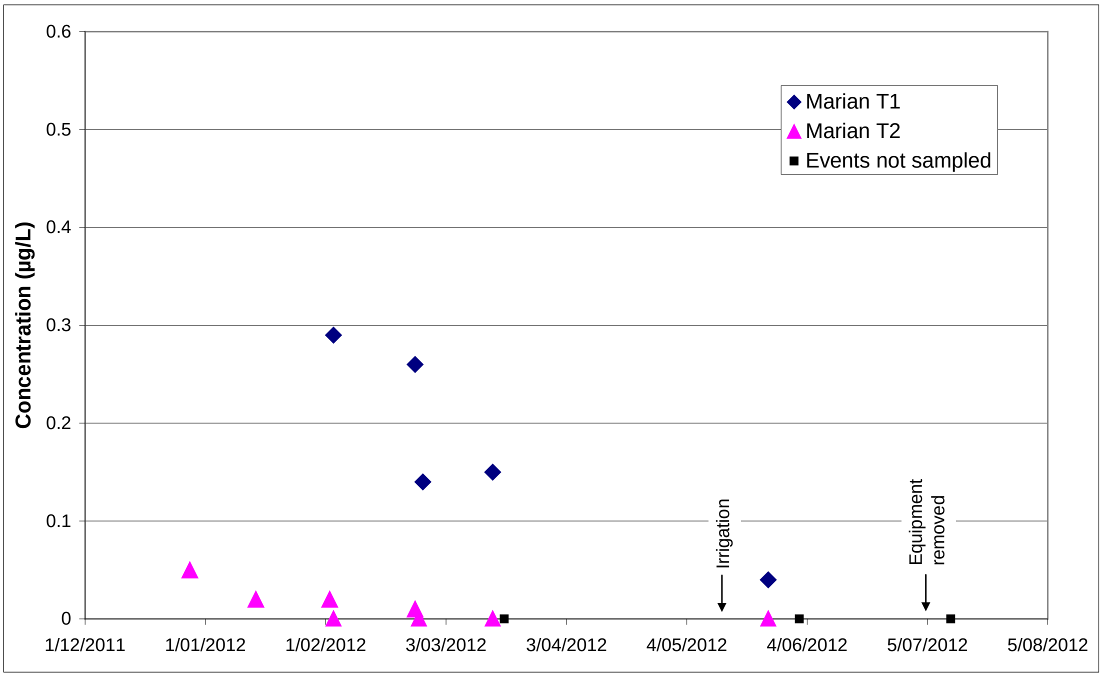

Figure 23 Concentrations of hexazinone in runoff, Marian site
(Note - Herbicides applied on 28th November 2011)

3.3.5 Drainage water quality

3.3.5.1 Nitrogen

Three nutrient samples were collected from soil solution samplers (0.9 m depth) 124-173 days after nutrient application, except Treatment 5 (two samples were collected, 143-173 samples after nutrient application).

Concentrations of NO_x-N, urea-N, ammonium-N and FRP were generally similar between Treatments 1-3, and higher in Treatments 4 and 5 (Table 14). There was no discernible trend in nutrient concentrations through the season, which may be partly due to the period of first sample after nutrient application, and the short period of time the samples were collected over.

Table 14 Concentrations (µg N or P/L) of NO_x-N, urea-N, ammonium-N and FRP in drainage water, Marian site

	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
NO_x-N range	11-39	29-99	30-37	61-351	27-69
(average)	(24)	(66)	(34)	(171)	(12)
Urea-N range	103-124	75-91	14-127	107-192	129-148
(average)	(111)	(86)	(86)	(164)	(139)
Ammonium-N	17-31	15-50	13-23	60-280	25-154
range (average)	(26)	(30)	(17)	(135)	(90)
FRP range	5-22	4-19	2-11	76-179	9-24
(average)	(12)	(12)	(7)	(127)	(17)

3.3.5.2 Herbicides

Herbicide samples were collected from soil solution samplers (0.9 m depth) for all treatments, except Treatment 1 (insufficient sample volume for analysis). Samples were collected 49-98 days after herbicide application, and no herbicides were detected in any samples – diuron or hexazinone in Treatment 2 (<0.01 µg/L), isoxaflutole in Treatments 3 and 5 (<1 µg/L) and 2,4-D in Treatment 4 (<0.1 µg/L).

3.3.6 Agronomic

Yield and percent recoverable sugar (PRS) information collected during machine harvest and processing showed that cane yield trended with the amount of nitrogen applied (Table 15). The cane yield from Treatment 5 (skip row) was 71% of Treatment 3 (solid plant, same nitrogen rate), despite only having 56% of the area planted to cane (10 cane rows and 8 “skip” rows).

Table 15 Machine harvest yield results for each treatment, Marian site

	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
N applied (kg/ha)	197	197	159	53	159
Cane (t/ha)	100	103	83	59	59
PRS	15.03	14.92	15.57	15.25	15.63
Sugar (t/ha)	15.0	15.4	13.0	9.0	9.3

3.4 Multi-block and Multi-farm sites

As in previous years, there were difficulties with determining accurate flow rates through the Multi-block and Multi-farm weirs when there was sufficient runoff to overtop the drains and spread out into nearby cane paddocks. During large events, the water depth in the Multi-farm site drain was high enough to flood into the Multi-block drain, further confounding flow estimates. During several flow events, water would back up across the Multi-block weir after the downstream dam and channel filled; causing significant flow rates to be recorded when there was virtually no flow across the weir. **It was therefore not possible to determine accurate volumes of runoff for events, and consequently loads could not be calculated for the Multi-block site. Runoff and load calculations for the Multi-farm site should be treated with caution.**

Due to the low runoff volumes in the initial runoff events at both sites, no water quality samples were collected until 29th December 2011 at the Multi-farm site, and 15th January 2012 at the Multi-block site.

3.4.1 Rainfall and runoff

A total of 2241 mm of rainfall was recorded at the Multi-farm site between 1st December 2011 and 31st July 2012. At the Multi-block site, 1957 mm was recorded between 1st December 2011 and 30th June 2012 (equipment removed in early July). These totals are higher than the estimated long-term average of 1498 mm (Te Kowai Research Station, records since 1889) for December to July. The highest daily total recorded at the Multi-farm site was 257 mm and 239 mm at the Multi-block site, both on 21st March 2012.

Total wet season runoff from the Multi-farm site was 649 mm (Table 16), or 29% of rainfall.

Table 16 Event rainfall and runoff during the 2011/12 wet season, Multi-farm site

Event	Start date	Rainfall		Runoff	
		Total (mm)	Max. intensity (mm/hr)	Total (mm)	Peak discharge (cumecs)
1	06/12/11	115.8	192	0.4	0.2
2	28/12/11	79.2	108	28.9	7.4
3	14/01/12	118.8	108	9.9	4.2
4	24/01/12	34.0	72	0.1	0.1
5	27/01/12	41.6	84	2.5	0.8
6	30/01/12	40.4	48	10.2	2.3
7	02/02/12	129.0	84	79.9	12.8
8	07/02/12	20.6	132	4.2	1.7
9	24/02/12	269.8	108	125	12.6
10	15/03/12	911.2	168	287	16.4
11	25/05/12	20.0	24	0.6	0.2
12	01/06/12	21.2	24	33.5	7.1
13	10/07/12	106.4	36	67.2	8.2
Total				**649**	

3.4.2 Runoff water quality

3.4.2.1 Total suspended solids, turbidity and electrical conductivity

Only five TSS samples were collected from the Multi-block site (early February to mid-March). All samples had low concentrations (range 26-46 mg/L, mean 33 mg/L) (Figure 24). This range is similar to that measured in the 2010/11 season (24-46 mg/L, excluding an initial concentration of 160 mg/L). Due to the low range of concentrations, there was no significant relationship with turbidity. Similar to TSS, there was very little variability in EC (range 43-64 µS/cm, mean 56 µS/cm). This range and mean is lower than that measured in the 2010/11 season (range 46-133 µS/cm, mean 73 µS/cm).

At the Multi-farm site, the range of TSS concentrations was much higher than the Multi-block site (Figure 24). The low concentrations (9-18 mg/L) in the initial sampled events may be due to the low discharge rates and/or runoff from the immediate area surrounding the monitoring site. The total estimated seasonal sediment load was 779 kg/ha, with a flow-weighted mean concentration of 120 mg/L (Table 17).

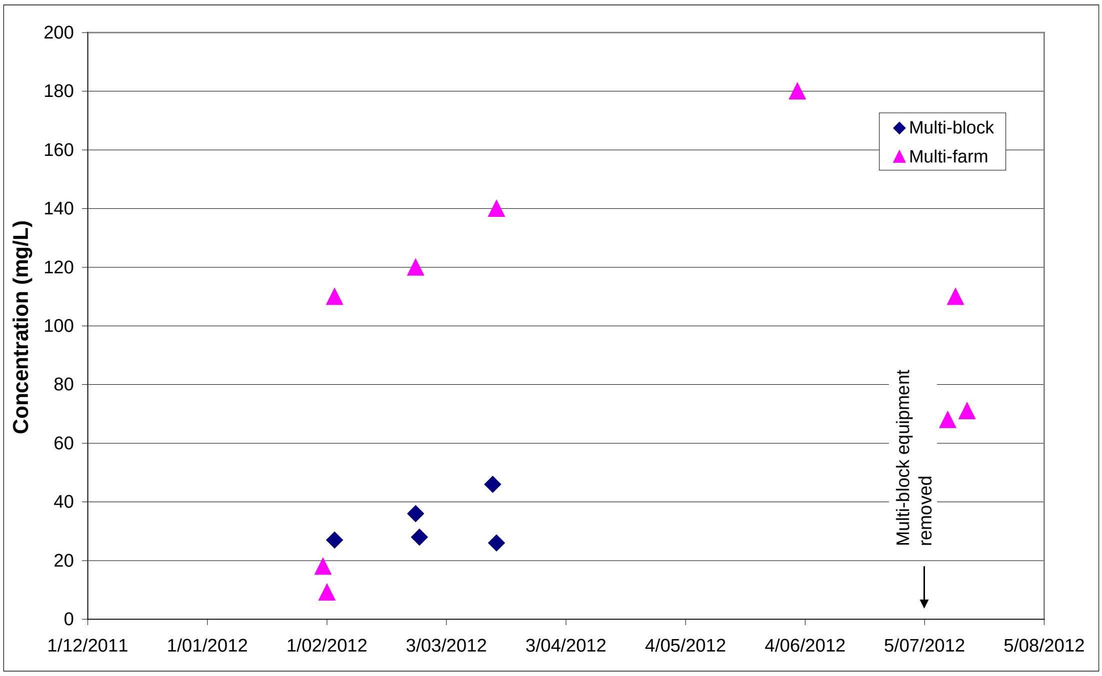

Figure 24 Concentrations of TSS in runoff, Multi-block and Multi-farm sites

Table 17 Calculated loads of sediment, nutrients and herbicides from runoff, Multi-farm site

Event	**Start date**	**TSS (kg/ha)**	**TKN (kg/ha)**	**NO_x-N (kg/ha)**	**TKP (kg/ha)**	**FRP (kg/ha)**	**Ametryn (g/ha)**	**Atrazine (g/ha)**	**Diuron (g/ha)**	**Hexazinone (g/ha)**
1	06/12/11	*0*	*0.02*	*0.01*	*0.00*	*0.00*	0.00	*0.04*	*0.04*	*0.01*
2	28/12/11	*19*	1.47	1.15	0.25	0.13	0.38	3.18	2.89	0.69
3	14/01/12	*4*	0.32	0.17	0.08	0.05	0.07	*0.62*	*0.57*	*0.15*
4	24/01/12	*0*	*0.00*	*0.00*	*0.00*	*0.00*	0.00	*0.01*	*0.01*	*0.00*
5	27/01/12	*0*	0.17	0.01	0.03	0.02	0.02	0.04	0.04	0.01
6	30/01/12	1	0.13	0.01	0.10	0.01	0.01	0.08	0.14	0.04
7	02/02/12	88	0.87	0.09	0.30	0.13	0.04	0.38	0.69	0.16
8	07/02/12	*1*	*0.05*	*0.00*	*0.01*	*0.01*	0.00	*0.02*	*0.03*	*0.01*
9	24/02/12	150	1.77	0.03	0.30	0.22	0.06	0.45	0.85	0.15
10	15/03/12	401	2.05	0.18	1.23	0.42	0.03	0.57	0.66	0.11
11	25/05/12	*0*	*0.01*	*0.00*	*0.00*	*0.00*	0.00	*0.00*	*0.00*	*0.00*
12	01/06/12	60	0.54	0.10	0.13	0.05	0.00	0.02	0.03	0.01
13	10/07/12	55	0.98	0.06	0.25	0.09	0.00	0.12	0.12	0.01
Total load		**779**	**8.4**	**1.8**	**2.7**	**1.1**	**0.60**	**5.5**	**6.1**	**1.4**
Flow weighted seasonal av. conc.		**120 mg/L**	**1294 µg N/L**	**283 µg N/L**	**211 µg P/L**	**172 µg P/L**	**0.09 µg/L**	**0.82 µg/L**	**0.94 µg/L**	**0.21 µg/L**

(Note – TSS and nutrient figures in *italics* indicate loads generated from regression curves (Table 9). Herbicide figures in *italics* indicate loads generated from estimated concentrations as described in Section 2.4.2)

3.4.2.2 Nitrogen

Concentrations of NO_x-N at the Multi-block site were highest in the initial sampled event (5180 µg N/L on 15th January 2012) and declined to be <250 µg N/L by early February (Figure 25). These concentrations (range 30-5180 µg N/L, mean 979 µg N/L) are higher than those detected in the 2010/11 season (range 28-511 µg N/L, mean 149 µg N/L).

Similar to the Multi-block site, the highest NO_x-N concentrations (1757-4030 µg N/L) at the Multi-farm site were detected in the initial sampled events, with concentrations declining to be <250 µg N/L by late January. Similar to the Multi-block site, these concentrations are higher than those detected in the 2010/11 season (range 28-2511 µg N/L, mean 393 µg N/L).

The total loss of NO_x-N in runoff at the Multi-farm site was estimated to be 1.8 kg/ha (Table 17) (flow-weighted seasonal average concentration of 283 µg N/L).

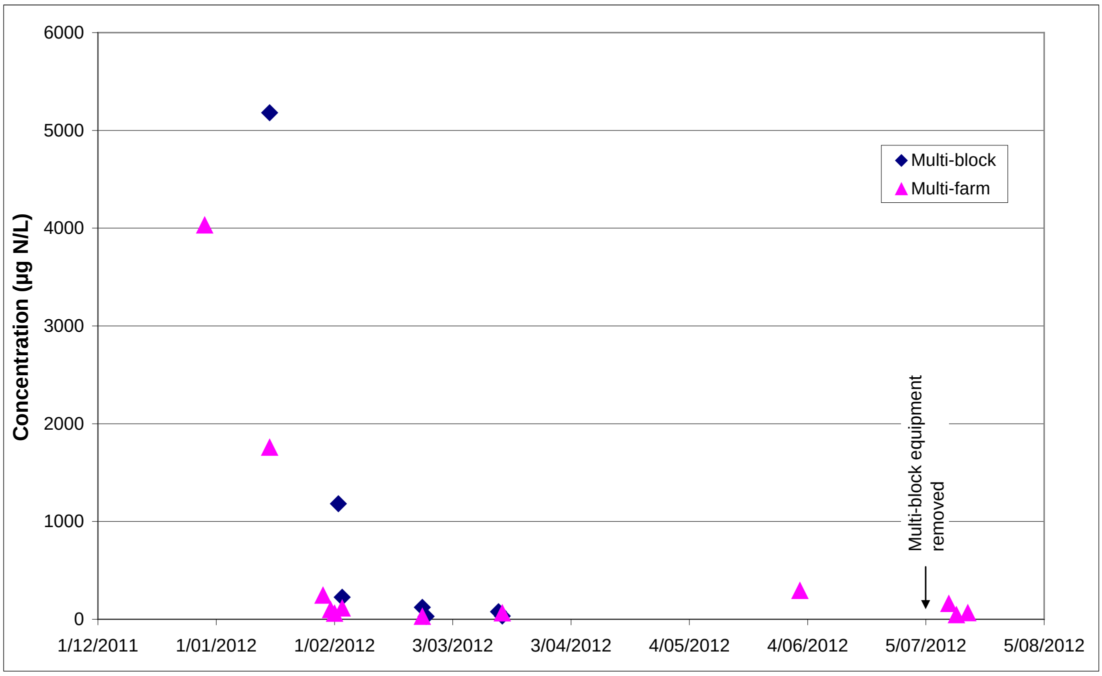

Figure 25 Concentrations of NO_x-N in runoff, Multi-block and Multi-farm sites

3.4.2.3 Phosphorus

The Multi-block site generally recorded FRP concentrations double that of the Multi-farm site (Figure 26). Concentrations at the Multi-block site showed a general decline throughout the wet season. At the Multi-farm site, concentrations tended to increase until 29th January 2012, and then suddenly decreased to consistent concentrations (108-174 µg P/L) for the remainder of the season. It is thought that the high concentrations detected at the Multi-farm site may be a result of localised runoff close to the monitoring site where background soil phosphorus levels are known to be high.

The total loss of FRP in runoff at the Multi-farm site was estimated to be 1.1 kg/ha (Table 17) (flow-weighted seasonal average concentration of 172 µg P/L).

Similar to the Marian site, FRP at the Multi-block site comprised the majority (90%) of the TFP signature, and 73% of TP. The Multi-block site was similar to the Victoria Plains site: FRP comprised 71% of the TFP signature and approximately half of the TP.

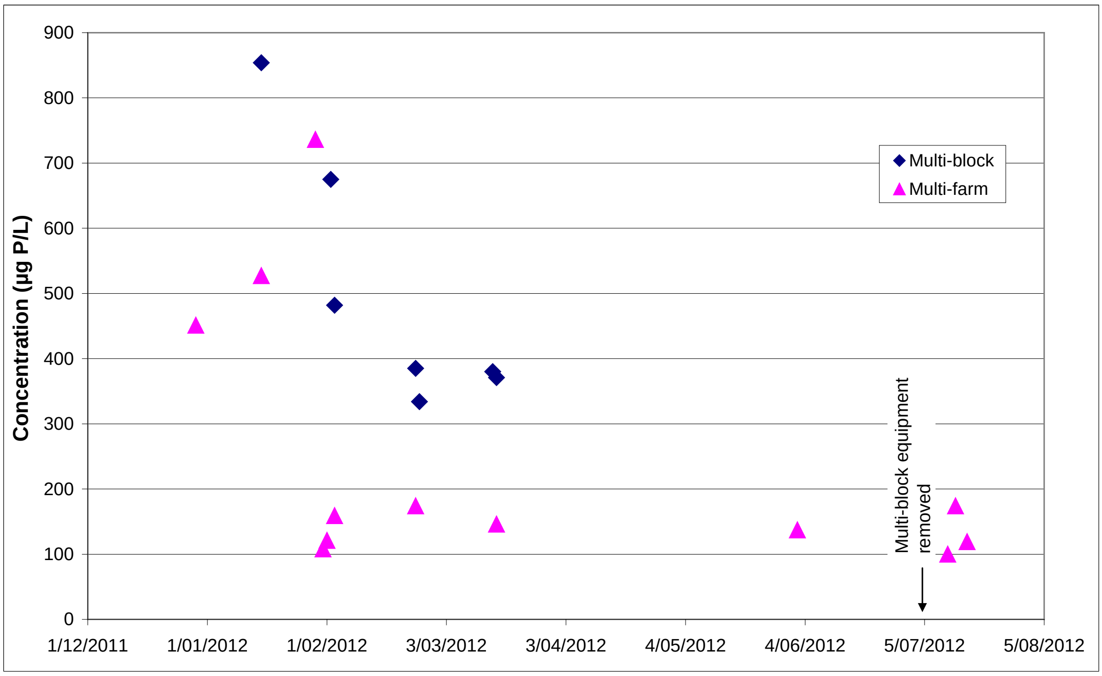

Figure 26 Filterable reactive phosphorus concentrations in runoff, Multi-block and Multi-farm sites

3.4.2.4 Ametryn

Ametryn was detected at low concentrations (0.01-0.02 µg/L) in runoff at the Multi-block site up to 24th February 2012, but was not detected in events after this. In the 2010/11 season, ametryn concentrations at the Multi-block site were higher (<0.01-0.74 µg/L, mean 0.15 µg/L).

At the Multi-farm site, ametryn was detected at higher concentrations than the Multi-block site (<0.01-1.3 µg/L), with the maximum concentration occurring in the first sampled event (29th December 2011). The total seasonal ametryn load was 0.60 g/ha, with a flow-weighted seasonal mean concentration of 0.09 µg/L (Table 17). It is estimated that the first 50% of the total seasonal ametryn load was delivered in the initial 4% of the seasonal runoff (Figure 27).

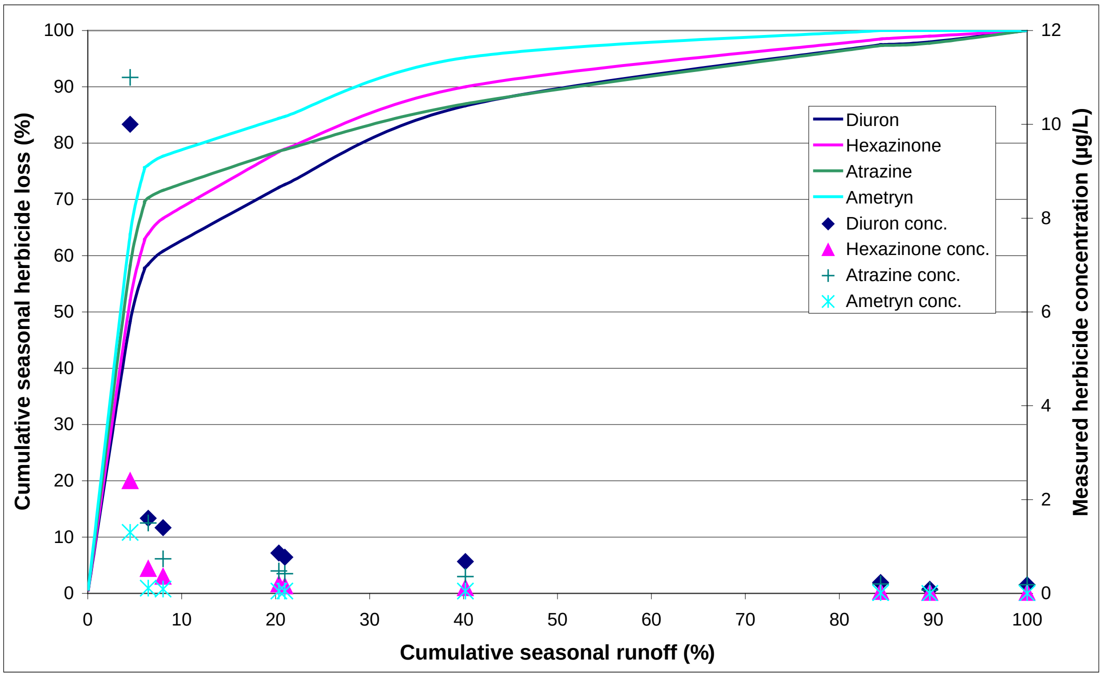

Figure 27 Cumulative seasonal runoff and herbicide loss, Multi-farm site

3.4.2.5 Atrazine

Atrazine concentrations at the Multi-block site ranged from 0.40-2.55 µg/L, with the maximum concentration detected in early February (Figure 28). The average atrazine concentration this season (1.06 µg/L) was similar to the 2009/10 season (1.07 µg/L), but higher than the 2010/11 season (0.6 µg/L).

Atrazine concentrations at the Multi-farm site declined rapidly from 11 µg/L in late December to <2 µg/L by late January, and were <0.5 µg/L by early February (Figure 28). The total seasonal calculated atrazine load was 5.5 g/ha (Table 17), with a flow-weighted seasonal mean concentration of 0.82 µg/L. It is estimated that the first 50% of the total seasonal atrazine load was delivered in the initial 4% of the seasonal runoff (Figure 27).

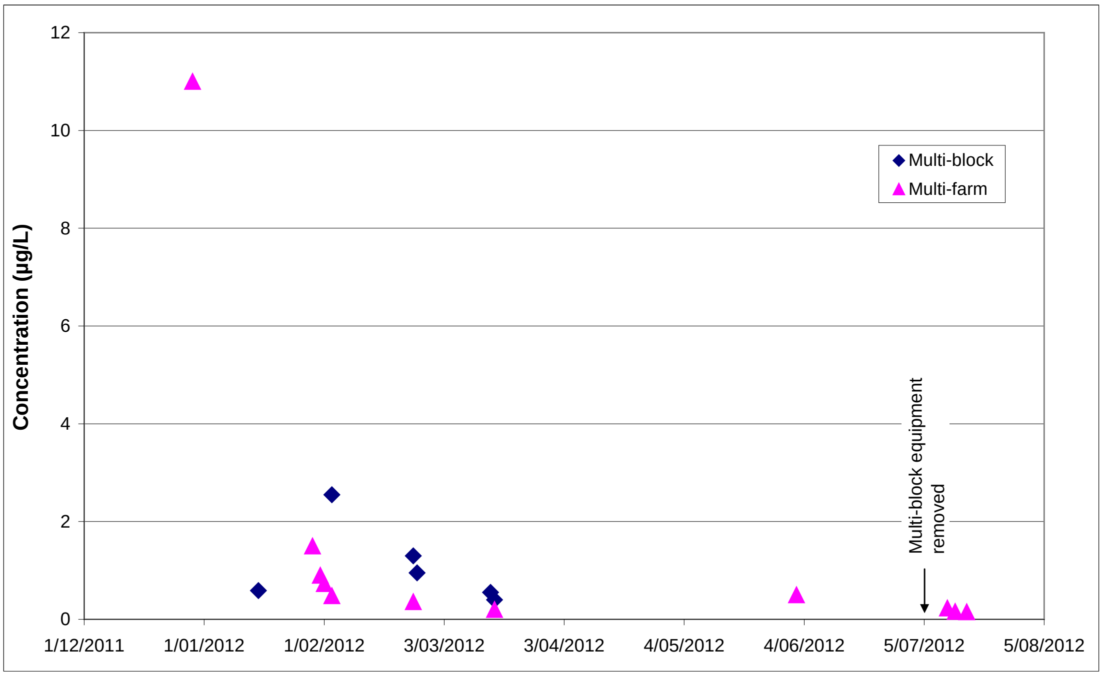

Figure 28 Atrazine concentrations in runoff, Multi-block and Multi-farm sites

3.4.2.6 Diuron

Diuron concentrations at the Multi-block site ranged from 0.25-6.6 µg/L, with the maximum concentration detected in early February (Figure 29). The average diuron concentration this season (1.67 µg/L) was higher than the 2010/11 season (0.95 µg/L, range 0.09-5.9 µg/L), but lower than the 2009 season (11 µg/L, range 1.1-43 µg/L).

At both sites, diuron concentrations followed a similar trend to atrazine. Concentrations at the Multi-farm site declined from 10 µg/L in late December to <1 µg/L by early February and <0.5 µg/L by mid-March (Figure 29). The average diuron concentration this season (1.86 µg/L) was lower than the 2010/11 season (2.9 µg/L, range 0.23-8.3 µg/L), but higher than the 2009/10 season (1.1 µg/L, range 0.24-3.1 µg/L). The total calculated diuron load for the current season was 6.1 g/ha (Table 17), with a flow-weighted seasonal mean concentration of 0.94 µg/L. It is estimated that the first 50% of the total seasonal diuron load was delivered in the initial 5% of the seasonal runoff (Figure 27).

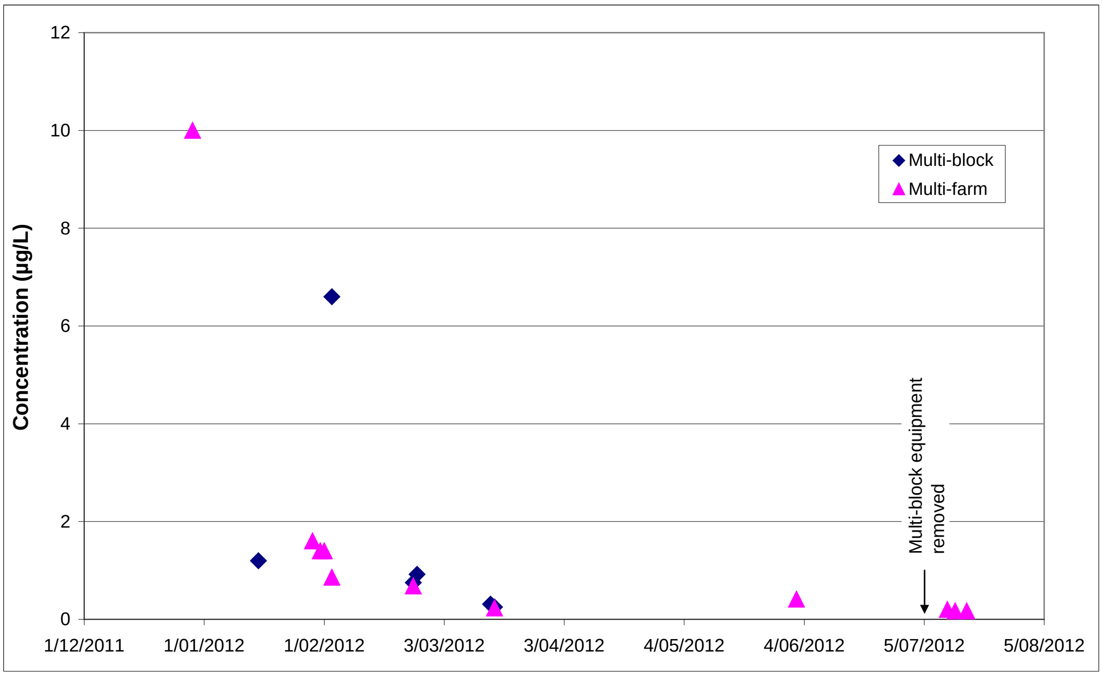

Figure 29 Diuron concentrations in runoff, Multi-block and Multi-farm sites

3.4.2.7 Hexazinone

Hexazinone concentrations detected at the Multi-block site were low and consistent throughout the season (range 0.01-0.06 µg/L, mean 0.03 µg/L) (Figure 30). These concentrations are similar to those detected in the 2010/11 season (0.02-0.07 µg/L, mean 0.04 µg/L), but much lower than the 2009/10 season (0.26-16 µg/L, mean 4.3 µg/L).

At the Multi-farm site, concentrations were highest in the initial sampled event, and then declined throughout the season (Figure 30). These concentrations (0.02-2.4 µg/L, mean 0.46 µg/L) are higher than those detected in the 2010/11 season (<0.01-0.44 µg/L, mean 0.08 µg/L) but similar to the 2009/10 season (0.05-2.9 µg/L, mean 0.60 µg/L). The total calculated hexazinone load for the current season was 1.4 g/ha (Table 17), with a flow-weighted mean average concentration of 0.21 µg/L. It is estimated that the first 50% of the total seasonal atrazine load was delivered in the initial 4% of the seasonal runoff (Figure 27).

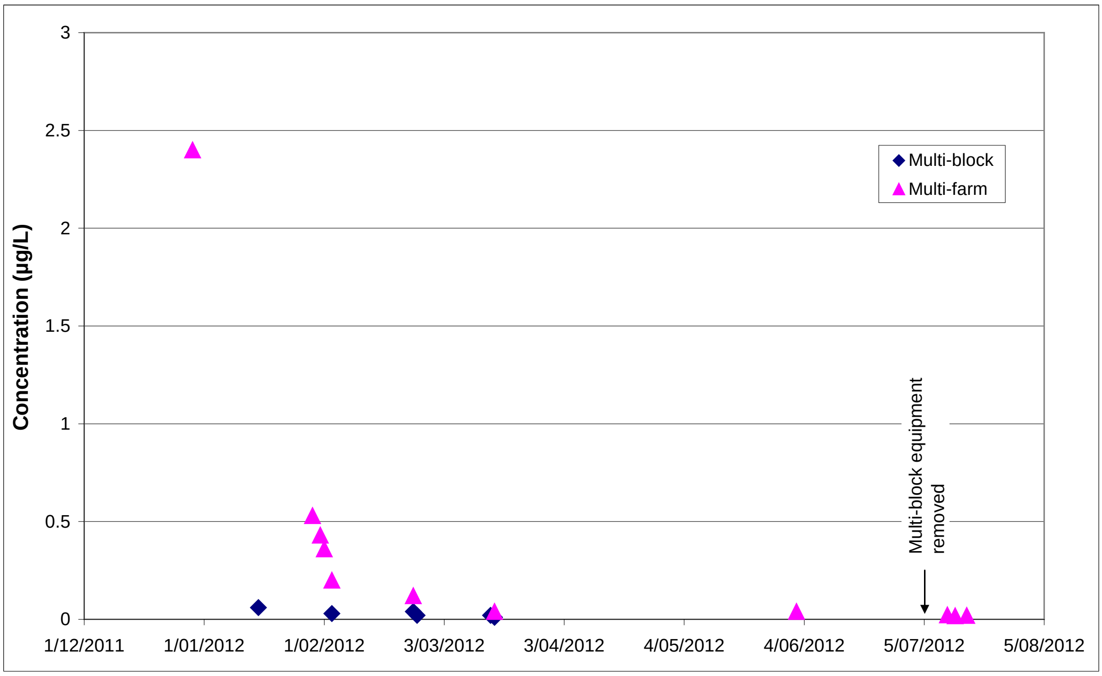

Figure 30 Hexazinone concentrations in runoff, Multi-block and Multi-farm sites

3.4.2.8 Other pesticides

Metolachlor was detected in all samples collected from the Multi-block site (0.03-2.7 µg/L, mean 0.75 µg/L), which is in contrast to previous seasons when it was only detected in one or two samples. At the Multi-farm site, it was detected in the majority of samples collected, with the maximum concentration (0.13 µg/L) being detected in June.

Prometryn and metolachlor (0.02 and 0.03 µg/L, respectively) were only detected in the initial event sampled at the Multi-farm site, and prometryn was not detected at the Multi-block site.

In contrast to previous seasons, imidacloprid was detected (0.01-0.02 µg/L) in all but the initial sample from the Multi-block site. It had not been detected in previous seasons. At the Multi-farm site, it was detected in the majority of samples (0.01-0.04 µg/L), which is similar to previous seasons.

4 DISCUSSION

4.1 Effects of row spacing/wheel traffic on runoff

The results from the two treatments at the Victoria Plains site allows for a comparison of row spacing/wheel traffic effects on runoff. Due to flooding at the Marian site, this comparison is not possible.

At the Victoria Plains site, Treatment 2 (1.8 m row spacing, controlled traffic) had 13.7% less runoff than Treatment 1 (1.5 m row spacing) across the 2011/12 wet season. This reduction in runoff, presumably due to controlled traffic, is less than the 18% reduction measured in the 2009/10 season (Rohde and Bush 2011) and similar to the 13.6% reduction measured in the 2010/11 season (Rohde *et al.* 2011). The commencement of runoff was delayed on average by approximately 9 minutes (~6 minutes in both previous seasons), and peak runoff rates reduced by 23% (2% in 2009/10 and 33% in 2010/11). These results are comparable to other soil compaction and controlled traffic studies.

On a heavy clay soil, it has been demonstrated that wheeling (uncontrolled traffic) in a broadacre grain production system produced a large (44%) and consistent increase in runoff compared with non-wheeling (Tullberg *et al.* 2001). In that study, treatment effects were greater on dry soil, but were also maintained during large and intense rainfall events on wet soil. Similarly, non-wheel traffic furrows yielded 36% less runoff than that of wheel-track furrows under conditions conducive to runoff (moist, crusted, bare soil) on a Vertosol (Silburn *et al.* 2012). Results from a rainfall simulation study on a Marian soil showed that runoff averaged 43% less from 2 m controlled traffic cane treatments compared to 1.5 m current practice treatments on dry soil, to 30% less on wetter soils (Masters *et al.* 2008; Masters *et al.* 2012). All of these studies support our findings of reduced treatment differences in runoff due to the prolonged wet season and wetter soils.

The reductions in start time to runoff (~9 minutes) and reduced peak runoff rates (average 23%), which were observed in the wider row spacing treatment, were consistent with reduced compaction and improved infiltration. In the rainfall simulation study of Masters *et al.* (2012), they found that the bulk densities of current practice treatments (1.5 m) were significantly higher (and hence more compact) in the top 30 cm of the mid-section of the cane bed. This reflects the straddling effect of wheels in uncontrolled traffic and therefore greater area of compaction under current practice (1.5 m) compared to controlled traffic (2 m). Differences in our bulk density treatment differences (Rohde *et al.* 2011) were not as evident as those observed in the rainfall simulation study. However, the treatments at the Victoria Plains site had only been in place for one season, whereas the treatments used in the rainfall simulation study were in place for four years. Also, the difference between the row spacing treatments (0.3 m difference) in place at the Victoria Plains site was not as great as the difference in treatments used in the rainfall simulation study (0.5 m difference). These factors are likely to explain why the runoff treatment differences from this study were not as pronounced.

4.2 Factors affecting sediment (TSS) concentrations in runoff

The flow-weighted mean TSS concentrations measured at the Victoria Plains site this season (22-24 mg/L) are much lower than the mean TSS concentrations measured in previous seasons (631-826 mg/L in 2009/10 and 135-158 mg/L in 2010/11). Total soil erosion this season was estimated to be ~0.2-0.3 t/ha, at least an order of magnitude lower than previous seasons. This may be due to the green cane trash blanket this season, compared with the bare, cultivated soil in the 2009/10 season, and the reduced runoff (approximately halved) compared to the 2010/11 season.

At the Marian site, TSS concentrations (13-140 mg/L, average 40 mg/L) were lower than previous years; 36-330 mg/L (average 127 mg/L) in 2009/10 (initially bare plant cane) and 23-1100 mg/L (average 289 mg/L) in 2010/11 (burnt cane and one cultivation). These results are expected, as the main factors found to affect soil erosion are tillage and ground cover (Connolly *et al.* 1997; Prove *et al.* 1995; Silburn and Glanville 2002).

The estimated seasonal soil erosion (~0.2-0.3 t/ha) measured from the Victoria Plains site is much lower than that historically recorded. Soil erosion rates of 42-227 t/ha/year have been recorded in the Mackay region under conventional tillage and burnt cane harvesting (Sallaway 1979). With the move to green cane harvesting, trash blanketing and minimum tillage, soil erosion rates have dropped to <5-15 t/ha/year (Prove *et al.* 1995). Although the soil erosion measured this season is considered low, it is similar to the rate of soil formation (~0.3 t/ha) resulting from basaltic lava flows in semi-arid tropical Australia (Pillans 1997).

Sediment concentration in runoff is driven by peak runoff rate, cover and roughness; while peak runoff is influenced by rainfall intensity, runoff depth and ground cover (Freebairn *et al.* 2009). Freebairn *et al.* (2009) report that peak discharge was the most important factor influencing sediment concentration (accounting for 41% of variation), as it best represents stream power, a measure of energy available for detachment and transport of soil in runoff. In our study at the Victoria Plains site, there was a general trend of increasing TSS concentration with increasing peak runoff rate.

4.3 Factors affecting nutrients in runoff

In this season, two main factors appear to control nitrogen and phosphorus concentrations in runoff; the amount of product applied (fertiliser) and background soil nutrient levels. Direct comparisons of nitrogen between seasons are difficult, due to the period of time between application and runoff (influencing the nitrogen species in runoff) and the different products (formulations being used).

At the Victoria Plains site, nitrogen in the first runoff event (75 days after application) was dominated by NO_x-N, with concentrations reflecting the amount of nitrogen applied. Ammonium-N and urea-N concentrations were generally low. This is in contrast to the previous season (first runoff three days after application), where initial nitrogen concentrations were dominated by urea-N. Findings were similar at the Marian site, but average NO_x-N concentrations did not follow the trend of nitrogen application. This is likely due to the variability in the number of samples collected and events sampled.

These relatively low concentrations of nitrogen (particularly urea-N) are encouraging for riverine and marine water quality. Elevated concentrations of urea-N have been shown to be a preferred form of nitrogenous nutrient for many phytoplankton, including some dinoflagellates which form harmful algal blooms (Glibert *et al.* 2005).

The total wet season loss of NO_x-N and urea-N (being the dominant nitrogen fractions and sourced from applied fertiliser) in the runoff from the Victoria Plains site for Treatment 1 was estimated to be 1.8 kg/ha and 1.6 kg/ha from Treatment 2; approximately 1% of the applied nitrogen. **These losses are an order of magnitude lower than previous seasons**, when runoff occurred within 10 days of application.

Concentrations of FRP in runoff from the Victoria Plains site were slightly lower (flow-weighted mean 47-48 µg P/L) this season than the previous season (57-77 µg P/L), but higher than the 2009/10 season (31-34 µg P/L). This is thought to be due to the period of time between application and runoff: 75 days this season, three days for the previous season and 176 days for 2009/10. In contrast, average FRP concentrations were similar between seasons at the Marian site: 355-499 µg P/L this season, 403-628 µg P/L last season and 347-563 µg P/L in 2009/10. The difference in runoff concentrations between the sites (soils) (~8 times higher at the Marian site) is thought to be associated with the background levels of soil phosphorus. Surface (0-0.1 m) soil phosphorus concentrations at harvest (prior to application) in 2011 at the Marian and Victoria Plains site were 290-862 µg/kg and 108-163 µg/kg, respectively.

4.4 Factors affecting herbicides in runoff

Timing of rainfall after herbicide application in this study greatly influenced the concentrations of herbicides detected in runoff water. At the Victoria Plains site, the first runoff event occurred 128 days after herbicide application (7-8 days in previous seasons).

The total diuron loss for the season (3.0 g/ha) was <0.2% of the applied diuron (11.8% last season), whereas <0.4% of the applied hexazinone (17.8% last season) was lost in runoff. Single event runoff losses of herbicides in the range of 1-2% are not uncommon, however losses greater than this are generally considered only to occur as a result of extreme environmental conditions (Wauchope 1978). Wauchope's (1978) study defined runoff events as "critical" if they occurred within a two week period of application and had a runoff volume which was 50% or more of the rainfall.

Initial concentrations of herbicides detected in runoff at the Victoria Plains site this season (6.9 and 3.8 µg/L for diuron and hexazinone, respectively) were much lower than those detected in previous seasons (240 and 98 µg/L last season and 18 and 41 µg/L in 2009/10 for diuron and hexazinone, respectively). Herbicide loss in runoff is strongly influenced by rainfall immediately following herbicide application, and by environmental conditions, such as crop residue cover and soil water content (Smith *et al.* 2002). They showed that in a rainfall simulation experiment, a post-herbicide irrigation ("rain-in" of 4-8 mm) reduced atrazine mass loss by 33% one day after application, largely due to the resulting reduction in the surface soil concentration of the herbicide. In another rainfall simulation study, irrigation substantially reduced the total amount and rate of metolachlor runoff (Potter *et al.* 2008). In our study this season, 22.8 mm of rain was recorded within 10 days of herbicide application, and a further 200 mm fell before the first runoff event. This compares to no rainfall between application and the first runoff event in 2010/11, and 7.6 mm in 2009/10. This rainfall, and the longer period to runoff, has led to lower cane trash and surface soil herbicide concentrations and consequently less herbicide available to be lost in runoff.

5 CONCLUSIONS

Total suspended solids, nutrients and herbicide residues in runoff events from contrasting sugarcane management practice treatments were measured from two soil types at the paddock scale.

At the Victoria Plains site (cracking clay), controlled traffic on wider row spacings resulted in a reduction in runoff. Specifically:

- Total runoff from individual runoff events from Treatment 2 (1.8 m row spacing) averaged 13.7% less than Treatment 1 (1.5 m row spacing) (816 mm and 946 mm, respectively from 2213 mm rainfall). Runoff from Treatment 2 was delayed on average by ~9 minutes compared with Treatment 1, and the peak runoff rate was ~23% lower, all contributing to reduced runoff. These findings are similar to previous seasons.
- Total suspended solids (TSS) concentrations were low (14-61 mg/L) and consistent throughout the season. The wet season flow-weighted TSS concentrations were similar between treatments: 22 mg/L and 24 mg/L for Treatments 1 and 2, respectively.
- Total estimated wet season soil loss for Treatment 1 was 217 kg/ha, lower than that of Treatment 2 (298 kg/ha). These sediment loads are much lower than measured in previous seasons due to the low sediment concentrations, the reduced runoff compared to the 2010/11 season, and the green cane trash blanket.
- Initial nitrogen concentrations in runoff (first runoff event 75 days after application) were dominated by NO_x-N, with concentrations highest in Treatment 1 (higher application rate). In contrast to the previous season, urea-N concentrations were low, presumably due to the longer period between application and first runoff this season. The total wet season loss of NO_x-N and urea-N was 1.8 kg/ha and 1.6 kg/ha for Treatments 1 and 2, respectively. This represents ~1% of the nitrogen applied to each treatment, much lower than the ~10% measured in previous seasons.
- The filterable reactive phosphorus (FRP) flow-weighted wet season concentration was similar between treatments: 48 and 47 µg P/L for Treatments 1 and 2 respectively, lower than that measured last season.
- The calculated half-lives of diuron, hexazinone and imazapic were 74, 39 and 47 days, respectively from surface soil field dissipation measured 10-203 days after application. For cane trash, the calculated half-lives were 30, 22 and 33 days for diuron, hexazinone and imazapic, respectively.
- Herbicide residues of diuron and hexazinone were detected in runoff in low concentrations (compared to previous seasons) from Treatment 1 (Bobcat applied 128 days prior to the first runoff event, compared to Velpar K4 applied 7-8 days prior to the first runoff event in previous seasons). Less than 0.4% of the applied product was lost in the season’s runoff, with 50% of that lost in the initial 10-15% of the season’s runoff.
- Imazapic was only detected in one runoff sample at 1 µg/L.
- Low concentrations (<0.01-0.05 µg/L) of atrazine were detected in runoff from Treatment 1, despite no application this season. It is thought that the source of this atrazine may be from the source water used in the spray tank mixture, rather than persistence in the environment.

- Only two drainage water samples were collected from each treatment for the season. As a result, no meaningful conclusions can be made, but concentrations of nutrients and herbicides were much lower than in the previous season.
- Machine harvest yield results of the second ratoon cane crop were very similar – 90.4 t/ha for Treatment 1 and 90.6 t/ha for Treatment 2, despite Treatment 2 receiving 61 kg/ha less nitrogen than Treatment 1.

At the Marian site (duplex soil), total runoff was confounded by the site flooding several times. Therefore, it is not possible to derive accurate runoff figures or water quality loads.

- Total suspended solid concentrations were generally low (13-140 mg/L), but slightly higher than the Victoria Plains site. The treatment average concentrations (26-77 mg/L) were less than one third of those measured in the previous season, which appears to be due to the green cane trash blanket and lack of cultivation.
- Nitrogen concentrations in rainfall runoff were low compared to the previous season, and dominated by NO_x-N. For the events sampled, average NO_x-N concentrations did not follow the rate of nitrogen application, presumably due to the variability in the number of events sampled. In contrast to rainfall runoff, the samples collected from the irrigation runoff event had relatively high NO_x-N concentrations, presumably due to the high nitrate content of the irrigation water.
- Average FRP concentrations (355-499 µg P/L) were ~10-fold more than those detected at the Victoria Plains site, following a similar trend to the surface soil phosphorus concentrations.
- Using the surface soil field dissipation data of 25-105 days after application, the calculated half-lives of diuron and hexazinone were 45 and 31 days, respectively (Treatment 1 only) and 34 days for paraquat (average of Treatments 3-5). For cane trash, the calculated half-lives were 12 and 11 days for diuron and hexazinone, respectively. Concentrations of paraquat on cane trash were very variable over time, and no clear trend in dissipation could be detected.
- Herbicide residues of diuron and hexazinone detected in runoff this season were low ($\leq$ 0.5 µg/L) (Treatments 1 and 2; first runoff samples collected 30 and 67 days after application, respectively) and isoxaflutole (Treatments 3 and 5) was not detected in any runoff samples (<1 µg/L).
- Machine harvest yield results of the second ratoon cane crop showed that cane yield (59-103 t/ha) trended with the amount of nitrogen applied. The skip row treatment (Treatment 5) yielded 71% of Treatment 3 (solid plant, same nitrogen rate), despite only having 56% of the area planted to cane.

At the Multi-block and Multi-farm sites:

- Total seasonal runoff from the Multi-farm site was estimated to be 649 mm from 2241 mm of rainfall. Determining accurate volumes of runoff (and therefore water quality loads) at the Multi-block site are not possible due to flooding issues.
- Total suspended solid concentrations at the Multi-block site (26-46 mg/L) were generally lower than the Multi-farm site (9-180 mg/L). These concentrations are lower than those detected in the previous season, and may be attributed to the variance in ground cover levels on paddocks within each of the monitoring catchments.
- Total estimated wet season sediment yield for the Multi-farm catchment was 779 kg/ha, with a flow-weighted seasonal mean concentration of 120 mg/L.

- At both sites, NO_x-N concentrations were highest in the initial sampled event, with the seasonal average and range of concentrations being higher than the previous season. This may reflect the timing of nitrogen application prior to the initial runoff event. The total estimated wet season loss of NO_x-N in runoff from the Multi-farm site was 1.8 kg/ha (flow-weighted seasonal average concentration of 283 µg N/L).
- Filterable reactive phosphorus concentrations at the Multi-block site were consistently higher than those of the Multi-farm site. Similar to the paddock data, this may reflect the variable phosphorus levels in the surface soil.
- Maximum herbicide residue concentrations were generally higher at the Multi-farm site than the Multi-block site. This may be a reflection of the different periods of application (and the products applied) between the two catchments.

In summary, results from the 2011/12 season showed similar trends between treatments and sites as those observed in previous seasons, although concentrations were generally lower this season due to the delay in commencement of runoff (compared to when treatment applications were applied). Green cane trash blanket results in an approximate ten-fold decrease in suspended sediment losses compared to previous seasons (plant cane) with bare soil. Differences between sites highlights the importance of soil characteristics, input application rates, and the duration between application and the first runoff event on nutrient and herbicide losses in runoff water. Higher nitrogen inputs and high background soil phosphorus levels can lead to larger runoff losses. Matching row spacing to machinery track width can reduce runoff and therefore reduce off-site transport of nutrients and herbicides.

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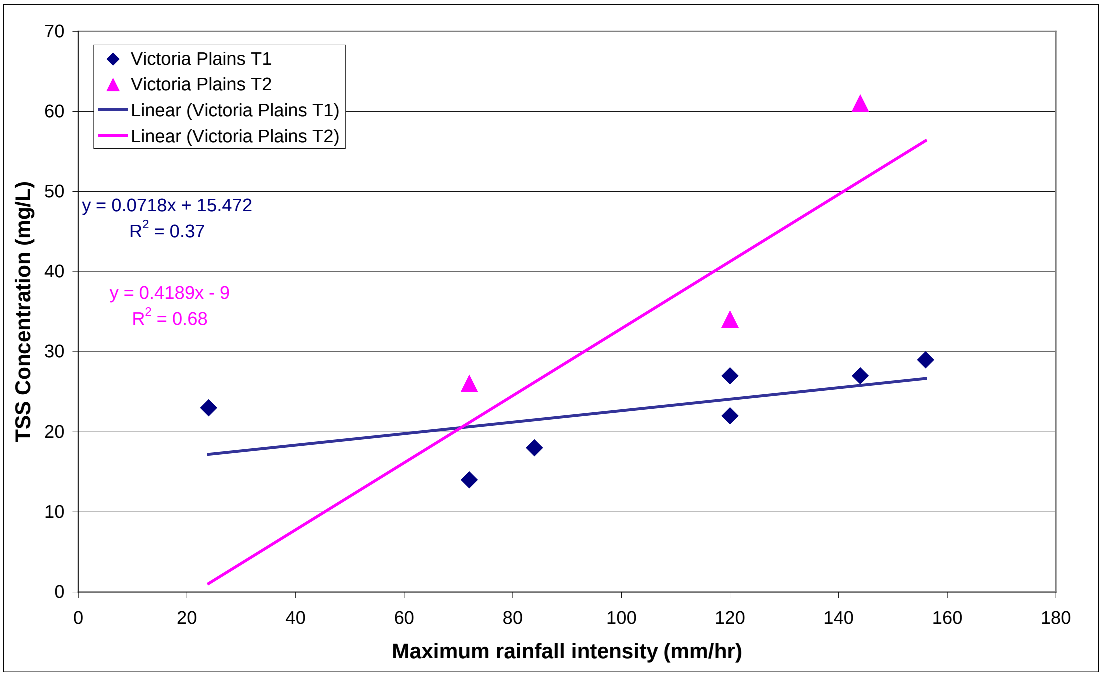
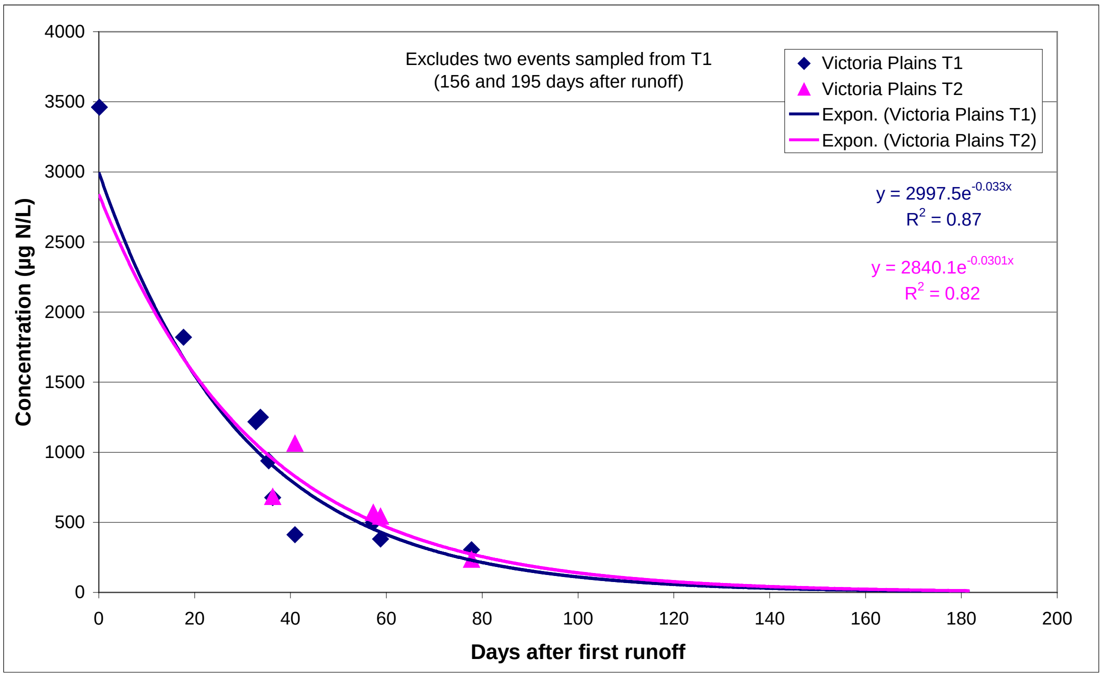
7 APPENDICES

7.1 Regression plots used to estimate concentrations for runoff load calculations, Victoria Plains site

7.1.1 Total suspended solids

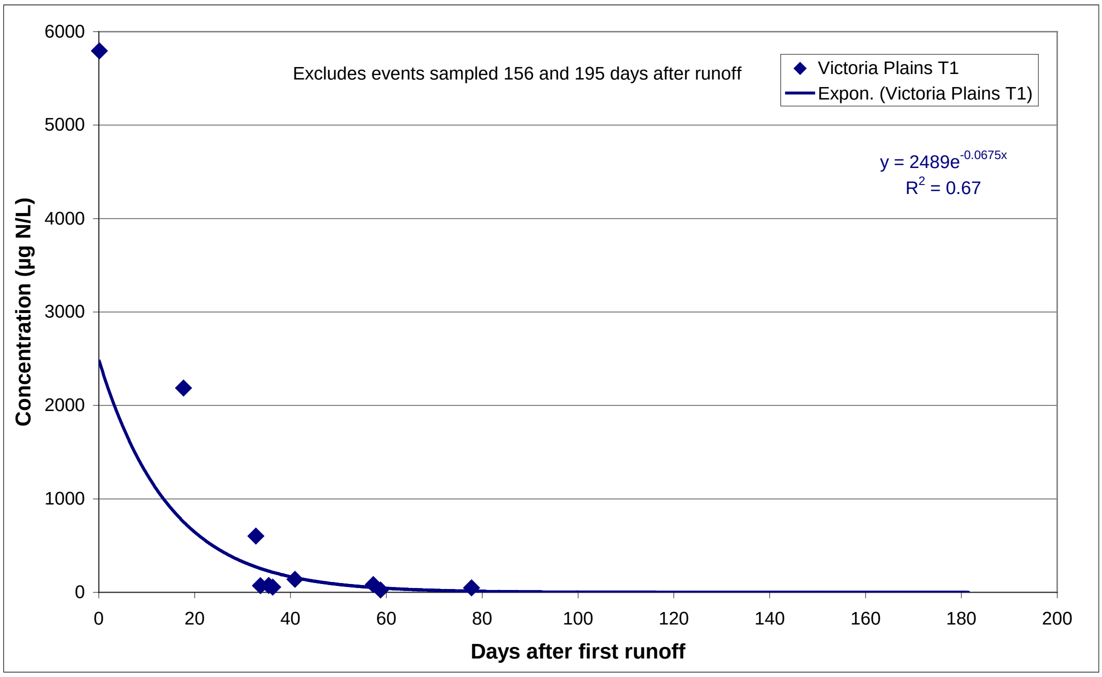


7.1.2 Total Kjeldahl nitrogen

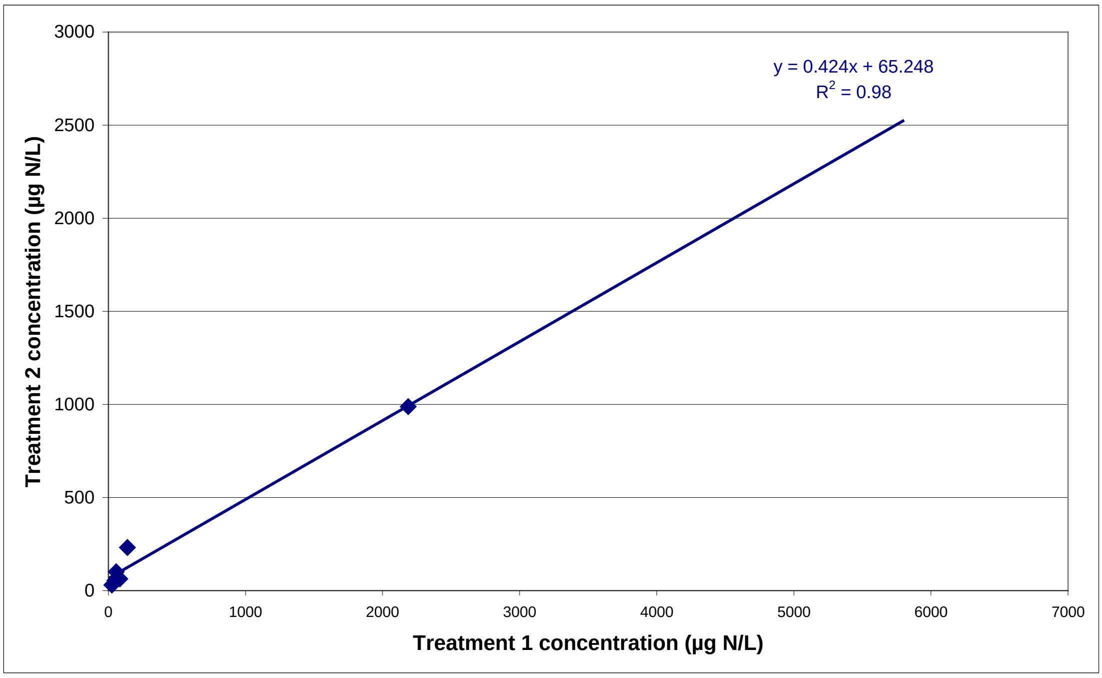


7.1.3 NO_x-N

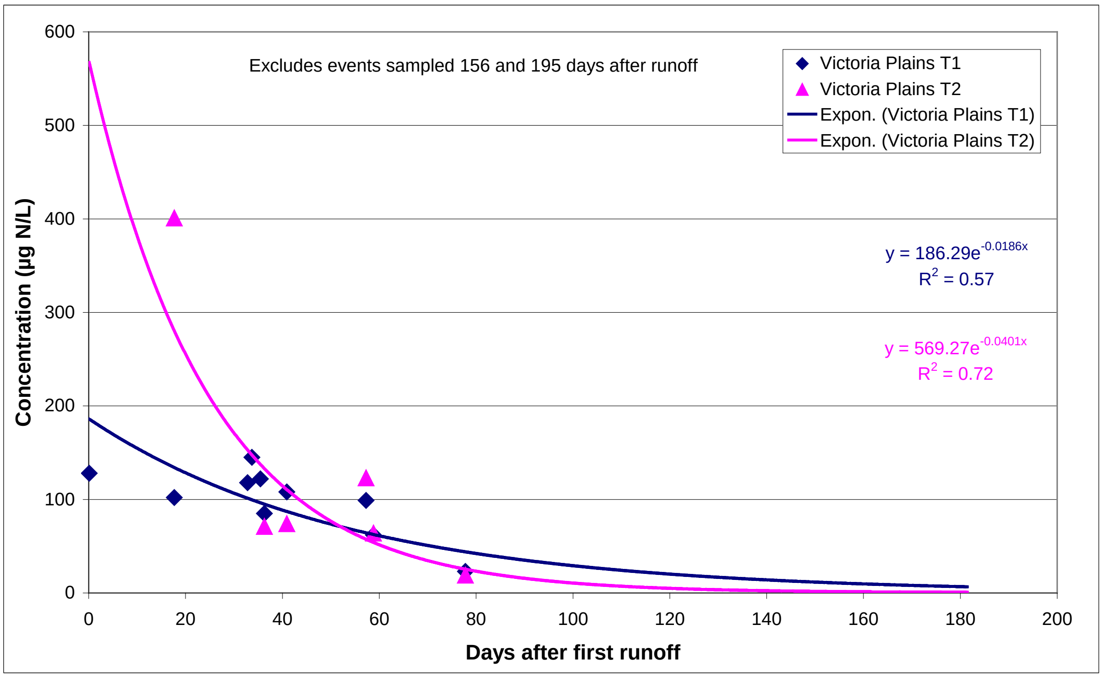
7.1.3.1 Treatment 1



7.1.3.2 Treatment 2

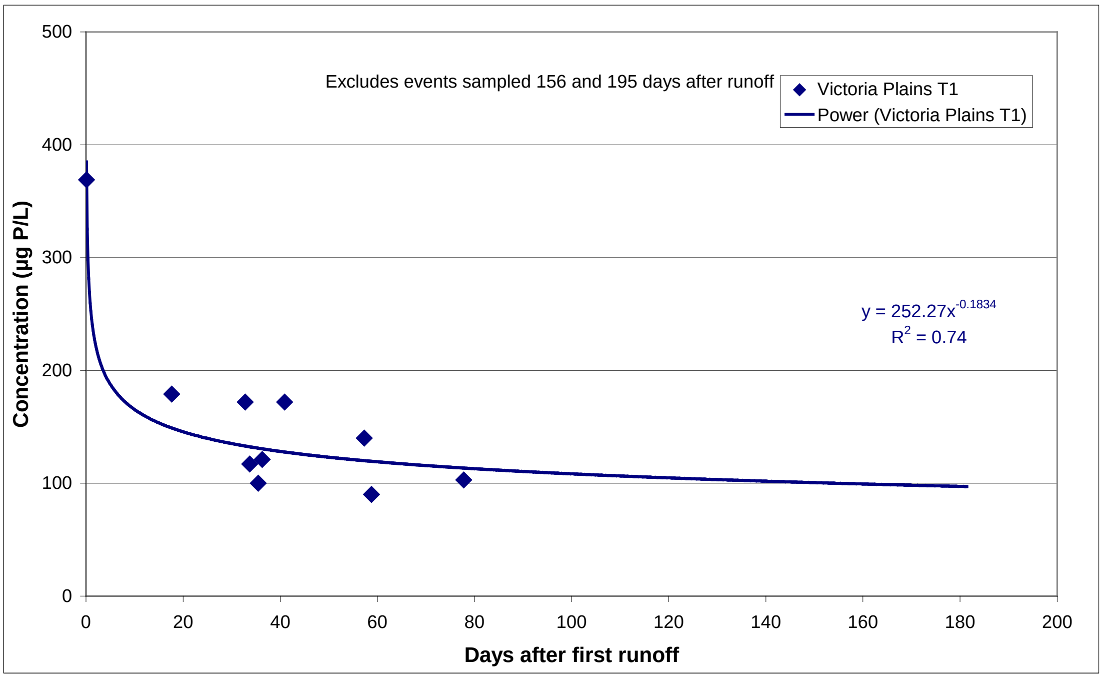


7.1.4 Urea-N

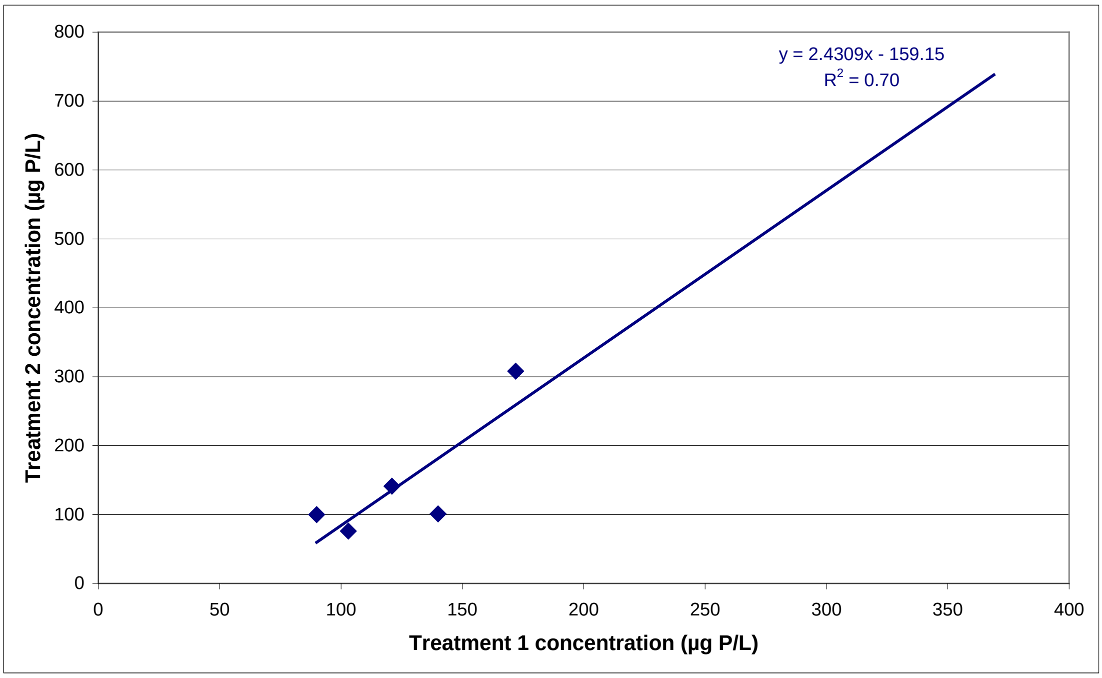


7.1.5 Total Kjeldahl phosphorus

7.1.5.1 Treatment 1

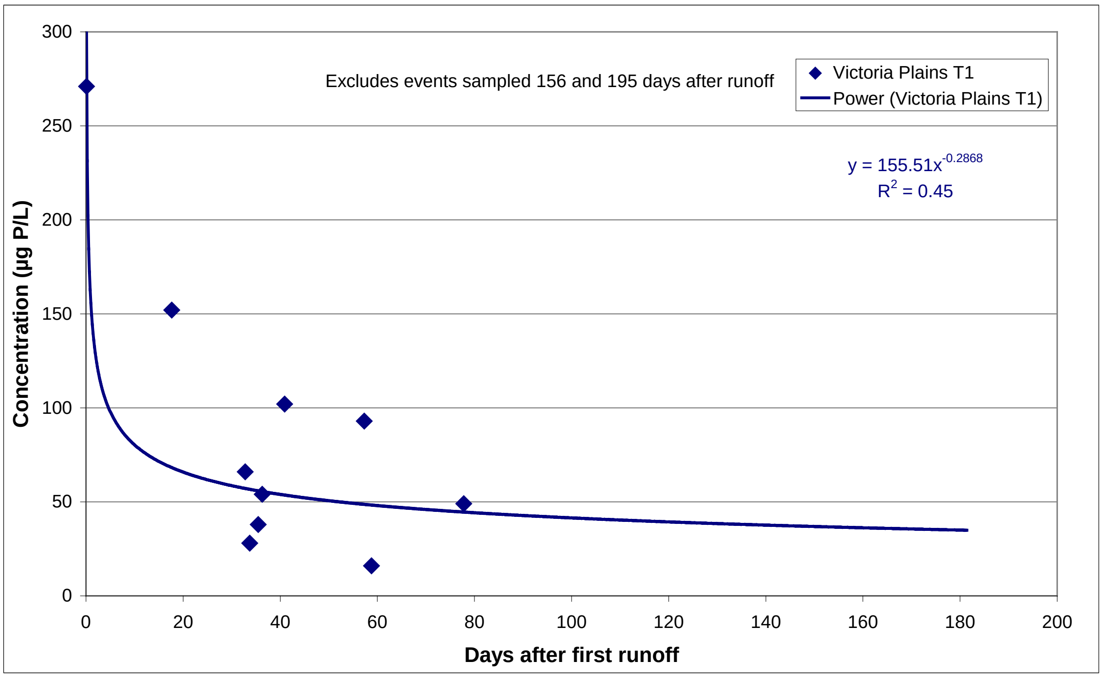


7.1.5.2 Treatment 2

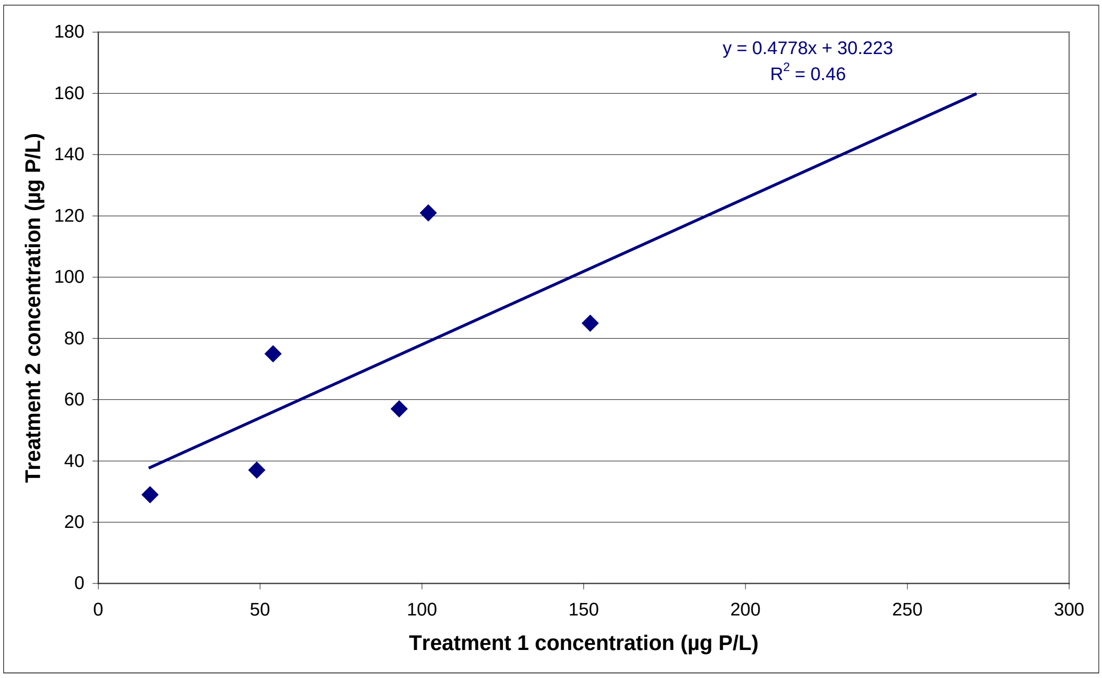


7.1.6 Filterable reactive phosphorus

7.1.6.1 Treatment 1

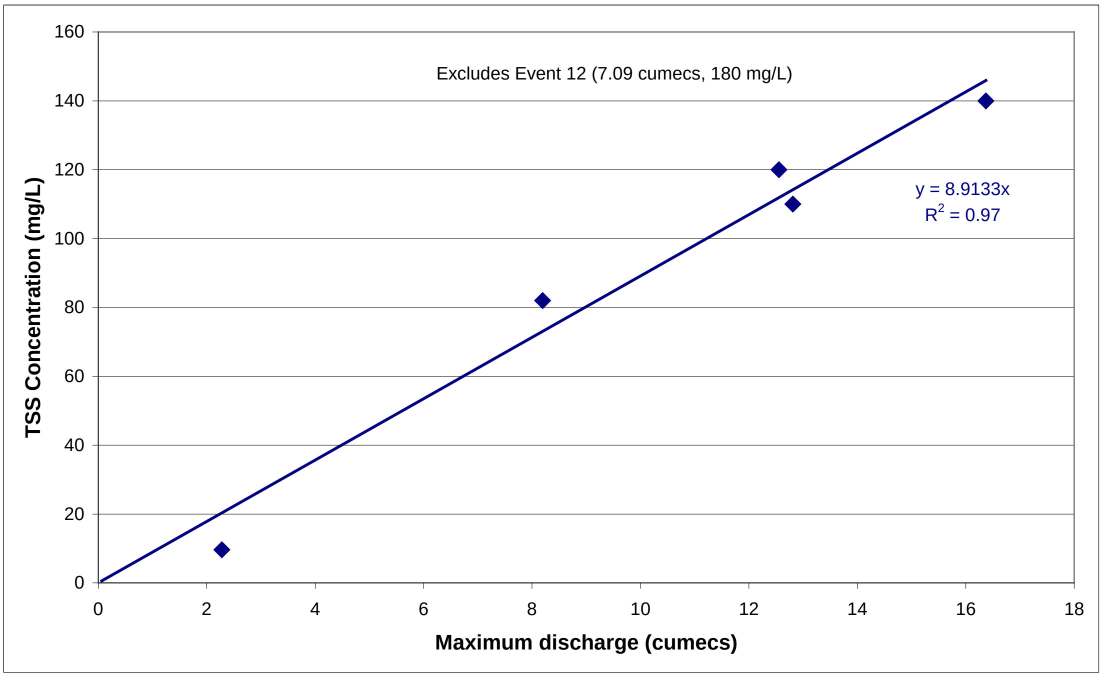


7.1.6.2 Treatment 2



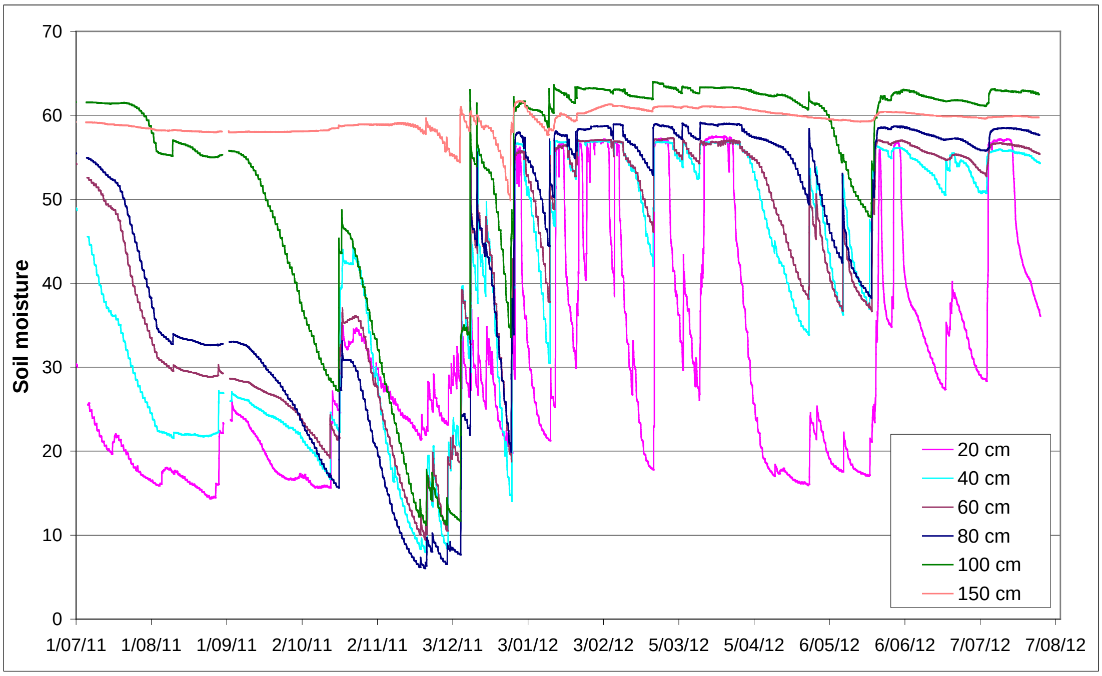
7.2 Regression plots used to estimate concentrations for load calculations, Multi-farm site

7.2.1 Total suspended solids

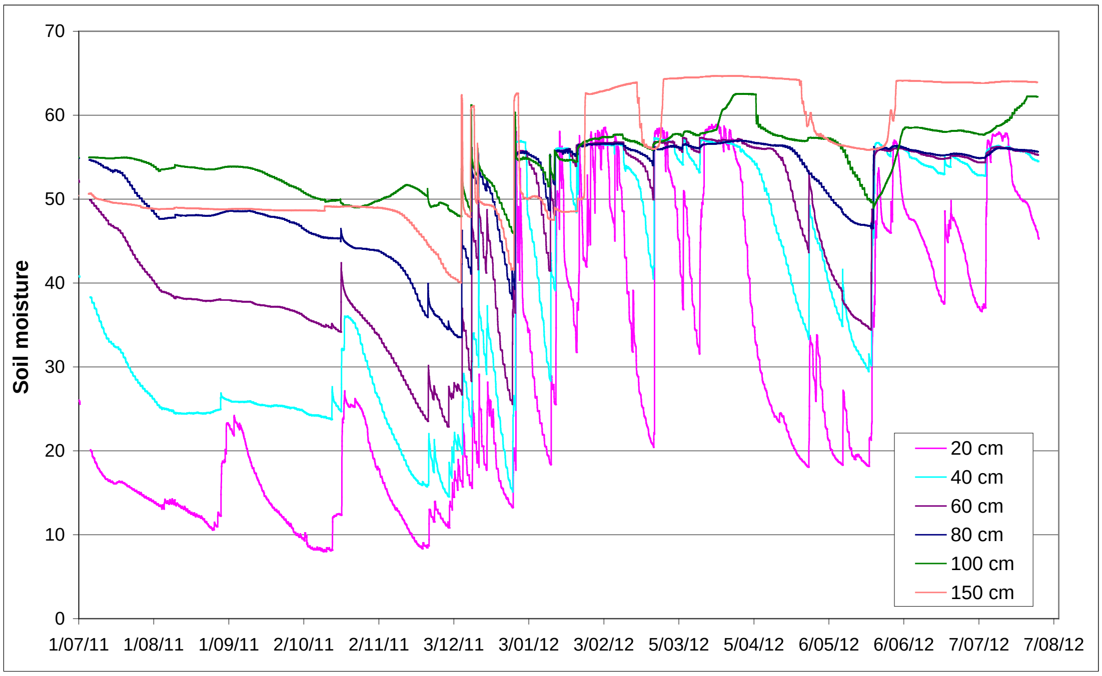


7.3 Soil moisture plots

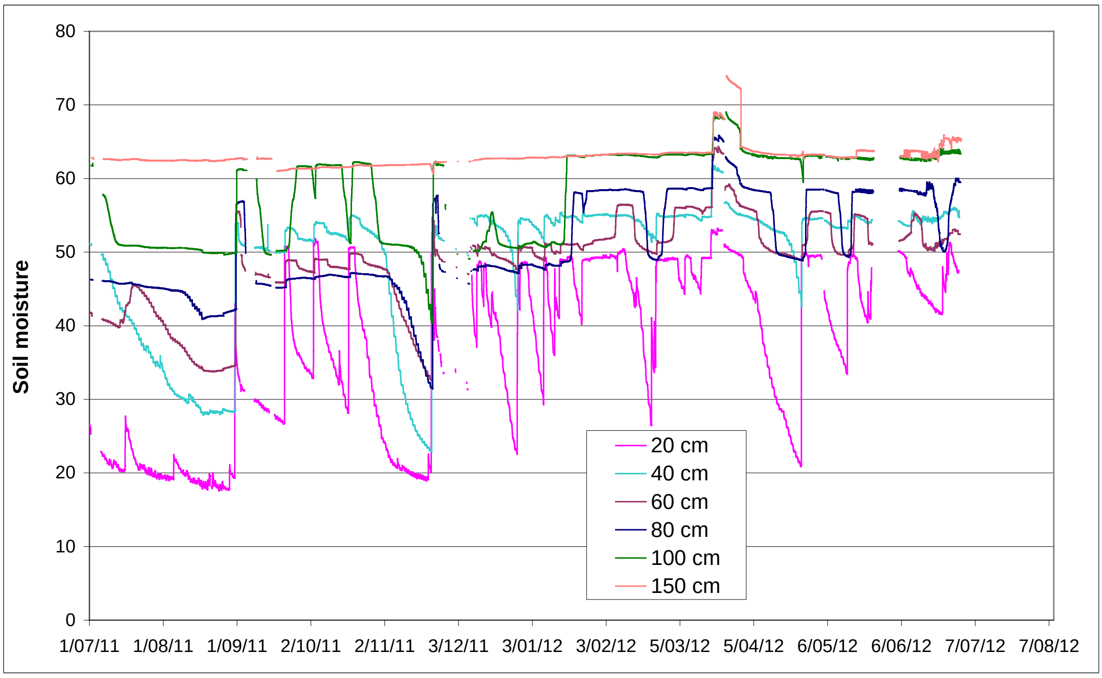
7.3.1 Victoria Plains Treatment 1



7.3.2 Victoria Plains Treatment 2

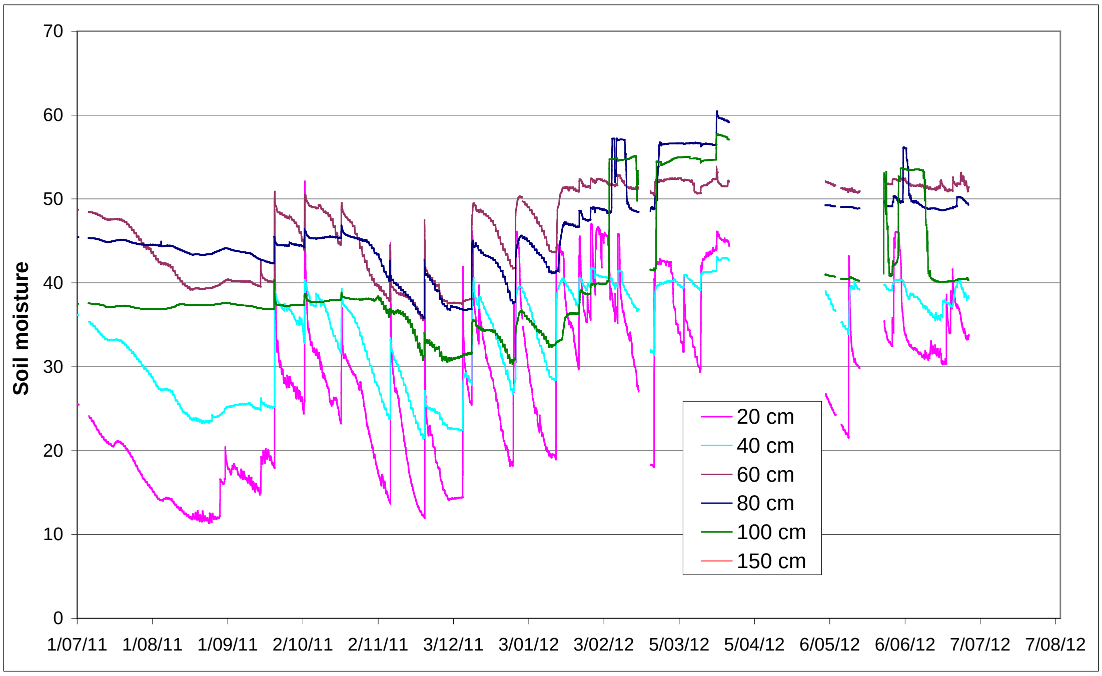


7.3.3 Marian Treatment 1



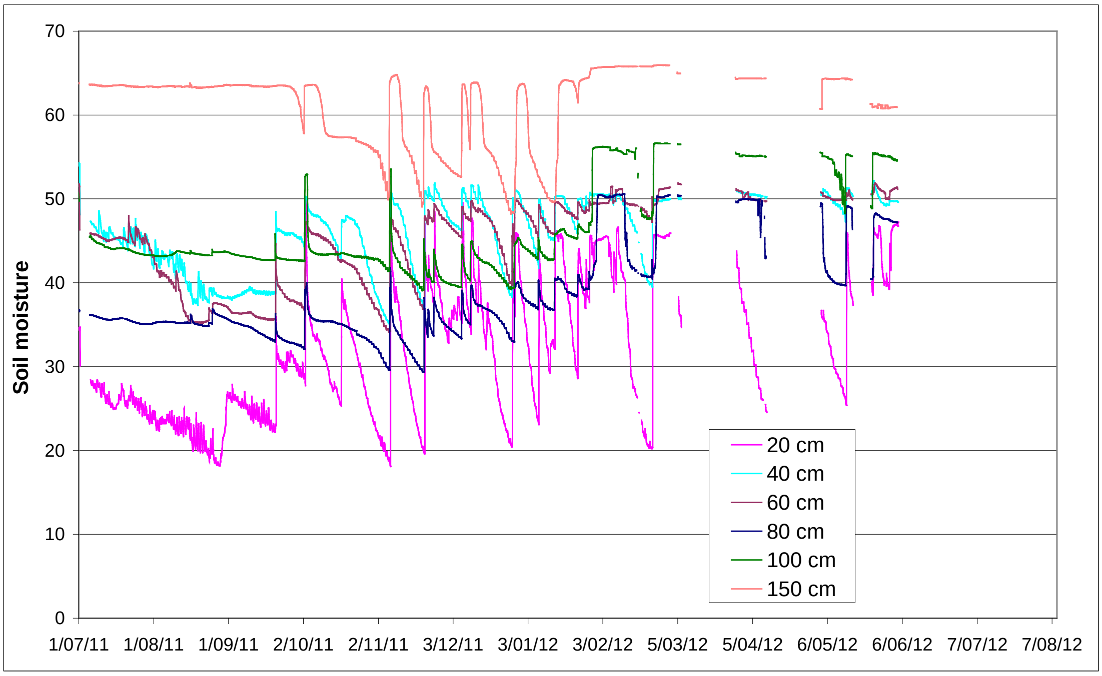
Note: Increases in soil moisture above "normal" values (18th-29th March 2012) are when the site flooded and soil moisture sensors were wet. Data gaps are due to equipment failures.

7.3.4 Marian Treatment 2



Note: Sensor at 150 cm not working. Increases in soil moisture above "normal" values (18th-29th March 2012) are when the site flooded and soil moisture sensors were wet. Data gaps are due to equipment failures.

7.3.5 Marian Treatment 5



Note: Increases in soil moisture above "normal" values (18th-29th March 2012) are when the site flooded and soil moisture sensors were wet. Data gaps are due to equipment failures.