Department of Environment
and Resource Management

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

Interim Report
2010/2011 Wet Season

Mackay Whitsunday Region

Tomorrow's Queensland: strong, green, smart, healthy and fair

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Queensland Government

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Mackay Whitsunday Region

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Funding provided by Reef Catchments (Mackay Whitsunday Isaac) Limited through the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program and Project Catalyst

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October 2011

Prepared by:
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Department of Environment and Resource Management

ISBN 9-311662-200501

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Citation
Rohde K, Bush A and Agnew J. 2011. Paddock to Sub-catchment Scale Water Quality Monitoring of Sugarcane Management Practices. Interim Report 2010/11 Wet Season, Mackay Whitsunday Region. Department of Environment and Resource Management, Queensland Government for Reef Catchments (Mackay Whitsunday Isaac) Limited, Australia.

Acknowledgements
We would like to give a special thanks to the cooperating landholders for allowing us to conduct the research trials on their properties, and to the landholders, their families and staff for applying the nutrient and herbicide treatments, harvesting of the individual treatments, and general site maintenance.

We also greatly appreciate the many individuals for their assistance in the collection of soil, water and trash samples throughout the prolonged wet season, and those that have provided comments and reviews on various versions of this report.

Thank you to Sue Burt for assistance with the profile nutrient soil sampling, and Bruce Cowie and Monique Pierce for undertaking the bulk density sampling.

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EXECUTIVE SUMMARY

The Australian and Queensland Government's 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 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.* in press). 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.* in press). 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.

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	Residual
Treatment 2	BBB	1.8 m controlled traffic	Six easy steps	Knockdown
Marian site – duplex soil				
Treatment 1	CCC	1.5 m current practice	Generalised recommendation	Residual
Treatment 2	BCC	1.8 m controlled traffic	Generalised recommendation	Residual
Treatment 3	BBB	1.8 m controlled traffic	Six easy steps	Knockdown
Treatment 4	BAB	1.8 m controlled traffic	Nutrient replacement	Knockdown
Treatment 5	ABB	1.8 m controlled traffic, skip row	Six easy steps[2]	Knockdown

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES

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).

Outcomes from the second year of monitoring 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 averaged 14% less than Treatment 1 (1751 and 2025 mm, respectively from 3300 mm rainfall). Runoff from Treatment 2 was delayed on average by ~11 minutes compared with Treatment 1, and the peak runoff rate was ~33% lower, all contributing to reduced runoff.
- Total suspended solids (TSS) concentrations showed a general increasing trend throughout the wet season, with concentrations also increasing with increasing maximum rainfall intensity. The wet season flow-weighted TSS concentration was lower in Treatment 1 (135 mg/L) than Treatment 2 (158 mg/L).
- Total estimated wet season soil loss for both treatments was similar: 2743 kg/ha for Treatment 1, and 2766 kg/ha for Treatment 2.
- After nitrogen application, initial nitrogen concentrations in runoff were dominated by urea-N, with concentrations highest in Treatment 1 (higher application rate). Concentrations of NO_x-N (nitrate and nitrite) peaked ~26 days after application, and concentrations of all nitrogen species were lower by mid-November (~two months after application). The total wet season loss of urea (the highest nitrogen species load) in runoff from Treatment 1 was 16 kg/ha and 13 kg/ha from Treatment 2.
- The filterable reactive phosphorus (FRP) flow-weighted wet season concentration was higher for Treatment 2 (77 µg P/L) than for Treatment 1 (57 µg P/L), although similar phosphorus rates were applied. Due to the lower runoff volumes from Treatment 2, total loss was similar between treatments (~5% of applied P).
- Using the surface soil field dissipation data of 10-100 days after application, the calculated half-lives of diuron, hexazinone and imazapic were 199, 53 and 118 days, respectively. For canetrash, the calculated half-lives were 11, 9 and 13 days for diuron, hexazinone and imazapic, respectively.
- Herbicide residues of diuron and hexazinone were particularly elevated in the initial runoff event from Treatment 1, which was seven days after the application of Velpar K4. Within one month of application, ~92% of the total seasonal loss of diuron and hexazinone in runoff had occurred (but only 6% of the seasonal runoff).
- Imazapic was not detected in any runoff samples from Treatment 2; however samples were not collected until 85 days after application.
- There was a strong relationship between herbicide concentrations (diuron and hexazinone) detected in the surface runoff water and those detected in the drainage soil solution samples.
- Machine harvest cane yield results of the first ratoon cane crop were 62 t/ha for Treatment 1 and 48 t/ha for Treatment 2. The lower yield from Treatment 2 is thought to be due to the lower application of nitrogen and the wet, waterlogged conditions.

At the Marian site (duplex soil), total runoff was compounded 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 much higher than those recorded from the Victoria Plains site (treatment averages 176-772 mg/L), presumably due to low cover from cultivation and lack of a trash blanket.
- Nitrogen concentrations in runoff were low prior to harvest and nitrogen application. After application, NO_x-N concentrations remained above background concentrations for ~2 months with Treatment 5 (1.8 m controlled traffic, skip row) having the highest average concentration. This may be attributed to the release of nitrogen from the previous peanut crop residue and nitrogen being applied to the skip area, especially since this area was not planted this season. Average NO_x-N concentrations for the remaining 1.8 m treatments trended with the rate of nitrogen applied.
- Average FRP concentrations (403-835 µg P/L) were ~10-fold more than those detected at the Victoria Plains site, following a similar trend to the surface soil phosphorus levels.
- Herbicide concentrations in the surface soil were quite variable across the treatments, despite identical application rates being applied. Using the field dissipation data of 1-83 days after application, the calculated half-lives of paraquat, 2,4-D and atrazine were 27, 34 and 116 days, respectively.
- As with soil herbicide concentrations, runoff concentrations were also variable, but followed a similar trend to the soil concentrations. Paraquat was not detected in any runoff samples.
- Machine harvest cane yield results of the first ratoon cane crop were similar between treatments (38-43 t/ha), except for the skip row treatment (21 t/ha) due to only 56% of the treatment area planted to cane.

At the Multi-block and Multi-farm sites:

- Total suspended solid concentrations at the Multi-block site (24-160 mg/L) were lower than those measured at the Multi-farm site (32-430 mg/L). These values are within the range of the results observed at the paddock scale, and may be attributed to the variance in ground cover levels on paddocks within each of the monitoring catchments.
- Concentrations of NO_x-N were much lower than those detected in the 2009/10 season, possibly the result of the extended wet season which limited the opportunities for growers to apply nutrients.
- 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.
- Herbicide residues were generally similar between the two sites, but periods of application (and therefore maximum concentrations) are more clearly defined at the Multi-block site. The range of herbicide concentrations detected is different to the 2009/10 season, which may be due to the herbicides applied and the timing of those applications.

In summary, results from the 2010/11 season showed the same trends between treatments as those observed for the 2009/10 season, despite the higher than average rainfall that occurred in 2010/11. 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. The 1.5 m and 1.8 m row spacing treatments produced similar cane yields, particularly at the Marian site with wet and waterlogged conditions limiting full yield potential.

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 between now and 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/2008/reef-rescue.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. From 2010 to 2014, the project aims to translate the Mackay Whitsunday experience to "cutting-edge" cane growers throughout the GBR catchment, as well as 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.* in press). 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 Rescue regulations coming into effect to determine any change in water quality. At the paddock scale, plots will be established utilising differing levels of soil management, pesticide and herbicide application on sugarcane, horticulture crops and grazing lands. These plots will be used to determine how the different land management practices (A, B, C and D classes) affect water quality. Collected water quality data will be used to validate and calibrate the models at each scale. Annual reporting will be 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 Environment and Resource Management, AgriServ Central, Reef Catchments (Mackay Whitsunday Isaac) Limited and individual cane farmers.

This report outlines the second year (2010/2011 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).

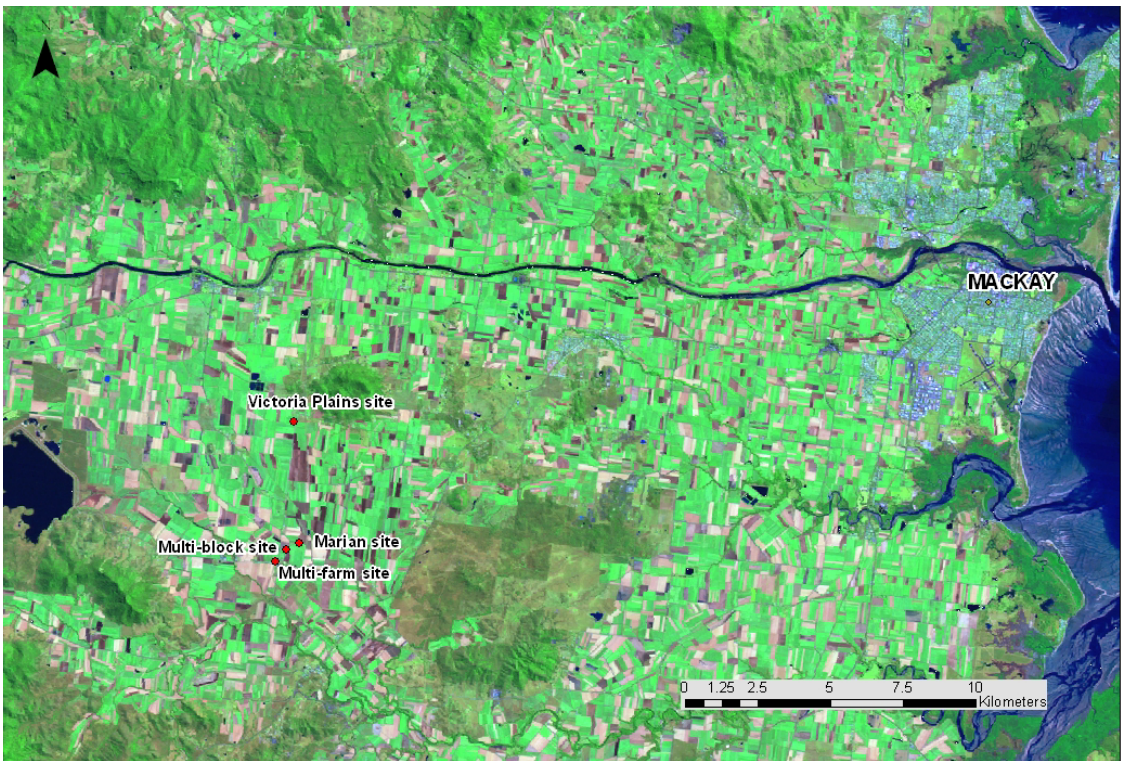

Figure 1 Locality map of monitoring sites

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	Residual
Treatment 2	BBB	1.8 m controlled traffic	Six easy steps[2]	Knockdown

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES

2.1.1.1 Harvest, nutrient and herbicide applications

Both treatments were machine harvested on 3rd September 2010 (plant cane). 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 13th September 2010 (Table 2). Nutrient treatments were applied on 17th September 2010 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	13th September 2010	Velpar K4 (3.8 kg/ha)	diuron (1778 g a.i./ha) and hexazinone (502 g a.i./ha)
2	13th September 2010	Flame (0.4 L/ha)	imazapic (96 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	BKN 230 (3300 kg/ha)	6.05	0.79	2.57	0.85	200	26	85	28
2	Liquid Pre-plant (3200 kg/ha)	4.27	0.8	2.66	0.7	136	25	80	29

The first ratoon cane crop was machine harvested on 10th August 2011. 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. 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	Residual
Treatment 2	BCC	1.8 m controlled traffic	Generalised recommendation	Residual
Treatment 3	BBB	1.8 m controlled traffic	Six easy steps[2]	Knockdown
Treatment 4	BAB	1.8 m controlled traffic	Nutrient replacement	Knockdown
Treatment 5	ABB	1.8 m controlled traffic, skip row	Six easy steps	Knockdown

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES

2.1.2.1 Harvest, nutrient and herbicide applications

All treatments were burnt prior to machine harvesting on 29th October 2010 (plant cane). This was a decision made by the grower due to the season outlook and the high risk of the ratoon cane being waterlogged if a trash blanket was left.

A single cultivation (two-row multiweeder) was undertaken on 30th October 2010 to remove some of the compaction effects of the machine harvesting operations. No canetrash remained on the soil surface.

Initial nutrient treatments were applied on 3rd November 2010 as a liquid mix to the cane stool (Table 5).

On 26th January 2011, a "top-up" rate of ammonium sulphate (300 kg/ha; 61 kg N/ha and 72 kg S/ha banded on the cane stool) was applied to all treatments (except Treatment 5 where only the planted area was fertilised). This was applied to attempt to overcome some of the wet season effects on the cane growth (excessive rain and waterlogging causing denitrification and crop yellowing).

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)	4.69	0.48	2.6	0.65	197	20	110	25
2	LOS+P (4200 kg/ha)	4.69	0.48	2.6	0.65	197	20	110	25
3	MKY170 (4200 kg/ha)	3.78	0	2.73	0.44	159	0	115	18
4	Liquid 50/50 (4100 kg/ha)	2.9	0	2.78	0.39	119	0	114	16
5	MKY170 (4200 kg/ha)	3.78	0	2.73	0.44	159	0	115	18

Due to the continuing wet weather post-harvest, the herbicide treatments could not be applied according to the original project design. On 14th December 2010 and 26th January 2011, herbicide treatments were applied as a directed spray to the interspace and base of the cane stool (Table 6).

Table 6 Application of herbicide treatments to the Marian site

Treatment(s)	Date	Product (amount applied)	Active ingredients (amount applied)
1	14th December 2010	Actril DS (1 L/ha)	2,4-D ester (577 g a.i./ha) and ioxynil (100 g a.i./ha)
		Asulox (6 L/ha)	asulam (2400 g a.i./ha)
1-2	26th January 2011	Atradex 900 (2 kg/ha)	atrazine (1800 g a.i./ha)
1-5	26th January 2011	Gramoxone 250 (1.2 L/ha)	paraquat (300 g a.i./ha)
		Amicide 625 (1 L/ha)	2,4-D amicide (625 g a.i./ha)

The first ratoon cane crop was machine harvested on 30th August 2011. The cane was harvested green, the trash blanket was left on the soil surface and no cultivation was undertaken.

2.1.3 Soil and canetrash 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. At the Victoria Plains site, samples were collected on 6th September 2010 (post-harvest, pre-nutrient application) and 25th October 2010 (38 days after nutrient application) at depth increments of 0-0.15, 0.15-0.3, 0.3-0.6, 0.6-1.0, and 1.0-1.5 m. At the Marian site, samples were collected on 1st November 2010 only (post-harvest and cultivation, pre-nutrient application) 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 Bulk density

Soil cores for bulk density were collected on 12th October 2010 at the Victoria Plains site (39 days after harvest) and on 2nd November 2010 at the Marian site (4 days after

harvest). Cores were taken from the bottom of the furrow, mid-section of the bed (mid-slope) and centre of the bed (Figure 2) from two locations in the 1.5 m and 1.8 m treatments (Treatments 1 and 2 for Victoria Plains site, and Treatments 1 and 4 for Marian site). Cores were taken using a 10 cm diameter thin walled push tube. Each core was cut into sections (10 cm increments to 60 cm depth for the Victoria Plains site; and 0-5 cm, 5-10 cm and 10 cm increments thereafter to 60 cm depth) using thin wire and accurately measured for length. Samples were dried at 105^{o}C until the weight was constant, giving a dry mass of soil from a known volume. The sample volume was calculated using the area of the tube tip and the length of each sample.

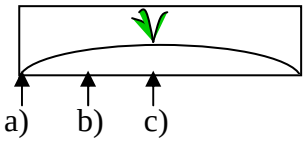

Figure 2 Bulk density sampling locations for a) furrow bottom, b) mid-slope and c) centre of the bed
(Source: Masters *et al.* 2008)

2.1.3.3 Soil and canetrash herbicides

Samples of canetrash (Victoria Plains site only) were collected prior to herbicide application, and 0.3-100 days after application. Three samples (using 8x12 cm quadrats) were taken from the centre of the bed, 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 overnight on ice.

Soil samples (0-2.5 cm) were collected in conjunction with the canetrash sampling. Samples were also collected from the Marian site (1-83 days after herbicide application). The soil samples were collected from immediately below where the canetrash 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 (number depending on herbicide analyses required) with teflon lined lids. As with the canetrash samples, soil samples were immediately stored on ice then refrigerated before being transported to the laboratory overnight on ice.

2.1.3.4 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 3) 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:

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

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 2.5.1.1), nutrients (total and filtered; Section 2.5.1.3), and herbicides (Section 2.5.1.4) 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.

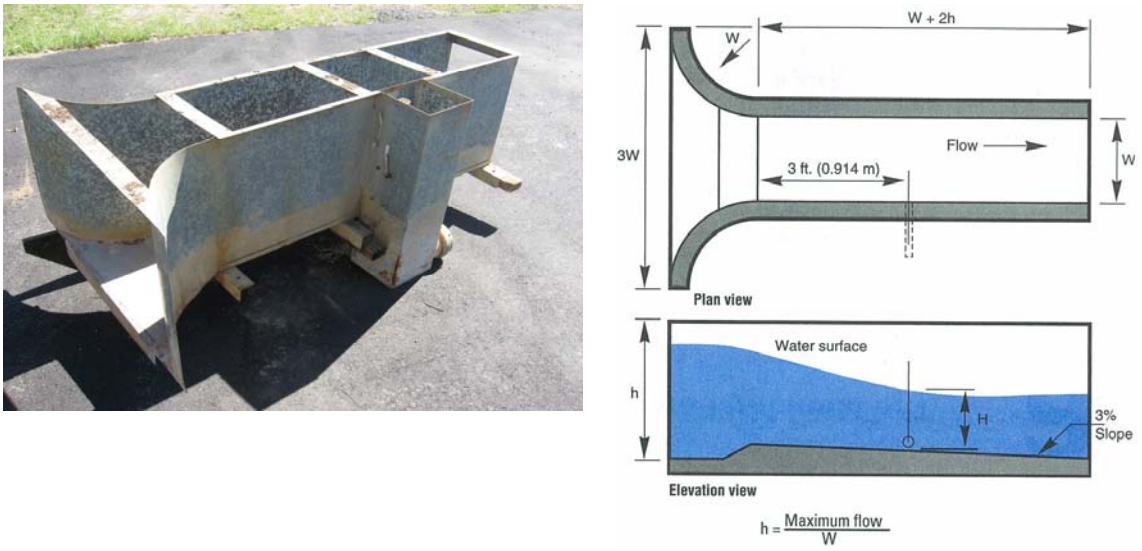

Figure 3 A 300 mm San Dimas flume (left) and critical design dimensions (right)

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.

2.1.5 Drainage water quality

Drainage water quality below the rooting depth (0.9 m) was sampled between September 2010 and March 2011 following seven runoff events using soil solution samplers ("suction cups"). Two soil solution samplers were installed in each treatment (in close proximity to the subsurface EnviroSCAN's). A soil solution sampler at the Marian site (Treatment 5) was destroyed during soil preparation 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, dead leaf and green leaf) 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 Victoria Plains site on 10th August 2011 and at the Marian site on 30th August 2011. 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.

Measurements of PRS were not obtained from two of the Marian site treatments due to either insufficient yield or non-consecutive bins at the cane siding.

2.2 Multi-block scale

At the Multi-block scale (21^{o} 13' 36"S 148^{o} 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 2.5.1) for nutrients (total and filtered), herbicides and TSS, with priority being given to nutrients, then herbicides depending on the volume of sample collected.

2.2.1 Management practices

Approximately 71% of the Multi-block catchment has sugarcane growing on 1.8 m row spacing, 22% on 1.6 m row spacing, and the remainder of the cropped area was fallow. More than 10% of the catchment area (6.9 ha) was stand-over sugarcane from the previous season, and therefore had no nutrients or herbicides applied.

The total nitrogen and phosphorus applied to the catchment area was 5371 and 698 kg, respectively. This represents an average nitrogen rate of 148 kg N/ha for plant cane and 174 kg N/ha for ratoon cane. Average phosphorus rates were 37 kg P/ha and 20 kg P/ha for plant and ratoon cane, respectively.

Atrazine was the only ERA (environmentally relevant activity; includes ametryn, atrazine, diuron, hexazinone and tebuthiuron) herbicide applied within the catchment area, and was applied to ~10% of the catchment area at an average rate of 1.6 kg/ha. Imazapic was also applied to almost half of the catchment, but was not analysed for in runoff.

2.3 Multi-farm scale

At the Multi-farm scale (21^{o} 13' 49"S 148^{o} 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 – 0.675 m	Subject to final gauging measurements	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. Accurate flow rates could not be gauged when water overtopped the channel and spread out over the surrounding area. The bulked sample was sub-sampled and analysed for nutrients (total and filtered), herbicides and sediments (Section 2.5.1).

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 and equipment being turned off to reduce excessive sample numbers. Therefore, a regression curve was fitted to known concentrations (TSS, nutrients and herbicides) with time after first runoff (or maximum rainfall intensity for TSS) to estimate concentrations in non-sampled runoff events (Table 9). 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 site

Parameter	Treatment 1	Treatment 2	Notes
TSS (mg/L)	$y=1.0643x+14.173$ ($R^2=0.50$)	$y=1.2642x-4.3559$ ($R^2=0.50$)	x = maximum rainfall intensity (mm/hr)
Urea-N (µg N/L)	$y=3907.6x^{-0.9084}$ ($R^2=0.69$)	$y=2201.1x^{-0.7849}$ ($R^2=0.74$)	x = days after first runoff
FRP (µg P/L)	$y=382.12x^{-0.6057}$ ($R^2=0.52$)	$y=348.57x^{-0.6141}$ ($R^2=0.59$)	x = days after first runoff
TKN (µg N/L)	$y=7239.5x^{-0.4521}$ ($R^2=0.67$)	$y=6710x^{-0.4504}$ ($R^2=0.75$)	x = days after first runoff
TKP (µg P/L)	$y=668.42x^{-0.2839}$ ($R^2=0.60$)	$y=686.27x^{-0.3376}$ ($R^2=0.84$)	x = days after first runoff
Diuron (µg/L)*	$y=82.435e^{-0.0667x}$ ($R^2=0.93$)	Not applied	x = days after first runoff
Hexazinone (µg/L)*	$y=45.789e^{-0.0645x}$ ($R^2=0.96$)	Not applied	x = days after first runoff

(Note: Refer to section 2.5.1.3 for nutrient parameter acronyms. * - equations based on first 83 days after initial runoff. A small increase in herbicide concentrations was observed after this, and therefore a new equation was derived. Regression plots are shown in Section 7.1)

2.5 Laboratory methodologies

2.5.1 Water analyses

Analysis of TSS, turbidity, electrical conductivity, and nutrients (filtered and unfiltered) are conducted by the Australian Centre for Tropical Freshwater Research (ACTFR) laboratory, James Cook University, Townsville. Herbicide samples are analysed by the Queensland Health Forensic and Scientific Services (QHFSS) laboratory, Brisbane and the ACS Laboratories (Australia), Kensington. All laboratories hold appropriate National Association of Testing Authorities (NATA) accreditation.

2.5.1.1 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).

2.5.1.2 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).

2.5.1.3 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.

2.5.1.4 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).

Paraquat and imazapic analysis is 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.

2.5.2 Soil and canetrash analysis

Analysis of samples for atrazine, diuron and hexazinone are conducted at QHFSS. Samples are fully 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 analysis is also 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 was

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 30 runoff events were recorded at each of the paddock scale monitoring sites, with the first runoff event occurring on 20th September 2010. A runoff event was defined as rainfall that caused enough runoff for samples to be collected (>3 mm of runoff). The final runoff event at the Victoria Plains site occurred on 1st April 2011, and 18th April at the Marian site. Due to the magnitude of the wet season, the automatic samplers were turned off and on throughout the season to limit the number of events being sampled; hence not all runoff events have associated water quality data.

Irrigation was not applied to either site during the reporting period.

3.1.2 Multi-block and Multi-farm scale

More than 20 runoff events were measured at the Multi-block and Multi-farm scale sites. Similar to the Marian paddock site, the first runoff event was recorded on 20th September 2010, with the final event on 18th April 2011. It was difficult to define individual runoff events at these sites, as flows were still being recorded when the next rainfall event occurred. The Multi-farm site flowed continuously from 9th November 2010 to 16th April 2011.

3.2 Victoria Plains site

3.2.1 Bulk density

Bulk density results (taken 39 days after harvest) show very little difference between the row spacing treatments (Figure 4).

3.2.2 Soil nutrients

Soil nitrate-N concentrations after harvest and prior to nutrient applications (6th September 2010) were <2 mg/kg in both treatments (row and interspace) at all depths, except for the surface layer (0-0.15 m) of the row in Treatment 1 (3 mg/kg). Similar results were found for ammonium-N: <2 mg/kg, except for the row in Treatment 1 (5 mg/kg at 0-0.15 m, and 3 mg/kg at 0.6-1.0 m).

On 25th October 2010 (38 days after nutrient application; 286 mm of rain), soil nitrate-N concentrations were <1 mg/kg at all depths in the interspace of both treatments. In the row area, Treatment 2 had higher concentrations (average 24 mg/kg at 0-0.3 m) than Treatment 1 (average 12 mg/kg at 0-0.3 m) despite a lower rate of nitrogen applied (136 kg N/ha and 200 kg N/ha applied, respectively).

Soil phosphorus concentrations were similar between treatments, with an increase in Treatment 2 at 0.3-0.6 m depth (row and interspace combined) (Figure 5). When the site was re-sampled 38 days after the application of 25-26 kg P/ha, concentrations at all depths had increased.

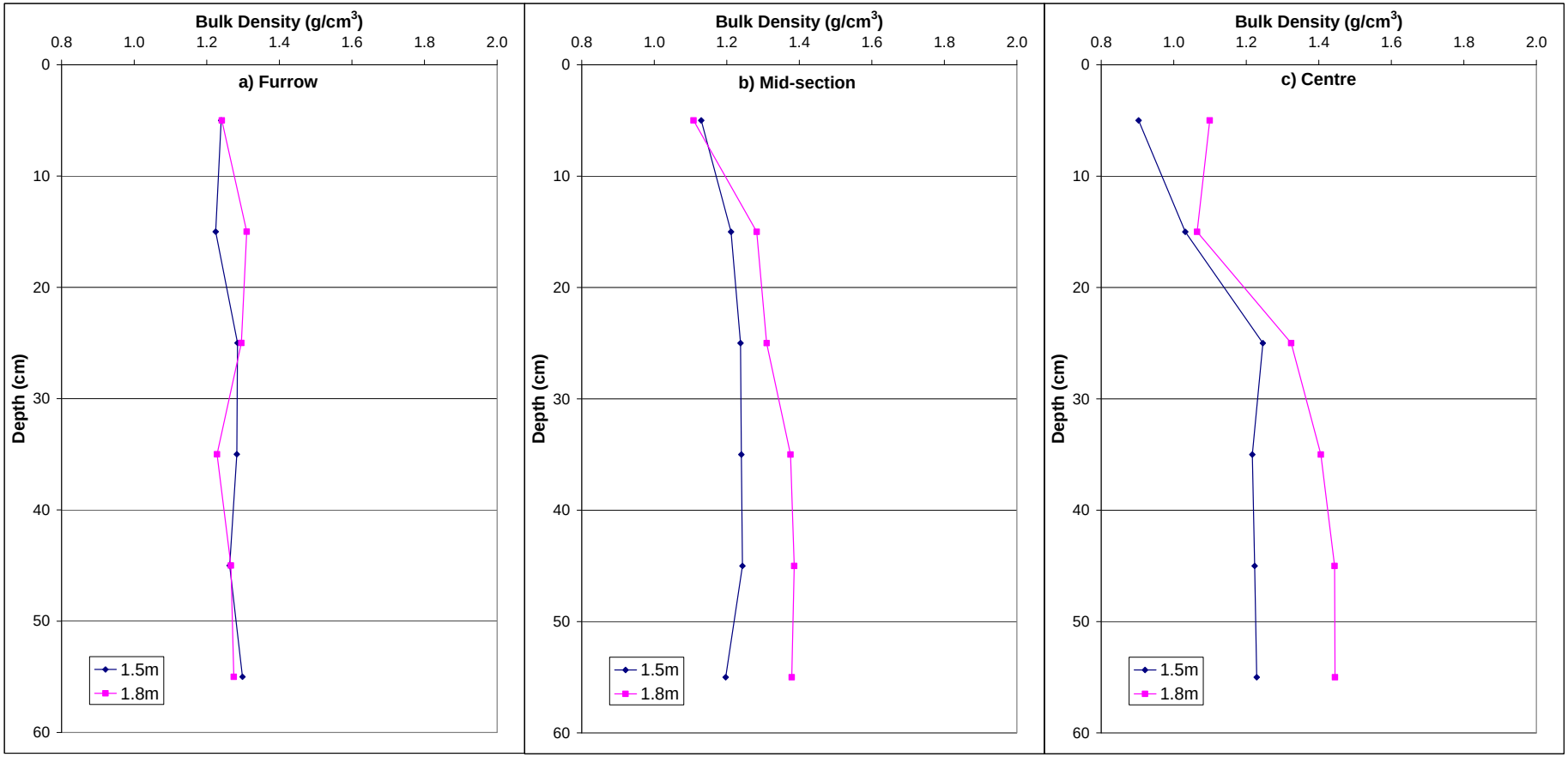

Figure 4 Bulk density of a) furrow, b) mid-section and c) centre of beds for 1.5 m (Treatment 1) and 1.8 m (Treatment 2) row spacings, Victoria Plains site

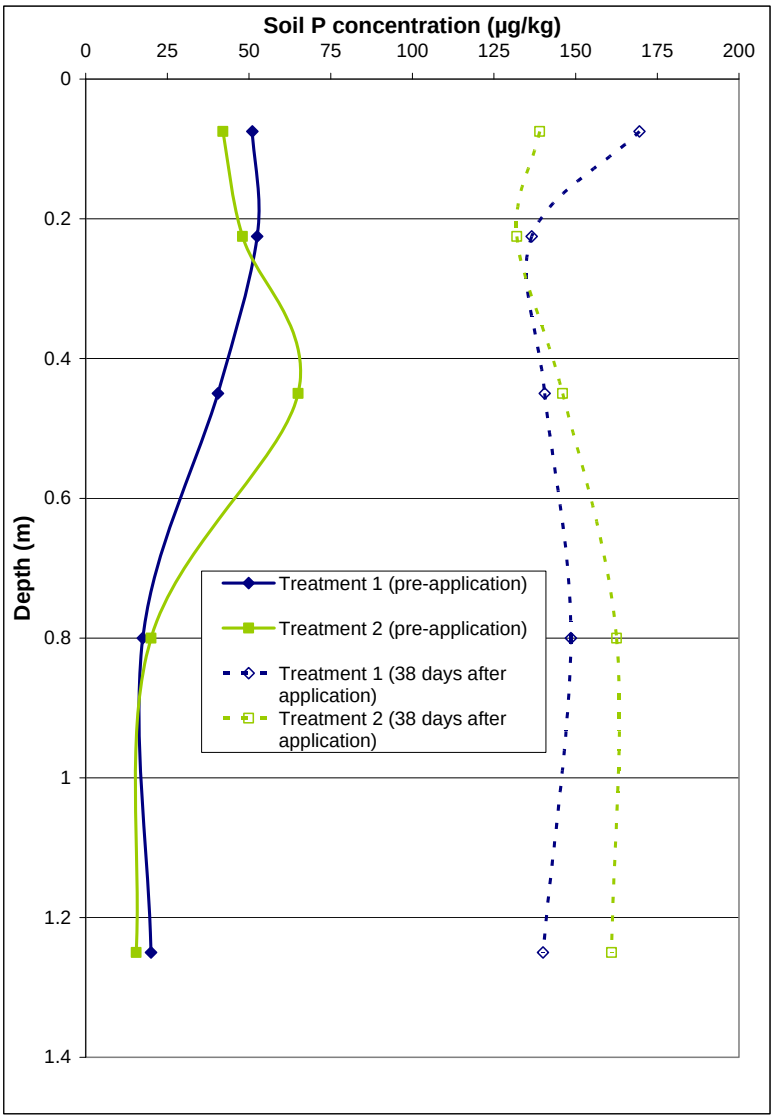

Figure 5 Soil phosphorus concentrations in the soil profile prior to nutrient applications, and 38 days after application (row and interspace combined), Victoria Plains site

3.2.3 Soil and canetrash herbicides

Surface soil (0-2.5 cm) and canetrash samples were collected for herbicide analysis prior to herbicide application, and on eight occasions (0.3-100 days) after application. During this sampling period, 1090 mm of rainfall was recorded.

Concentrations of diuron and hexazinone were detected (0.17 and 0.019 mg/kg, respectively) in the surface soil prior to application this season (239 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 6), as the herbicide was applied to the canetrash blanket. During this 10 day period, 143 mm of rain was recorded (first rain was recorded seven days after application). Using the field dissipation data of 10-100 days after application, the calculated half-lives of diuron, hexazinone and imazapic in the soil were 199, 53 and 118 days, respectively.

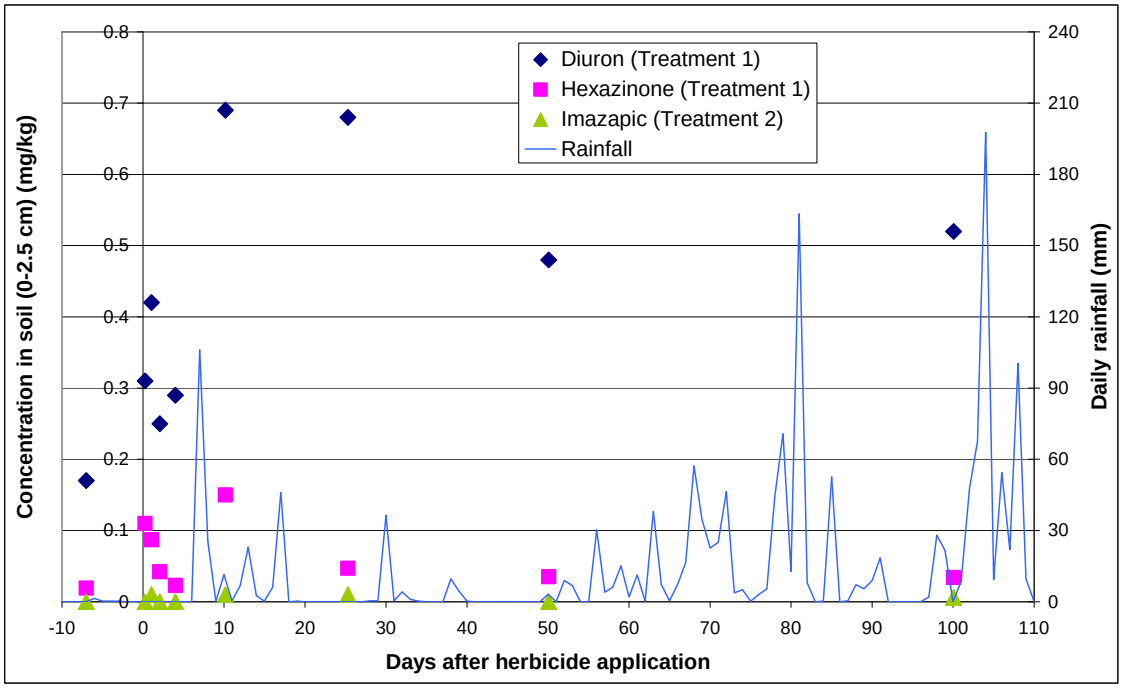

Figure 6 Field dissipation of diuron, hexazinone and imazapic in the surface soil (0-2.5 cm), Victoria Plains site

Similar to the surface soil, diuron and hexazinone were detected (0.096 and 0.019 mg/kg, respectively) on the canetrash blanket prior to application this season, whereas imazapic was not detected (<0.01 mg/kg). Peak concentrations of all herbicides were detected at the first sampling after application (Figure 7), and rapidly declined within 10 days of application. Imazapic was not detected on the canetrash blanket 100 days after application. Using this field dissipation data, the calculated half-lives for diuron, hexazinone and imazapic on the canetrash blanket were 11, 9 and 13 days, respectively.

3.2.4 Soil moisture

Total profile soil water extraction by the crop was limited to a short period of the year prior to the first runoff event, and after the final runoff event (Figure 8), and for short durations in between. Interpreting the soil water extraction patterns is complicated by the presence of a shallow water table, which was evident in Treatment 2 (within 1 m of the soil surface) from November to May (see Section 7.2 for plots of soil moisture at individual depth sensors). This may explain the difference between the treatments during this period of time.

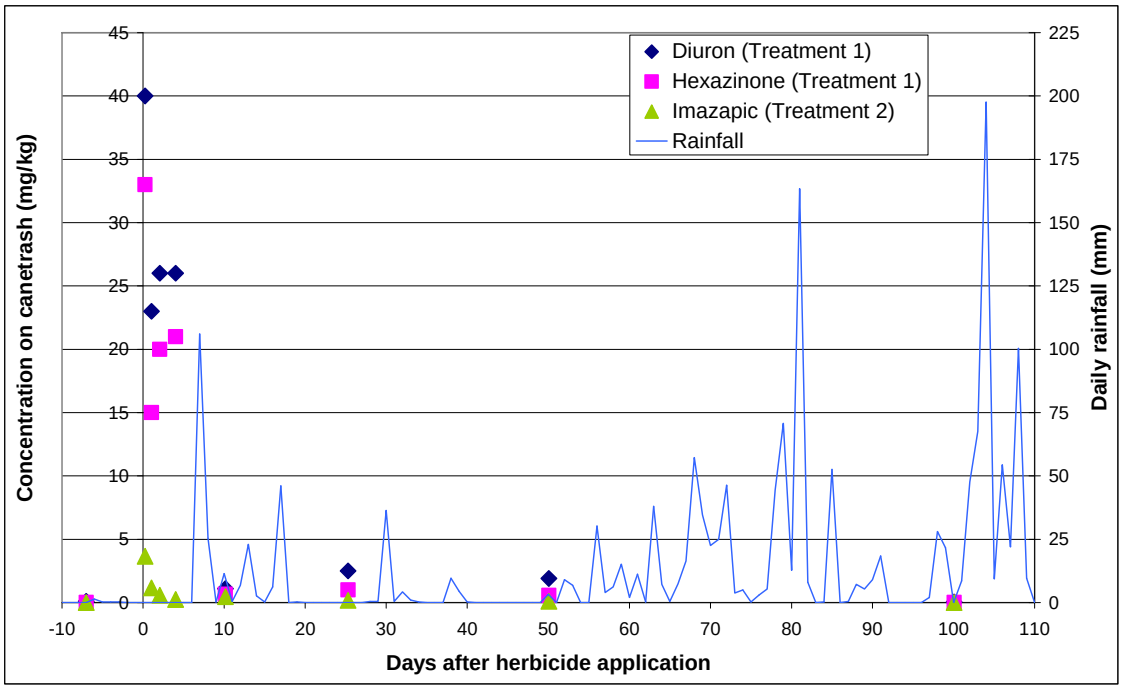

Figure 7 Field dissipation of diuron, hexazinone and imazapic on the canetrash blanket, Victoria Plains site

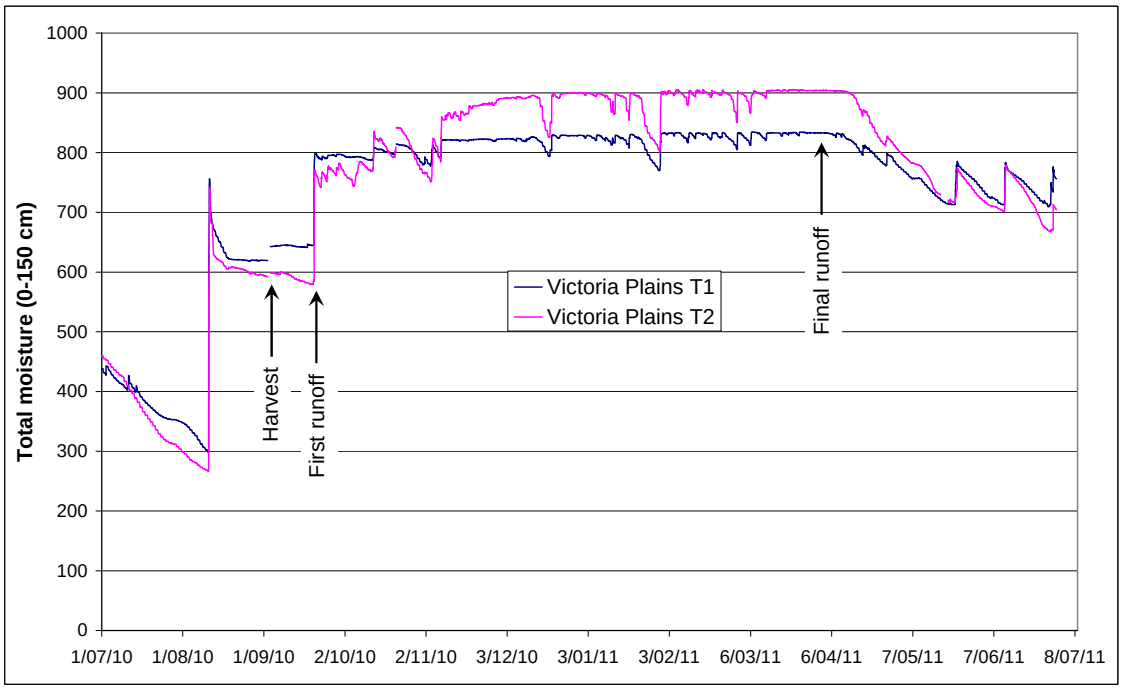

Figure 8 Total moisture in the soil profile (0-150 cm), Victoria Plains site

3.2.5 Rainfall and runoff

A total of 3300 mm of rainfall was recorded at the Victoria Plains site between 1st September 2010 and 30th April 2011, well above the estimated long-term average of 1468 mm (Te Kowai Research Station, records since 1889). The highest daily totals recorded were 197.6 mm on 26th December 2010 and 197.2 mm on 31st March 2011.

Total wet season runoff (Table 10) from Treatment 2 (1.8 m row spacing) averaged 13.6% less than Treatment 1 (1.5 m row spacing) (1751 mm and 2025 mm, respectively). Runoff from Treatment 2 was delayed by ~11 minutes on average compared with Treatment 1, and the peak runoff rate was 33% lower.

Table 10 Event rainfall and runoff during the 2010/11 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	20/09/10	131.4	96	73.7	19.1	70.5	19.2
2	25/09/10	32.4	48	12.9	4.1	9.8	5.7
3	29/09/10	45.8	120	32.7	10.8	28.5	15.3
4	12/10/10	35.2	96	5.4	2.1	4.2	2.2
5	07/11/10	30.0	108	11.7	5.6	10.0	6.5
6	10/11/10	21.4	36	7.5	2.8	3.2	2.5
7	15/11/10	48.6	48	32.4	14.9	32.1	17.6
8	18/11/10	23.0	36	14.4	2.7	7.8	2.1
9	19/11/10	72.8	60	65.5	9.8	68.1	11.2
10	21/11/10	38.0	72	29.4	10.8	26.6	9.8
11	22/11/10	30.2	36	13.5	3.9	12.6	7.2
12*	23/11/10	362.4	132	320	48.0	244	24.0
13	06/12/10	52.6	120	41.5	29.1	17.1	9.7
14	12/12/10	23.8	60	16.5	14.2	9.1	8.3
15	19/12/10	23.8	108	3.6	5.7	1.9	2.5
16	20/12/10	21.6	96	18.8	25.3	19.0	14.1
17	23/12/10	53.2	84	26.7	13.9	31.9	12.4
18*	24/12/10	495.2	144	462	61.2	393	30.2
19	06/01/11	20.8	96	13.9	24.5	8.3	7.5
20	06/01/11	38.4	144	36.6	46.2	34.7	29.8
21	13/01/11	37.0	144	24.8	35.8	22.2	21.6
22	30/01/11	144.2	72	68.2	30.3	58.1	28.0
23	02/02/11	49.0	24**	24.6	27.6	22.0	18.7
24	05/02/11	18.0**	12**	20.5	21.8	12.8	9.3
25	10/02/11	70.4	168	44.9	39.5	33.8	24.0
26	13/02/11	43.6	96	14.1	17.0	9.4	8.3
27	15/02/11	24.8	96	17.4	21.7	15.2	16.8
28	23/02/11	28.4	60	18.1	6.6	13.2	5.4
29	01/03/11	45.6	72	21.8	23.6	15.3	17.1
30*	12/03/11	296.8	180	197	71.1	161	34.4
31	20/03/11	22	120	7.4	5.4	8.8	4.1
32	24/03/11	160.8	33	94.7	33.2	102	27.6
33*	28/03/11	362.0	108	212	34.9	224	25.3
34	01/04/11	50.0	60	20.5	8.0	20.6	8.5
Total				**2025**		**1751**	

(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)

3.2.6 Runoff water quality

3.2.6.1 Total suspended solids, turbidity and electrical conductivity

Concentrations of TSS across the samples collected showed a general increase through time (Figure 9). There was also a trend of increasing TSS concentration with increasing maximum rainfall intensity (and therefore peak runoff rate) (Section 7.1.1). Concentrations ranged from 30-230 mg/L for Treatment 1 and 48-250 mg/L for Treatment 2. The total sediment load for the wet season was similar for each

treatment (~ 2750 kg/ha; Table 11). The flow-weighted TSS concentration for Treatment 1 (135 mg/L) was lower than Treatment 2 (158 mg/L).

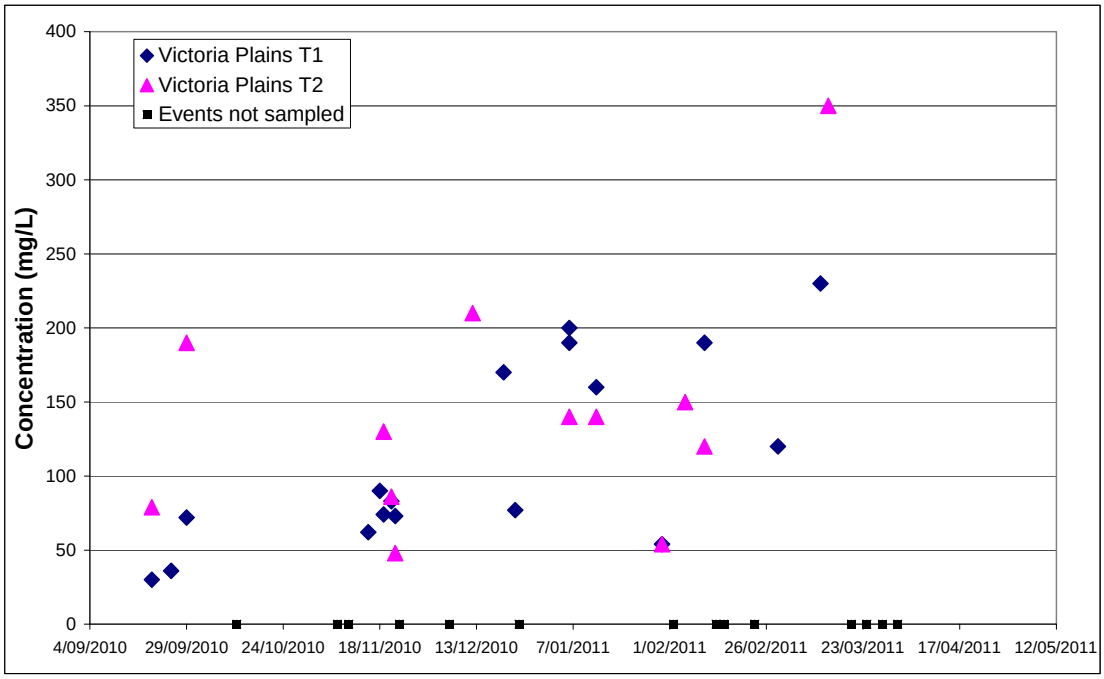

Figure 9 Concentrations of total suspended solids measured in runoff, Victoria Plains site

Runoff turbidity also showed a general increase as the wet season progressed. Treatment 1 had a greater range of turbidity (24-760 NTU) than Treatment 2 (90-360 NTU). When samples from each treatment were combined, there was a good relationship (R^2=0.78) between TSS concentration and turbidity (Figure 10).

Electrical conductivity (EC) values were similar between the treatments (31-426 µS/cm), and declined through the season. The initial runoff events (late September) had the highest EC values (>100 µS/cm), and remained below 75 µS/cm for the remainder of the wet season.

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

Event	Start	TSS (kg/ha		TKN (kg/ha)		Urea-N (kg/ha)		TKP (kg/ha)		FRP (kg/ha)	
	Date	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
1	20/09/10	22	56	17.0	13.5	14.2	11.2	0.95	1.11	0.62	0.87
2	25/09/10	5	*8*	0.28	0.38	0.08	0.03	0.04	0.03	0.02	0.01
3	29/09/10	24	54	0.59	0.64	0.27	0.09	0.11	0.12	0.06	0.06
4	12/10/10	*6*	*6*	0.15	*0.07*	0.02	*0.01*	0.02	*0.01*	0.01	*0.00*
5	07/11/10	*15*	*14*	0.34	*0.12*	0.00	*0.01*	0.03	*0.02*	0.02	*0.00*
6	10/11/10	*4*	*2*	0.13	*0.04*	0.01	*0.00*	0.02	*0.01*	0.01	*0.00*
7	15/11/10	20	*27*	0.33	*0.35*	0.04	*0.03*	0.08	*0.07*	0.03	*0.01*
8	18/11/10	13	*6*	0.22	*0.08*	0.02	*0.01*	0.03	*0.02*	0.01	*0.00*
9	19/11/10	48	89	0.73	0.87	0.11	0.08	0.09	0.12	0.01	0.03
10	21/11/10	24	23	0.28	0.24	0.03	0.03	0.05	0.04	0.01	0.01
11	22/11/10	10	6	0.07	0.08	0.02	0.03	0.04	0.02	0.00	0.00
12	23/11/10	*496*	*411*	*3.52*	*2.51*	*0.28*	*0.20*	*0.66*	*0.50*	*0.10*	*0.07*
13	06/12/10	*59*	*27*	*0.42*	0.08	*0.03*	0.02	*0.08*	0.03	*0.01*	0.00
14	12/12/10	*13*	19	0.17	0.06	0.02	0.00	0.03	0.01	0.00	0.00
15	19/12/10	*5*	*3*	0.07	*0.02*	0.00	*0.00*	0.01	0.00	0.00	*0.00*
16	20/12/10	32	*25*	0.15	0.20	0.03	0.01	0.04	0.04	0.00	0.00
17	23/12/10	21	*38*	0.19	0.64	0.06	0.06	0.10	0.04	0.00	0.00
18	24/12/10	*773*	*708*	*4.26*	*3.38*	*0.29*	*0.24*	*0.85*	*0.72*	*0.11*	*0.08*
19	06/01/11	28	*11*	0.16	*0.07*	0.02	*0.00*	0.02	*0.01*	0.00	*0.00*
20	06/01/11	70	49	0.68	0.28	0.07	0.03	0.09	0.06	0.01	0.01
21	13/01/11	40	31	0.15	0.30	0.02	0.03	0.03	0.04	0.01	0.02
22	30/01/11	37	31	0.57	0.43	0.02	0.18	0.06	0.04	0.02	0.03
23	02/02/11	*10*	*13*	*0.19*	*0.16*	*0.01*	*0.01*	*0.04*	*0.04*	*0.00*	*0.00*
24	05/02/11	*6*	19	*0.16*	0.13	*0.01*	0.00	*0.03*	0.02	*0.00*	0.01
25	10/02/11	*87*	41	*0.12*	0.08	*0.02*	0.00	*0.05*	0.05	*0.01*	0.01
26	13/02/11	*16*	*12*	0.05	0.06	0.00	0.00	0.02	0.01	0.00	0.00
27	15/02/11	*20*	*20*	0.17	0.17	0.00	0.00	0.03	0.02	0.00	0.00
28	23/02/11	*14*	*13*	*0.13*	*0.09*	*0.01*	*0.01*	*0.03*	*0.02*	*0.00*	*0.00*
29	01/03/11	26	*16*	0.13	0.09	0.00	0.00	0.02	0.01	0.01	0.00
30	12/03/11	454	563	2.63	1.65	0.05	0.06	0.47	0.25	0.01	0.05
31	20/03/11	*10*	*14*	*0.05*	*0.06*	*0.00*	*0.00*	*0.01*	*0.01*	*0.00*	*0.00*
32	24/03/11	*47*	*70*	*0.65*	*0.65*	*0.03*	*0.04*	*0.14*	*0.15*	*0.02*	*0.01*
33	28/03/11	*274*	*322*	*1.44*	*1.42*	*0.07*	*0.08*	*0.32*	*0.34*	*0.03*	*0.03*
34	01/04/11	*16*	*20*	*0.14*	*0.13*	*0.01*	*0.01*	*0.03*	*0.03*	*0.00*	*0.00*
Total		**2743**	**2766**	**36.3**	**29.0**	**15.9**	**12.5**	**4.63**	**4.05**	**1.16**	**1.34**

(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)

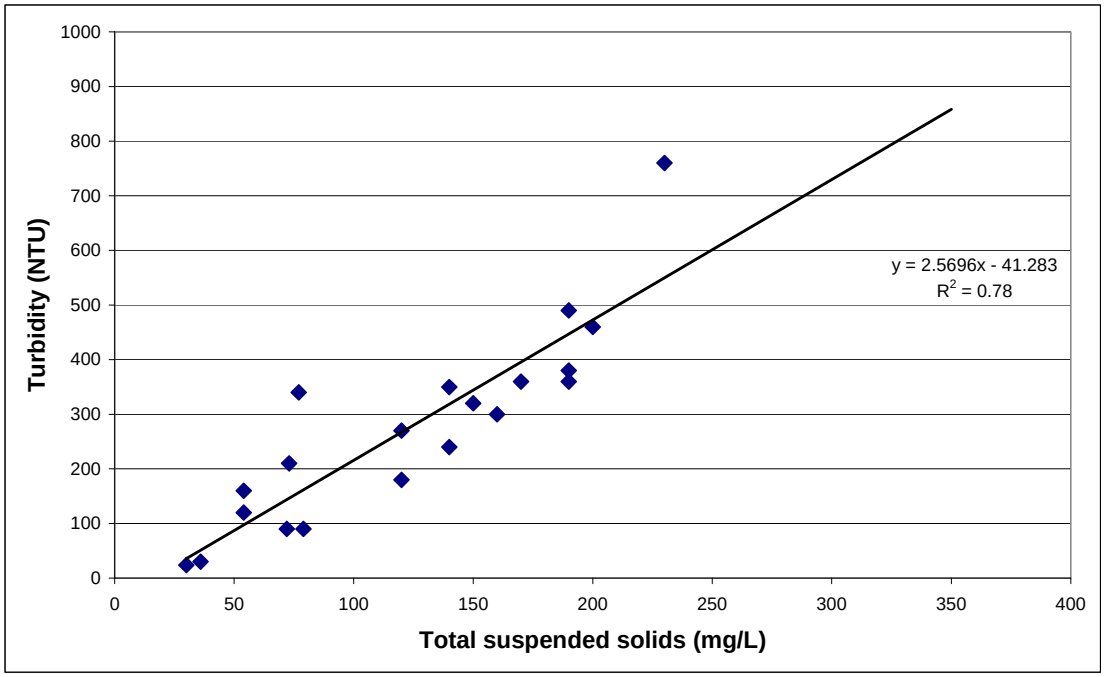

Figure 10 Relationship between total suspended solids and turbidity, Victoria Plains site (both treatments combined)

3.2.6.2 Nitrogen

Nitrogen concentrations in the first runoff event (20th September 2010, 3 days after application) were dominated by urea-N (Figure 11). Initial concentrations were highest in Treatment 1 (19,294 µg N/L), then rapidly declined to 647 µg N/L in the following event and averaged 167 µg N/L for the remainder of the season. Treatment 2 followed a similar trend to Treatment 1, but concentrations were lower due to the lower application rate of nitrogen.

In contrast to urea, NO_x-N concentrations were low (305-756 µg N/L) in the initial event (Figure 11), and increased to a maximum of 11,755 µg N/L (Treatment 2, no sample collected from Treatment 1) in mid-October (26 days after application). Concentrations subsequently declined to be <700 µg N/L by mid-November.

Ammonium-N concentrations were highest (1921 µg N/L) in the initial events (Figure 11) before declining to low concentrations (<600 µg N/L) from late September onwards.

The total loss of urea-N was estimated to be 15.9 kg/ha and 12.5 kg/ha from Treatment 1 and 2, respectively (Table 11). This represents ~8-9% of the applied nitrogen for each treatment and ~18-21% of the total nitrogen load (TKN) in runoff (Table 11). Ammonium-N and NO_x-N loads were not calculated due to missing samples from critical runoff events (particularly Treatment 2).

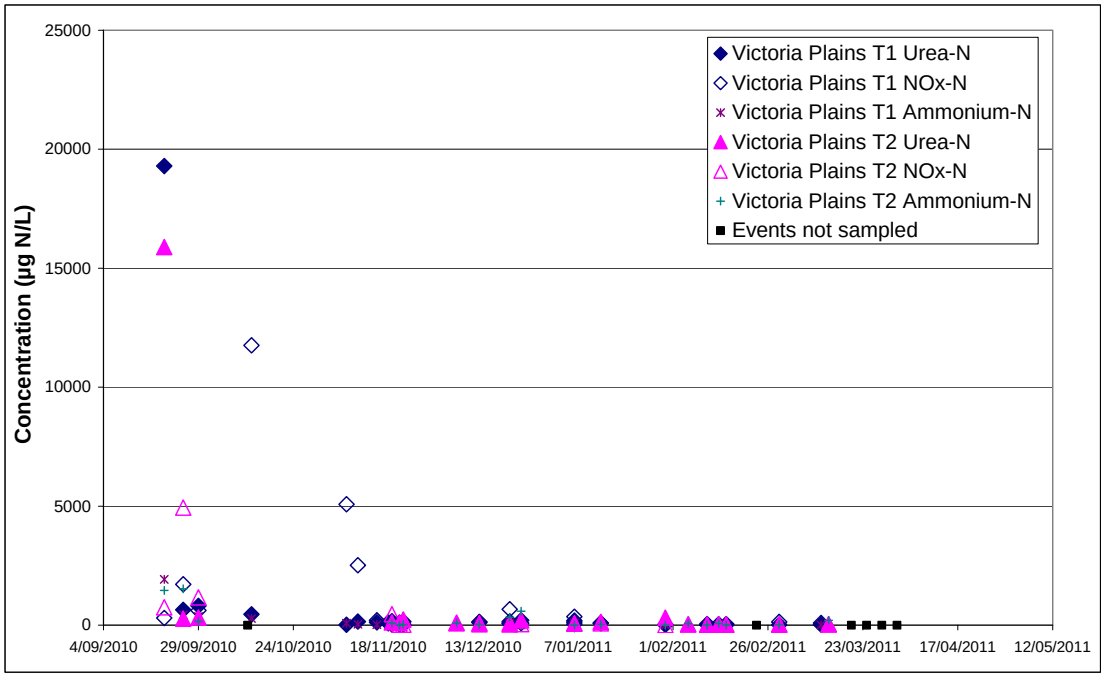

Figure 11 Urea-N, NO_x-N, and ammonium-N concentrations in runoff, Victoria Plains site

3.2.6.3 Phosphorus

Phosphorus was applied to both treatments at similar rates (25-26 kg P/ha), resulting in similar concentrations in runoff (Figure 12). As with most other parameters, FRP concentrations were highest (>800 µg P/L) in the first runoff event after application, then decreased rapidly (<100 µg P/L) by mid-October. The total FRP loss in runoff for the wet season was similar (Table 11) between treatments (~5% of the applied P). However, the flow-weighted mean concentration was higher in Treatment 2 (77 µg P/L) than Treatment 1 (57 µg P/L), due to less runoff from Treatment 2. These concentrations are much higher than 2009/10, presumably due to the shorter period of time between application and runoff this season. Across all of the samples collected, FRP comprised ~61% of the TFP signature. Of those samples with both FRP and TP data, FRP was ~20% of the TFP signature (TP analysis commenced 6th December 2010).

3.2.6.4 Herbicides

Diuron and hexazinone were detected in relatively high concentrations in runoff from Treatment 1 in the first runoff event (Figure 13), which was seven days after application. There was no rainfall during that period (prior to the event that caused runoff). Concentrations rapidly declined, but there was an increase in the diuron concentration detected on 20th December 2010. By mid-October (within one month of herbicide application), ~92% of the total loss of diuron and hexazinone in runoff had occurred for the wet season (Table 12), despite only 6% of runoff having been experienced.

Imazapic was not analysed in runoff samples from Treatment 2 until 7th December 2010, and was not detected (<1 µg/L) in any samples.

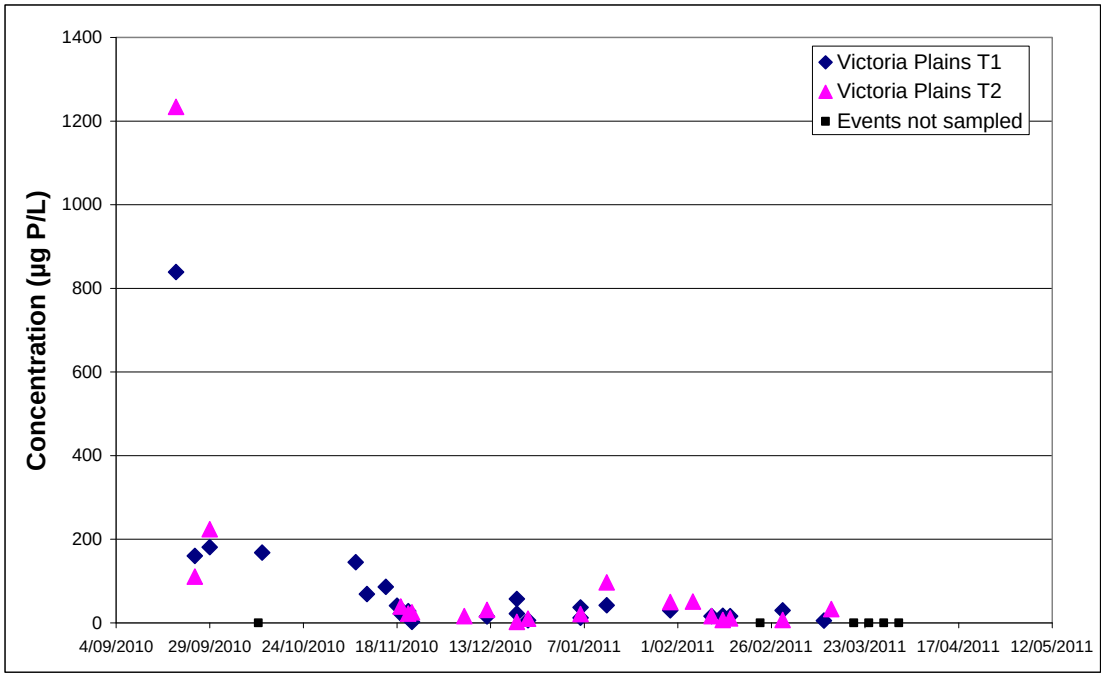

Figure 12 Filterable reactive phosphorus concentrations in runoff, Victoria Plains site

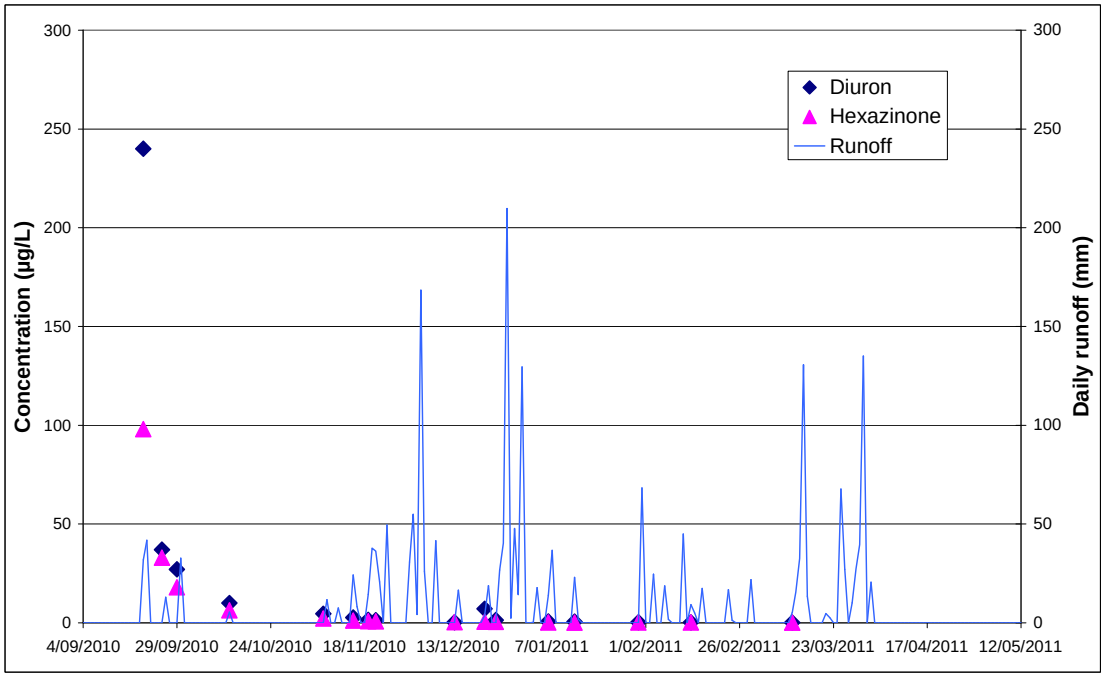

Figure 13 Diuron and hexazinone concentrations in runoff from Treatment 1, Victoria Plains site

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	20/09/10	0.15	176.82	72.20
2	25/09/10	0.02	4.77	4.26
3	29/09/10	0.04	8.84	5.89
4	12/10/10	0.01	0.54	0.34
5	07/11/10	0.01	0.54	0.26
6	10/11/10	*0.00*	*0.20*	*0.13*
7	15/11/10	0.02	0.87	0.36
8	18/11/10	*0.01*	*0.23*	*0.15*
9	19/11/10	0.03	0.98	0.54
10	21/11/10	0.01	0.38	0.20
11	22/11/10	*0.01*	*0.17*	*0.11*
12	23/11/10	*0.17*	*3.93*	*2.27*
13	06/12/10	*0.02*	*0.20*	*0.13*
14	12/12/10	0.01	0.05	0.06
15	19/12/10	*0.16*	*0.10*	*0.01*
16	20/12/10	2.26	1.33	0.11
17	23/12/10	0.53	0.37	0.12
18	24/12/10	*11.06*	*8.22*	*1.59*
19	06/01/11	*0.15*	*0.15*	*0.04*
20	06/01/11	0.28	0.24	0.07
21	13/01/11	0.08	0.13	0.02
22	30/01/11	0.08	*0.16*	0.15
23	02/02/11	*0.04*	*0.08*	*0.04*
24	05/02/11	*0.03*	*0.06*	*0.03*
25	10/02/11	*0.05*	*0.11*	*0.06*
26	13/02/11	0.01	0.03	0.02
27	15/02/11	*0.01*	*0.03*	*0.02*
28	23/02/11	*0.01*	*0.03*	*0.02*
29	01/03/11	*0.01*	*0.02*	*0.02*
30	12/03/11	*0.03*	*0.14*	*0.13*
31	20/03/11	*0.00*	*0.00*	*0.00*
32	24/03/11	*0.01*	*0.04*	*0.05*
33	28/03/11	*0.01*	*0.08*	*0.10*
34	01/04/11	*0.00*	*0.01*	*0.01*
Total		**15.3**	**210**	**89.5**
Product transported in runoff (% of applied)		**not applied**	**11.8**	**17.8**

(Note – figures in *italics* indicate loads estimated from regression curves (Table 9) where samples were not collected)

Although atrazine was not applied as part of our trial, it was detected at 0.20-0.28 µg/L in the first runoff event from both treatments. Analysis continued in Treatment 1 only, and concentrations declined until mid-December. On 20th December 2010, concentrations increased to 12 µg/L (smaller increase also detected in diuron), and declined through the remainder of the season.

Other herbicides detected were bromacil (0.02 and 0.01 µg/L) in the first two runoff events of Treatment 1. Simazine was only detected in two runoff events in mid-December (0.12 and 0.01 µg/L), and are the same events where atrazine was detected in higher concentrations.

Using the herbicide concentration decline in runoff over time and subsequent regression equations in Table 9, the runoff-available half-life was 11 days for both diuron and hexazinone (Treatment 1).

3.2.7 Drainage water quality

Seven water samples were collected from soil solution samplers (0.9 m depth) between 23rd September 2010 and 4th February 2011 (6-180 days after nutrient application, and 10-184 days after herbicide application). To minimize analysis costs, only those herbicides applied to the treatments were analysed for (LCMS herbicides for Treatment 1, and imazapic for Treatment 2). Analysis for imazapic only commenced on 15th November 2010.

3.2.7.1 Nitrogen

Urea-N analyses were not undertaken on the first two samples, so a full interpretation of results is not possible. In these samples, NO_x-N and ammonium-N concentrations were much higher in Treatment 1 than Treatment 2 (Figure 14). This may reflect the higher nitrogen application to Treatment 1. From November to February, concentrations were similar between treatments, with concentrations of urea-N being slightly higher than NO_x-N and ammonium-N. In the final sampling (mid-March), urea-N concentrations had reduced to levels similar to NO_x-N and ammonium-N.

Using the NO_x-N concentration decline in drainage over time (Figure 14), the half-life of NO_x-N (Treatment 1) was calculated to be 36 days.

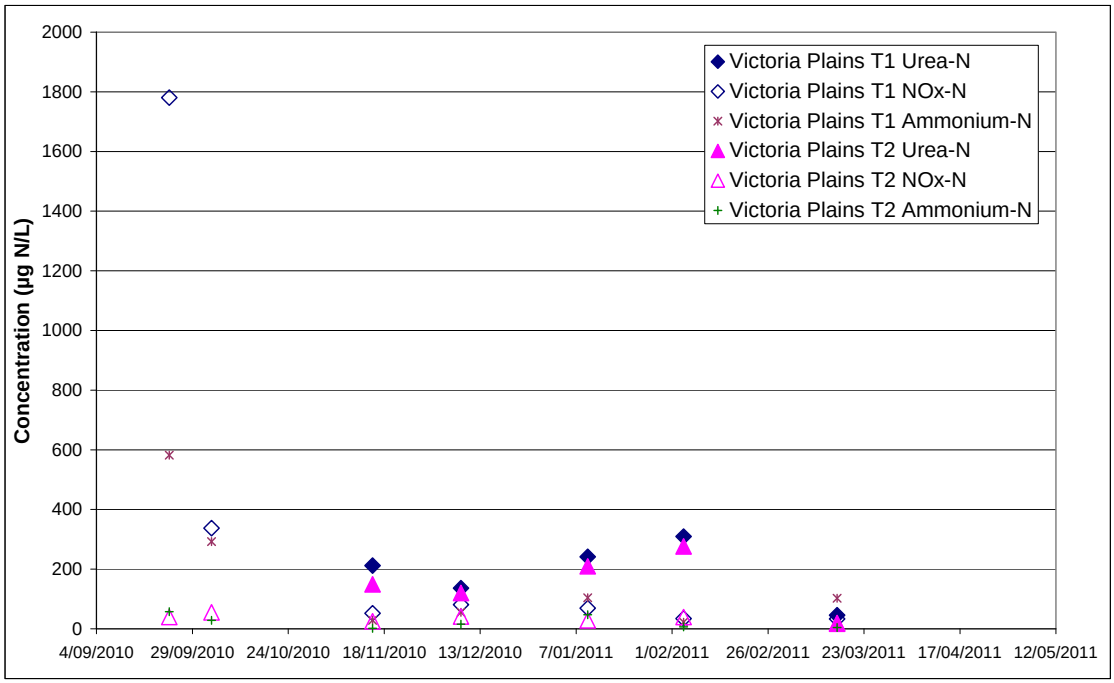

Figure 14 Urea-N, NO_x-N and ammonium-N concentrations in drainage soil solution, Victoria Plains site

3.2.7.2 Herbicides

No drainage samples were analysed for herbicides prior to herbicide application. Peak concentrations of diuron and hexazinone were recorded in the first sample (10 days after application) and declined through time (Figure 15). These concentrations are significantly higher than those collected in the 2009/10 season (<0.07 µg/L for both diuron and hexazinone), and may be an indication of the increased deep drainage during the current season. There was also a clear relationship between herbicide

concentrations in the surface runoff water and that detected in the drainage soil solution samples (Figure 16).

Although atrazine was not applied as part of our trial, it was detected (0.01 µg/L) in the initial two samples collected and not detected in subsequent samples.

Imazapic was not detected (<1 µg/L) in any samples collected from Treatment 2.

Using the herbicide concentration decline in drainage over time and subsequent regression equations in Figure 15, the half-lives of diuron and hexazinone (Treatment 1) in drainage are 58 and 59 days, respectively (~5.25 times greater than surface runoff).

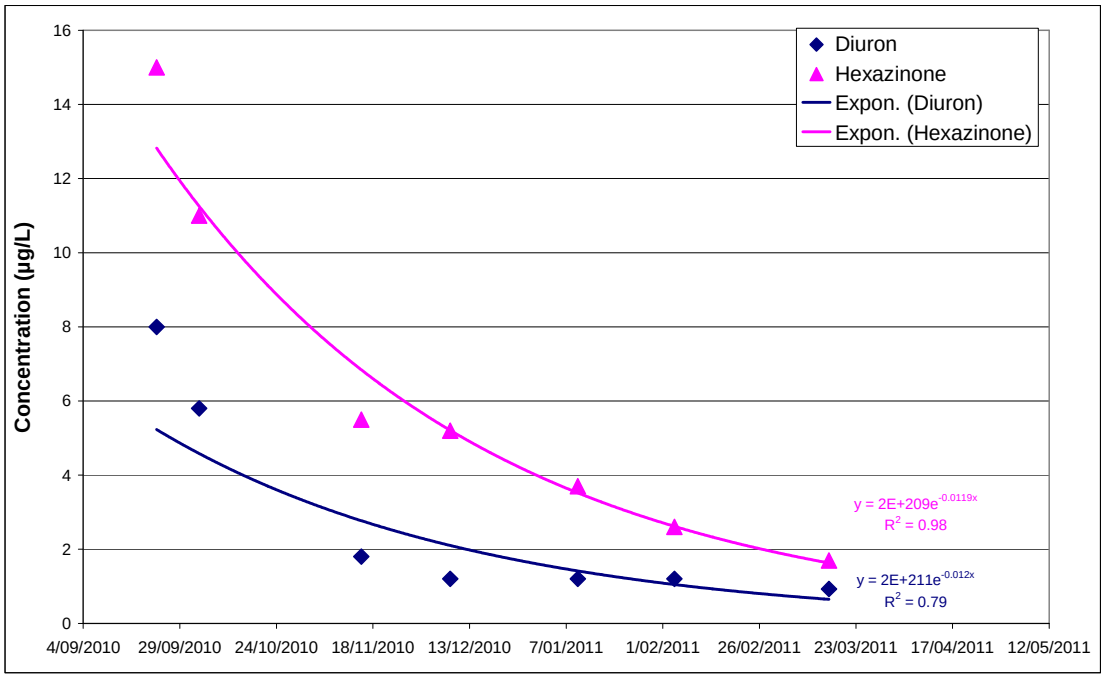

Figure 15 Diuron and hexazinone concentrations in drainage soil solution from Treatment 1, Victoria Plains site

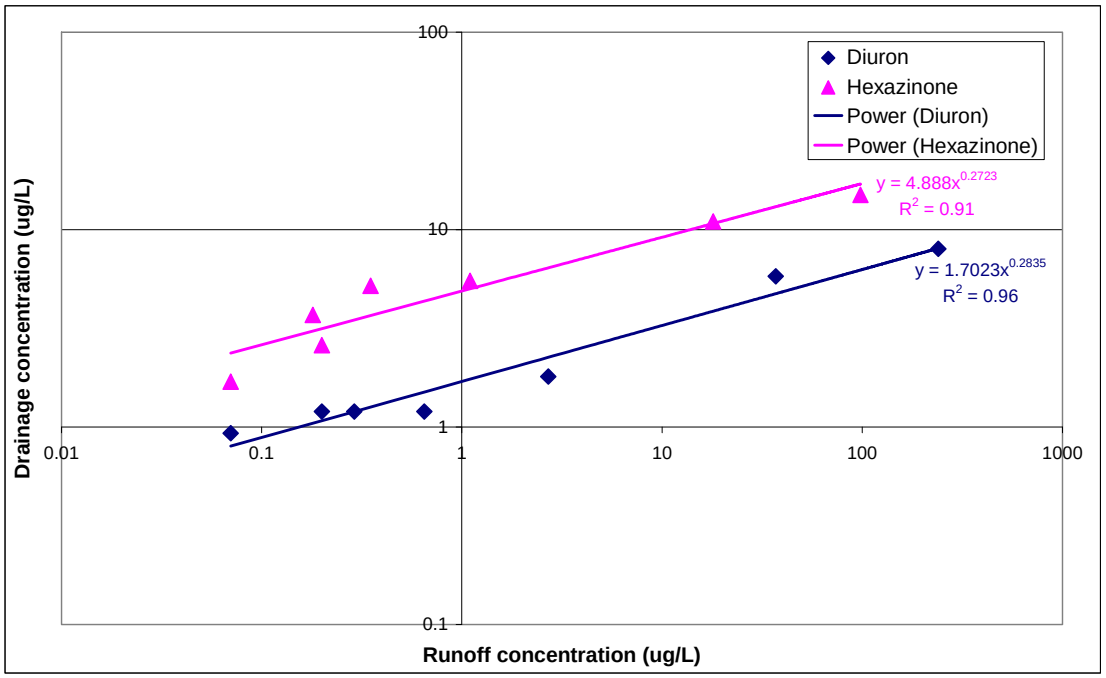

Figure 16 Relationship between surface runoff and drainage soil solution herbicide concentrations from Treatment 1, Victoria Plains site
Note: log scale on both axes

3.2.8 Agronomic

Yield and percent recoverable sugar (PRS) information collected during machine harvest and processing showed a lower cane yield (and PRS) from Treatment 2 (1.8 m row spacing, 136 kg N/ha) than from Treatment 1 (1.5 m row spacing, 200 kg N/ha) (Table 13). The reduced yield from Treatment 2 is likely due to the lower nitrogen application rate and the wet and waterlogged conditions.

Table 13 Machine harvest yield results, Victoria Plains site

	Treatment 1	Treatment 2
Cane (t/ha)	62.1	48.2
PRS	15.5	14.32
Sugar (t/ha)	9.63	6.90

3.3 Marian site

3.3.1 Bulk density

Bulk density results (four days after harvest) were similar within furrows, and consistent down the profile (Figure 17). In the mid-section of the beds, bulk density in the 1.5 m treatment was similar to the furrow, whereas the surface (0-5 cm) of the 1.8 m treatment was lower. This reflects the straddling effects of unmatched wheel traffic and therefore greater area of compaction under 1.5 m row spacing than 1.8 m row spacing.

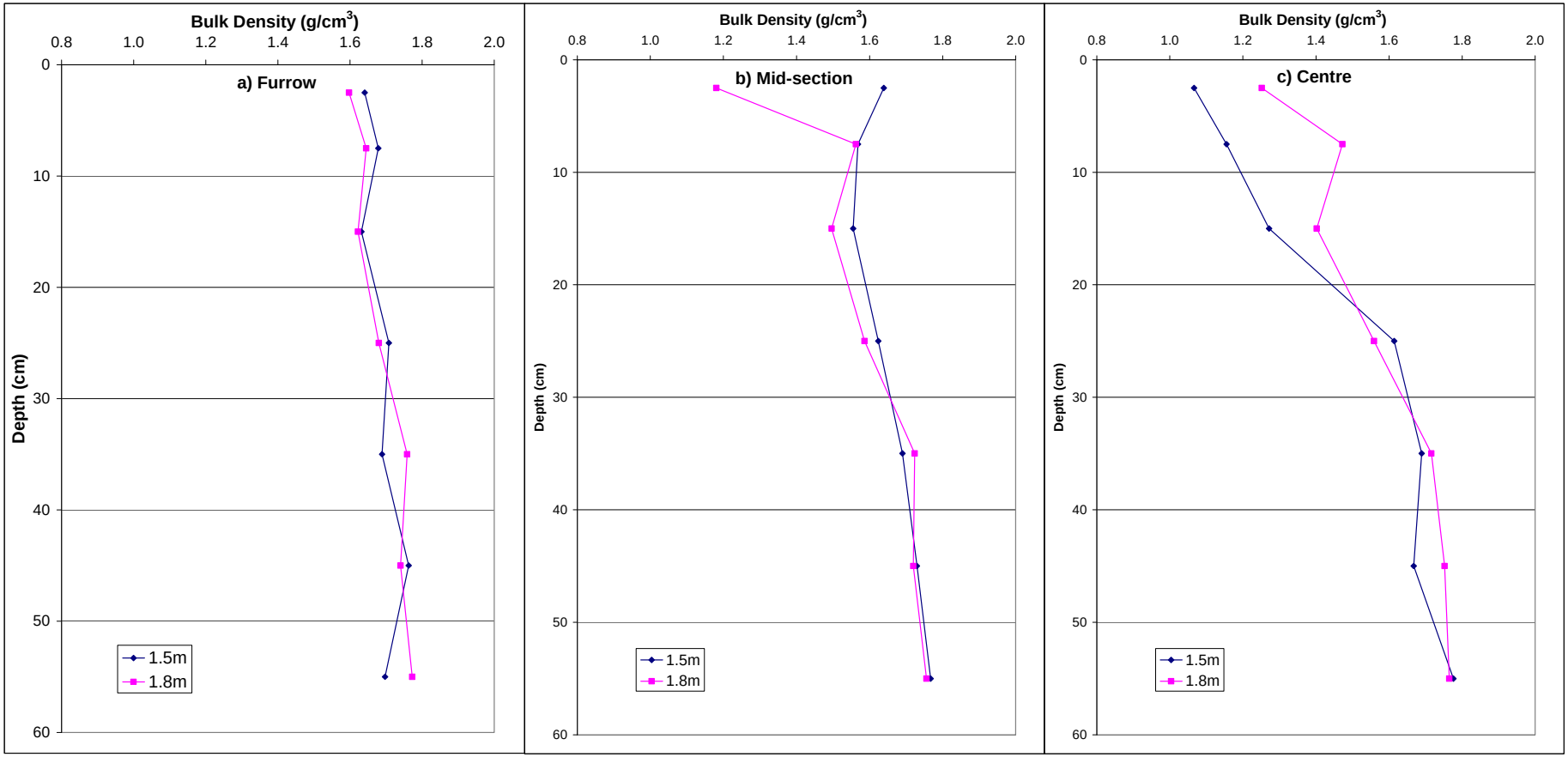

Figure 17 Bulk density of a) furrow, b) mid-section and c) centre of beds for 1.5 m (Treatment 1) and 1.8 m (Treatment 4) row spacings, Marian site

3.3.2 Soil nutrients

Soil nitrate-N concentrations after harvest and prior to nutrient applications (1st November 2010) were <1 mg/kg in all treatments (row and interspace) at all depths, except for the interspace of Treatment 2 (1 mg/kg at 0-0.1 m) and Treatment 3 (3-4 mg/kg at 0-0.2 m). Similar results were found for ammonium-N: <1 mg/kg for most treatments and depths, with an occasional concentration of 2 mg/kg. Seasonal conditions did not allow further soil sampling after nitrogen was applied.

Surface soil phosphorus concentrations after harvest and prior to nutrient applications were variable across the treatments (row and interspace), and ranged from 316-900 µg/kg at the surface (0-0.1 m). Concentrations then generally decreased to be consistent (111-165 µg/kg) below 0.6 m depth across all treatments (Figure 18).

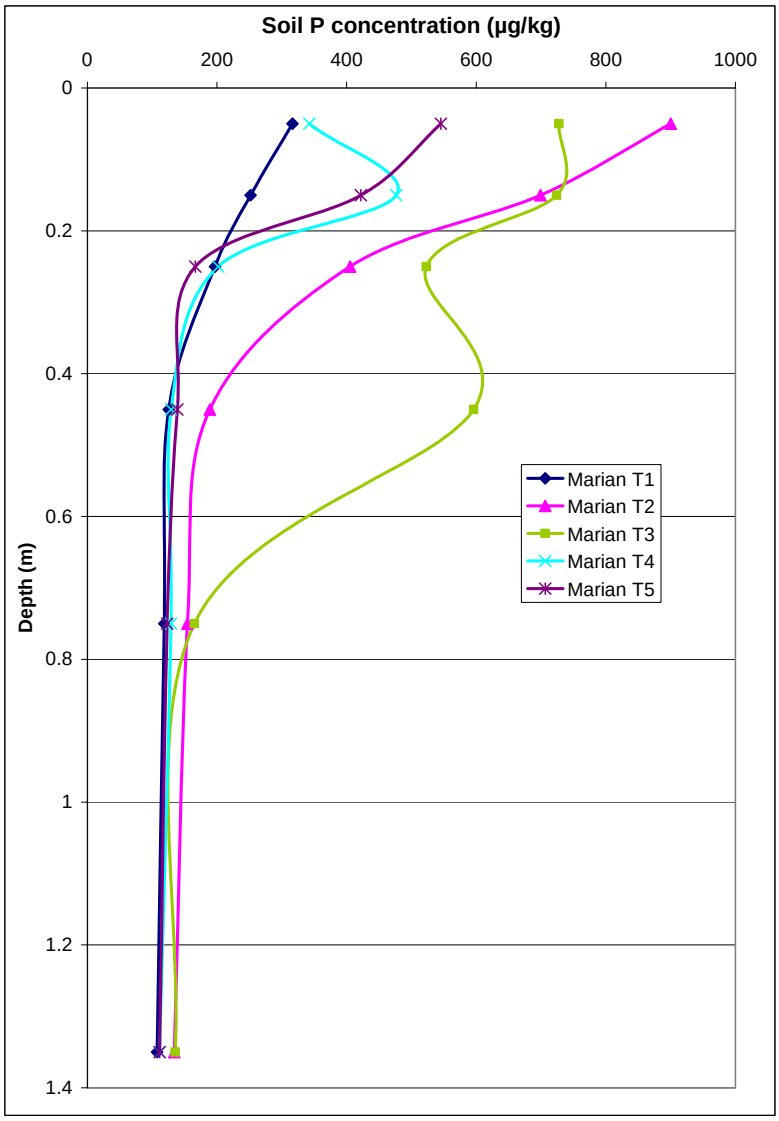

Figure 18 Soil phosphorus concentrations (row and interspace combined) prior to nutrient applications, Marian site

3.3.3 Soil herbicides

Surface soil (0-2.5 cm) samples were collected for herbicide analysis on six occasions (from 1-83 days after application). During this sampling period, 1482 mm of rainfall was recorded.

Herbicide concentrations in the surface soil were variable across the treatments, despite identical application rates being applied. Paraquat and 2,4-D were applied to all treatments, whereas atrazine was only applied to Treatments 1 and 2. The data presented here is a site average. For all herbicides applied, concentrations were highest within two days of application, and then dissipated over time (Figure 19). The calculated half-lives of paraquat, 2,4-D and atrazine in the surface soil were 27, 34 and 116 days respectively.

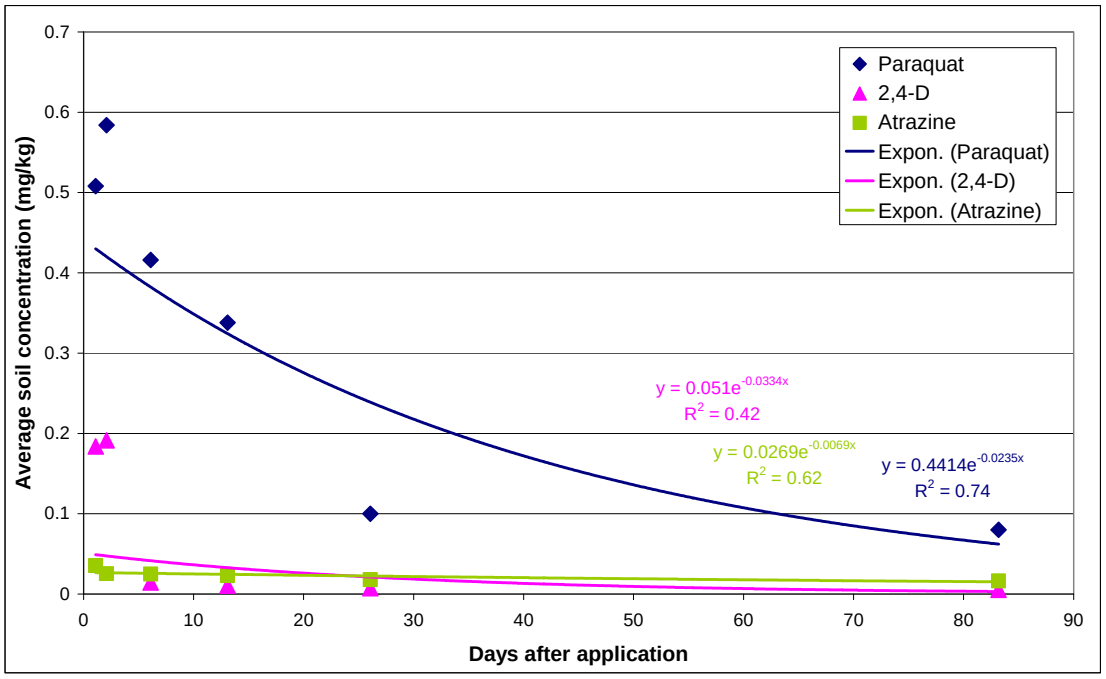

Figure 19 Field dissipation of paraquat, 2,4-D and atrazine in the surface soil (0-2.5 cm), Marian site

3.3.4 Soil moisture

Total profile soil water extraction was limited to a short period of the year prior to the first runoff event, and after the final runoff event (Figure 20). Interpreting the soil water extraction patterns is further complicated by the presence of a shallow water table, particularly for Treatment 1. Treatment differences in total moisture are likely to be related to the clay content differences across the treatments, rather than treatment effects. 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).

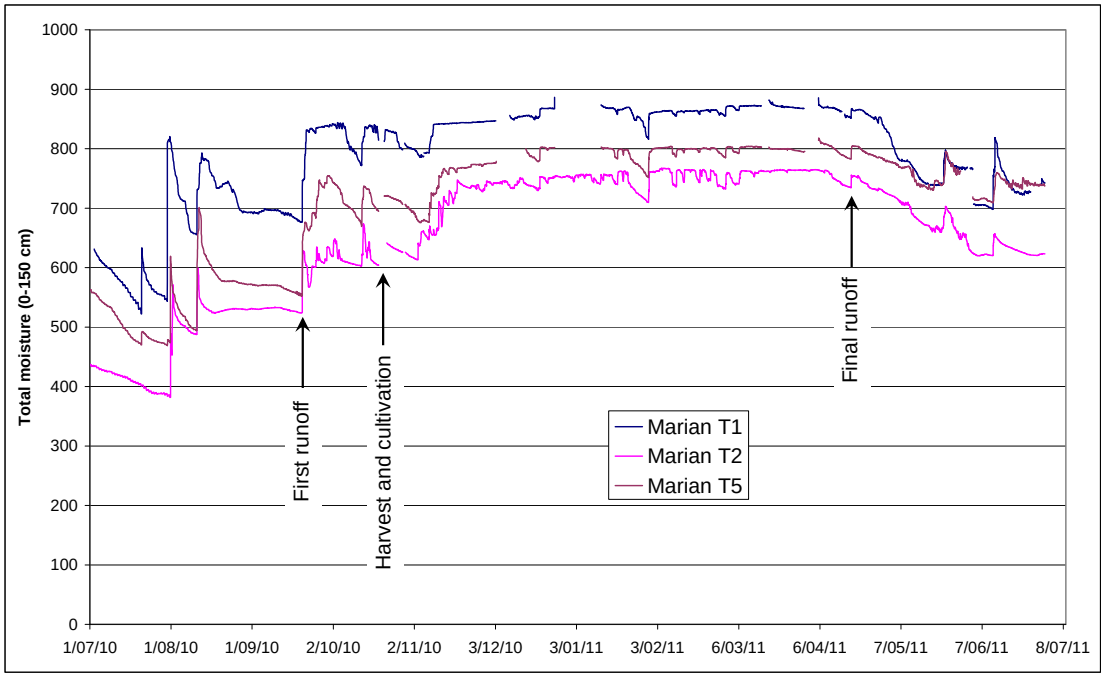

Figure 20 Total moisture in the soil profile (0-150 cm), Marian site

3.3.5 Rainfall and runoff

A total of 3243 mm of rainfall was recorded at the Marian site between 1st September 2010 and 30th April 2011, well above the estimated long-term average of 1468 mm (Te Kowai Research Station, records since 1889). The highest daily total of 211 mm was recorded on 31st March 2011.

As with the 2009/10 wet season, 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.**

3.3.5.1 Total suspended solids, turbidity and electrical conductivity

Concentrations of TSS were lowest and most consistent (between treatments) in the two runoff events prior to harvest on 29th October 2010 (Figure 21). The overall average TSS concentration of these samples was 36 mg/L (range 23-48 mg/L). Concentrations after harvest (burnt) and cultivation (19th November 2010) increased ~10-fold due to the low cover and disturbed soil. These concentrations then tended to decrease as the season progressed, although increases were observed during January. Of the samples collected, Treatment 1 (1.5 m row spacing) produced the highest mean TSS concentration (772 mg/L) and Treatment 2 (1.8 m row spacing) had the lowest (176 mg/L). It is thought that these results are due to site effects (number of samples collected), rather than treatment effects.

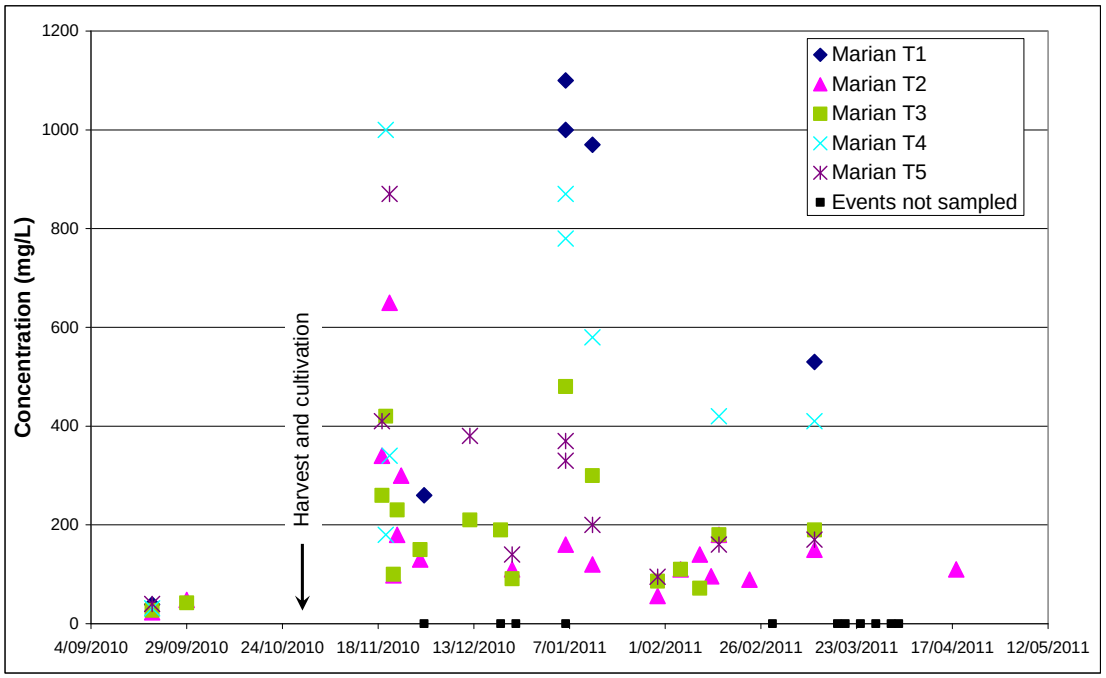

Figure 21 Concentrations of total suspended solids in runoff, Marian site

Similar to TSS concentrations, the lowest turbidity levels were observed prior to harvest (23-48 NTU). The turbidity range after harvest (75-1900 NTU) of each treatment was dependant on the number of samples collected, but the average from each treatment produced a similar trend to TSS concentrations. When samples from all treatments were combined, there was a strong relationship (R^2=0.89) between TSS concentration and turbidity (Figure 22).

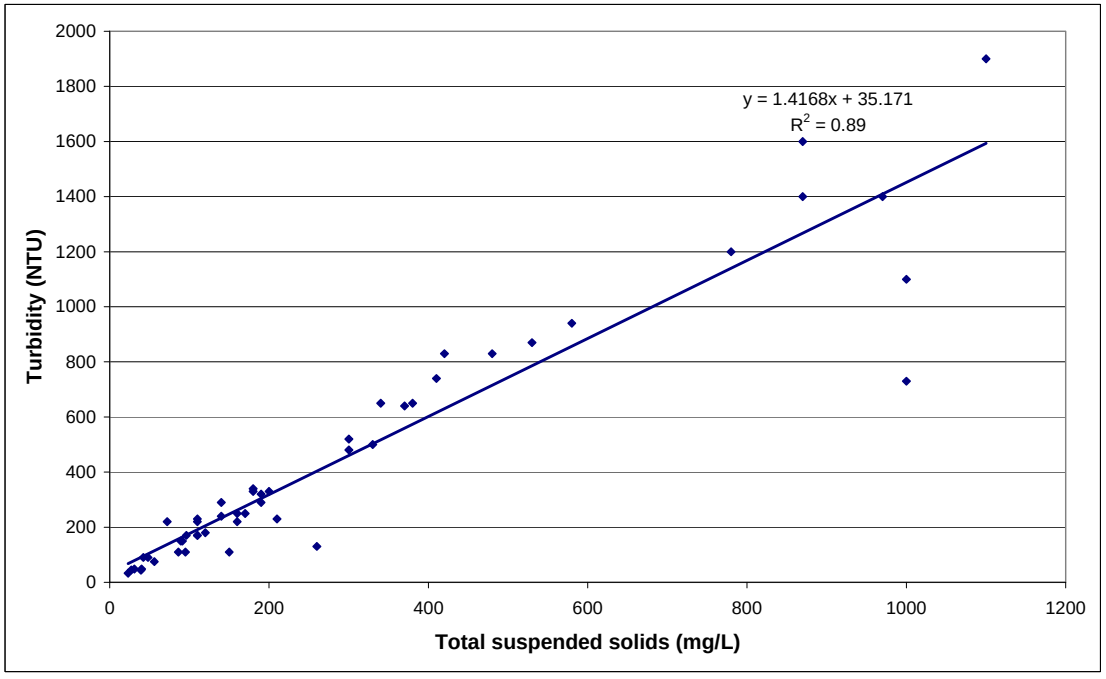

Figure 22 Relationship between total suspended solids and turbidity, Marian site

The EC of runoff water varied across the treatments; with an overall range of 26-255 µS/cm (2009/10 range was 48-160 µS/cm). In contrast to the 2009/10 season, Treatments 1 and 4 had the lowest average EC (57 and 84 µS/cm, respectively), with Treatments 2, 3 and 5 having a similar average EC (112, 109 and 100 µS/cm, respectively). These treatment averages are within the range of the treatment averages of the 2009/10 season (81-133 µS/cm).

3.3.5.2 Nitrogen

Prior to harvest and the application of nitrogen on 3rd November 2010, NO_x-N concentrations were low (17-161 µg N/L). After nitrogen application, NO_x-N concentrations increased to 3500-5000 µg N/L in the first runoff event (19th November 2010) and decreased rapidly to be <1000 µg N/L by mid-December (Figure 23). The application of "top-up" nutrients on 26th January 2011 (61 kg N/ha) had very little effect on NO_x-N concentrations in following events, although there was a general decline in concentrations for the remainder of the season (<165 µg N/L by mid-February).

Overall, Treatment 5 (1.8 m skip row, 220 kg N/ha applied) had the highest average NO_x-N concentration (724 µg N/L). The relatively high concentration could be attributed to nutrients being applied to the skip area, which had no crop planted to uptake the nutrients (although it was planned to plant a crop in this area) and the previous peanut crop residue supplying additional nitrogen. Average NO_x-N concentrations for the remaining 1.8 m treatments trended with the rate of nitrogen applied: Treatment 2 (602 µg N/L, 258 kg N/ha applied), Treatment 3 (485 µg N/L, 220 kg N/ha applied) and Treatment 4 (365 µg N/L, 180 kg N/ha applied). Treatment 1 (220 kg N/ha applied) produced the lowest average NO_x-N concentration (342 µg N/L), but this is thought to be due to the limited numbers of samples collected in the initial runoff events following nutrient application, rather than a treatment effect.

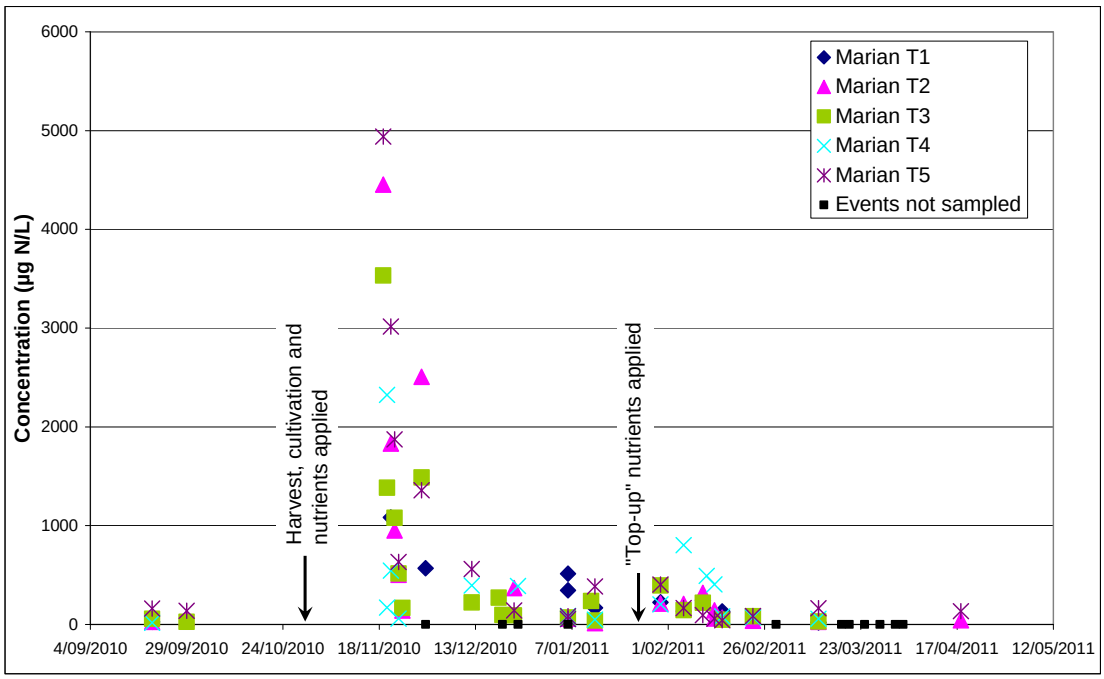

Figure 23 Concentrations of NO_x-N in runoff, Marian site

Urea-N concentrations in runoff were variable, and unlike the Victoria Plains site they did not show a clear application and seasonal pattern. In the initial two runoff events (prior to harvest and nitrogen application), concentrations ranged from 89-472 µg N/L across all treatments. In the first runoff event (16 days after nitrogen application), urea-N concentrations were similar (167-262 µg N/L) and then declined slightly (Figure 24). Concentrations after the application of the "top-up" nutrients were variable, with a general increase in concentrations across the treatments.

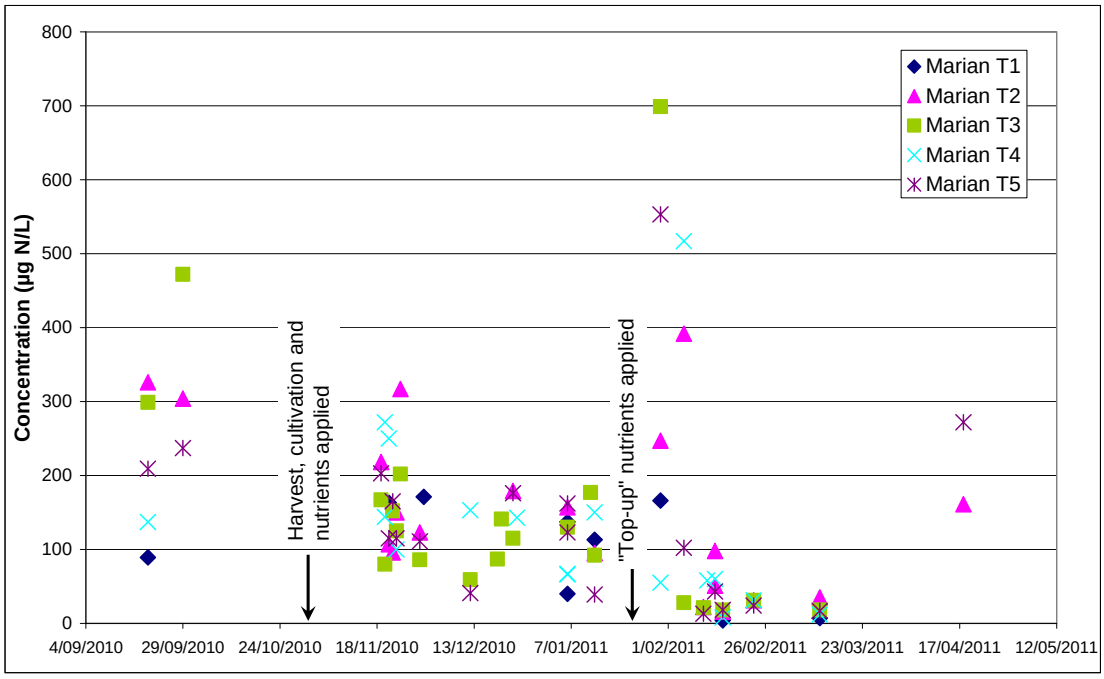

Figure 24 Urea-N concentrations in runoff, Marian site

Ammonium-N concentrations in runoff were low (22-134 µg N/L) prior to harvest and nitrogen application (Figure 25). Maximum concentrations were similar in the first runoff event after each nitrogen application, despite the application rates being different. Concentrations rapidly declined with time to be generally <200 µg N/L.

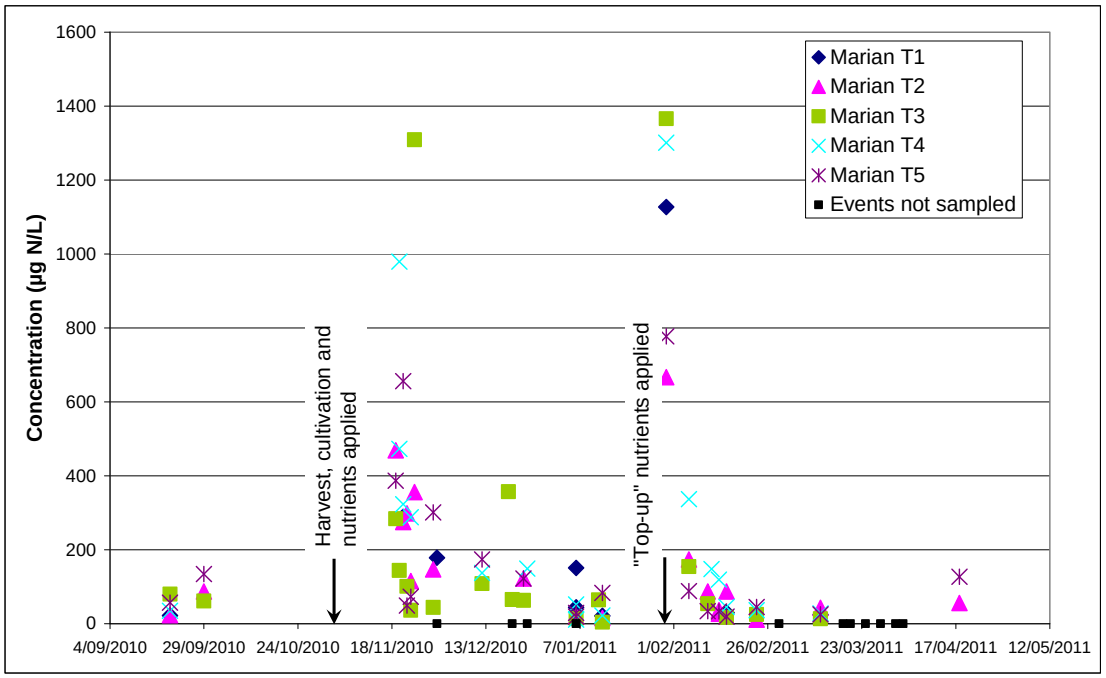

Figure 25 Ammonium-N concentrations in runoff, Marian site

3.3.5.3 Phosphorus

Filterable reactive phosphorus concentrations prior to harvest and nutrient applications were generally 500-1000 µg P/L. After fertilizer application, initial concentrations increased to 1000-2000 µg P/L before declining to be generally <500 µg P/L by January (Figure 26). The exception to this was Treatment 5, which showed no increase in FRP concentrations. Concentrations of FRP again increased (to 500-1000 µg P/L) following the application of the "top-up" nutrients (ammonium sulphate) which is surprising, as ammonium sulphate does not contain phosphorus. Concentrations again declined to be generally <500 µg P/L by late February. Overall, treatment averages were 403-628 µg P/L (similar to 2009/10 season), except Treatment 2 (835 µg P/L). Across all of the samples collected, FRP comprised the majority (89%) of the TFP signature. Of those samples with both FRP and TP data, FRP was half of TP.

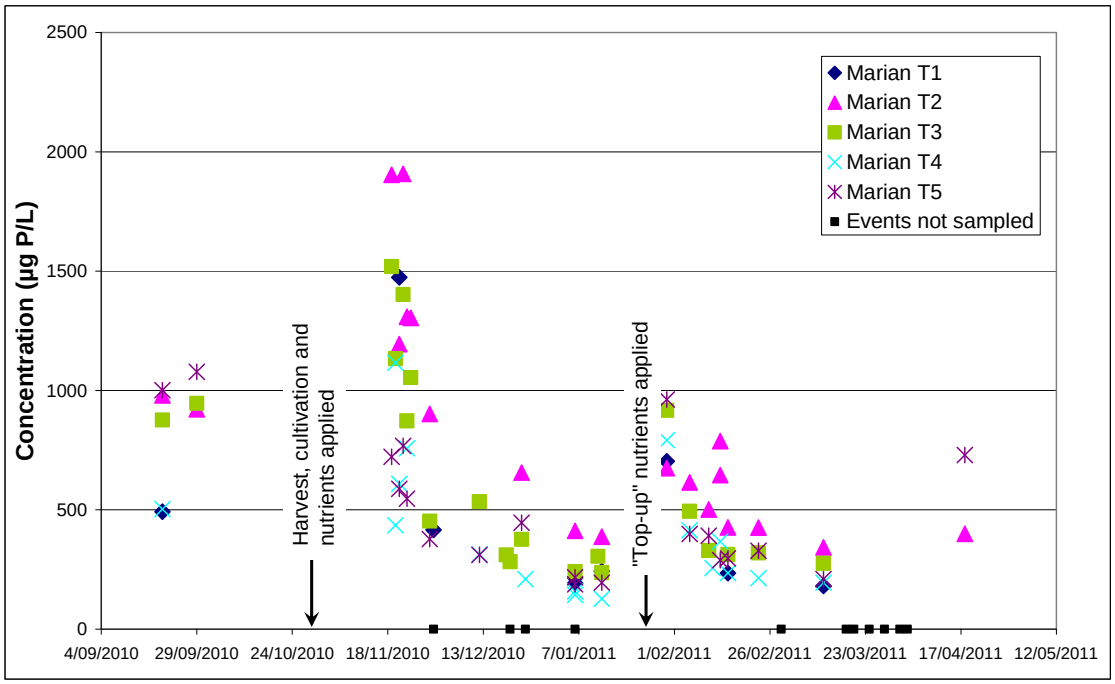

Figure 26 Filterable reactive phosphorus concentrations in runoff, Marian site

3.3.5.4 Herbicides

The main herbicide treatments were not applied until 26th January 2011. Prior to this, LCMS herbicide analyses were undertaken to detect residual traces of these herbicides from the previous season's application. After the herbicide treatments were applied, only those herbicides applied to the treatments were analysed. The first runoff event was four days after herbicide application.

Neither paraquat nor diquat were detected in any runoff samples (<10 µg/L for the first two runoff events post-application, and <1 µg/L for all other events).

Prior to application this season, atrazine was detected at low concentrations in all treatments (<0.09 µg/L) except for samples collected on 23rd December 2010 (Figure 27). Compared to previous events, these two samples had elevated concentrations of atrazine (1.7 µg/L for Treatment 2 and 0.42 µg/L for Treatment 3). Following the application of atrazine to Treatments 1 and 2, runoff concentrations were much higher in Treatment 2 (5.2 µg/L) than Treatment 1 (0.33 µg/L). This follows a similar trend to soil herbicide concentrations, where Treatment 2 had a much higher concentration than Treatment 1.

No runoff samples were analysed for 2,4-D prior to application. Following the application to all treatments, runoff concentrations were highest in Treatments 3 and 5 (51-52 µg/L) in the first runoff event four days after application (Figure 28). These concentrations then declined rapidly to be <1.1 µg/L in the following event (10 days after application). Concentrations from Treatment 2 were <1 µg/L for all samples, despite this treatment having the highest soil concentration after application.

The variability observed in the soil and runoff concentrations from each of these treatments, where the same herbicide rates were applied, is likely to be a result of the application/sampling method. The high density of weeds at the time of application

may have contributed to variability in the amount of herbicide that reached the soil surface, while the soil sampling approach may not have allowed for collection of sufficient sample points to account for this variability.

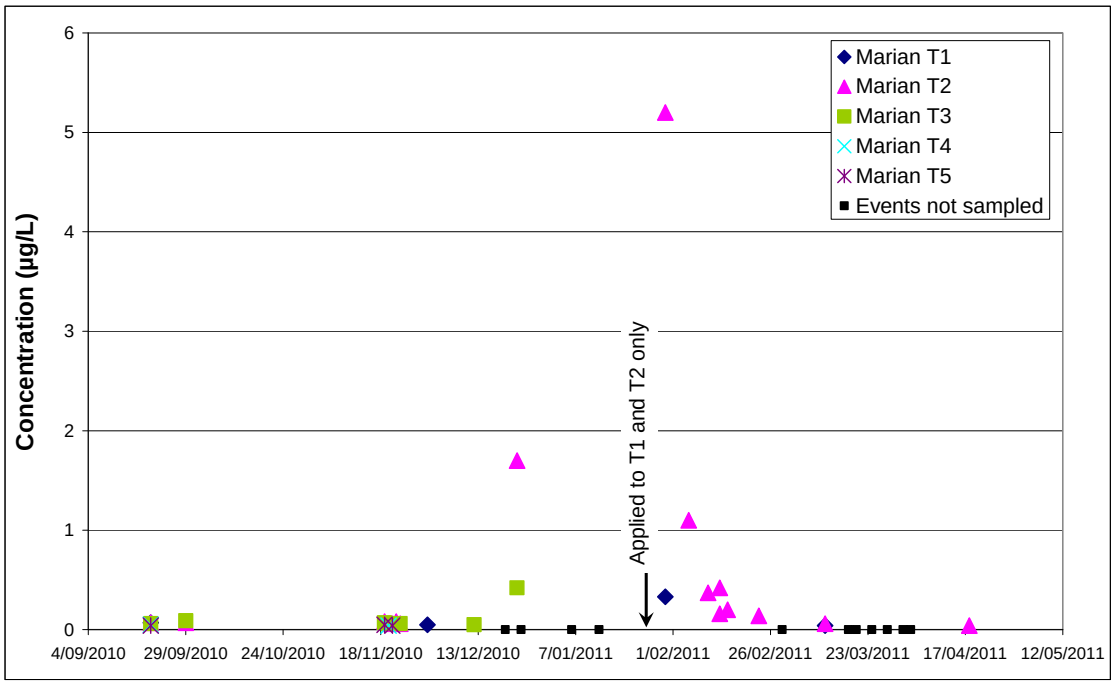

Figure 27 Atrazine concentrations in runoff, Marian site

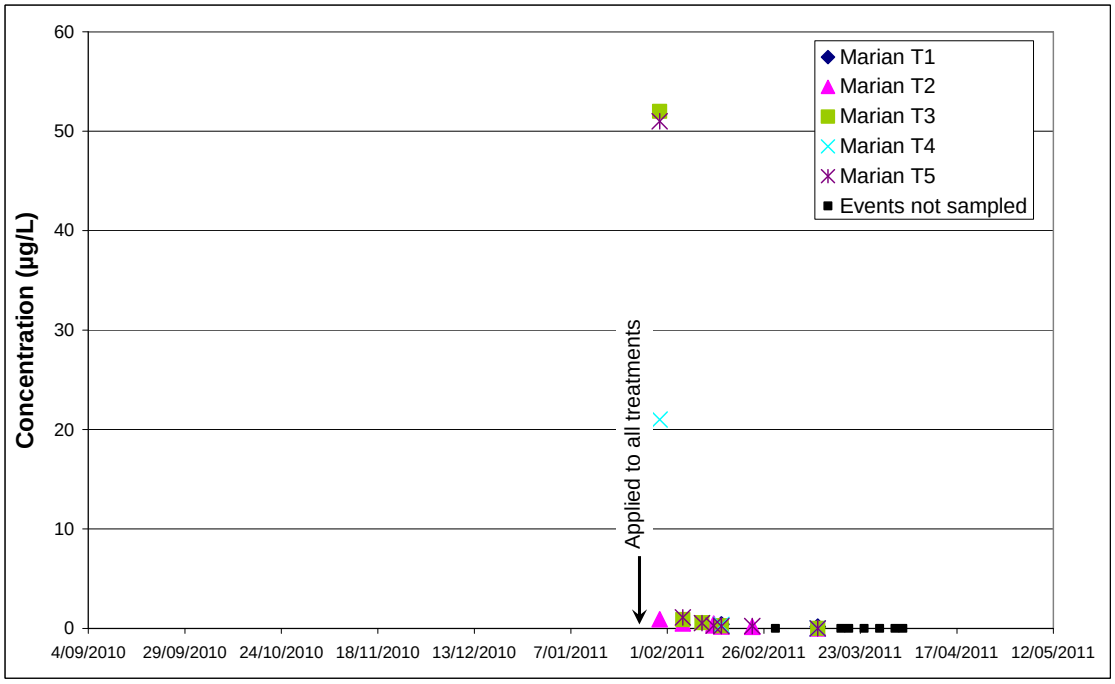

Figure 28 Concentrations of 2,4-D in runoff, Marian site

3.3.6 Drainage water quality

Soil moisture data suggests that an elevated water table was evident within 1 m of the soil surface from late September 2010 for Treatments 1 and 5, and mid-November for Treatment 2 (Sections 7.2.3-7.2.5). This has confounded the quality of data from the

soil solution samplers, and therefore only a limited interpretation is possible (and consequently no data is presented).

3.3.7 Agronomic

Yield and percent recoverable sugar (PRS) information collected during machine harvest and processing showed a similar cane yield (and PRS) from Treatments 1-4 (Table 14). Due to the wet and waterlogged conditions, the cane yields from all treatments were low. The cane yield from Treatment 5 (skip row) was ~51% of Treatment 3 (solid plant, same nitrogen rate) due to it only having 56% of the area planted to cane (10 cane rows and 8 "skip" rows).

Table 14 Machine harvest yield results for each treatment, Marian site

	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
Cane (t/ha)	43	43	41	38	21
PRS	No sample	12.62	13.44	12.71	No sample
Sugar (t/ha)	-	5.5	5.5	4.9	-

3.4 Multi-block and Multi-farm sites

3.4.1 Runoff water quality

As previously highlighted, 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. This problem was more prevalent at the Multi-farm site which overtopped its banks several times throughout the wet season and would remain that way for days at a time. 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.**

3.4.1.1 Total suspended solids, turbidity and electrical conductivity

The initial runoff event at the Multi-block site (20th September 2010) produced the highest TSS concentration (160 mg/L) for this site, with all other TSS concentrations ranging from 24-46 mg/L. This range (and maximum) was lower than that measured at the Multi-farm site. TSS concentrations ranged from 32-430 mg/L at the Multi-farm site, with the highest concentrations measured in mid-season (late January/early February).

Turbidity levels for the Multi-block site were generally below 100 NTU, except for an outlier of 530 NTU on 12th December 2010 (TSS only 37 mg/L). Turbidity at the Multi-farm site was also generally below 100 NTU, except for two events mid-season (late January/early February, 130 and 240 NTU) when TSS concentrations were also highest. Linear regression curves fitted to turbidity and TSS showed a strong correlation for the Multi-farm site (R^2=0.89) (data not shown).

The Multi-block site tended to have a smaller range (46-133 µS/cm) but higher mean (73 µS/cm) EC than the Multi-Farm site (30-164 µS/cm, mean 57 µS/cm). There was a general trend of declining EC throughout the season at both sites.

3.4.1.2 Nitrogen

Concentrations of NO_x-N at the Multi-block site remained quite consistent throughout the season (range 28-511 µg N/L, mean 149 µg N/L) (Figure 29). These concentrations are generally much lower than those detected in the 2009/10 season (range 18-1623 µg N/L, mean 437 µg N/L).

At the Multi-farm site, the highest NO_x-N concentrations (1402-2551 µg N/L) were detected in the initial runoff events, with concentrations declining to be generally <500 µg N/L. Similar to the Multi-block site, these concentrations are much lower than those detected in the 2009/10 season (range 12-5520 µg N/L, mean 714 µg N/L).

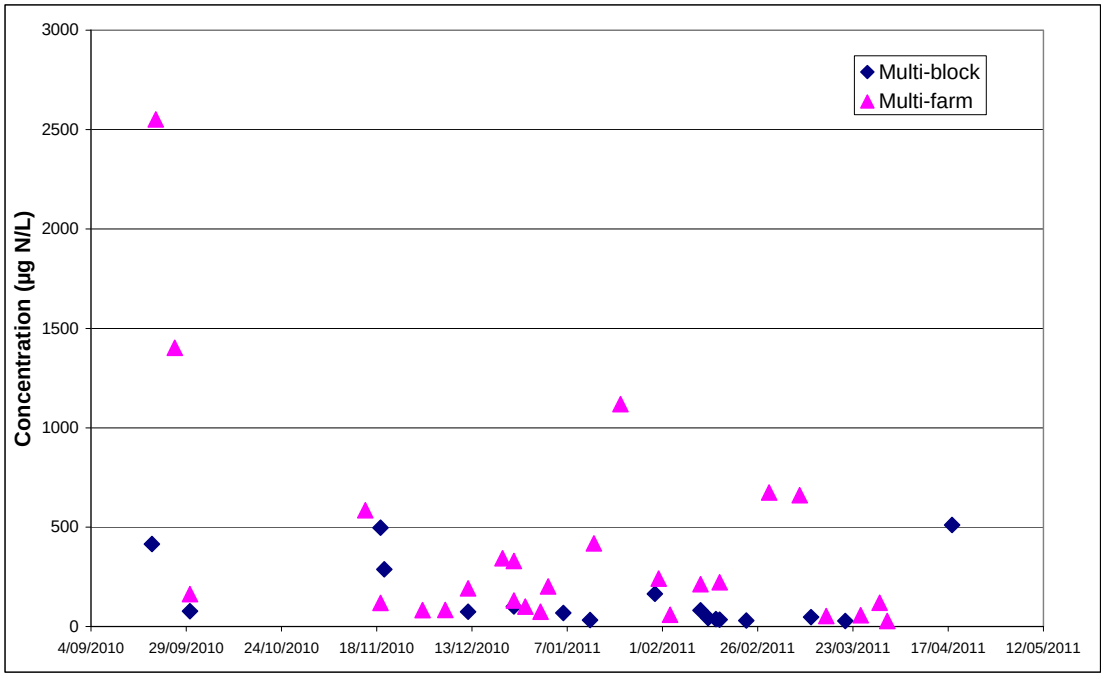

Figure 29 Concentrations of NO_x-N in runoff, Multi-block and Multi-farm sites

3.4.1.3 Phosphorus

The Multi-block site consistently recorded FRP concentrations at least double that of the Multi-farm site (Figure 30). Concentrations showed a general decline throughout the wet season, with the trend more evident at the Multi-block site. At both sites, the highest concentration was recorded in mid-November. Concentrations ranged from 294-1238 µg P/L at the Multi-block site (mean 562 µg P/L) and 35-351 µg P/L at the Multi-farm site (mean 104 µg P/L). These averages are slightly lower than the 2009/10 season: 683 µg P/L and 178 µg P/L for the Multi-block and Multi-farm sites, respectively.

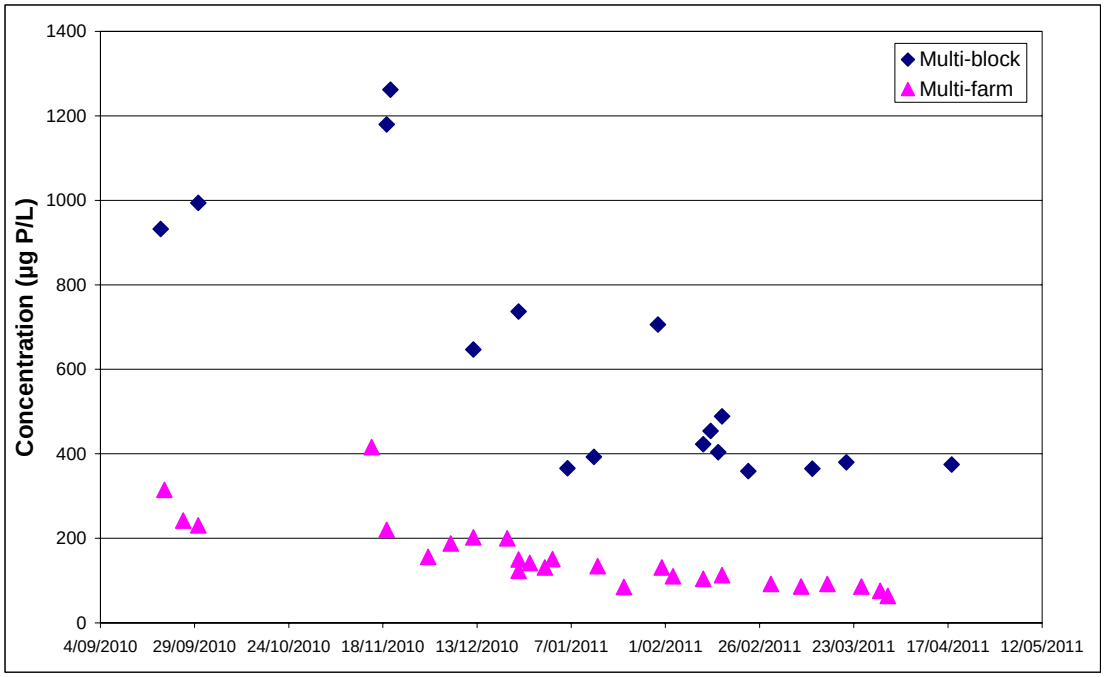

Figure 30 Filterable reactive phosphorus concentrations in runoff, Multi-block and Multi-farm sites

3.4.1.4 Ametryn

Ametryn was not detected in the first sample collected from the Multi-block site, but was then detected in all samples from both sites at low concentrations (<0.8 µg/L). Concentrations at the Multi-block site ranged from <0.01-0.74 µg/L (mean 0.15 µg/L) and <0.01-0.89 µg/L for the Multi-farm site (mean 0.13 µg/L). From mid-November onwards, there was a general decline in concentrations at both sites, except for one sample collected from the Multi-block site (24th December 2010, 0.74 µg/L).

In the 2009/10 season, ametryn concentrations at the Multi-block site were much lower (range <0.01-0.07 µg/L, mean 0.01 µg/L,) than the 2010/11 season, as was the case at the Multi-farm site (range 0.03-0.20 µg/L, mean 0.09 µg/L).

3.4.1.5 Atrazine

The first atrazine sample at the Multi-farm site was collected in mid-November (2.7 µg/L). Concentrations then declined, with small increases in late December and again in late January (Figure 31). These increases and subsequent decline could be attributed to multiple application times throughout the catchment. Overall, the average atrazine concentration was 0.60 µg/L (range 0.06-2.7 µg/L).

Atrazine concentrations at the Multi-block site were low (<0.05 µg/L) until 24th December 2010 when the concentration increased to 10 µg/L (Figure 31), and rapidly declined until 30th January 2011 when concentrations again increased. These increases could be attributed to atrazine being applied to 5.34 ha (~10%) of the catchment area.

Atrazine was not applied to the Multi-block catchment in the 2009/10 season; therefore concentrations were much lower than the 2010/11 season. In contrast, the range of atrazine concentrations detected at the Multi-farm site was similar between

seasons, with a lower average concentration this season (0.60 µg/L compared to 1.07 µg/L in the 2009/10 season).

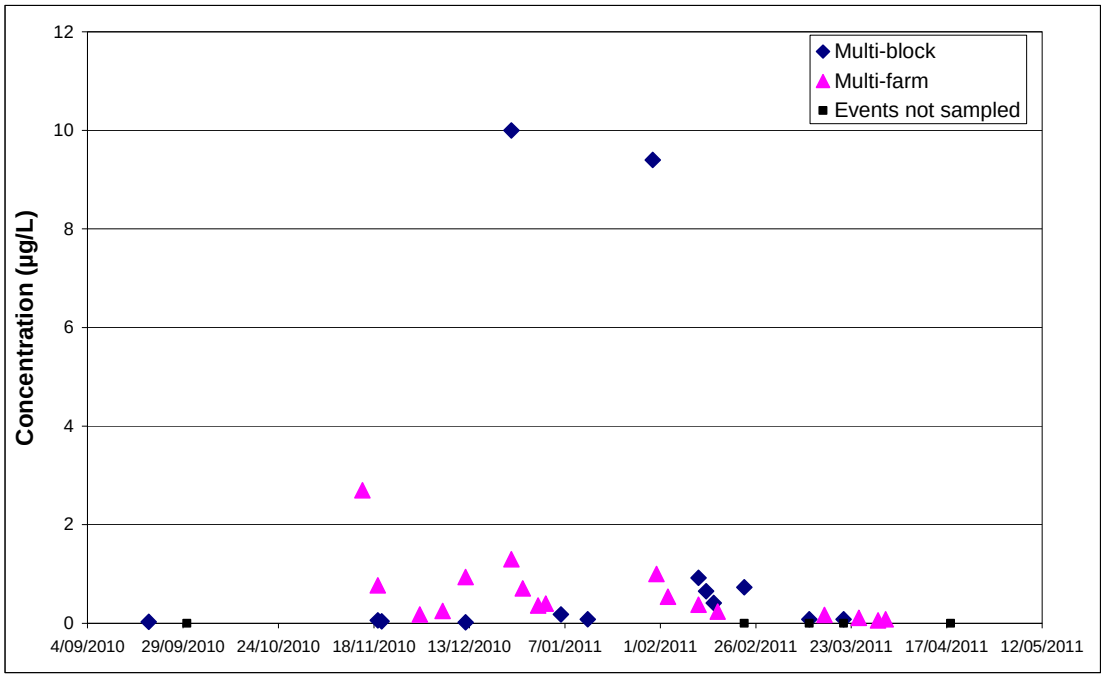

Figure 31 Atrazine concentrations in runoff, Multi-block and Multi-farm sites

3.4.1.6 Diuron

At the Multi-block site, initial diuron concentrations were low (0.16 µg/L). By the next sample (19th November 2010), the concentration had increased to 5.9 µg/L (Figure 32) even though it was not applied in the catchment area. Concentrations then declined rapidly to 0.49 µg/L by mid-December and 0.09 µg/L by mid-February.

Diuron concentrations at the Multi-farm site followed a similar trend to atrazine. The first diuron sample was collected in mid-November (2.8 µg/L). Concentrations then declined, with increases in late December and again in late January (Figure 32). Similar to atrazine, these increases and subsequent decline could be attributed to multiple application times throughout this catchment.

Overall, diuron concentrations at the Multi-block site ranged from 0.09-5.9 µg/L (mean 0.95 µg/L) and 0.24-3.1 µg/L for the Multi-farm site (mean 1.1 µg/L). These concentrations (range and mean) are much lower than those detected in the 2009/10 season: mean of 11 µg/L and 2.9 µg/L for the Multi-block and Multi-farm sites, respectively.

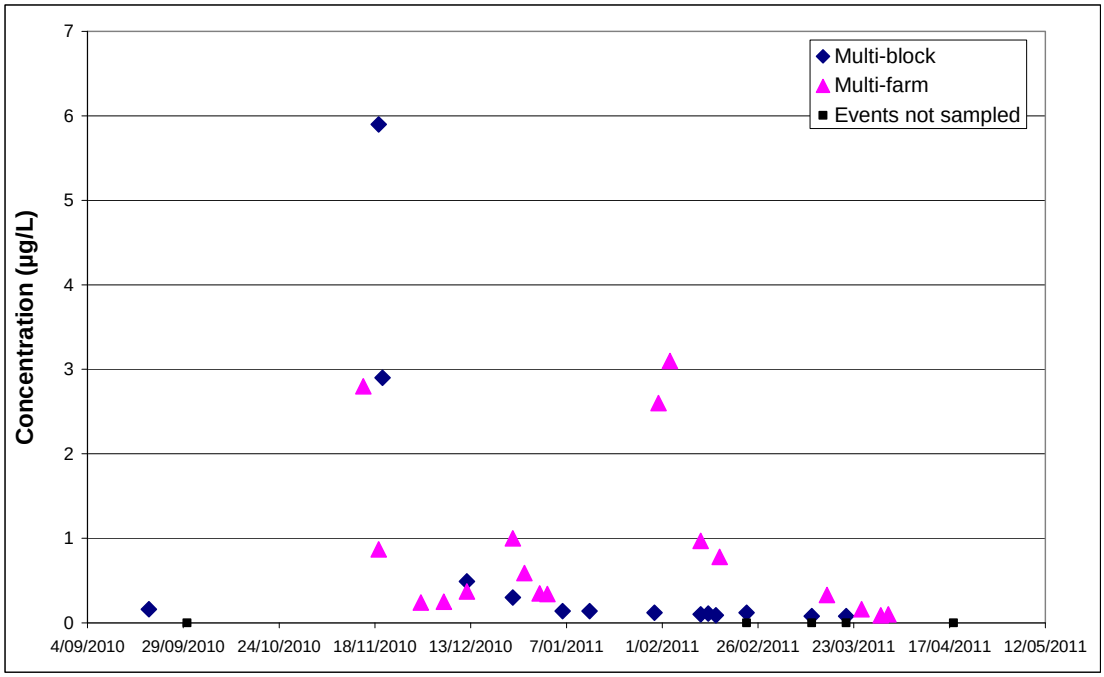

Figure 32 Diuron concentrations in runoff, Multi-block and Multi-farm sites

3.4.1.7 Hexazinone

Hexazinone concentrations detected at the Multi-block site were low and consistent throughout the season (range 0.02-0.07 µg/L, mean 0.04 µg/L). At the Multi-farm site, concentrations were highest in the initial two events sampled (mid-November) and then were consistent (<0.01-0.08 µg/L) for the remainder of the season (Figure 33). Again, these concentrations are much lower than those detected in the 2009/10 season: mean of 4.31 µg/L and 0.64 µg/L for the Multi-block and Multi-farm sites, respectively.

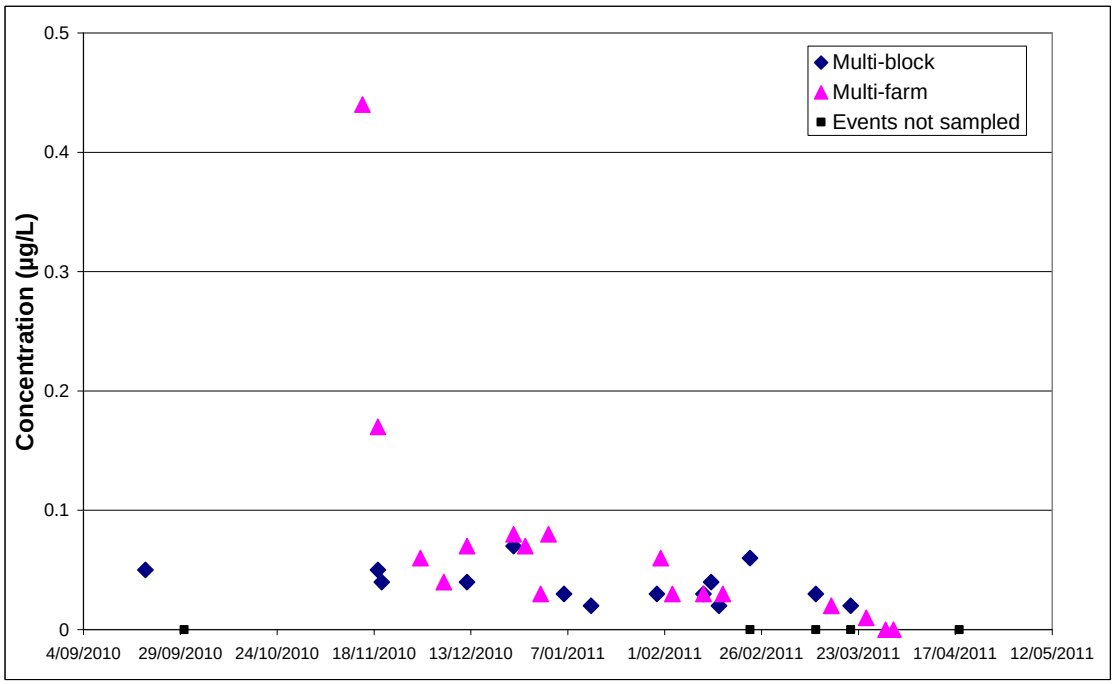

Figure 33 Hexazinone concentrations in runoff, Multi-block and Multi-farm sites

3.4.1.8 Other pesticides

Fluometuron was only detected (0.05 µg/L) in the first runoff event at the Multi-block site. It was not detected (<0.01 µg/L) in any of the Multi-farm samples. Prometryn was also detected in a single sample (0.01 µg/L) from the Multi-block site (24th December 2010), and also in a single sample (0.02 µg/L) from the Multi-farm site (15th November 2010). Simazine was detected twice at the Multi-block site (0.05 µg/L on 24th December 2010, and 0.04 µg/L on 30th January 2011), and was not detected in any Multi-farm samples. Metolachlor was also detected in just one sample from each of the Multi-block (0.01 µg/L on 19th November 2010) and Multi-farm (0.02 µg/L) sites.

A limited number of samples were analysed for 2,4-D. It was not detected (<0.1 µg/L) on 6th January 2011, but was detected at 1.5 µg/L on 12th March 2011 at the Multi-block site. It was detected in the three samples collected from the Multi-farm site (0.28-0.3 µg/L in late December, and 0.12 µg/L in early February). Three samples (late November and late December) from the Multi-farm site were also analysed for imazapic, which was not detected (<1 µg/L).

The insecticide imidacloprid was not detected in any of the Multi-block samples, but was detected in all Multi-farm samples (0.01-0.05 µg/L).

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 13.6% less runoff than Treatment 1 (1.5 m row spacing) across the 2010/11 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). The 2010/11 wet season was much wetter and prolonged (3300 mm rainfall across eight months) than the 2009/10 season (1636 mm across four months). The commencement of runoff was delayed on average by approximately 11 minutes (~6 minutes in 2009/10), and peak runoff rates reduced by 33% (2% in 2009/10). 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.* in press). 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.* in press). All of these studies support our findings of reduced treatment difference in runoff due to the prolonged wet season and wetter soils.

The reductions in start time to runoff (~11 minutes) and reduced peak runoff rates (average 33%), 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.* (in press), 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). Our bulk density treatment differences 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 (135-158 mg/L) are much lower than the mean TSS concentrations measured in the 2009/10 season (631-826 mg/L). Total soil erosion this season was estimated to be ~2.75 t/ha, ½-¼ of what was measured in 2009/10 (despite receiving 2.5 times the runoff). This may be due to the green cane trash blanket this season, compared with the bare, cultivated soil the previous season.

At the Marian site, two runoff events were sampled prior to cane harvest and had low TSS concentrations (average of all samples 36 mg/L). Concentrations after harvest (burnt) and cultivation increased ~10-fold due to the low ground cover and disturbed soil. These higher concentrations were similar to those measured in the 2009/10 season (similar conditions – bare, cultivated soil). 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 (2.75 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).

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 study, 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 different products (formulations) being used.

At the Victoria Plains site, nitrogen concentrations in the first runoff event (three days after application) were dominated by urea-N, with concentrations reflecting the amount of nitrogen applied. Ammonium-N concentrations were also elevated and NO_x-N concentrations were low. By 27 days after application, nitrogen concentrations were dominated by NO_x-N and by two months after application, concentrations of urea-N, ammonium-N and NO_x-N were similar. At the Marian site where nitrogen rates and product applied (except the "top-up" application) were similar to the Victoria Plains site, initial nitrogen concentrations (16 days after application) were dominated by NO_x-N, then ammonium-N and urea-N. Ammonium-N and NO_x-N concentrations rapidly decreased with time, whereas urea-N concentrations remained similar to or lower than those detected prior to nitrogen

application. It is interesting to note that the highest urea-N concentrations were detected in runoff events after the "top-up" application of nitrogen, with a much reduced increase in NO_x-N concentrations.

Although reported urea-N analyses in runoff water are rare, it would be expected that the change in nitrogen species in runoff over time would reflect changes in the soil surface layer (including volatilisation). Many interrelating factors influence the amount of nitrogen lost through ammonium volatilisation. These include urease activity (the decomposition of urea to ammonium and carbon dioxide), temperature, soil moisture, application method, soil pH, and soil cation exchange capacity (Bovis and Touchton 1998). The greatest losses will most likely occur when urea or urea-containing fertiliser is surface-applied to a soil where high amounts of plant residue are present. Urease activity is higher on plant surfaces and organic residues than in soil, and urea hydrolyses rapidly when in contact with these residues. This could be a possible explanation of the site differences in urea-N concentrations in runoff: applied to organic residue (canetrash blanket) at the Victoria Plains site and applied to bare soil at the Marian site. Another possible explanation is the time from application to runoff: three days at the Victoria Plains site and 16 days at the Marian site. Elevated concentrations of urea-N in runoff are of concern, because this form of nitrogen has 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 urea-N (being the dominant nitrogen fraction) in runoff from the Victoria Plains site for Treatment 1 was 15.9 kg/ha and 12.5 kg/ha from Treatment 2; 8.0% and 9.2% of the applied nitrogen for Treatments 1 and 2, respectively. Loads of NO_x-N could not be calculated, as critical runoff events were not sampled (particularly in Treatment 2), but is estimated that it would be ~4 kg/ha, adding ~2% to the nitrogen wet season loss. The proportional nitrogen loss is similar to that measured last season in this trial: 9.8-12.8% of the applied nitrogen was lost as NO_x-N in runoff (NO_x-N being the dominant nitrogen source that season). A similar cane study near Mossman in far North Queensland also found that the total loss of nitrogen is roughly proportional to the amount of fertiliser applied (Bartley *et al.* 2005; Webster and Brodie 2008). They found that the lower fertiliser rate (98 kg N/ha) lost ~16% of the fertiliser to surface or sub-surface waters, and the higher rate (190 kg N/ha) lost ~15%. This suggests a consistent loss of 10-15% of applied nitrogen (to surface or sub-surface waters) across a number of studies and climatic conditions.

Concentrations of FRP in runoff from the Victoria Plains site were much higher (flow-weighted mean 57-77 µg P/L) this season than the previous season (31-34 µg P/L) even though less phosphorus was applied. This is thought to be due to the period of time between application and runoff: three days this season, and 176 days the previous season. In contrast, average FRP concentrations were similar between seasons at the Marian site: 403-628 µg P/L this season, and 347-563 µg P/L in the previous season. The difference in runoff concentrations between the sites (soils) (~7 times higher at Victoria Plains 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) at the Marian and Victoria Plains site were 311-900 µg/kg and 42-51 µg/kg, respectively.

4.4 Factors affecting herbicides in runoff and drainage

Timing of rainfall after herbicide application in this study greatly influenced the concentrations of herbicides detected in runoff water. At the Victoria Plains site, three runoff events occurred within 20 days of herbicide application. These events (6% of the seasonal runoff) contributed ~92% of the season's diuron and hexazinone loss in runoff (analyses for imazapic did not commence until 85 days after application, by which time all concentrations were <1 µg/L). The total diuron loss for the season (210 g/ha) was 11.8% of the applied diuron, whereas 17.8% of the applied hexazinone (89 g/ha) 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). In our study, 10-14% of the applied diuron and hexazinone was lost in the first runoff event seven days after application. Wauchope (1978) defined runoff events within a two week period of application and having a runoff volume which is 50% or more of the rainfall as "critical" (the first runoff event volume at Victoria Plains was ~55% of rainfall).

Initial concentrations of herbicides detected in runoff at the Victoria Plains site this season (240 and 98 µg/L for diuron and hexazinone, respectively) were much higher than in the 2009/10 season (18 and 41 µg/L 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 after application substantially reduced the total amount and rate of metolachlor runoff (Potter *et al.* 2008). In our study, 7.6 mm of rain was recorded seven days after herbicide application in the 2009/10 season, whereas no rainfall was recorded between application and the first runoff event in the 2010/11 season. This appears to have led to lower soil surface herbicide concentrations and consequently lower concentrations in runoff in the 2009/10 season.

Initial soil water content has also been shown to influence herbicide concentrations in runoff. When initial soil water content was 24% (versus 12%), two to three times more herbicide loss mass was observed when runoff occurred one and eight days after herbicide application (Smith *et al.* 2002). In our study, surface (20 cm) soil moisture at the commencement of the first rainfall runoff event after herbicide application was 2.3 times greater in the 2010/11 season than the 2009/10 season, contributing to higher herbicide concentrations in runoff in 2010/11.

Several factors may contribute to a reduction in field half-lives of pesticides (Laabs *et al.* 2002), and therefore soil surface concentrations available for transport in runoff. These factors include high air temperatures, intense rainfall and soil microbial activity. In a field study in USA, it was found that the rate of disappearance of atrazine in the surface soil was considerably higher (52.9 versus 25 days) in the absence of a sugarcane mulch residue compared with that of a no-till plot (Selim *et al.* 2003). Higher microbial activity and photodegradation were responsible for the higher rate of atrazine disappearance in the absence of residue on the soil surface.

This may also be an influencing factor in the higher herbicide concentrations detected in the 2010/11 season.

Similar to surface runoff, herbicide concentrations detected in drainage soil solution samples were much higher this season than in the 2009/10 season. Diuron was detected in soil solution (0.9 m depth) at 8 µg/L ten days after application while hexazinone was detected at 15 µg/L. These concentrations then decreased at a calculated half-life rate of ~58 days for both diuron and hexazinone. Diuron concentrations in water collected from lysimeters (0.5 m deep) in a cotton farm in Brazil had a similar range – up to 6.29 µg/L (Dores *et al.* 2009). Hexazinone concentrations are expected to be higher than diuron due to its higher solubility: 33,000 mg/L for hexazinone and 42 mg/L for diuron (Wauchope *et al.* 1992). In a pesticide leaching study of silt loams in New Zealand, it was found that hexazinone was the most mobile of the pesticides studied (atrazine, bromacil, diazinon, hexazinone and terbuthylazine) (Close *et al.* 2006). Sorption studies of a number of herbicides on six Brazilian soils found that hexazinone was a "leacher" in all soils studied (Oliveira Jr *et al.* 2001).

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 averaged 14% less than Treatment 1 (1751 and 2025 mm, respectively from 3300 mm rainfall). Runoff from Treatment 2 was delayed on average by ~11 minutes compared with Treatment 1, and the peak runoff rate was ~33% lower, all contributing to reduced runoff.
- Total suspended solids (TSS) concentrations showed a general increasing trend throughout the wet season, with concentrations also increasing with increasing maximum rainfall intensity. The wet season flow-weighted TSS concentration was lower in Treatment 1 (135 mg/L) than Treatment 2 (158 mg/L).
- Total estimated wet season soil loss for both treatments was similar: 2743 kg/ha for Treatment 1, and 2766 kg/ha for Treatment 2.
- After nitrogen application, initial nitrogen concentrations in runoff were dominated by urea-N, with concentrations highest in Treatment 1 (higher application rate). Concentrations of NO_x-N (nitrate and nitrite) peaked ~26 days after application, and concentrations of all nitrogen species were lower by mid-November (~two months after application). The total wet season loss of urea (the highest nitrogen species load) in runoff from Treatment 1 was 16 kg/ha and 13 kg/ha from Treatment 2.
- The filterable reactive phosphorus (FRP) flow-weighted wet season concentration was higher for Treatment 2 (77 µg P/L) than for Treatment 1 (57 µg P/L), although similar phosphorus rates were applied. Due to the lower runoff volumes from Treatment 2, total loss was similar between treatments (~5% of applied P).
- Using the surface soil field dissipation data of 10-100 days after application, the calculated half-lives of diuron, hexazinone and imazapic were 199, 53 and 118 days, respectively. For canetrash, the calculated half-lives were 11, 9 and 13 days for diuron, hexazinone and imazapic, respectively.
- Herbicide residues of diuron and hexazinone were particularly elevated in the initial runoff event from Treatment 1, which was seven days after the application of Velpar K4. Within one month of application, ~92% of the total seasonal loss of diuron and hexazinone in runoff had occurred (but only 6% of the seasonal runoff).
- Imazapic was not detected in any runoff samples from Treatment 2; however samples were not collected until 85 days after application.
- There was a strong relationship between herbicide concentrations (diuron and hexazinone) detected in the surface runoff water and those detected in the drainage soil solution samples.
- Machine harvest cane yield results of the first ratoon cane crop were 62 t/ha for Treatment 1 and 48 t/ha for Treatment 2. The lower yield from Treatment 2 is thought to be due to the lower application of nitrogen and the wet, waterlogged conditions.

At the Marian site (duplex soil), total runoff was compounded 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 much higher than those recorded from the Victoria Plains site (treatment averages 176-772 mg/L), presumably due to low cover from cultivation and lack of a trash blanket.
- Nitrogen concentrations in runoff were low prior to harvest and nitrogen application. After application, NO_x-N concentrations remained above background concentrations for ~2 months with Treatment 5 (1.8 m controlled traffic, skip row) having the highest average concentration. This may be attributed to the release of nitrogen from the previous peanut crop residue and nitrogen being applied to the skip area, especially since this area was not planted this season. Average NO_x-N concentrations for the remaining 1.8 m treatments trended with the rate of nitrogen applied.
- Average FRP concentrations (403-835 µg P/L) were ~10-fold more than those detected at the Victoria Plains site, following a similar trend to the surface soil phosphorus levels.
- Herbicide concentrations in the surface soil were quite variable across the treatments, despite identical application rates being applied. Using the field dissipation data of 1-83 days after application, the calculated half-lives of paraquat, 2,4-D and atrazine were 27, 34 and 116 days, respectively.
- As with soil herbicide concentrations, runoff concentrations were also variable, but followed a similar trend to the soil concentrations. Paraquat was not detected in any runoff samples.
- Machine harvest cane yield results of the first ratoon cane crop were similar between treatments (38-43 t/ha), except for the skip row treatment (21 t/ha) due to only 56% of the treatment area planted to cane.

At the Multi-block and Multi-farm sites:

- Total suspended solid concentrations at the Multi-block site (24-160 mg/L) were lower than those measured at the Multi-farm site (32-430 mg/L). These values are within the range of the results observed at the paddock scale, and may be attributed to the variance in ground cover levels on paddocks within each of the monitoring catchments.
- Concentrations of NO_x-N were much lower than those detected in the 2009/10 season, possibly the result of the extended wet season which limited the opportunities for growers to apply nutrients.
- 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.
- Herbicide residues were generally similar between the two sites, but periods of application (and therefore maximum concentrations) are more clearly defined at the Multi-block site. The range of herbicide concentrations detected is different to the 2009/10 season, which may be due to the herbicides applied and the timing of those applications.

In summary, results from the 2010/11 season showed the same trends between treatments as those observed for the 2009/10 season, despite the higher than average rainfall that occurred in 2010/11. 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. The 1.5 m and 1.8 m row spacing treatments produced similar cane yields, particularly at the Marian site with wet and waterlogged conditions limiting full yield potential.

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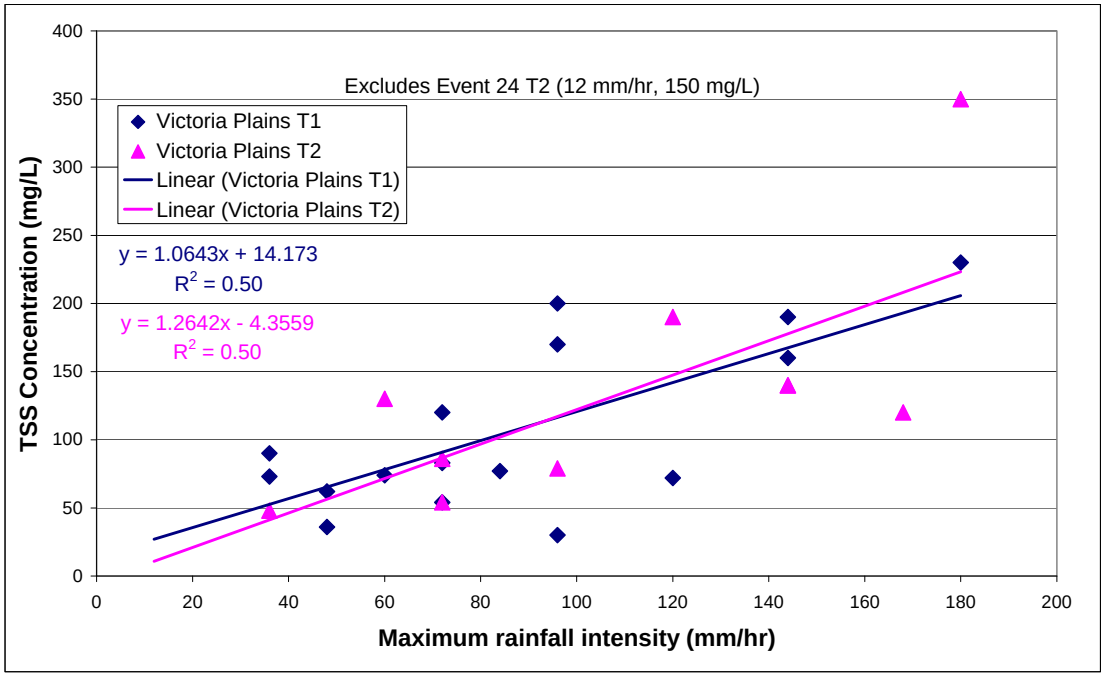
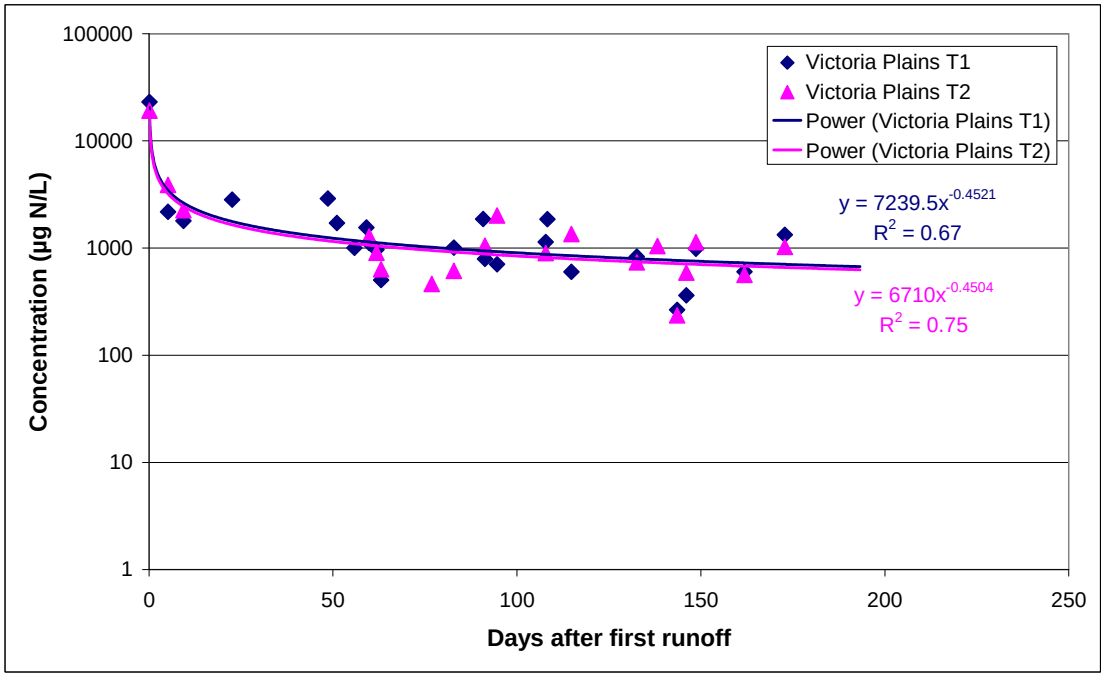
7 APPENDICES

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

7.1.1 Total suspended solids

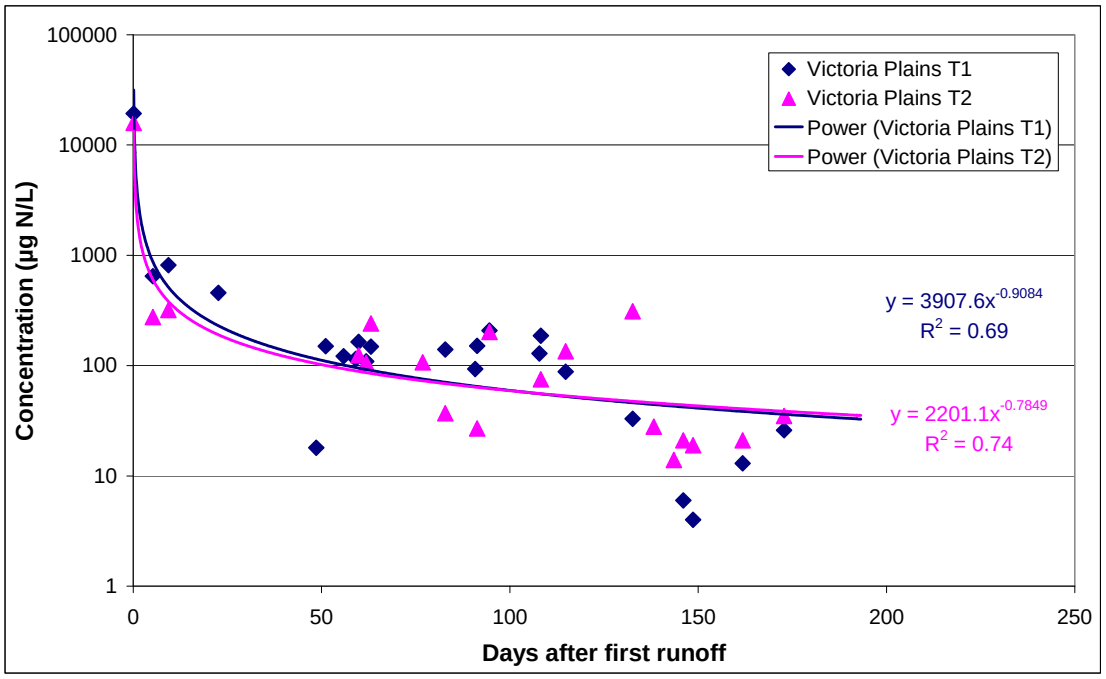


7.1.2 Total Kjeldahl nitrogen



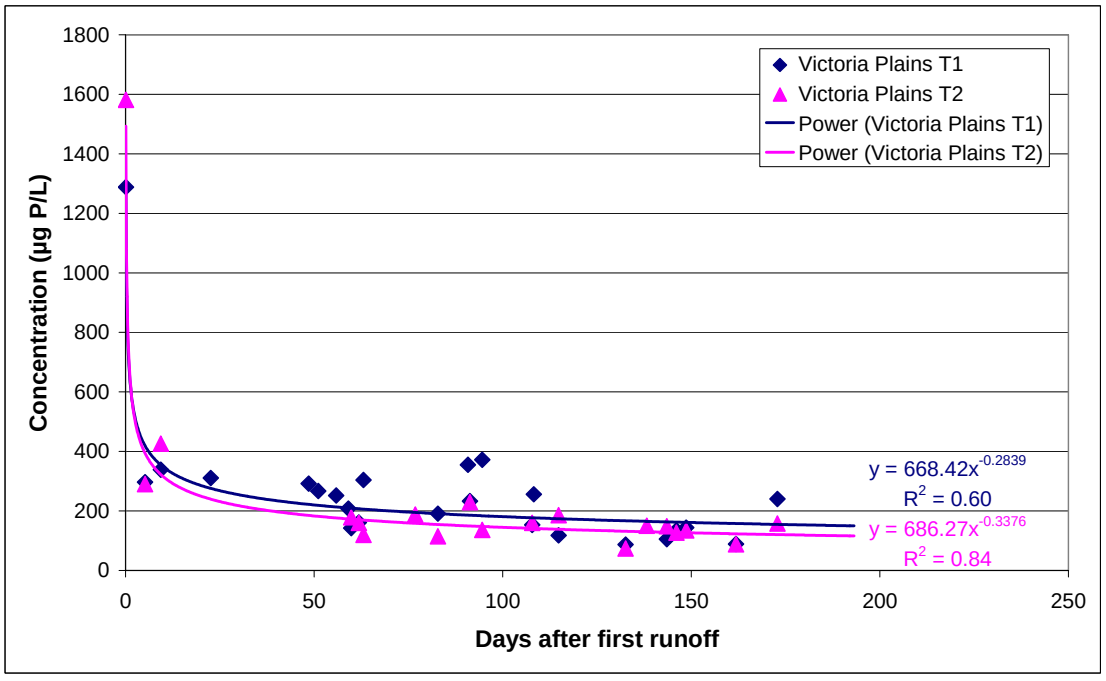
Note: log scale on y-axis

7.1.3 Urea-N

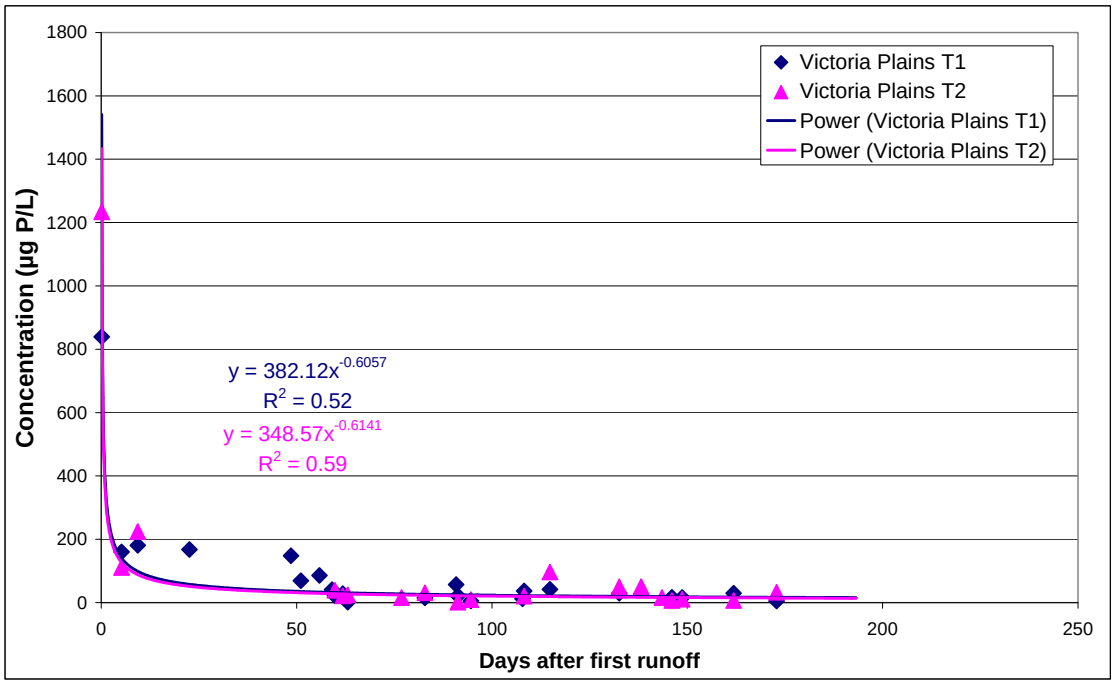


Note: log scale on y-axis

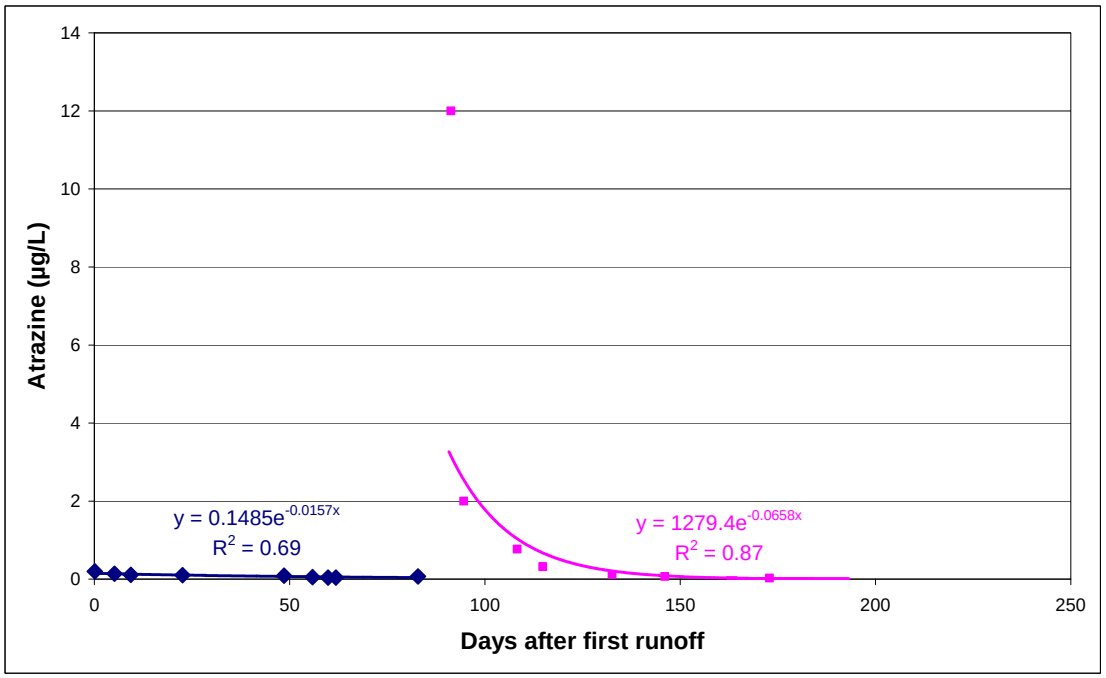
7.1.4 Total Kjeldahl phosphorus



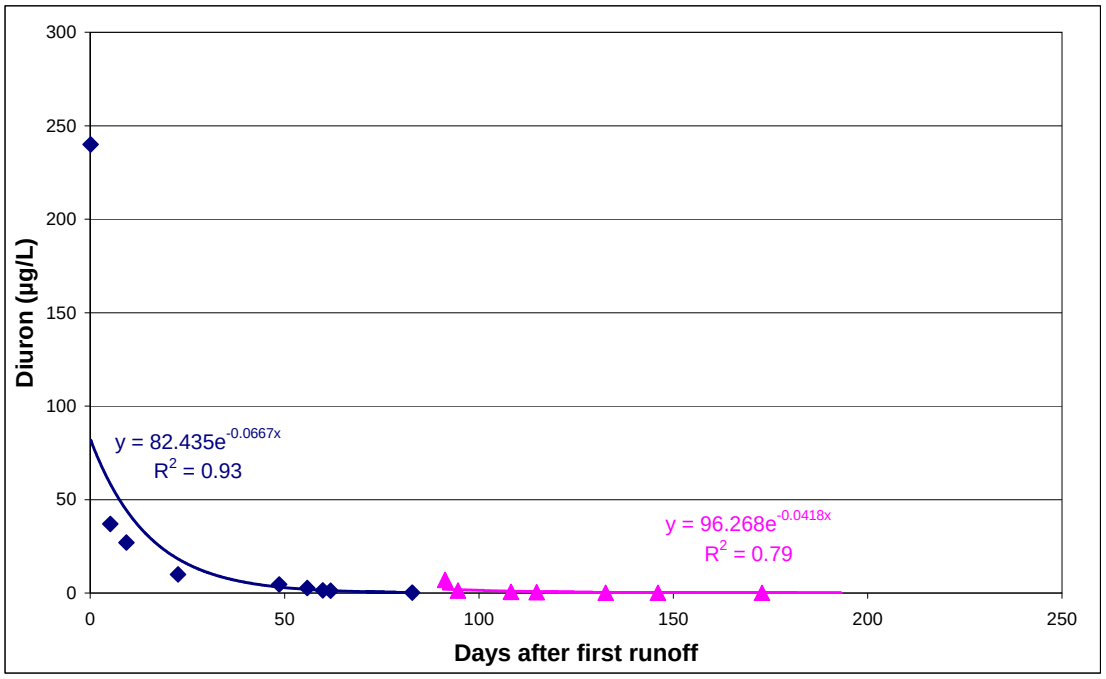
7.1.5 Filterable reactive phosphorus



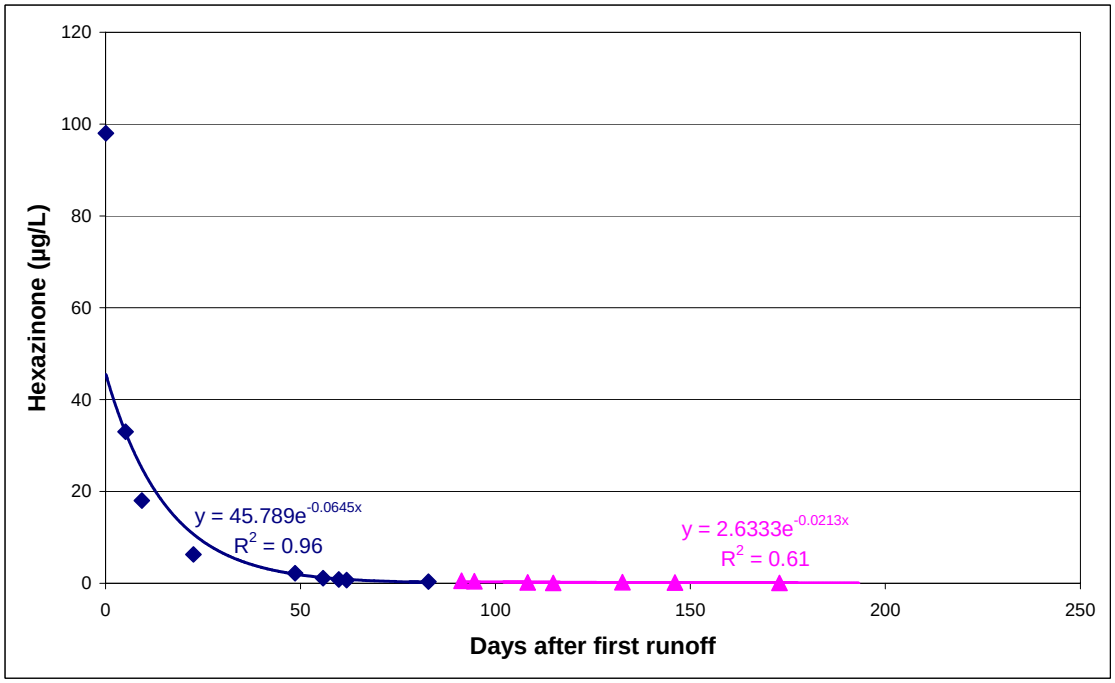
7.1.6 Atrazine (Treatment 1 only)



7.1.7 Diuron (Treatment 1 only)

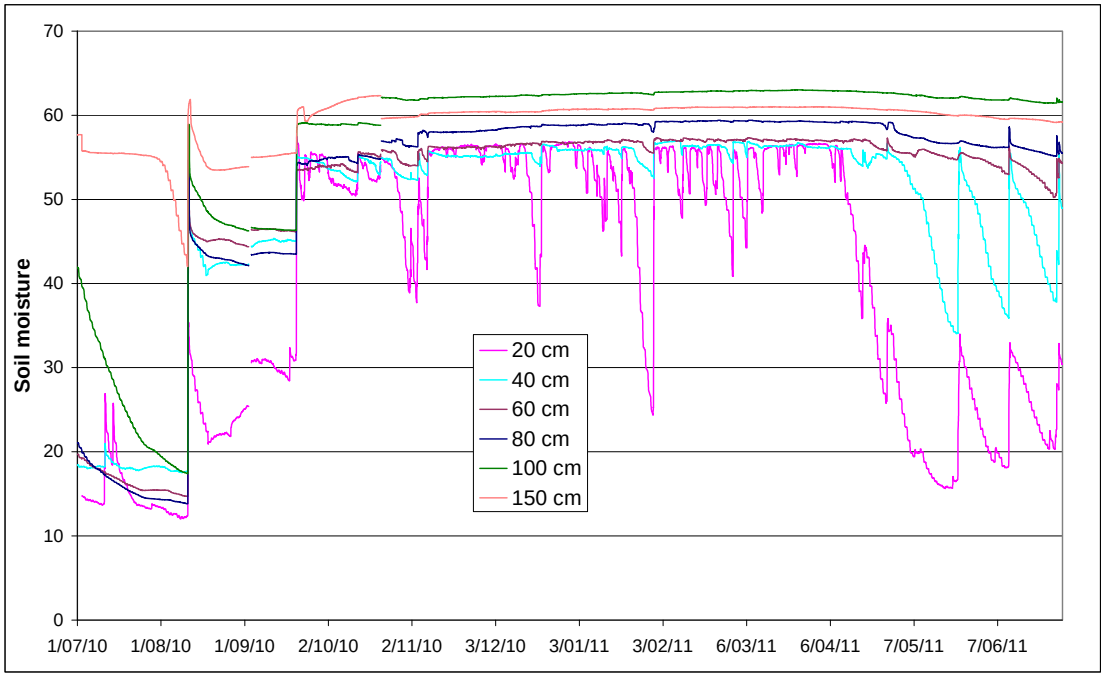


7.1.8 Hexazinone (Treatment 1 only)

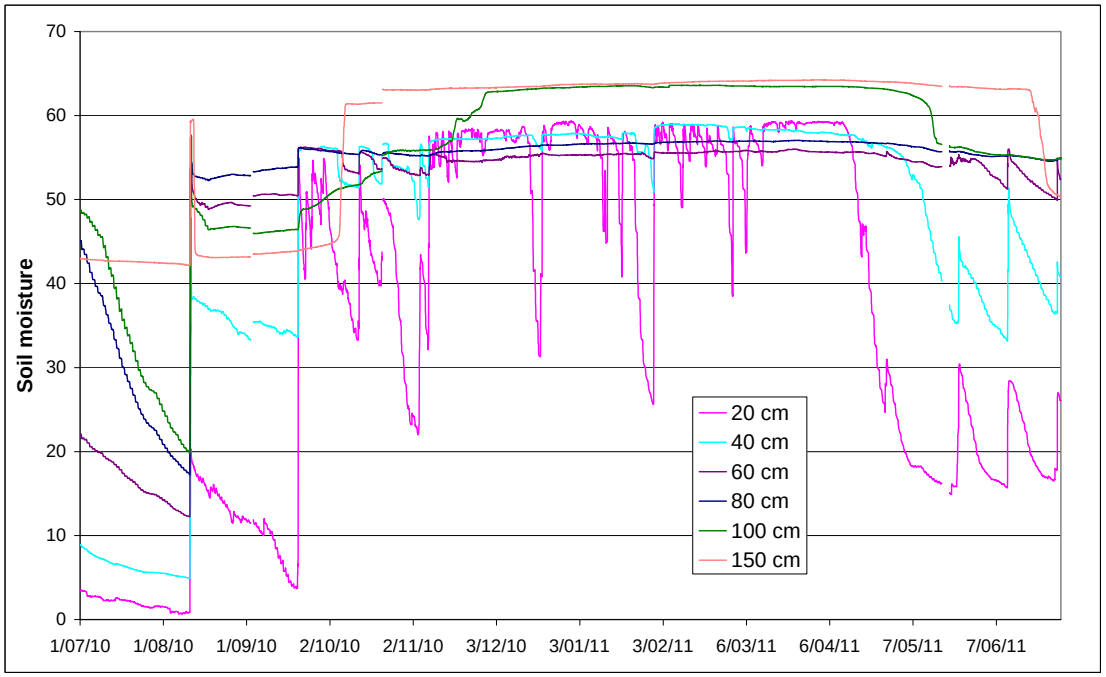


7.2 Soil moisture plots

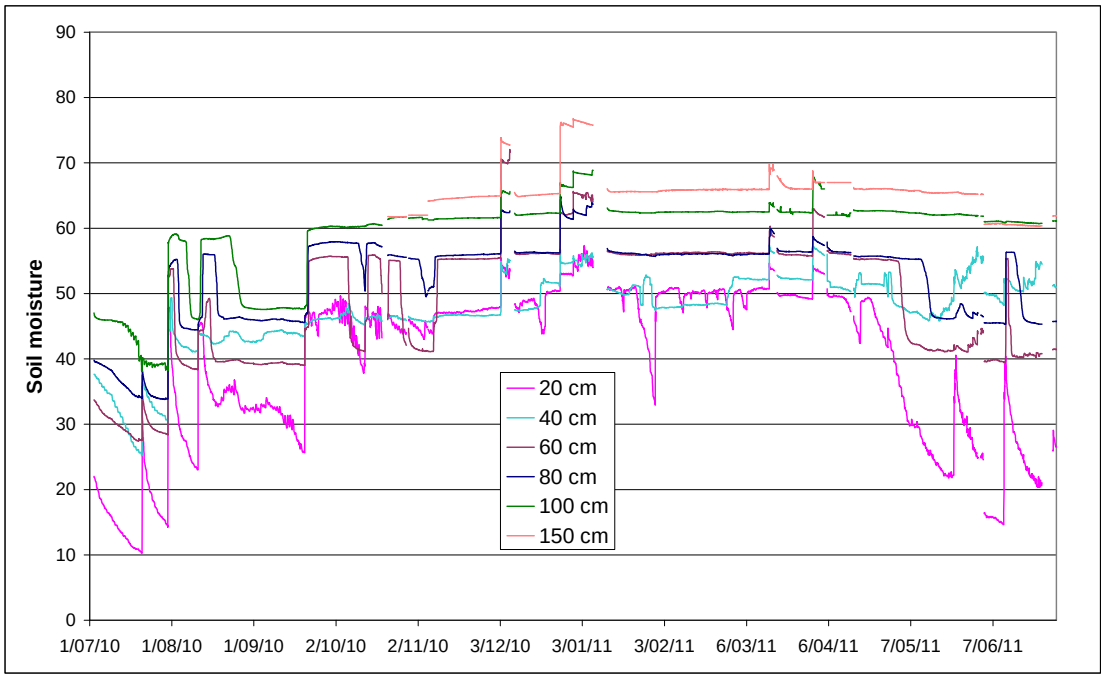
7.2.1 Victoria Plains Treatment 1



7.2.2 Victoria Plains Treatment 2

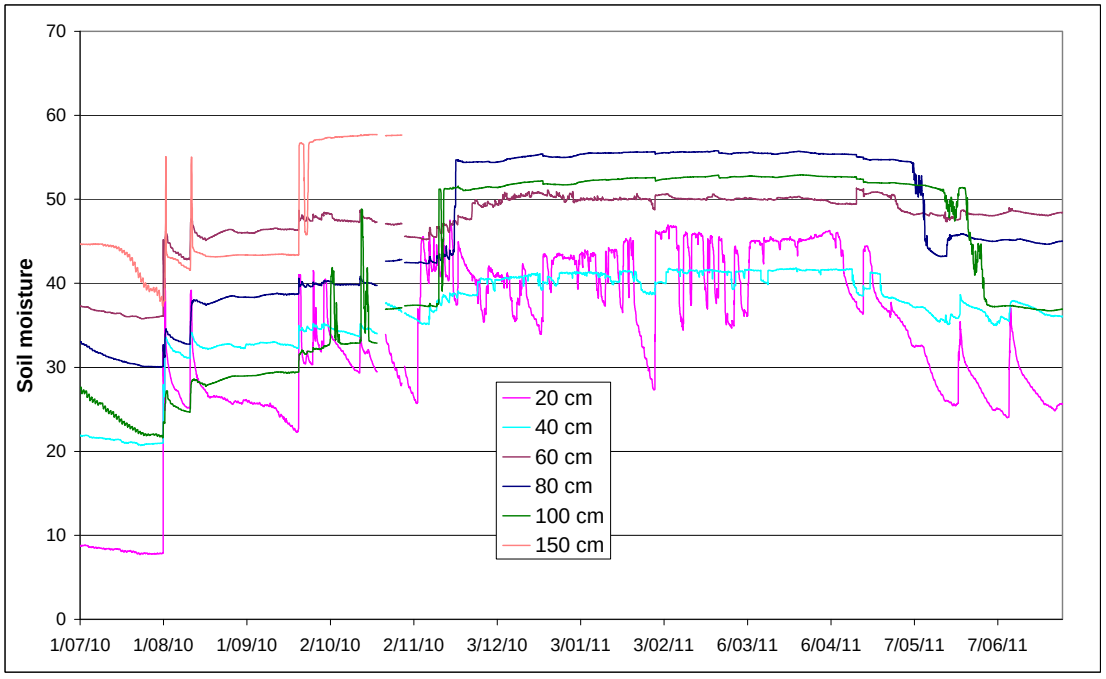


7.2.3 Marian Treatment 1



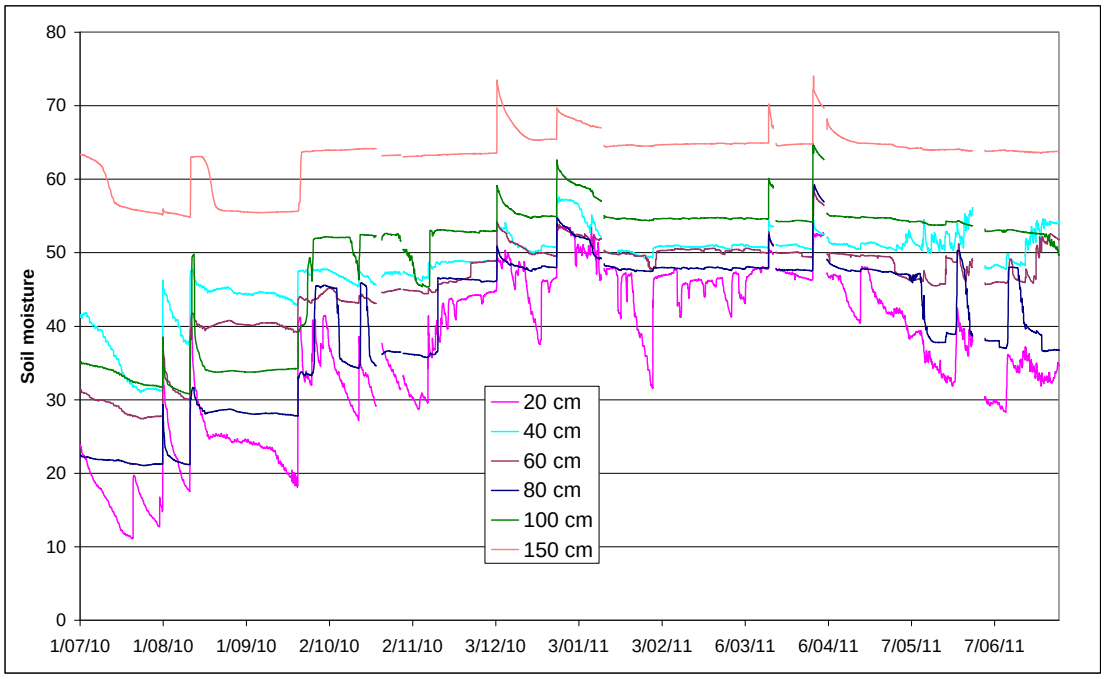
Note: Sensor at 150 cm not working prior to 22nd October 2010. Increases in soil moisture above "normal" values (3rd and 25th December 2010, and 14th and 31st March 2011) are when the site flooded and soil moisture sensors were wet.

7.2.4 Marian Treatment 2



Note: Sensor at 150 cm not working after 28th October 2010

7.2.5 Marian Treatment 5



Note: Increases in soil moisture above "normal" values (3rd and 25th December 2010, and 14th and 31st March 2011) are when the site flooded and soil moisture sensors were wet.