

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

**Final Report
2009/10 to 2011/12 Wet Seasons**

Mackay Whitsunday Region



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Table of Contents

EXECUTIVE SUMMARY	VII
1 INTRODUCTION	1
1.1 REEF PLAN	1
1.2 REEF RESCUE	2
1.3 WATER QUALITY IMPROVEMENT PLANS	2
1.4 PROJECT CATALYST	2
1.5 PADDOCK TO REEF INTEGRATED MONITORING, MODELLING AND REPORTING PROGRAM	3
1.6 PROJECT INTENT	3
2 METHODOLOGY	5
2.1 PADDOCK-SCALE	5
2.1.1 <i>Victoria Plains site</i>	5
2.1.1.1 Management practices	8
2.1.2 <i>Marian site</i>	9
2.1.2.1 Management practices	10
2.1.3 <i>Soil and cane trash sampling</i>	13
2.1.3.1 Soil nutrients	13
2.1.3.2 Soil and cane trash herbicides	13
2.1.3.3 Soil moisture	13
2.1.4 <i>Rainfall, runoff and water quality</i>	14
2.1.5 <i>Drainage water quality</i>	15
2.1.6 <i>Agronomic sampling</i>	15
2.2 MULTI-BLOCK SCALE	16
2.2.1 <i>Management Practices</i>	16
2.2.1.1 Row spacing	17
2.2.1.2 Nutrients	17
2.2.1.3 Herbicides	17
2.3 MULTI-FARM SCALE	17
2.3.1 <i>Management Practices</i>	18
2.3.1.1 Row spacing	18
2.3.1.2 Nutrients	18
2.3.1.3 Herbicides	19
2.4 WATER QUALITY LOAD CALCULATIONS	19
2.5 LABORATORY METHODOLOGIES	20
2.5.1 <i>Soil nutrients</i>	20
2.5.2 <i>Water analyses</i>	20
2.5.2.1 Total suspended solids and turbidity	20
2.5.2.2 Electrical conductivity	20
2.5.2.3 Nutrients	20
2.5.2.4 Herbicides	21
2.5.3 <i>Soil and cane trash analysis</i>	21
2.6 SPATIAL RAINFALL VARIABILITY	21
2.7 DATA MANAGEMENT	21
3 RESULTS	23
3.1 OVERVIEW OF ANNUAL RAINFALL	23
3.2 OVERVIEW OF RUNOFF EVENTS	24
3.2.1 <i>Paddock scale</i>	24
3.2.2 <i>Multi-block and Multi-farm scale</i>	24
3.3 VICTORIA PLAINS SITE	24
3.3.1 <i>Soil nutrients</i>	24
3.3.2 <i>Soil and cane trash herbicides</i>	26
3.3.3 <i>Soil moisture</i>	26
3.3.4 <i>Rainfall and runoff</i>	27
3.3.5 <i>Runoff water quality</i>	28
3.3.5.1 Total suspended solids, turbidity and electrical conductivity	28
3.3.5.2 Nitrogen	32
3.3.5.3 Phosphorus	32

3.3.5.4	Herbicides	33
3.3.6	<i>Drainage water quality</i>	35
3.3.7	<i>Agronomic</i>	35
3.4	MARIAN SITE	36
3.4.1	<i>Soil nutrients</i>	36
3.4.2	<i>Soil and cane trash herbicides</i>	39
3.4.3	<i>Soil moisture</i>	39
3.4.4	<i>Rainfall and runoff water quality</i>	40
3.4.4.1	Total suspended solids, turbidity and electrical conductivity	41
3.4.4.2	Nitrogen	42
3.4.4.3	Phosphorus	43
3.4.4.4	Herbicides	44
3.4.5	<i>Drainage water quality</i>	44
3.4.6	<i>Agronomic</i>	44
3.5	MULTI-BLOCK AND MULTI-FARM SITES	46
3.5.1	<i>Rainfall and runoff</i>	46
3.5.2	<i>Runoff water quality</i>	47
3.5.2.1	Total suspended solids, turbidity and electrical conductivity	47
3.5.2.2	Nitrogen (NO _x -N)	48
3.5.2.3	Phosphorus (FRP)	49
3.5.2.4	Ametryn	50
3.5.2.5	Atrazine	50
3.5.2.6	Diuron	50
3.5.2.7	Hexazinone	51
3.5.2.8	Other pesticides.....	52
4	DISCUSSION	53
4.1	EFFECTS OF ROW SPACING/WHEEL TRAFFIC ON RUNOFF	53
4.2	FACTORS AFFECTING SEDIMENT (TSS) CONCENTRATIONS IN RUNOFF	53
4.3	FACTORS AFFECTING NUTRIENTS IN RUNOFF	54
4.4	FACTORS AFFECTING HERBICIDES IN RUNOFF	55
5	CONCLUSIONS	57
5.1	RECOMMENDATIONS FOR FURTHER RESEARCH.....	59
6	REFERENCES	61
7	APPENDICES	65
7.1	SOIL MOISTURE PLOTS	65
7.1.1	<i>Victoria Plains Treatment 1</i>	65
7.1.2	<i>Victoria Plains Treatment 2</i>	65
7.1.3	<i>Marian Treatment 1</i>	66
7.1.4	<i>Marian Treatment 2</i>	66
7.1.5	<i>Marian Treatment 5</i>	67
7.2	RAINFALL INTENSITY-FREQUENCY-DURATION GRAPH.....	67

List of Figures

Figure 1	Locality map of monitoring sites.....	5
Figure 2	Treatment layout of the Victoria Plains site	6
Figure 3	Treatment layout of the Marian site	10
Figure 4	A 300 mm San Dimas flume (left) and critical design dimensions (right)	15
Figure 5	Annual (October-September) rainfall for the three monitored years.....	23
Figure 6	Soil phosphorus concentrations (KCl extraction; air dry) in the soil profile after each harvest (row/interspace and treatments combined), Victoria Plains site.....	25
Figure 7	Total moisture in the soil profile (0-150 cm), Victoria Plains site	27
Figure 8	Annual rainfall and runoff, Victoria Plains site.....	28
Figure 9	Concentrations of total suspended solids measured in runoff, Victoria Plains site	29
Figure 10	Measured seasonal sediment loads, Victoria Plains site.....	29
Figure 11	Relationship between turbidity and total suspended solids concentration in runoff, Victoria Plains and Marian sites	30
Figure 12	Seasonal runoff loads of urea-N and NO _x -N, Victoria Plains site.....	32
Figure 13	Filterable reactive phosphorus concentrations in runoff, Victoria Plains site	33
Figure 14	Diuron and hexazinone concentrations in runoff from Treatment 1, Victoria Plains site	34
Figure 15	Hexazinone concentrations in runoff from Treatment 1, Victoria Plains site	34
Figure 16	Relationship between surface runoff and drainage soil solution herbicide concentrations in 2010/11 from Treatment 1, Victoria Plains site.....	35
Figure 17	Nitrogen and phosphorus content of the cane stalk prior to harvest of first and second ratoon crops, Victoria Plains site.....	37
Figure 18	Soil phosphorus concentrations (KCl extraction; air dry) in the soil profile following each harvest, Marian site	38
Figure 19	Total moisture in the soil profile (0-150 cm), Marian site.....	40
Figure 20	Box plot of concentrations of total suspended solids in runoff, Marian site	41
Figure 21	Scatter plot of concentrations of total suspended solids in runoff, Marian site	42
Figure 22	Concentrations of NO _x -N in runoff, Marian site	43
Figure 23	Filterable reactive phosphorus concentrations in runoff, Marian site.....	44
Figure 24	Nitrogen and phosphorus content of the cane stalk prior to harvest of first and second ratoon crops, Marian site	46
Figure 25	Concentrations of TSS in runoff, Multi-block and Multi-farm sites	47
Figure 26	Relationship between turbidity and TSS concentration, Multi-farm site	48
Figure 27	Concentrations of NO _x -N in runoff, Multi-block and Multi-farm sites.....	49
Figure 28	Filterable reactive phosphorus concentrations in runoff, Multi-block and Multi-farm sites	50
Figure 29	Concentrations of a) ametryn, b) atrazine, c) diuron and d) hexazinone in runoff, Multi-block and Multi-farm sites	51

List of Tables

Table 1	Selected soil properties at different depths for the Victoria Plains site	7
Table 2	Selected soil properties at different depths for the Marian site	7
Table 3	Summary of treatments applied at the Victoria Plains site	8
Table 4	Application of nutrient treatments to the Victoria Plains site	8
Table 5	Application of herbicide treatments to the Victoria Plains site.....	9
Table 6	Summary of treatments applied at the Marian site	10
Table 7	Application of nutrient treatments to the Marian site	11
Table 8	Application of herbicide treatments to the Marian site	12
Table 9	Summary of post-application soil and cane trash herbicide sampling, Victoria Plains and Marian sites	13
Table 10	Discharge equations used at the Multi-block site	16
Table 11	Average fertiliser application rates applied in the Multi-block sub-catchment for the three monitored seasons.....	17
Table 12	Discharge equations used at the Multi-farm site.....	18
Table 13	Average fertiliser application rates and total amount applied in the Multi-farm sub-catchment for the three monitored seasons.....	19
Table 14	Amount of ametryn, atrazine, diuron and hexazinone applied to the Multi-farm sub-catchment for each of the monitored seasons	19
Table 15	Soil nitrate-N and ammonium-N concentrations post-harvest of the plant cane, first ratoon and second ratoon cane crops, Victoria Plains site	25
Table 16	Calculated field dissipation half-lives (days) of diuron, hexazinone and imazapic on cane trash and surface soil (0-2.5 cm), Victoria Plains site	26
Table 17	Calculated loads of sediment and nutrients from runoff, Victoria Plains site.....	31
Table 18	Calculated loads of herbicides from Treatment 1 runoff, Victoria Plain site	31
Table 19	Machine harvest yield results, Victoria Plains site	36
Table 20	Calculated field dissipation half-lives (days) of applied herbicides on cane trash and surface soil (0-2.5 cm), Marian site.....	39
Table 21	Machine harvest yield results for each treatment, Marian site.....	45
Table 22	Seasonal rainfall, runoff and TSS loads and concentrations during the monitored wet seasons, Multi-farm site	47
Table 23	Calculated loads of nutrients from runoff, Multi-farm site.....	48
Table 24	Seasonal loads and concentrations of herbicides from runoff, Multi-farm site	52

EXECUTIVE SUMMARY

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

To achieve the water quality targets in the plan, investments were made through Reef Rescue, industry organisations and voluntarily by sugarcane growers and other landholders to improve management practices at a farm scale. Thus, it was 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* uses multiple lines of evidence to report on the effectiveness of these investments and whether targets are being met (Carroll *et al.* 2012). One of these lines of evidence is practice effectiveness in improving water quality at the paddock (edge-of-field) scale.

Under the P2R program, paddock scale monitoring of water quality from various levels of management practices was implemented in selected GBR catchments and agricultural industries (Carroll *et al.* 2012). As part of this program and in conjunction with *Project Catalyst*, monitoring was also undertaken at Multi-block and Multi-farm scales.

Two sugarcane farms in the Mackay Whitsunday region were selected for the paddock scale monitoring. Sampling for sediment, nutrient and herbicide concentrations in runoff were undertaken. Different sugarcane management strategies were investigated, with the emphasis on improving water quality with improved management practices.

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

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

¹ – ABCD classifications for soil/sediment, nutrients and herbicides, respectively

² – Farm-specific nutrient management plan designed by BSES

³ – Herbicides identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

⁴ – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

For the Multi-block and Multi-farm scales, two additional sites 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 total (unfiltered) herbicides).

Results from the three years of monitoring (2009/10 to 2011/12 season) are outlined for each site below.

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

- Total runoff from individual runoff events from Treatment 2 (1.8 m row spacing) averaged 14.5% less than Treatment 1 (1.5 m row spacing) (3232 mm and 3781 mm, respectively; or 42% and 49% of rainfall). Runoff from Treatment 2 was delayed on average by ~17 minutes compared with Treatment 1, and the peak runoff rate was ~18% lower, all contributing to reduced runoff.
- Total suspended solids (TSS) concentrations were slightly higher in Treatment 2, but concentrations at both sites reduced each season: 631-826 mg/L (excluding 3000 mg/L from Treatment 1) in the plant cane phase (cultivated) to 22-24 mg/L in the second ratoon (green cane trash blanket).
- Excluding 2009/10 (unexplained treatment variability), total estimated wet season soil loss was also slightly higher in Treatment 2, but both treatments also reduced from plant cane (~3 t/ha) to second ratoon (~0.3 t/ha).
- Initial nitrogen concentrations in runoff are dependent on the amount applied and period of time between application and first runoff. In the first two seasons, ~10% of the applied nitrogen (as NO_x-N and/or urea-N) was lost in runoff when soil nitrate concentrations were high (2009/10 season), or when runoff occurred within three days of application (2010/11 season). Runoff losses in 2011/12 were much lower (~1% of applied nitrogen) when runoff first occurred 78 days after fertiliser application.
- Filterable reactive phosphorus (FRP) concentrations in runoff were similar between treatments due to similar rates of phosphorus applied. Median concentrations tended to increase each season, reflecting the increasing soil phosphorus levels and possible over-application of phosphorus. However, these concentrations (runoff and soil) were much lower than the Marian site.
- The calculated half-lives of diuron, hexazinone and imazapic varied with each season. In 2010/11, much shorter half-lives (by more than half) were measured on trash when 1090 mm of rain fell within 100 days of application (compared with 98 mm in 2011/12). In contrast, soil herbicide half-lives were much longer (~1.3-3 times), due to the extreme rainfall in the 2010/11 season “trickle feeding” the surface soil (after being washed from the trash).
- Timing of rainfall after herbicide application was a critical factor in seasonal runoff losses of herbicides. In the 2010/11 season, 12% of the applied diuron (and 18% for hexazinone) was lost in runoff when the first event occurred seven days after application. This was reduced to <0.5% in 2011/12 when the first runoff occurred 128 days after herbicide application.
- Imazapic has only been detected in one runoff sample (1 µg/L), although analyses did not occur until part way through the 2010/11 season. As a result, no loads can be calculated.

- Machine harvest yield results show an average 7% lower cane yield from Treatment 2, despite receiving 41% less nitrogen. As a result, there was no difference in net economic return.

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

- Total suspended solids concentrations varied with cover and cultivation: 36-330 mg/L (average 127 mg/L) in 2009/10 (initially bare plant cane); 23-1100 mg/L (average 289 mg/L) in 2010/11 (burnt cane and one cultivation); and 13-140 mg/L (average 40 mg/L) in 2011/12 (green cane trash blanket).
- Concentrations of NO_x-N (median and maxima) in rainfall runoff were highest in the 2010/11 season when runoff was first recorded 16 days after nutrient application (102-105 days for other seasons). Similar to the Victoria Plains site, NO_x-N concentrations were highest in the first runoff events after application, and then declined as the season progressed. Across the three seasons, Treatment 5 (1.8 m skip row, Six Easy Steps) had the highest median NO_x-N concentration (151 µg N/L), thought to be due in part to nutrients being applied to the skip area and no peanut crop planted (although it was planned) to uptake the nutrients and supply additional nitrogen. The median concentration of other treatments were consistent (80-93 µg N/L), except for Treatment 1 (150 µg N/L). In contrast to rainfall runoff, the samples collected from the irrigation runoff on 13th May 2012 had relatively high NO_x-N concentrations (4037-4505 µg N/L; 242 days after nutrient application).
- Seasonal median filterable reactive phosphorus (FRP) concentrations tended to increase for Treatments 1 and 2 (where 20 kg/ha of phosphorus was applied each season) and remained steady for Treatments 3-5 (when no phosphorus was applied other than at cane planting). When data from the three seasons was combined, treatment medians were similar (362-416 µg P/L), except Treatment 2 (645 µg P/L). These concentrations are much higher than the Victoria Plains site due to the higher soil phosphorus concentrations.
- Interpreting herbicide runoff concentrations across the three seasons is difficult, due to the different products used each season. As with the Victoria Plains site, herbicide concentrations were highest in the initial runoff events following application, but maximum concentrations have been lower.
- There was very little difference in the cane yield of Treatments 1-4 during the first two years (plant cane and first ratoon). In the third year (second ratoon), the cane yield of Treatment 4 (N replacement) was reduced due to the low nitrogen application rate. The cane yield of Treatment 3 (Six Easy Steps) was also lower than Treatments 1 and 2, possibly due to the lower nitrogen application rate and/or no phosphorus applied. Treatment 5 (skip row, Six Easy steps) yielded ~70% of solid plant (Treatment 3) in “reasonable” seasons (plant cane and second ratoon crops), but only yielded 50% in the wet year (first ratoon crop).

At the Multi-block and Multi-farm sites:

- Total runoff for the three seasons from the Multi-farm site was 2765 mm (average 922 mm/year), or 36% of rainfall. Determining accurate volumes of runoff (and therefore water quality loads) at the Multi-block site are not possible due to flooding issues.
- Concentrations of total suspended solids (TSS) were low and consistent across the three seasons (generally <70 mg/L, except for 160 mg/L in the first runoff event of

the 2010/11 season). At the Multi-farm site, TSS concentrations were higher and tended to increase each season.

- Average estimated seasonal sediment yield for the Multi-farm catchment was 1128 kg/ha, with a flow-weighted mean concentration of 122 mg/L.
- Similar to the paddock sites, the highest NO_x-N concentrations were recorded in the first sample of every season. The average seasonal NO_x-N load from the Multi-farm site was 2.0 kg/ha, with a flow-weighted seasonal concentration of 221 µg N/L.
- Filterable reactive phosphorus (FRP) concentrations at the Multi-block site were consistently higher (~3 times) than those of the Multi-farm site. Similar to the paddock data, this may reflect the variable phosphorus levels in the surface soil. The average seasonal FRP loss in runoff at the Multi-farm site was 1.1 kg/ha, with a flow-weighted seasonal average of 123 µg P/L.
- Herbicide residue concentrations were variable between the two sites, which may be a reflection of the different periods of application (and the products applied) between the two catchments.

In summary, results from the three seasons show similar trends between treatments and sites, although concentrations vary (mainly due to the period from application to first runoff). The presence of a green cane trash blanket results in an approximate ten-fold decrease in suspended sediment losses compared to cultivated plant cane. 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.

Recommendations for further research

Due to on-going seasonal flooding issues, the runoff and water quality monitoring equipment from the Marian and Multi-block sites have already been removed. Given that the Victoria Plains and Multi-farm sites continue to function adequately in the wet seasons experienced, it is recommended that these sites continue to be funded. Other recommendations include the following:

- Continue the agronomic treatments at the Marian site through a full cane cycle to identify continuing treatment responses (or otherwise). No further water quality monitoring will be undertaken at this site.
- Continuing the Victoria Plains site will allow the monitoring of a full cane cycle, and then the opportunity to undertake various fallow management treatments (including presence/absence of legumes and/or cultivation) before entering the next cane cycle. This will include runoff and water quality monitoring, and other data sets for modeling.
- Continued monitoring of water quality at the Multi-farm site and management practice adoption within the catchment over the coming seasons will hopefully identify improved water quality due to improved management within the catchment.
- These sites are all contained within the Sandy Creek catchment, which also contains a catchment monitoring site. If a marine monitoring site was located near the mouth of Sandy Creek, this will allow a nested catchment approach to monitoring management practice adoption and resulting water quality from a paddock to marine scale.

1 INTRODUCTION

Several water quality studies in the past decade have focused on quantifying the pollutants generated by the major land uses within the Great Barrier Reef (GBR) catchments. Sugarcane farming has been found to export high concentrations (compared to “natural” sites) of dissolved inorganic nitrogen (DIN or $\text{NO}_x\text{-N}$, 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 farming land-use (Bainbridge *et al.* 2009, Rohde *et al.* 2008, Faithful *et al.* 2006, Lewis *et al.* 2009). Sediment fluxes from sugarcane farming land-use 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” to guide Reef Rescue investments and to advise industry.

The following sections outline some of the planning and funding initiatives that have been implemented within the Great Barrier Reef catchments to improve water quality.

1.1 Reef Plan

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

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

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

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

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

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

1.2 Reef Rescue

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

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

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. In 2012, *Project Catalyst* had 27 cane growers adopting A class management practices in the Mackay Whitsunday region (<http://projectcatalyst.net.au/>) and 73 cane growers in total throughout the GBR catchment (<http://reefcatchments.com.au/land/project-catalyst/>). In the future, *Project Catalyst* aims to translate the experience gained from the GBR catchment to the global sugar industry. *Project Catalyst* has part-funded the work undertaken in this report.

1.5 Paddock to Reef Integrated Monitoring, Modelling and Reporting Program

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

1.6 Project Intent

The purpose of this Mackay Whitsunday region project as part of the P2R Program was 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 involved collaboration between the Department of Natural Resources and Mines, Mackay Area Productivity Services (MAPS), Reef Catchments (Mackay Whitsunday Isaac) Limited and individual cane farmers.

This report outlines the three wet seasons (2009/10, 2010/11 and 2011/12) 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 were three monitoring scales from the plot (paddock) to sub-catchment (multi-farm) scale. These included management treatment plots at the paddock scale; a multi-block scale site and a multi-farm scale site (Figure 1). There were seven treatments at the paddock scale – two treatments at the Victoria Plains site and five at the Marian site. All sites were 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° 11' 3"S 148° 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).

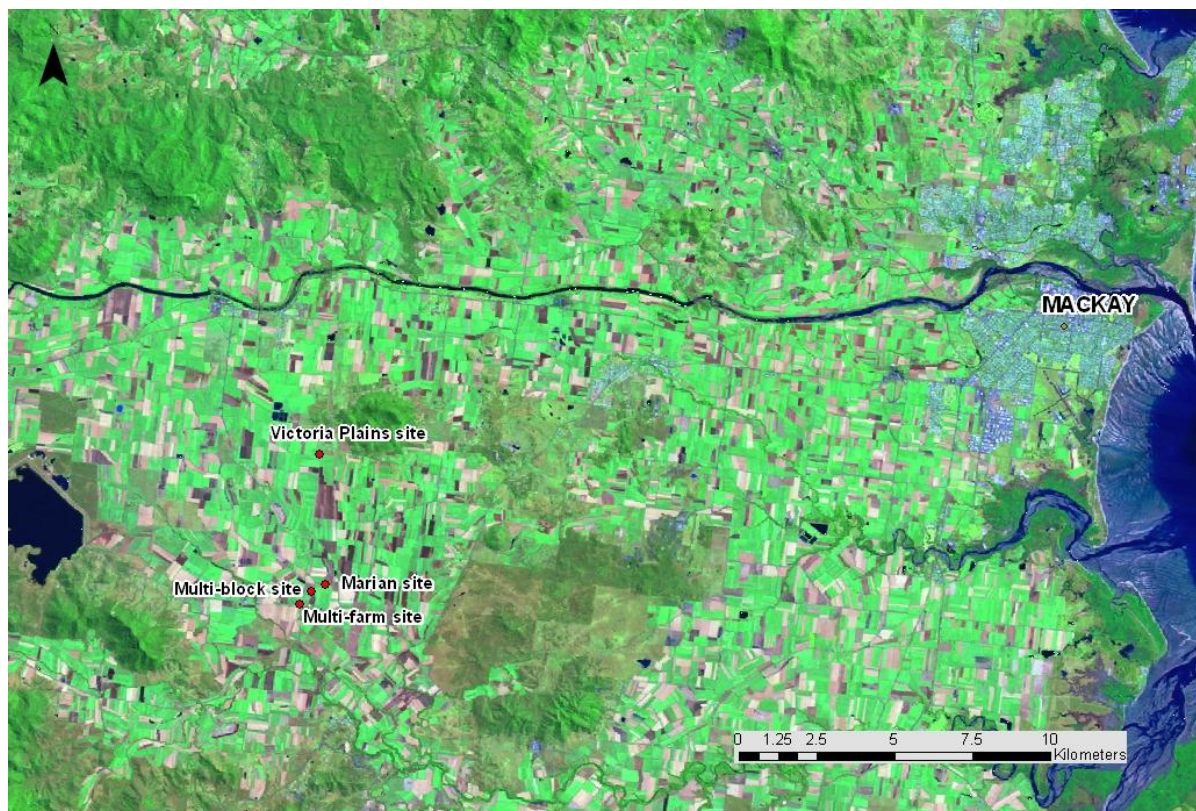


Figure 1 Locality map of monitoring sites

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 (Table 1) 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 (Figure 2; Table 3) of 30 rows. Row length across the entire block ranged from approximately 225-300 m.

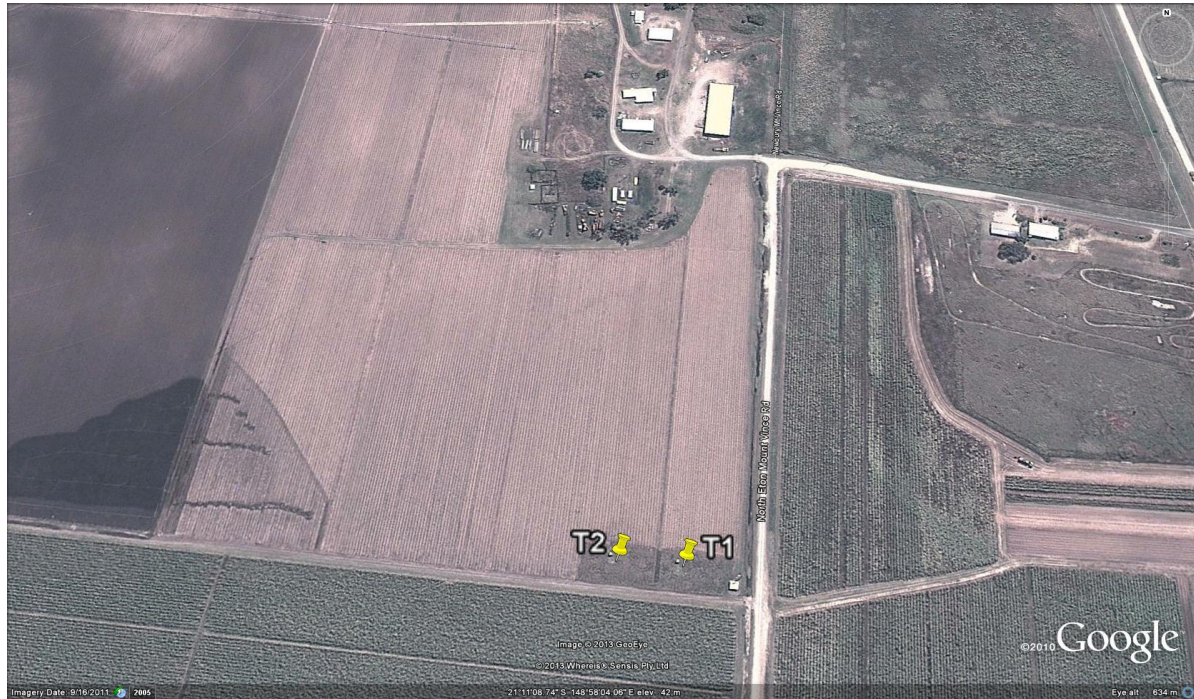


Figure 2 Treatment layout of the Victoria Plains site

Table 1 Selected soil properties at different depths for the Victoria Plains site

(Note: Data averaged across the two treatments)

Depth	pH	EC (dS/m)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	CEC (meq/100g)	Nitrate-N (mg/kg) NO ₃ -N	Phosphorus (mg/kg) P bicarb Colwell*	Total Organic Carbon (%)	Cl ⁻ (mg/kg)
0-0.1m	5.85	0.14	5.0	23.5	24.0	50.5	40.5	37.0	20	2.56	47.5
0.2-0.3m	6.05	0.08	4.5	24.0	24.5	53.0	41.5	21.5		1.99	25.0
0.5-0.6m	6.95	0.07	4.5	20.5	21.5	57.5	43.0	6.0		1.32	25.0
0.8-0.9m	7.80	0.07	3.5	20.5	20.0	60.5	44.5	1.75		0.87	33.5
1.1-1.2m	8.40	0.27	5.0	18.5	20.5	59.5	43.5	1.0		0.60	43.5
1.4-1.5m	8.50	0.26	6.5	17.0	21.0	58.5	39.0	<1		0.35	61.5

* Surface Bulk

Table 2 Selected soil properties at different depths for the Marian site

(Note: Data averaged across the five treatments)

Depth	pH	EC (dS/m)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	CEC (meq/100g)	Nitrate-N (mg/kg) NO ₃ -N	Phosphorus (mg/kg) P bicarb Colwell*	Total Organic Carbon (%)	Cl ⁻ (mg/kg)
0-0.1m	6.70	0.13	27.2	42.4	14.4	19.6	12.2	13.2	95	1.35	83.8
0.2-0.3m	6.88	0.09	28.4	38.8	12.0	24.2	10.0	5.3		0.86	47.2
0.5-0.6m	7.74	0.12	25.8	32.8	7.2	37.8	13.8	<1		0.34	43.2
0.8-0.9m	7.90	0.14	23.0	40.0	7.0	34.0	13.4	<1		0.20	56.0
1.1-1.2m	7.94	0.12	22.6	35.6	10.2	34.6	15.4	<1		0.13	65.8
1.4-1.5m	8.02	0.12	22.4	35.8	14.8	30.2	15.0	<1		<0.15	71.0

* Surface Bulk

Table 3 Summary of treatments applied at the Victoria Plains site

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

¹ – ABCD classifications for soil/sediment, nutrients and herbicides, respectively

² – Farm-specific nutrient management plan designed by BSES

³ – Herbicides identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

⁴ – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

2.1.1.1 Management practices

After the soybean legume fallow crop was sprayed out, both treatments were cultivated (off-sets, ripper and rotary hoe) prior to cane being planted on 2nd August 2009. A number of in-crop cultivations (cutaway, hilling up and filling in) were undertaken in each treatment following cane planting. After the plant cane was harvested (3rd September 2010), no cultivation was undertaken and the green cane trash blanket remained on the soil surface (including the first and second ratoon crops; harvest dates 10th August 2011 and 17th October 2012). Nutrients and herbicides applied to each treatment are shown in Table 4 and Table 5, respectively.

Table 4 Application of nutrient treatments to the Victoria Plains site

Date	Product (amount applied)	Nutrient analysis (%)				Nutrient applied (kg/ha)			
		N	P	K	S	N	P	K	S
Treatment 1									
02/08/09	DAP (210 kg/ha)	18	20	0	2	38	42	0	4
06/10/09	Urea (207 kg/ha)	46	0	0	0	95	0	0	0
17/09/10	BKN 230 (3300 kg/ha)	6.05	0.79	2.57	0.85	200	26	85	28
14/10/11	BKN200 (3800 kg/ha)	5.28	0.79	2.6	0.94	200	30	99	36
	Total					533	98	184	68
	Annual average					178	33	61	23
Treatment 2									
02/08/09	DAP (210 kg/ha)	18	20	0	2	38	42	0	4
17/09/10	Liquid Pre-plant (3200 kg/ha)	4.27	0.8	2.66	0.7	136	25	80	29
14/10/11	PMR2 (3800 kg/ha)	3.66	0.68	2.69	1.16	139	26	102	44
	Total					313	93	182	77
	Annual average					104	31	61	26

Table 5 Application of herbicide treatments to the Victoria Plains site

Date	Product (amount applied)	Active ingredients (amount applied)	Comments
Treatment 1			
17/01/10	Velpar K4 (4 kg/ha)	diuron (1872 g/ha) hexazinone (528 g/ha)	Directed interspace
	Gramoxone 250 (1 L/ha)	paraquat (250 g/ha)	Directed interspace
	Baton (0.7 kg/ha)	2,4-D amine (560 g/ha)	Directed interspace
	MCPA (1.5 L/ha)	MCPA (938 g/ha)	Blanket application
	Starane (0.5 L/ha)	fluroxypyr (200 g/ha)	Blanket application
13/09/10	Velpar K4 (3.8 kg/ha)	diuron (1778 g/ha)	Blanket application
		hexazinone (502 g/ha)	
22/08/11	Bobcat (3.8 kg/ha)	diuron (1778 g/ha)	Blanket application
		hexazinone (502 g/ha)	
	Gramoxone 250 (0.5 L/ha)	paraquat (125 g/ha)	Blanket application
Treatment 2			
17/01/10	Gramoxone 250 (1 L/ha)	paraquat (250 g/ha)	Directed interspace
	Baton (0.7 kg/ha)	2,4-D amine (560 g/ha)	Directed interspace
	MCPA (1.5 L/ha)	MCPA (938 g/ha)	Blanket application
	Starane (0.5 L/ha)	fluroxypyr (200 g/ha)	Blanket application
13/09/10	Flame (0.4 L/ha)	imazapic (96 g/ha)	Blanket application
22/08/11	Flame (0.4 L/ha)	imazapic (96 g/ha)	Blanket application
	Gramoxone 250 (0.5 L/ha)	paraquat (125 g/ha)	Blanket application

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 (Table 2) can be found in the 2009/10 report (Rohde and Bush 2011).

Prior to cane being planted in August 2009 (when row spacing treatments were established), this block was in its final ratoon from a previous cane rotation which was subsequently ploughed out and replanted, with no fallow. Trash from the previous cane crop was burnt before replanting for ease of cultivation. This is not representative of current cane practice in the Mackay region with most growers choosing to undertake a fallow period or a nitrogen fixing crop rotation prior to planting; however suitable sites for this study were limited. The block was divided into five treatments (Figure 3; Table 6) of 18 rows each with an approximate row length of 260 m.

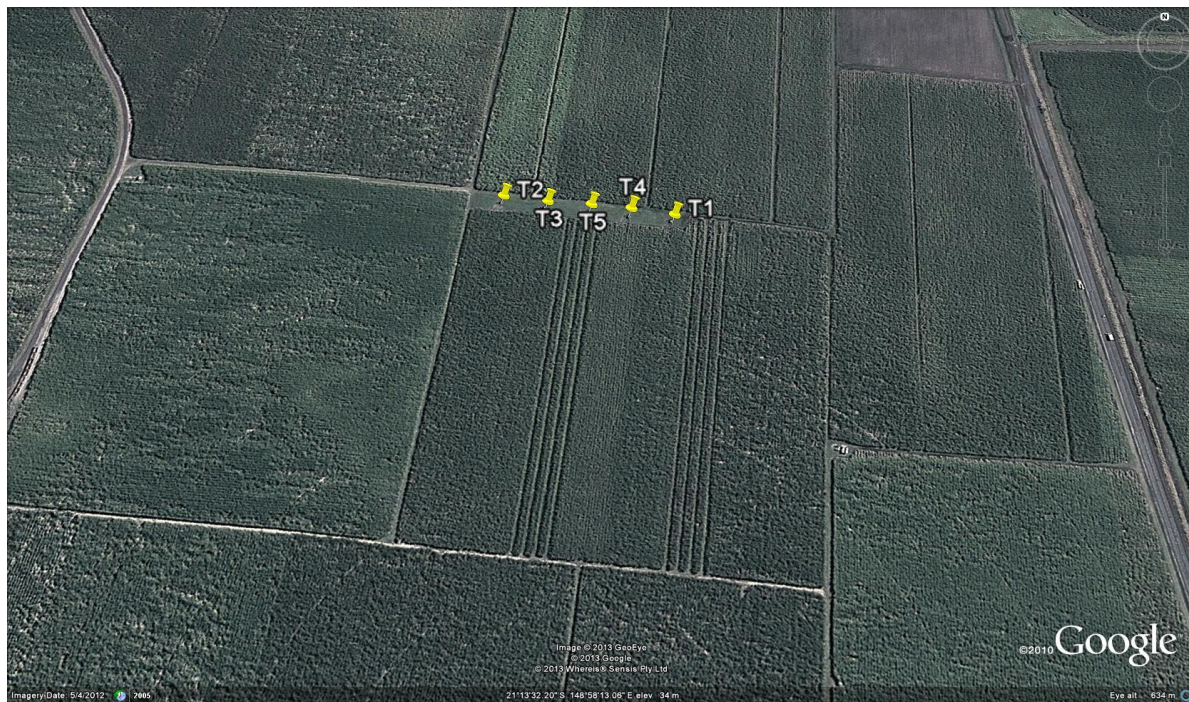


Figure 3 Treatment layout of the Marian site

Table 6 Summary of treatments applied at the Marian site

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

¹ – ABCD classifications for soil/sediment, nutrients and herbicides, respectively

² – Farm-specific nutrient management plan designed by BSES

³ – Herbicides identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

⁴ – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

2.1.2.1 Management practices

Prior to cane planting for this trial (15th August 2009), the site was cultivated (off-sets, ripper and rotary hoe). After planting, in-crop cultivation included cutaway, weeder rake and hilling up. The only other cultivation (multiweeder on 30th October 2010) was after the plant cane was burnt and harvested. The second ratoon cane crop was harvested green and the trash blanket left on the soil surface. Harvest dates were 29th October 2010 (plant cane), 30th August 2011 (first ratoon) and 18th September 2012 (second ratoon). Nutrients and herbicides applied to each treatment are shown in Table 7 and Table 8, respectively.

Table 7 Application of nutrient treatments to the Marian site

Date	Product (amount applied)	Nutrient analysis (%)				Nutrient applied (kg/ha)			
		N	P	K	S	N	P	K	S
Treatments 1 and 2									
15/08/09	DAP (250 kg/ha)	18	20	0	2	45	50	0	5
15/10/09	Custom (538 kg/ha)	27.1	0	16.5	3.4	146	0	89	18
18/11/09	Muriate of potash (70 kg/ha)	0	0	50	0	0	0	35	0
03/11/10	LOS+P (4200 kg/ha)	4.69	0.48	2.6	0.65	197	20	110	25
26/01/11	Ammonium sulfate (300 kg/ha)	20.2	0	0	24	61	0	0	72
14/09/11	LOS+P (4200 kg/ha)	4.69	0.48	2.6	0.65	197	20	110	25
	Total					646	90	344	145
	Annual average					215	30	115	48
Treatment 3									
15/08/09	DAP (250 kg/ha)	18	20	0	2	45	50	0	5
15/10/09	Custom (469 kg/ha)	27.1	0	16.5	3.4	127	0	77	16
18/11/09	Muriate of potash (70 kg/ha)	0	0	50	0	0	0	35	0
03/11/10	MKY170 (4200 kg/ha)	3.78	0	2.73	0.44	159	0	115	18
26/01/11	Ammonium sulfate (300 kg/ha)	20.2	0	0	24	61	0	0	72
14/09/11	MKY170 (4200 kg/ha)	3.78	0	2.74	0.41	159	0	115	17
	Total					551	50	342	128
	Annual average					184	17	114	43
Treatment 4									
15/08/09	DAP (250 kg/ha)	18	20	0	2	45	50	0	5
15/10/09	Custom (100 kg/ha)	27.1	0	16.5	3.4	27	0	17	3
15/11/09	Granam (125 kg/ha)	20.2	0	0	24	25	0	0	30
03/11/10	Liquid 50:50 (4100 kg/ha)	2.9	0	2.78	0.39	119	0	114	16
26/01/11	Ammonium sulfate (300 kg/ha)	20.2	0	0	24	61	0	0	72
15/09/11	MKY70 (3300 kg/ha)	1.61	0	2.84	0.34	53	0	64	11
	Total					330	50	195	137
	Annual average					110	17	65	46
Treatment 5									
15/08/09	DAP (250 kg/ha)	18	20	0	2	45	50	0	5
15/10/09	Custom (439 kg/ha)	27.1	0	16.5	3.4	119	0	72	15
18/11/09	Muriate of potash (70 kg/ha)	0	0	50	0	0	0	35	0
03/11/10	MKY170 (4200 kg/ha)	3.78	0	2.73	0.44	159	0	115	18
26/01/11	Ammonium sulfate (300 kg/ha)	20.2	0	0	24	61	0	0	72
14/09/11	MKY170 (4200 kg/ha)	3.78	0	2.74	0.41	159	0	115	18
	Total					543	50	337	128
	Annual average					181	17	112	43

Table 8 Application of herbicide treatments to the Marian site

Date	Product (amount applied)	Active ingredients (amount applied)	Comments
Treatment 1 and 2			
30/08/09	Hero (150 g/ha)	ethoxysulfuron (90 g/ha)	Blanket application
28/10/09	Amicide 625 (1 L/ha)	2,4-D amine (625 g/ha)	Blanket application
30/10/09	Atradex 900 (2.2 kg/ha)	atrazine (1980 g/ha)	Directed interspace
	Diurex 900 (2.2 kg/ha)	diuron (1980 g/ha)	Directed interspace
26/01/11	Atradex 900 (2 kg/ha)	atrazine (1800 g/ha)	Directed interspace
	Gramoxone 250 (1.2 L/ha)	paraquat (300 g/ha)	Directed interspace
	Amicide 625 (1 L/ha)	2,4-D amicide (625 g/ha)	Directed interspace
13/10/11	Gramoxone 250 (0.5 L/ha)	paraquat (125 g/ha)	Shielded sprayer
28/11/11	Gramoxone 250 (1 L/ha)	paraquat (250 g/ha)	Directed interspace
	Amicide 625 (1 L/ha)	2,4-D amicide (625 g/ha)	Blanket application
	Velpar K4 (2 kg/ha)	diuron (936 g/ha)	Directed interspace
		hexazinone (264 g/ha)	Directed interspace
Treatment 1 only			
14/12/10	Actril DS (1 L/ha)	2,4-D ester (577 g/ha)	Directed interspace
		ioxynil (100 g/ha)	Directed interspace
	Asulox (6 L/ha)	asulam 2400 g/ha)	Directed interspace
Treatment 3			
30/08/09	Hero (150 g/ha)	ethoxysulfuron (90 g/ha)	Blanket application
28/10/09	Amicide 625 (1 L/ha)	2,4-D amine (625 g/ha)	Blanket application
30/10/09	Dual Gold	s-metolachlor (1152 g/ha)	Directed interspace
26/01/11	Gramoxone 250 (1.2 L/ha)	paraquat (300 g/ha)	Directed interspace
	Amicide 625 (1 L/ha)	2,4-D amicide (625 g/ha)	Directed interspace
13/10/11	Gramoxone 250 (0.5 L/ha)	paraquat (125 g/ha)	Shielded sprayer
28/11/11	Balance (0.12 kg/ha)	isoxaflutole (90 g/ha)	Directed interspace
	Gramoxone 250 (1 L/ha)	paraquat (250 g/ha)	Directed interspace
	Amicide 625 (1 L/ha)	2,4-D amicide (625 g/ha)	Directed interspace
Treatment 4			
30/08/09	Hero (150 g/ha)	ethoxysulfuron (90 g/ha)	Blanket application
28/10/09	Amicide 625 (1 L/ha)	2,4-D amine (625 g/ha)	Blanket application
19/02/10	MCPA 625 (1 L/ha)	MCPA (625 g/ha)	Aerial application
	Starane 400 (0.3 L/ha)	fluroxypyr (120 g/ha)	Aerial application
26/01/11	Gramoxone 250 (1.2 L/ha)	paraquat (300 g/ha)	Directed interspace
	Amicide 625 (1 L/ha)	2,4-D amicide (625 g/ha)	Directed interspace
13/10/11	Gramoxone 250 (0.5 L/ha)	paraquat (125 g/ha)	Shielded sprayer
28/11/11	Gramoxone 250 (1 L/ha)	paraquat (250 g/ha)	Directed interspace
	Amicide 625 (1 L/ha)	2,4-D amicide (625 g/ha)	Directed interspace
Treatment 5			
30/08/09	Hero (150 g/ha)	ethoxysulfuron (90 g/ha)	Blanket application
28/10/09	Amicide 625 (1 L/ha)	2,4-D amine (625 g/ha)	Blanket application
19/02/10	MCPA 625 (1 L/ha)	MCPA (625 g/ha)	Aerial application
	Starane 400 (0.3 L/ha)	fluroxypyr (120 g/ha)	Aerial application
26/01/11	Gramoxone 250 (1.2 L/ha)	paraquat (300 g/ha)	Directed interspace
	Amicide 625 (1 L/ha)	2,4-D amicide (625 g/ha)	Directed interspace
13/10/11	Gramoxone 250 (0.5 L/ha)	paraquat (125 g/ha)	Shielded sprayer
28/11/11	Gramoxone 250 (1 L/ha)	paraquat (250 g/ha)	Directed interspace
	Amicide 625 (1 L/ha)	2,4-D amicide (625 g/ha)	Directed interspace
	Spinnaker (140 g/ha)	imazethapyr (98 g/ha)	Skip zone only
	Verdict (0.15 L/ha)	haloxyfop (78 mL/ha)	Skip zone only

2.1.3 Soil and cane trash sampling

2.1.3.1 Soil nutrients

Soil profile samples were collected to 1.5 m depth from four locations (row and interspace, top and bottom of paddock) in each treatment. Samples were collected post-harvest, but prior to the application of the next crops nutrients. Samples were also collected after the application of nutrient treatments (varying times depending on the site and rainfall), but for consistency, only the results from the post-harvest pre-nutrient applications are presented. Depth increments were generally at 0.1 m intervals to 0.3 m, and then 0.3 m intervals to 1.5 m.

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

2.1.3.2 Soil and cane trash herbicides

Samples of soil (0-2.5 cm) and cane trash were collected prior to herbicide application in 2010/11 and 2011/12 (no cane trash at Marian site in 2010/11), and six to nine times after application (Table 9). Three cane trash samples (using 8x12 cm quadrats) were taken from beside the cane stool, and three from the interspace (bottom of furrow). The six samples were bulked, and placed into alfoil lined bags. Samples were immediately stored on ice, and then refrigerated before being transported to the laboratory on ice.

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

Table 9 Summary of post-application soil and cane trash herbicide sampling, Victoria Plains and Marian sites

Site/season	Substrate sampled	Period of sampling (days after application)	Number of samples collected	Rainfall during sampling period (mm)
Victoria Plains				
2009/10	Nil			
2010/11	Soil and trash	0.3-100	8	1090
2011/12	Soil and trash	0.3-203	9	1093
Marian				
2009/10	Nil			
2010/11	Soil	1-83	6	1482
2011/12	Soil and trash	0.9-104	6	982

2.1.3.3 Soil moisture

Continuous soil moisture monitoring was 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 was recorded at one hourly intervals (using EnviroSCAN systems) and logged using the CR800

data loggers. Six sensors were 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 was controlled using a Campbell Scientific CR800 data logger housed in a weatherproof container. The logger was programmed to read all sensors every 60 seconds. When runoff water began to flow through the San Dimas flumes (see following), the station began the pre-programmed sampling routine.

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

San Dimas flumes (300 mm; Figure 4) were 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 were installed approximately five metres beyond the end of the sugarcane rows (outside of the actual cropped area), and rubber belting was 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 was:

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

Water depth was 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 converted pressure into water height.

Event integrated water samples were collected using an ISCO Avalanche refrigerated auto-sampler containing four 1.8 L glass bottles. The refrigeration system was activated after collection of the first sample. The sampler was triggered by the CR800 logger. Using the flume discharge equation above, the logger was 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 were sub-sampled and analysed for total suspended solids (TSS; Section 2.5.2.1), nutrients (total and filtered; Section 2.5.2.3), and herbicides (Section 2.5.2.4) where possible (depending on volume collected). Following smaller rainfall events with limited volume of sample collected, priority was given to analysis in the order of nutrients, herbicides and then TSS.

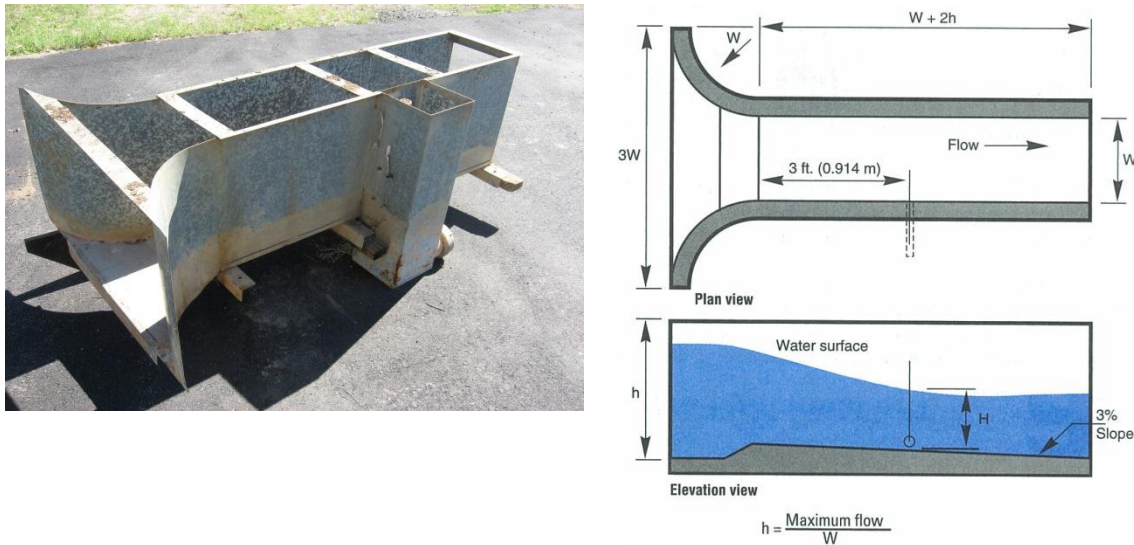


Figure 4 A 300 mm San Dimas flume (left) and critical design dimensions (right)

A radio telemetry network was established between sites that were “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 was two 100 A/hr sealed, deep cycle batteries, a 40 W solar panel and a power regulator.

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

2.1.5 Drainage water quality

Drainage water quality below rooting depth (0.9 m) was sampled during each wet season (number of samples/parameters varied each season and treatment) using soil solution samplers. Two soil solution samplers were installed in each treatment (in close proximity to the subsurface EnviroSCAN's) after the cane was planted. A soil solution sampler at the Marian site (Treatment 5) was destroyed during soil preparation (plant cane phase) prior to any sampling taking place and was not replaced. Samples were bulked from each treatment, and analysed for nutrients (total and filtered) and herbicides, if there was sufficient sample volume.

Due to the presence of a shallow water table each season affecting some treatments, it is thought that the data quality is compromised (sampling the water table rather than treatment drainage). As a result, only limited results and interpretation are reported.

2.1.6 Agronomic sampling

Cane was mechanically harvested at each site. 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.

Prior to harvesting the first and second ratoon crops, a 5 m row of standing cane (top and bottom of treatment) was hand cut and separated into leaf and stalk. Whole stalks were weighed and then processed through a garden mulcher in the paddock. Sub-samples were taken and fresh weights recorded. All samples were dried at 60°C for 14 days, and dry weights recorded. Samples were then sent to the Bureau of Sugar Experimental Stations Ltd., Brisbane for nutrient analysis of the dry matter. Due to a difference in how the cane leaf was sampled between seasons, only stalk nitrogen and phosphorus results are reported.

2.2 Multi-block scale

At the Multi-block scale (21° 13' 36"S 148° 57' 57"E; Figure 1), runoff was 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 10.

Table 10 Discharge equations used at the Multi-block site

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

As with the paddock sites, rainfall (amount and intensity) was measured using a Hydrological Services TB4 tipping bucket rain gauge. A Campbell Scientific CR800 data logger collected outputs from sensors and triggered the ISCO Avalanche refrigerated auto-sampler (with four 1.8 L glass bottle configuration). While submerged, an Analite NEP9510 turbidity probe continuously measured turbidity (data not reported), and water depth was 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. The accuracy of flow calculations was uncertain as water would back-up in the drain after a downstream storage dam filled, affecting flow rates over the weir. Additionally, as the drain overtopped water spread out across the paddocks making measuring water heights and flow rates somewhat problematic. Again bulked samples were analysed (Section 2.5.2) for nutrients (total and filtered), herbicides and TSS, with priority being given to nutrients, herbicides and then TSS depending on the volume of sample collected.

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

2.2.1 Management Practices

The following management practice information was collected from individual growers' records. The Multi-block catchment contains three part-farms and 19 blocks (some whole and others part). Note that this is a very small sample area and results cannot be extrapolated over larger areas and catchments. No specific ABCD management practice data are available.

2.2.1.1 Row spacing

For the 2009/10 season, 59% of the total area under cane was on 1.8 m row spacing, whilst the remainder (41%) was on 1.6 m row spacing. By the 2010/11 season, the proportion under 1.8 m row spacing had increased to 71%, the proportion under 1.6 m row spacing decreased to 22%, and the remainder was fallow. By the 2011/12 season, 100% of the total area under cane in the Multi-block sub-catchment was on 1.8 m row spacing.

2.2.1.2 Nutrients

For the Multi-block sub-catchment, the average fertiliser application rate varied each season, with the 2011/12 season having the highest rate of nitrogen applied (particularly in plant cane), but the lowest rate of phosphorus applied to ratoon cane (Table 11).

Table 11 Average fertiliser application rates applied in the Multi-block sub-catchment for the three monitored seasons

	Average N applied (kg/ha)		Average P applied (kg/ha)		Total applied (kg)	
	Plant cane	Ratoon cane	Plant cane	Ratoon cane	Nitrogen	Phosphorus
2009/10	185	159	55	19	6637	881
2010/11	148	174	37	20	5371	698
2011/12	201	173	50	3	7452	603

2.2.1.3 Herbicides

For the 2009/10 season, a total of 19.3 kilograms of diuron was applied to 12.9 hectares (average rate 1.5 kg/ha) and 4.2 kilograms of hexazinone was applied to 7.9 hectares (average rate 0.53 kg/ha). No atrazine was applied. It should be noted over 28 hectares (68%) was either untreated or treated with knockdown herbicides or other residuals.

For the 2010/11 season, approximately 8.5 kilograms of atrazine was applied to 5.3 hectares (average rate 1.60 kg/ha). Approximately 1.9 kilograms of imazapic was applied to 19.7 hectares (average rate 96 g/ha). It should be noted that the majority of the sub-catchment (over 36 hectares or 87%) was either untreated or treated with knockdown herbicides or other residuals.

In the 2011/12 season, approximately 24.1 kilograms of diuron was applied to 16.3 hectares (average rate 1.48 kg/ha). Approximately 4.4 kilograms of hexazinone was applied to 11 hectares (average rate 0.4 kg/ha) and approximately 4.8 kilograms of atrazine was applied to 5.3 hectares (average rate 0.9 kg/ha). It should be noted that about 25 hectares (61% of the sub-catchment) was untreated, or treated with knockdown or other residual herbicides. Actual average active ingredient rates/hectare applied were all below the maximum annual allowable rate.

2.3 Multi-farm scale

At the Multi-farm scale (21° 13' 49"S 148° 57' 45"E; Figure 1), runoff was 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 was 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 12.

Table 12 Discharge equations used at the Multi-farm site

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

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

2.3.1 Management Practices

The following management practice information for the Multi-farm sub-catchment was collected via face-to-face interviews with individual growers. The sub-catchment contains 48 farms (some whole and others part farms), and records were available for at least 80% of these farms. Data was then scaled proportionally to be representative of the entire sub-catchment. No specific ABCD management practice data are available.

2.3.1.1 Row spacing

For the 2009/10 season, 23% of the total area under cane was on 1.8 m row spacing, with 60% of the cane planted that season having 1.8 m or wider row spacing. For the 2010/11 season, 30% of the total area under cane was on 1.8 m or wider row spacing, with 49% of the cane planted having 1.8 m or wider row spacing. The plant cane phase, the most vulnerable phase for erosion, only occupied 15% of the area under sugarcane. Also, the majority of the sugarcane was cut green and its subsequent trash blanket was retained for moisture conservation, erosion control and weed suppression.

By the 2011/12 season, 32% of the total area in the Multi-farm sub-catchment was on 1.8 m or wider row spacing, with 57% of the cane planted having 1.8 m or wider row spacing. The plant cane phase only occupied 13% of the area under sugarcane. Also, the majority of the sugarcane was cut green and its subsequent trash blanket was retained for moisture conservation, erosion control and weed suppression.

2.3.1.2 Nutrients

It is estimated that the amount of nitrogen and phosphorus applied in the 2009/10 season was 10% less than 2010/11 season (Table 13). This may be due to the extreme weather conditions in 2010/11 season, which caused substantial waterlogging throughout the district, requiring higher nutrient inputs to maintain the health of the crop. The average phosphorus amounts applied to the ratoon cane for the 2010/11 and 2011/12 seasons were lower than plant cane (Table 13); however it is an acceptable practice to apply larger amounts of phosphorus at planting to cater for the needs of several crops. As such, this will eliminate the need to apply phosphorus to some or all of the ratoons in the crop cycle.

2.3.1.3 Herbicides

The amount of atrazine and diuron applied to the Multi-farm catchment were similar in 2009/10 and 2011/12, but lower than 2010/11 (Table 14). Hexazinone application increased each season, and ametryn applied in 2011/12 was much less than the previous seasons. No information was collected on the use of “emerging” herbicides (imazapic, isoxaflutole, etc.).

Table 13 Average fertiliser application rates and total amount applied in the Multi-farm sub-catchment for the three monitored seasons

	Average N applied (kg/ha)		Average P applied (kg/ha)		Total applied (t)	
	Plant cane	Ratoon cane	Plant cane	Ratoon cane	Nitrogen	Phosphorus
2009/10	Not recorded	Not recorded	Not recorded	Not recorded	437	30
2010/11	155	164	24	9	487	35
2011/12	166	163	27	10	493	37

Table 14 Amount of ametryn, atrazine, diuron and hexazinone applied to the Multi-farm sub-catchment for each of the monitored seasons

	Herbicides (active ingredient) applied (kg)			
	Ametryn	Atrazine	Diuron	Hexazinone
2009/10	190	820	540	30
2010/11	200	960	690	40
2011/12	30	820	520	70

2.4 Water quality load calculations

To estimate the total water quality loads for each wet season, constituent concentrations are required for every runoff event. This was not possible due to occasional equipment failure, insufficient sample volume or samplers being turned off during extreme weather events. Therefore, water quality concentrations need to be estimated for those events that were not sampled. Due to the inability to accurately determine flow rates at the Marian and Multi-block sites due to flooding, no water quality loads have been calculated for these sites.

The approach to estimate missing water quality concentrations varied depending on the site, season and water quality parameter, but included:

- Fitting a regression curve to known concentrations with time after first runoff (or maximum rainfall intensity for TSS at Victoria Plains)
- Fitting a linear regression between known concentrations of the two Victoria Plains treatments

Event water quality loads were calculated by multiplying the total event discharge by the concentration. Total seasonal loads are the sum of each event for that season, and the seasonal flow-weighted concentration is the total seasonal load divided by the total seasonal discharge.

Further details on the load calculation methodology used each season can be found in the annual technical reports (Reef Catchments website; <http://reefcatchments.com.au/project-reports/>; accessed May 2013):

- [2009/10 report](#) (Rohde and Bush 2011)
- [2010/11 report](#) (Rohde *et al.* 2011)
- [2011/12 report](#) (Rohde *et al.* 2012)

2.5 Laboratory methodologies

2.5.1 Soil nutrients

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

2.5.2 Water analyses

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

2.5.2.1 Total suspended solids and turbidity

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

Laboratory turbidity measurements (APHA 2130B) were 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 (APHA 1998). A formazin polymer was used as the primary standard reference suspension (turbidity of 4000 NTU).

2.5.2.2 Electrical conductivity

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

2.5.2.3 Nutrients

Nutrient samples from surface water runoff and drainage soil solution were analysed for ammonium-N, urea-N, oxidised nitrogen ($\text{NO}_x\text{-N}$, 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 were digested in an autoclave using an alkaline persulphate technique (modified from Hosomi and Sudo 1987) and the resulting solution simultaneously analysed for $\text{NO}_x\text{-N}$ and FRP using an ALPKEM (Texas, USA) Flow Solution II. The analyses of $\text{NO}_x\text{-N}$, ammonium-N and FRP were also conducted using segmented flow auto-analysis techniques following standard methods (APHA 2005).

For TKN and TKP, the samples were digested prior to analysis in the presence of sulphuric acid, potassium sulphate and a mercury catalyst. Total Kjeldahl nitrogen was then determined

using the indophenol reaction (Searle 1984) on an OI Analytical Flow Solution IV segmented flow analyzer. Total Kjeldahl phosphorus was determined using the phosphomolybdic blue reaction (Murphy and Riley 1962) on an OI Analytical Flow Solution IV segmented flow analyser.

2.5.2.4 Herbicides

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

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

2.5.3 Soil and cane trash analysis

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

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

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

2.6 Spatial rainfall variability

In addition to the tipping bucket rain gauges located at each monitoring site, five were located in the surrounding area, with one located near the top of the Multi-farm catchment. Annual rainfall totals (October to September) were spatially assessed and interpolated using the Spatial Analyst extension in ArcMap™ 10.1.

2.7 Data management

All data is stored in the DARTS (DAta Recording Tool for Science) database, available at <http://darts.information.qld.gov.au/darts/>.

DARTS enables the capture of scientific data in a format that is suitable for long-term storage, easy discovery, retrieval and reuse.

3 RESULTS

3.1 Overview of annual rainfall

All seasons were above the long-term October-September average of 1679 mm (median 1513 mm) (Te Kowai Research Station, 1889/90-2009/10; data extracted in April 2011 from <http://www.bom.gov.au/climate/data/>). The 2010/11 season was by far the wettest, with 2009/10 and 2011/12 being similar (Figure 5). Rainfall variability at the monitoring sites and immediate surrounds was quite low (<10%), except for 2009/10 (17%) where the top of the Multi-farm catchment received more rainfall than other sites. Based on the average 36-month total of all rain gauges (7673 mm), this is the wettest 36-month period since July 1988–June 1991 (7734 mm). A typical rainfall intensity-frequency-duration graph is contained in Appendix 7.2.

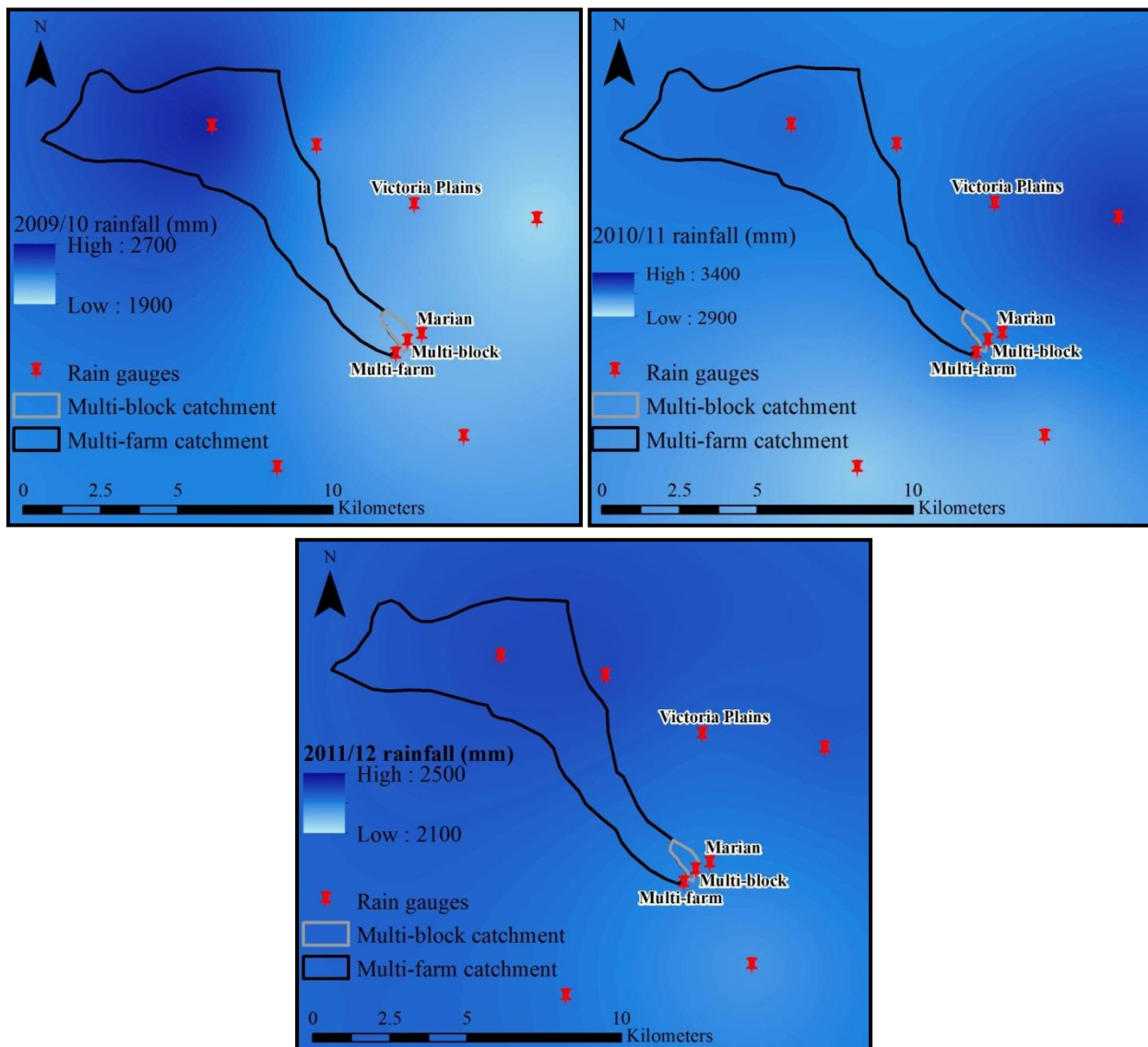


Figure 5 Annual (October-September) rainfall for the three monitored years

(Note the different rainfall range for each year)

3.2 Overview of runoff events

3.2.1 Paddock scale

In excess of 12 runoff events were recorded at the individual paddock monitoring sites each wet season, with the first event occurring on 25th January 2010. The final runoff event at the Victoria Plains site occurred on 10th July 2012, by which time all equipment had been removed from the Marian site (last monitored event occurred on 2nd June 2012). Due to the magnitude of the wet seasons, the automatic samplers were turned off and on throughout the wet seasons (particularly the 2010/11 season) to limit the number of events sampled; hence not all runoff events have associated water quality data.

Irrigation was applied to the Victoria Plains site via a spray line in mid-August and mid-October 2010 (total of 115 mm) during the plant cane phase. No other irrigation was applied. In contrast, the Marian site was irrigated (30-40 mm per application) by a low pressure centre pivot irrigator 16 times during the trial period (10 times in 2009/10, nil in 2010/11 and six times in 2011/12). The only irrigation event to cause runoff was the final irrigation event, May 2012.

3.2.2 Multi-block and Multi-farm scale

At the Multi-block and Multi-farm sites, approximately 10 to 20 runoff events were recorded each wet season. The first runoff event recorded was on 27th December 2009 at both sites, with the final event recorded on 10th July 2012 at the Multi-farm site. By this time, all monitoring equipment had been removed from the Multi-block site (last monitored event commenced on 2nd June 2012, but no water quality samples were collected).

3.3 Victoria Plains site

3.3.1 Soil nutrients

Each season, the soil nitrate-N concentrations (KCl extraction) after harvest were ≤ 2 mg/kg at all depths, with the majority below detection (<1 mg/kg) (Table 15). As a result, there was no treatment difference (for row and interspace) suggesting that the higher rate of nitrogen applied to Treatment 2 is not accumulating in the soil profile (to 1.5 m depth). The lack of detectable nitrate-N at any depth may be due to the well above average rainfall leaching nitrate-N below the sampled depths.

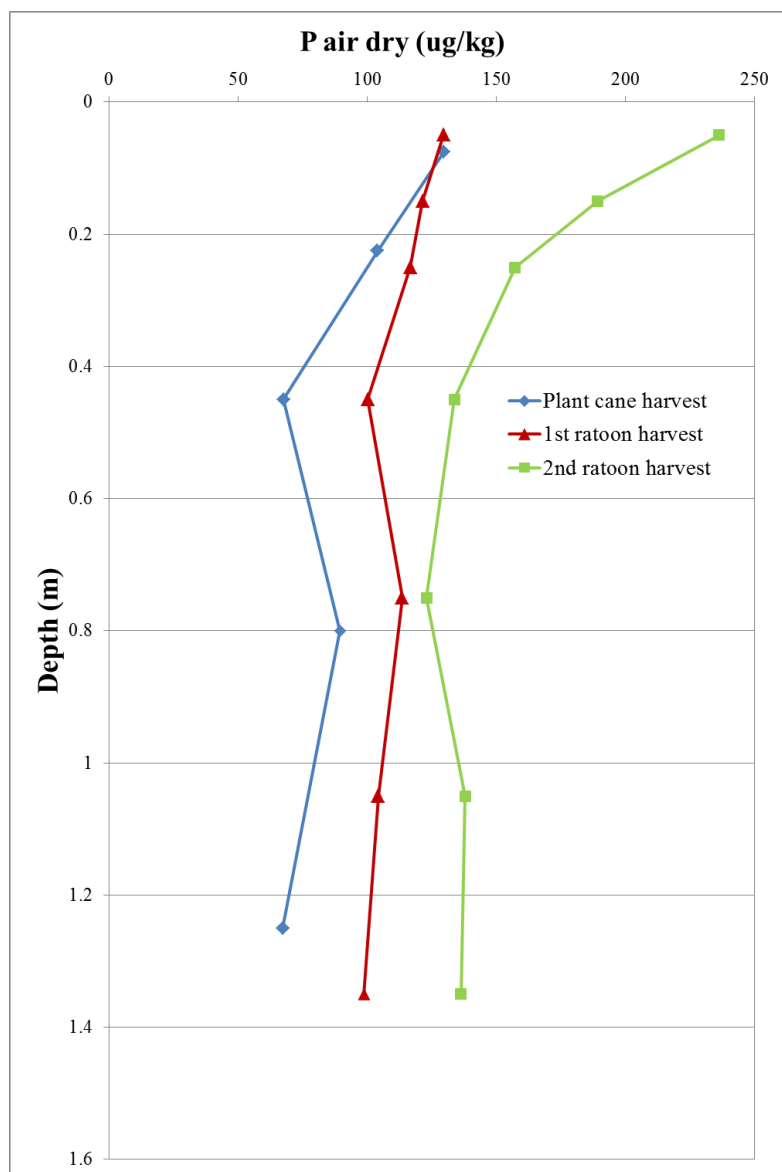
Ammonium-N concentrations decreased within each season and generally decreased with depth (Table 15). The surface (0-0.1 m) concentrations were higher in Treatment 1 each season than Treatment 2, possibly reflecting the higher nitrogen application rate to that treatment.

Soil phosphorus (KCl extraction) concentrations were similar between treatments at the harvest of each crop due to similar rates of phosphorus being applied (Table 4). Concentrations tended to increase between each season at all depths (Figure 6).

Table 15 Soil nitrate-N and ammonium-N concentrations post-harvest of the plant cane, first ratoon and second ratoon cane crops, Victoria Plains site

Depth (m)	Nitrate-N (mg/kg)						Ammonium-N (mg/kg)					
	Plant cane harvest		1 st ratoon harvest		2 nd ratoon harvest		Plant cane harvest		1 st ratoon harvest		2 nd ratoon harvest	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
0.0-0.1	2	2	<1	<1	2	2	9	7	2	<1	2	<1
0.1-0.2			<1	<1	2	2			1	1	<1	<1
0.2-0.3	2	2	<1	<1	<1	2	5	5	2	1	<1	<1
0.3-0.6	2	2	<1	<1	<1	<1	4	3	2	1	<1	<1
0.6-0.9	<1	<1	<1	<1	1	<1	2	2	<1	1	<1	<1
0.9-1.2			<1	<1	<1	1			1	<1	<1	<1
1.2-1.5	<1	<1	<1	<1	1	<1	2	2	2	1	<1	<1

(Note – row and interspace combined. Sampled depths for the plant cane harvest were 0-0.15, 0.15-0.3, 0.3-0.6, 0.6-1.0 and 1.0-1.5 m)

**Figure 6 Soil phosphorus concentrations (KCl extraction; air dry) in the soil profile after each harvest (row/interspace and treatments combined), Victoria Plains site**

3.3.2 Soil and cane trash herbicides

Surface soil (0-2.5 cm) and cane trash samples were collected for herbicide analysis prior to herbicide application in 2010 and 2011, and at multiple times after application.

Peak concentrations of all herbicides on the cane trash were detected within one day of application, and then declined. Using this field dissipation data (Table 16), the two seasons provided contrasting results. In the 2010/11 season, much shorter half-lives were measured than in the 2011/12 season. This is thought to be due to the higher rainfall (1090 mm within 100 days of application) washing the herbicide from the cane trash into the surface soil much more rapidly than the 2011/12 season when only 98 mm of rain fell within 100 days of application.

In contrast to the cane trash results, soil herbicide half-lives were much longer in the 2010/11 season than the 2011/12 season (Table 16). The extreme rainfall in the 2010/11 season was able to “trickle feed” the surface soil (after being washed from the trash), leading to longer field half-lives. Diuron and hexazinone were still being detected on the cane trash 100 days after application, whereas imazapic wasn’t detected 100 days after application. Maximum soil concentrations were measured ~10 days after application.

Table 16 Calculated field dissipation half-lives (days) of diuron, hexazinone and imazapic on cane trash and surface soil (0-2.5 cm), Victoria Plains site

	Sampling period (days after application)	Diuron	Hexazinone	Imazapic
2010/11 (applied 13/09/10; 1090 mm rainfall in first 100 days)				
Trash	0.3-100	11	9	13
Soil	10-100	199	53	118
2011/12 (applied 22/08/11; 98 mm rainfall in first 100 days)				
Trash	0.3-203	30	22	33
Soil	10-203	74	39	47

3.3.3 Soil moisture

Soil water extraction was evident throughout the growing seasons, with periods of saturation (water logging) evident (Figure 7), particularly during the extremely wet 2010/11 season. It is uncertain whether the differences in total moisture are likely to be related to the treatments or immediate site characteristics around each probe (given the response zone of the sensors is within 3 cm of the access tube).

Data from the individual depth sensors shows water extraction at 150 cm in Treatment 1 was evident in July 2010 and November/December 2011, and there was no clear evidence of a shallow water table during the reporting period (Section 7.1.1). Water extraction at 150 cm in Treatment 2 was only evident in November 2011. A water table was evident at 100 cm during each wet season (Section 7.1.2).

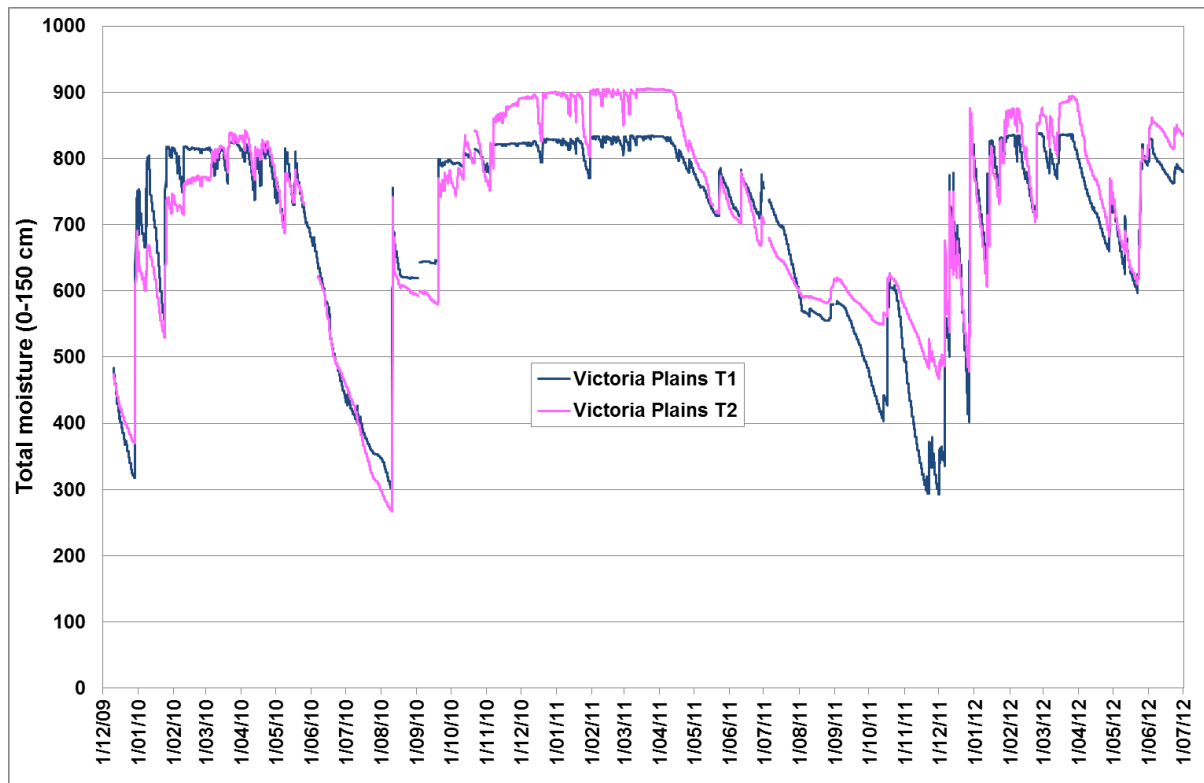


Figure 7 Total moisture in the soil profile (0-150 cm), Victoria Plains site

(Note – total moisture is uncalibrated volumetric water content)

3.3.4 Rainfall and runoff

A total of 7660 mm of rainfall (average 2553 mm/year) was recorded at the Victoria Plains site from October 2009 to September 2012, with 2010/11 being the wettest year (Figure 8). All years were above (28-89%) the long-term October-September water year average of 1679 mm (median 1513 mm) (Te Kowai Research Station, 1889/90-2009/10; data extracted in April 2011 from <http://www.bom.gov.au/climate/data/>).

Total runoff for the three seasons from Treatment 2 (1.8 m row spacing) averaged 14.5% less than Treatment 1 (1.5 m row spacing) (3232 mm and 3781 mm, respectively; or 42% and 49% of rainfall) (Figure 8). These treatment differences have been consistent across the three seasons, and varied from 14-18%. On average, across all runoff events, runoff from Treatment 2 was delayed by ~17 minutes, and the peak runoff was 18% lower.

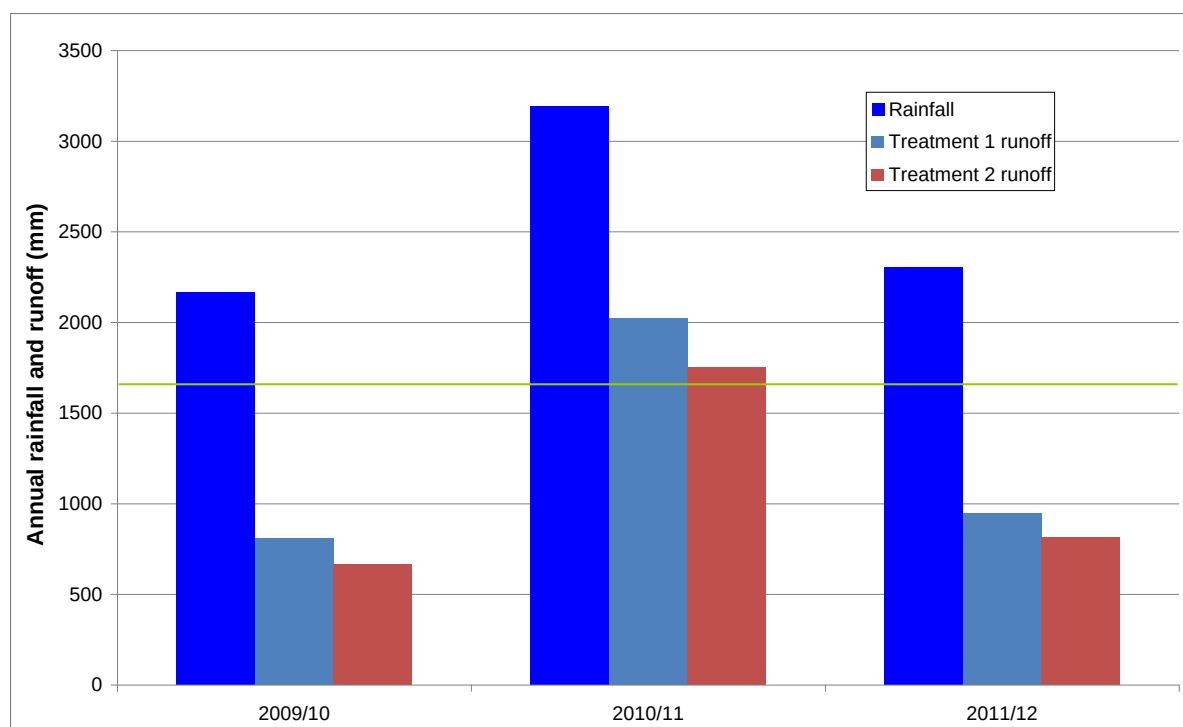


Figure 8 Annual rainfall and runoff, Victoria Plains site

(Note – the green line represents the long-term October-September water year average rainfall)

3.3.5 Runoff water quality

3.3.5.1 Total suspended solids, turbidity and electrical conductivity

There were similar concentrations of TSS across all of the samples collected between treatments (Figure 9), although the median concentration of Treatment 2 (1.8 m row spacing) was higher than Treatment 1 (1.5 m row spacing). Concentrations declined each year as the cane cycle progressed from cultivated plant cane (2009/10) to a green cane trash blanket in the subsequent ratoons. Due to the higher runoff in the 2010/11 season, trash was washed from the inter-row area (either to the side of row, or off the paddock) leaving it bare, and consequently TSS concentrations were higher than the 2011/12 season (even when the cane trash blanket remained intact).

The three year average estimated sediment load for Treatment 2 was 2000 kg/ha/year, which was lower than Treatment 1 (3290 kg/ha/year) (Figure 10). Similar to TSS concentrations, the annual sediment load declined as the cane cycle progressed to a trash blanket system (Table 17). The treatment difference in 2009/10 was mainly due to the TSS concentration difference in a single event in late January 2010 (3000 mg/L from Treatment 1, and 35 mg/L from Treatment 2). It is thought that the Treatment 2 concentration is low (rather than Treatment 1 being high), but the reason is unclear.

Similar to TSS concentrations, turbidity was similar between treatments. When samples from each treatment were combined, there was a good relationship between TSS concentration and turbidity (Figure 11).

Electrical conductivity (EC) values showed very little difference between treatments and seasons. When the data from the two treatments was combined, the seasonal median ranged from 52-70 $\mu\text{S}/\text{cm}$.

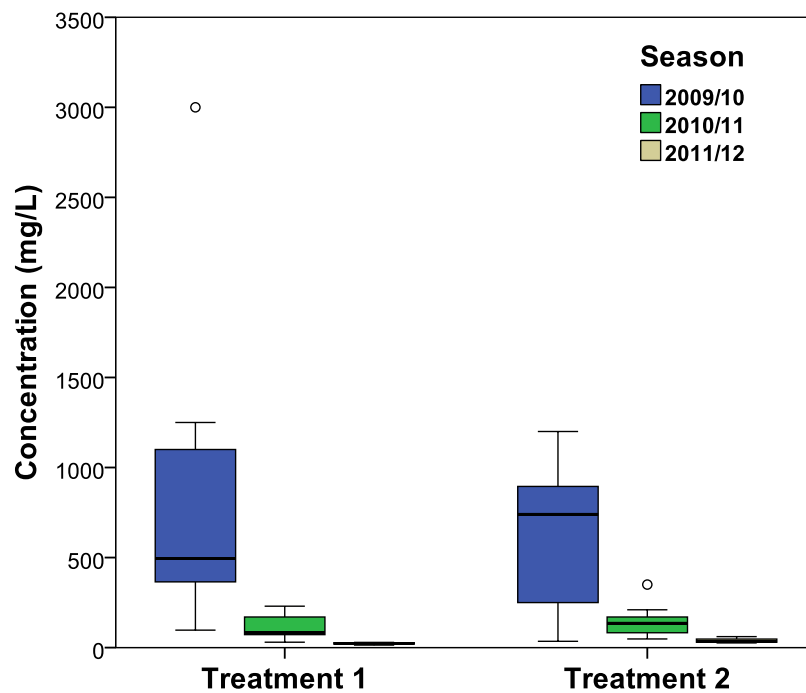


Figure 9 Concentrations of total suspended solids measured in runoff, Victoria Plains site

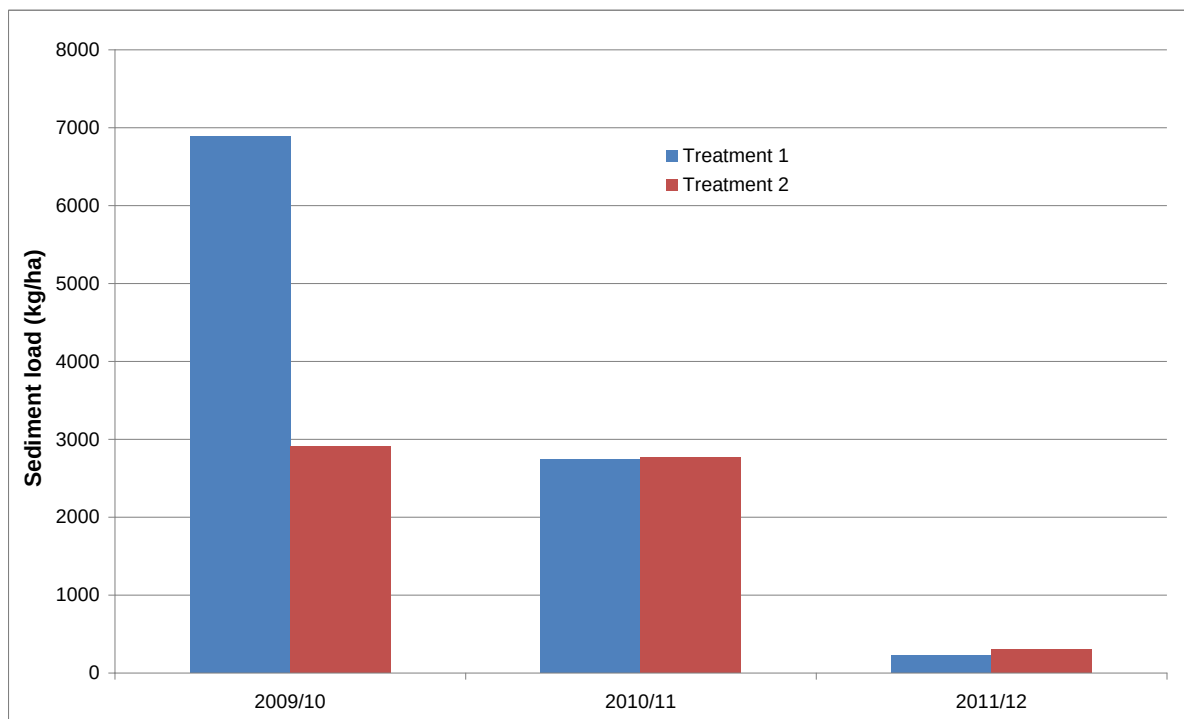


Figure 10 Measured seasonal sediment loads, Victoria Plains site

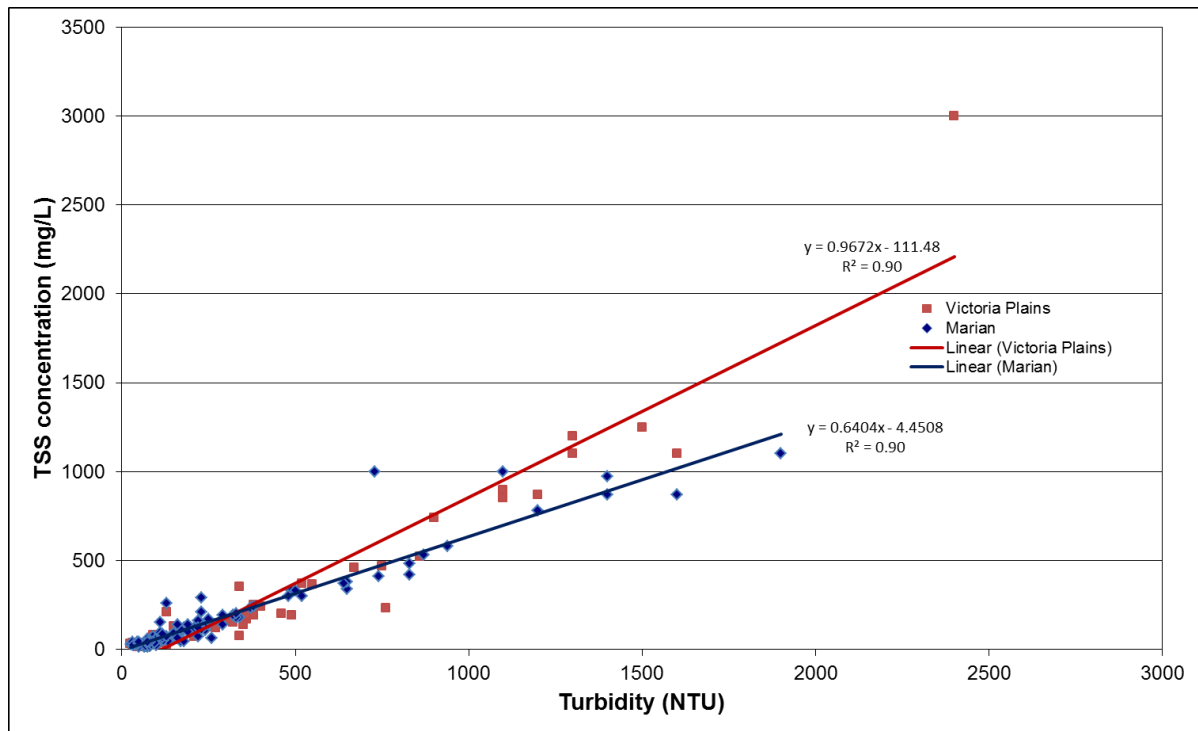


Figure 11 Relationship between turbidity and total suspended solids concentration in runoff, Victoria Plains and Marian sites

Table 17 Calculated loads of sediment and nutrients from runoff, Victoria Plains site

Season	TSS (kg/ha)		TKN (kg/ha)		NO _x -N (kg/ha)		Urea-N (kg/ha)		TKP (kg/ha)		FRP (kg/ha)	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
2009/10	6890	2920	18	22	13	4.9	Not sampled		2.6	2.7	0.22	0.21
2010/11	2740	2770	36	29	4.0	1.8	16	13	4.6	4.1	1.2	1.3
2011/12	228	299	4.3	2.9	1.3	1.2	0.50	0.43	1.1	0.96	0.51	0.57
Average load (kg/ha)	3290	2000	19	18	6.0	2.6	8.5	6.5	2.8	2.6	0.63	0.70
Flow-weighted concentration	261	185	1534	1671	476	244	555	506	220	241	50	65
	mg/L	mg/L	µg N/L	µg N/L	µg N/L	µg N/L	µg N/L	µg N/L	µg P/L	µg N/L	µg P/L	µg P/L

(Note – calculated loads include estimated concentrations when runoff events were not sampled. As urea-N was not analysed in 2009/10, total loads and flow weighted concentrations are for two years only)

Table 18 Calculated loads of herbicides from Treatment 1 runoff, Victoria Plain site

Season	Atrazine			Diuron			Hexazinone		
	Load (g/ha)	EMC (µg/L)	% of applied	Load (g/ha)	EMC (µg/L)	% of applied	Load (g/ha)	EMC (µg/L)	% of applied
2009/10	1.62	0.20	*	35.3	4.4	1.9	48.5	6.0	9.2
2010/11	15.3	0.76	*	210	10	12	89.5	4.4	18
2011/12	0.17	0.02	*	3.0	0.28	0.17	1.9	0.18	0.37
Seasonal flow-weighted av.	5.7	0.45	*	82.3	6.6	4.6	46.7	3.7	9.1

(Note – * atrazine was not applied as part of our trial, but was regularly detected in runoff. Calculated loads of all herbicides include estimated concentrations when runoff events were not sampled)

3.3.5.2 Nitrogen

The three monitored runoff seasons provided contrasts in nitrogen species (including concentrations and loads) in runoff. In the 2009/10 season, following the legume fallow (which resulted in high soil nitrate-N levels), the nitrogen concentrations in the first runoff event (176 days after fertiliser application) were dominated by $\text{NO}_x\text{-N}$ (although urea was not analysed), leading to relatively high seasonal nitrogen runoff losses (Table 17 and Figure 12). The first runoff in the 2010/11 season occurred 3 days after fertiliser application, and nitrogen loss was dominated by urea-N. Due to these initial high concentrations of urea-N, the seasonal nitrogen loss was also dominated by urea-N (Table 17). In the 2011/12 season, the first runoff occurred 78 days after application. Nitrogen loss was dominated by $\text{NO}_x\text{-N}$ although concentrations were much lower than the 2009/10 season, leading to lower seasonal loss (Table 17).

In all seasons, Treatment 1 lost more nitrogen than Treatment 2 presumably due to the higher application rates, although the percentage loss for each treatment was similar. In 2009/10 (when soil nitrate-N concentrations were high) and 2010/11 (when runoff occurred 3 days after fertiliser application), runoff losses ($\text{NO}_x\text{-N}$ plus urea-N) were ~10% of the applied fertiliser rate. In 2011/12, runoff losses were only ~1% of the applied fertiliser rate due to the lower soil nitrate-N concentrations and extended period between application and first runoff.

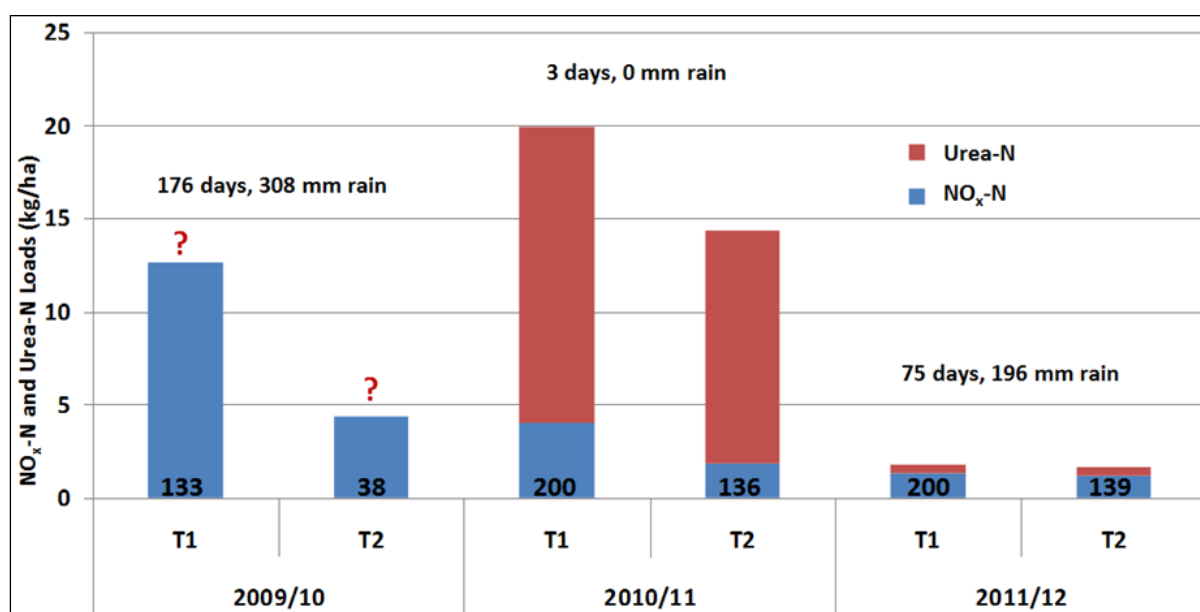


Figure 12 Seasonal runoff loads of urea-N and $\text{NO}_x\text{-N}$, Victoria Plains site

3.3.5.3 Phosphorus

Phosphorus was applied to both treatments at similar rates (25-42 kg/ha each season), resulting in similar concentrations in runoff between treatments (Figure 13). It is thought that the increasing median FRP concentration in runoff between each season is due to the increasing soil phosphorus levels (Figure 6). The high concentrations measured in both treatments in the 2010/11 season were from the first runoff event of the season (only three days after nutrient application). The average seasonal FRP loss in runoff was 0.63 kg/ha and 0.70 kg/ha for Treatments 1 and 2, respectively (Table 17). The flow-weighted seasonal average concentration was 50 $\mu\text{g P/L}$ and 65 $\mu\text{g P/L}$ for Treatments 1 and 2, respectively.

Across all of the samples collected, FRP comprised the majority (median 72%) of the TFP signature. Of those samples with both FRP and TP, FRP comprised 27% (median) of TP.

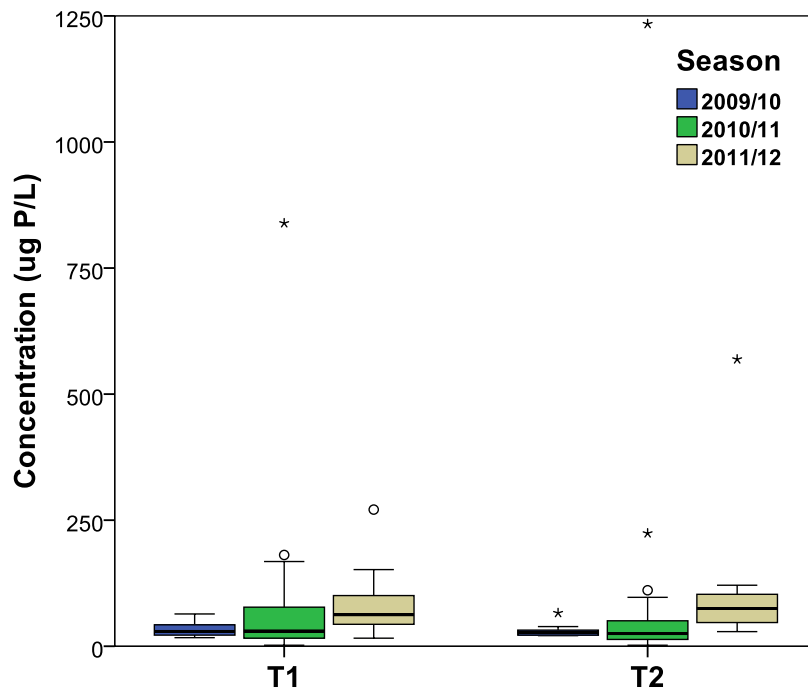


Figure 13 Filterable reactive phosphorus concentrations in runoff, Victoria Plains site

3.3.5.4 Herbicides

Diuron and hexazinone were detected in the highest concentrations from Treatment 1 in the 2010/11 season (Figure 14), when the first runoff event occurred seven days after application (no rainfall during that period). This is in contrast to the following season when the first runoff event occurred 128 days after application (243 mm of rain during that period) and concentrations were much lower (e.g. hexazinone, Figure 15).

The average seasonal calculated diuron and hexazinone loads from Treatment 1 were 83 g/ha (4.6% of applied) and 47 g/ha (9.1% of applied), with flow-weighted seasonal average concentrations of 6.6 µg/L and 3.7 µg/L, respectively (Table 18).

Although atrazine was not applied as part of our trial, it was detected at relatively low concentrations (≤ 2 µg/L, except for 12 µg/L in December 2010). Concentrations tended to decrease throughout each season, and it is thought that the source of this atrazine may be from the source water used in the spray tank mixture, rather than persistence in the environment (although it was detected in the lowest concentrations in the 2011/12 season). The average seasonal atrazine load was 5.7 g/ha, with a flow-weighted seasonal average of 0.45 µg/L (Table 18).

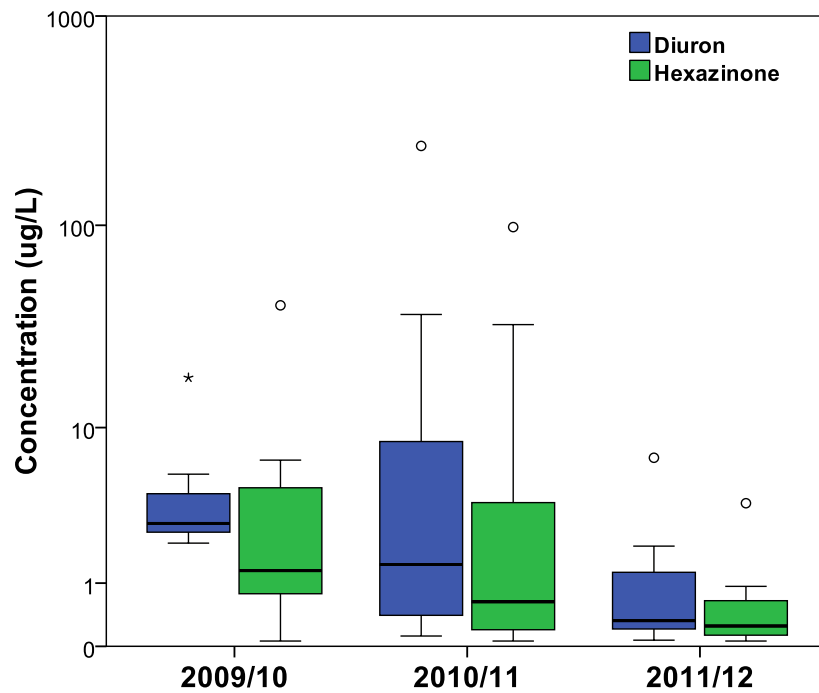


Figure 14 Diuron and hexazinone concentrations in runoff from Treatment 1, Victoria Plains site

(Note – log scale on y-axis)

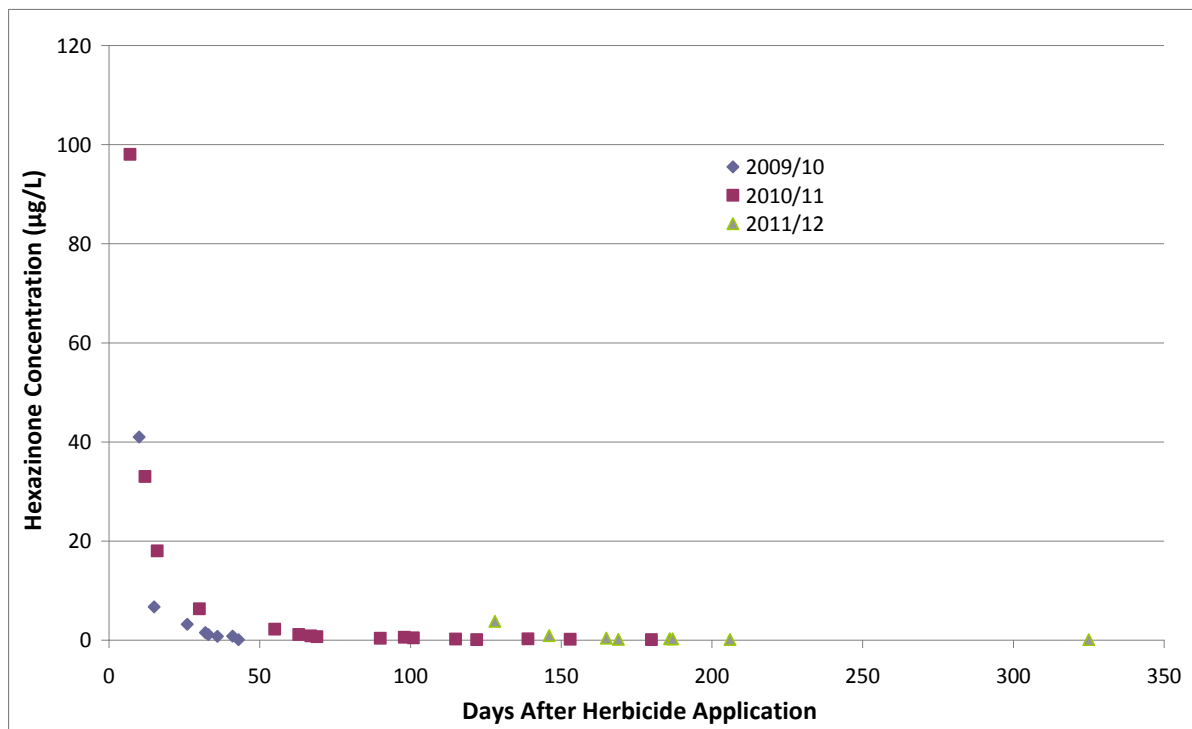


Figure 15 Hexazinone concentrations in runoff from Treatment 1, Victoria Plains site

Imazapic was only detected in one runoff sample (February 2012; 1 µg/L). It should be noted that imazapic analyses did not commence until part way through the 2010/11 season, so no samples have been collected close to application (as with diuron and hexazinone). Due to lack of detections, no imazapic runoff loads could be calculated.

3.3.6 Drainage water quality

Drainage samples collected from the soil solution samplers (0.9 m depth) were generally limited to 2-3 collected per season (seven collected in 2010/11). A detailed seasonal comparison is therefore difficult, but the following general trends and observations can be made:

- The highest NO_x-N concentrations were observed in 2009/10 when soil nitrate-N concentrations were high due to the soybean legume fallow. Concentrations were higher in Treatment 1 (11,196 µg N/L and 236 µg N/L) than Treatment 2 (4388 µg N/L and 49 µg N/L), due to the higher rate of nitrogen applied to Treatment 1. Concentrations in other seasons remained below 1000 µg N/L, except for the initial two samples collected from Treatment 1 in 2010/11 (6 and 17 days after application).
- Median FRP concentrations were similar between treatments and seasons (18-25 µg P/L).
- In 2010/11, there was a clear relationship between diuron and hexazinone concentrations detected in the surface runoff water and in the drainage soil solution samples of Treatment 1 (Figure 16). There were insufficient samples collected in other seasons to determine a relationship. Imazapic was only detected in one drainage sample from Treatment 2 (2 µg/L on 4th February 2012).

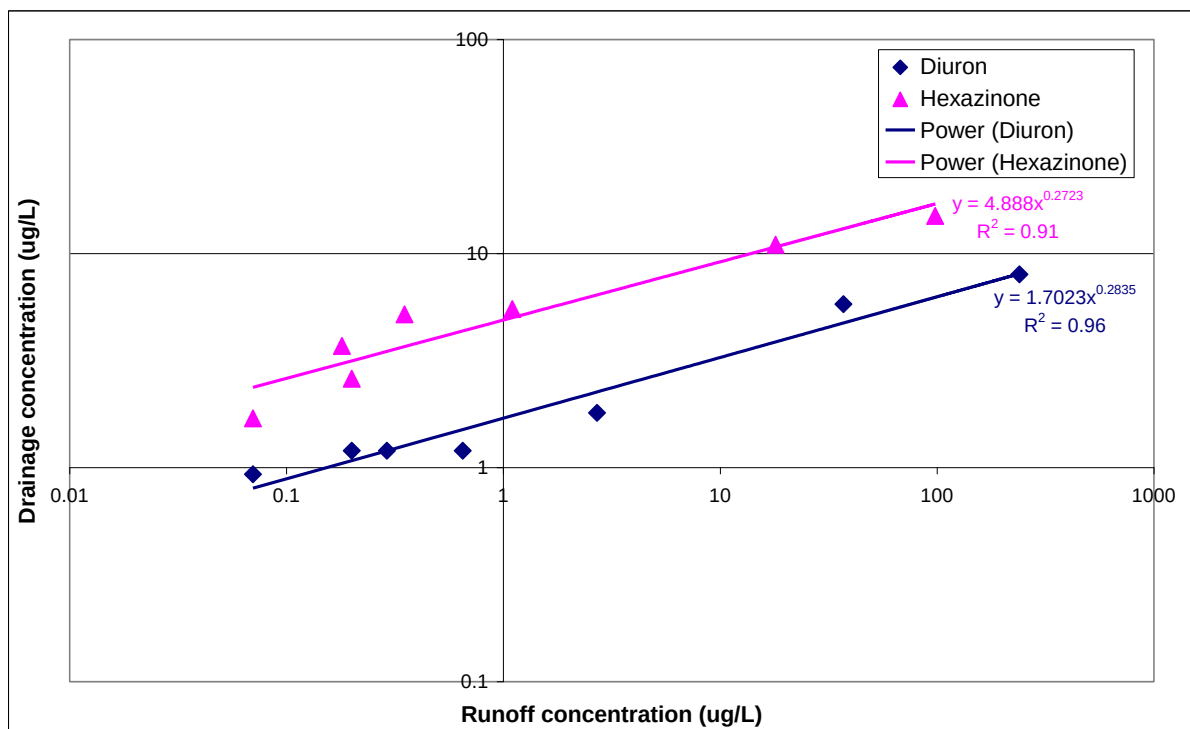


Figure 16 Relationship between surface runoff and drainage soil solution herbicide concentrations in 2010/11 from Treatment 1, Victoria Plains site

(Note – log scale on both axes)

3.3.7 Agronomic

There was very little difference between the machine harvest yield results and net return for the two treatments (Table 19), even though Treatment 2 had 41% less nitrogen applied. The poor yield from the first ratoon crop (following the very wet 2010/11 season) tends to dampen the average treatment differences. Treatment 2 yielded 22% less than Treatment 1,

which is possibly due to a combination of 41% less nitrogen applied and more water logging evident below 100 cm than Treatment 1 (see soil moisture plots in Section 7.1).

Table 19 Machine harvest yield results, Victoria Plains site

		Treatment 1	Treatment 2
Plant cane (harvested 03/09/10)	N applied (kg/ha)	133	38
	Cane (t/ha)	95	91
	PRS	15.7	15.7
	Sugar (t/ha)	14.9	14.3
	Net return (\$/ha)	2100	2400
First ratoon (harvested 30/08/11)	N applied (kg/ha)	200	136
	Cane (t/ha)	62	48
	PRS	15.5	14.3
	Sugar (t/ha)	9.6	6.9
	Net return (\$/ha)	1700	1200
Second ratoon (harvested 18/09/12)	N applied (kg/ha)	200	139
	Cane (t/ha)	90	91
	PRS	17.7	16.9
	Sugar (t/ha)	16.0	15.3
	Net return (\$/ha)	3100	3200
Average (of 3 seasons)	N applied (kg/ha)	178	104
	Cane (t/ha)	82	77
	PRS	16.3	15.6
	Sugar (t/ha)	13.5	12.2
	Net return (\$/ha)	2300	2300

The nitrogen and phosphorus content of the cane stalk prior to harvest showed no difference between treatments (Figure 17), but the second ratoon crop generally contained more nitrogen and phosphorus. This may reflect the better growing conditions of the second ratoon crop, and its ability to uptake and retain nutrients.

3.4 Marian site

3.4.1 Soil nutrients

Soil nitrate-N concentrations (KCl extraction) were generally not detected (<1 mg/kg) after the harvest of the plant cane crop, except for the surface soil (0-0.2 m) of Treatment 5 interspace (the “skip” area; 4 mg/kg). After harvest of the first ratoon cane crop, nitrate-N was generally not detected in Treatments 2 and 3. Similar to the previous year, it was detected in the interspace of Treatment 5 (up to 3 mg/kg). In Treatments 1 and 4, nitrate-N was detected at all depths (1-4 mg/kg). This pattern of detections appears to follow the order of treatments in the landscape (i.e. concentrations increase in treatments lower in the landscape), rather than being an actual treatment effect. This may be due to the increased water logging (and the inability for the cane crop to extract the soil nitrate) in those treatments lower in the landscape (Treatments 1 and 4). The only detection following the second ratoon cane crop was in the surface (0-0.1 m) of Treatment 5 interspace (1 mg/kg).

Ammonium-N was generally not detected (<1 mg/kg) following the harvest of any of the cane crops, although it was detected at some depths in all treatments (up to 4 mg/kg).

Soil phosphorus concentrations (KCl extraction) after harvest were variable across the treatments each season (Figure 18), and did not appear to reflect the application of phosphorus to Treatments 1 and 2 for the first and second ratoon crops.

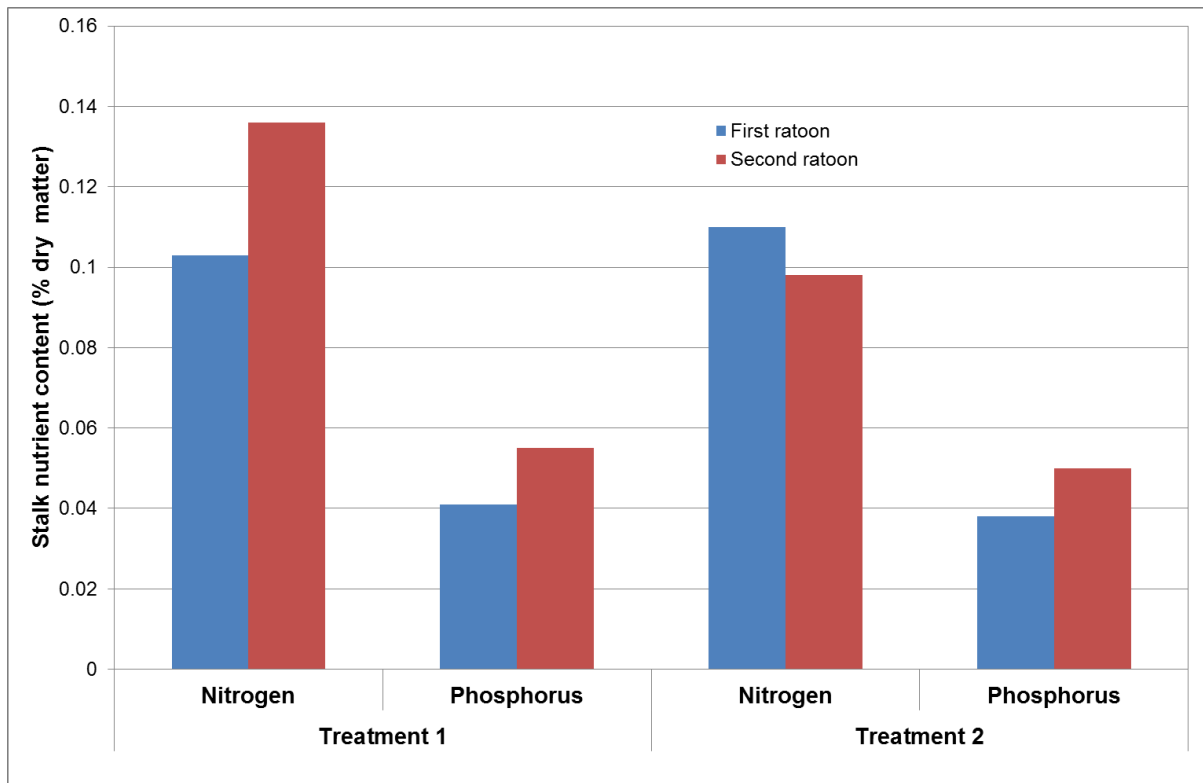


Figure 17 Nitrogen and phosphorus content of the cane stalk prior to harvest of first and second ratoon crops, Victoria Plains site

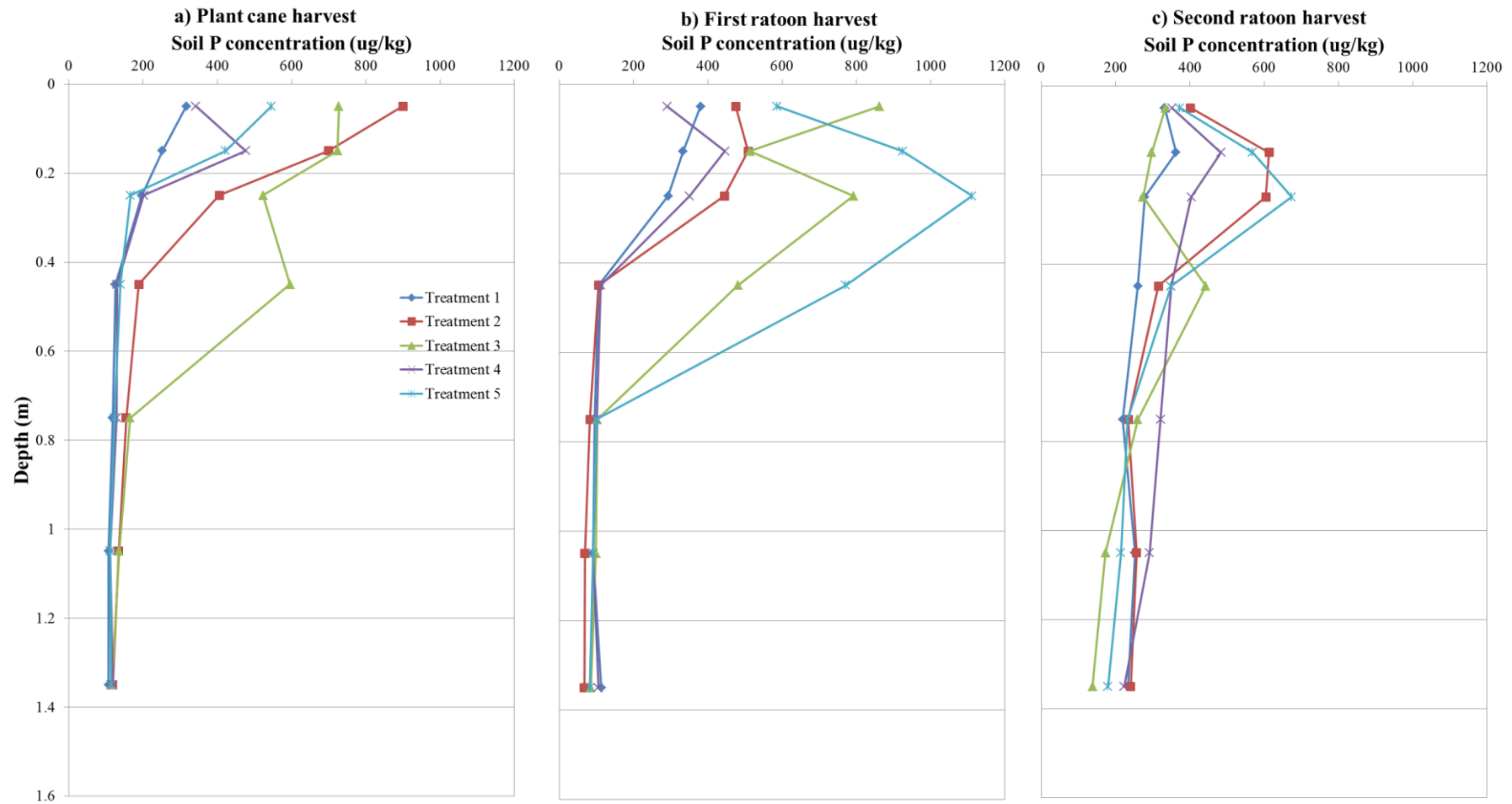


Figure 18 Soil phosphorus concentrations (KCl extraction; air dry) in the soil profile following each harvest, Marian site

3.4.2 Soil and cane trash herbicides

Surface soil (0-2.5 cm) samples were collected for herbicide analysis prior to application in January 2011, and six times after application. After herbicide application in November 2011, both surface soil and cane trash samples were collected six times for herbicide analysis.

The only herbicide applied consistently was paraquat, so a direct comparison between seasons is difficult. Also, due to the burning of the plant cane crop at harvest, no cane trash was available for sampling for the January 2011 herbicide application.

Despite herbicides being applied to multiple treatments at the same rate, the concentrations of herbicides on the cane trash and the surface soil were very variable. This resulted in variable calculated half-lives, so only treatment averages are presented (Table 20).

Peak diuron and hexazinone concentrations were detected on the cane trash blanket within two days of application (data from 2011/12 only), and then rapidly declined. Despite the same application rate, concentrations detected in Treatment 2 were much lower than Treatment 1 (reason unknown), and therefore not used. Using the available data, the calculated field half-lives of diuron and hexazinone on cane trash were 12 and 11 days, respectively (Table 20). Concentrations of paraquat were very variable over time, and no clear trend in dissipation could be detected (therefore data not presented).

Similar to the cane trash data, herbicide concentrations in the surface soil were variable across the treatments, despite identical application rates being applied to some treatments. In 2011/12 when herbicides were applied to the trash blanket, peak soil concentrations were not detected until ~25 days after application. During this 25 day period, 56 mm of rain was recorded. Paraquat is the only herbicide applied in both seasons, and the calculated soil half-life was slightly more in 2011/12 (than in 2010/11) when less rain fell within 100 days of application (Table 20).

Table 20 Calculated field dissipation half-lives (days) of applied herbicides on cane trash and surface soil (0-2.5 cm), Marian site

Sampling period (days after application)		Paraquat	2,4-D	Atrazine
2010/11 (applied 26/01/11; 1487 mm rainfall in first 100 days; ratoon, but trash burnt at harvest)				
Soil	10-83	27	34	116
		Paraquat	Diuron	Hexazinone
2011/12 (applied 28/11/11; 963 mm rainfall in first 100 days; ratoon trash retained)				
Trash	0.9-104	Unknown	12	11
Soil	25-104	34	45	31

3.4.3 Soil moisture

Soil water extraction was evident throughout the growing seasons, with periods of saturation (water logging) evident (Figure 19), particularly during the extremely wet 2010/11 season. Treatment differences in total moisture are likely to be related to clay content differences across the treatments, rather than treatment differences. Treatment 1 had the highest clay content (35-46%) and higher soil moisture than Treatment 5 (17-46% clay content) and Treatment 2 (15-39% clay content). Sudden increases in total moisture above “normal” maximum values are when the site flooded.

Data from the individual depth sensors shows no water extraction at 150 cm in Treatment 1, but was evident at 100 cm in May-July 2010 and November 2011 (Section 7.1.3). There were periods when the shallow water table rose to within 60 cm of the soil surface each season. In Treatment 2, water extraction was evident for a short period of time in July 2010 (unable to determine after October 2010 as the sensor stopped working and was unable to be replaced). A shallow water table was evident within 80 cm of the soil surface each season (Section 7.1.4). Soil water extraction at 150 cm was evident in Treatment 5 for periods during October 2011 – January 2012. Again, a shallow water table was evident within 100 cm of the soil surface each season (Section 7.1.5). The duration and location of the shallow water table was due to the location of the treatments in the landscape (Treatment 1 lowest in the landscape, followed by Treatment 5 then 2), and not the treatments themselves.

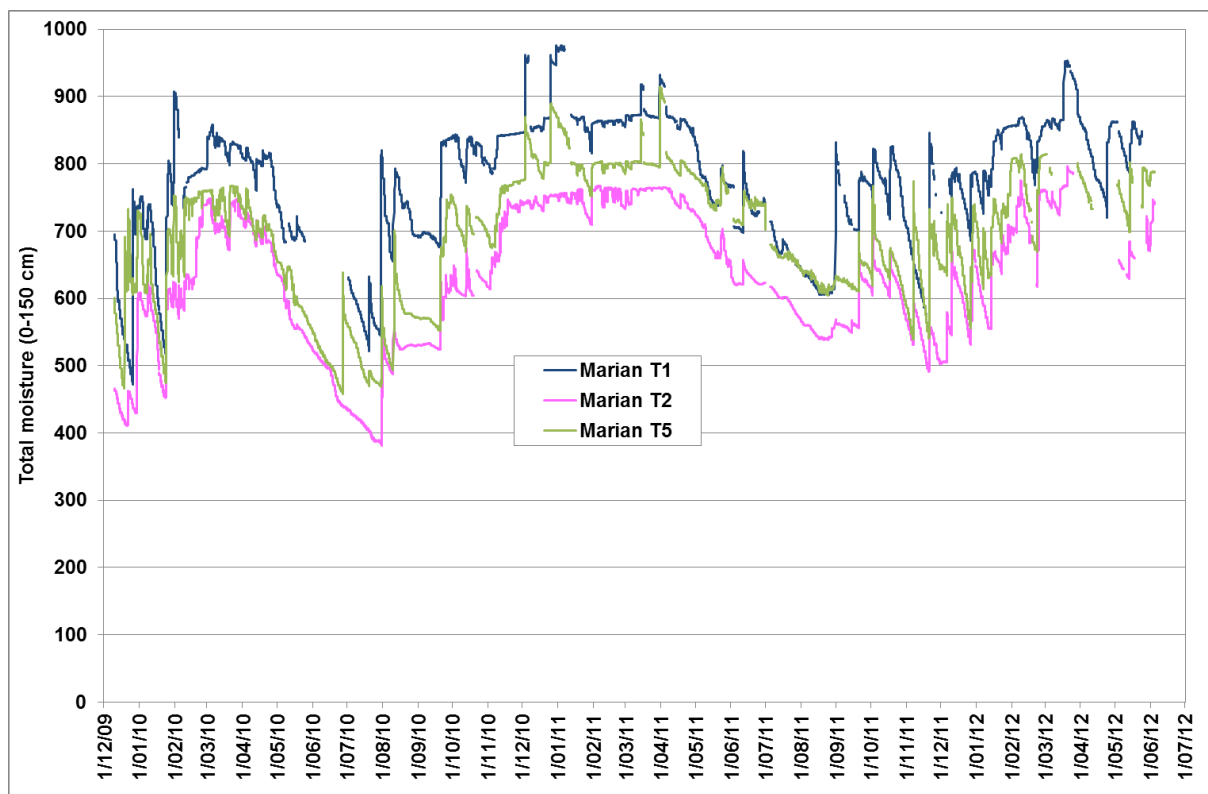


Figure 19 Total moisture in the soil profile (0-150 cm), Marian site

(Note – total moisture is an uncalibrated volumetric water content)

3.4.4 Rainfall and runoff water quality

A total of 7485 mm of rainfall (2722 mm/year) was recorded at the Marian site from October 2009 to June 2012, with 2010/11 being the wettest year (3168 mm). All years were above the long-term October-September water year average of 1679 mm (median 1513 mm) (Te Kowai Research Station, 1889/90-2009/10; data extracted in April 2011 from <http://www.bom.gov.au/climate/data/>).

As reported previously, 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 the uncertainty of flow rates through the flumes, **no water quality loads have been calculated for this site.**

3.4.4.1 Total suspended solids, turbidity and electrical conductivity

Total suspended solids concentrations varied considerably between treatments, and across seasons. It is thought that the variability between treatments is due to the number of samples collected (and which events were sampled, due in part to the flooding issues mentioned above) rather than the treatments themselves. Concentrations were the most variable in 2010/11 (Figure 20 and Figure 21) possibly accentuated by the low concentrations (23-48 mg/L) in runoff prior to harvest on 29th October 2010. Concentrations after harvest (burnt) and cultivation (29th November 2010) increased ~10-fold (compared to pre-harvest) due to the lack of cover and freshly disturbed soil. Even though the plant cane (2009/10 season) was cultivated, the soil had time to consolidate before the first runoff event leading to relatively low concentrations (36-330 mg/L). Concentrations in 2011/12 (13-140 mg/L) were lower than previous seasons due to the ground cover provided by the green cane trash blanket.

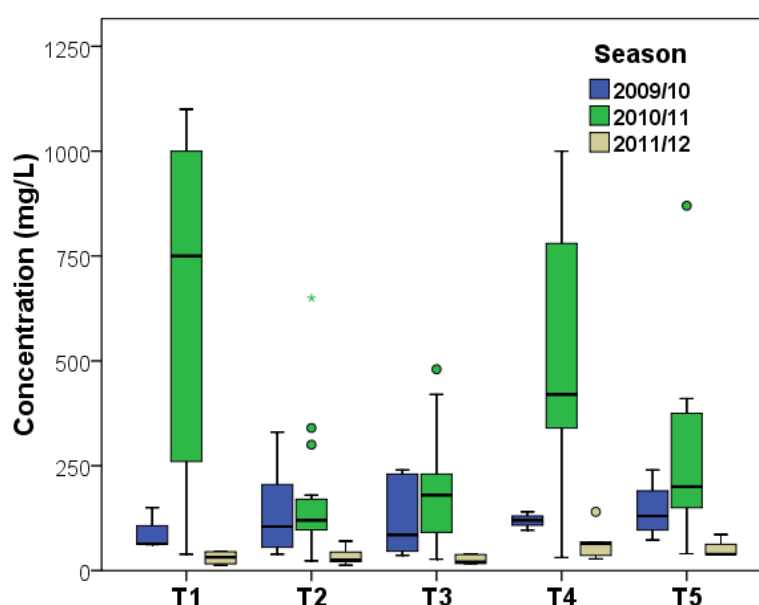


Figure 20 Box plot of concentrations of total suspended solids in runoff, Marian site

Similar to TSS concentrations, turbidity showed no obvious treatment effects. When all samples were combined (treatments and seasons), there was a good relationship between TSS concentration and turbidity (Figure 11).

The EC of rainfall runoff water was generally consistent between treatments and seasons; with an overall range of 26-255 $\mu\text{S}/\text{cm}$. These results are much lower than those samples collected from irrigation runoff water on 13th May 2012 (1171 $\mu\text{S}/\text{cm}$ and 1308 $\mu\text{S}/\text{cm}$ for Treatments 2 and 3, respectively), presumably due to groundwater being used for irrigation.

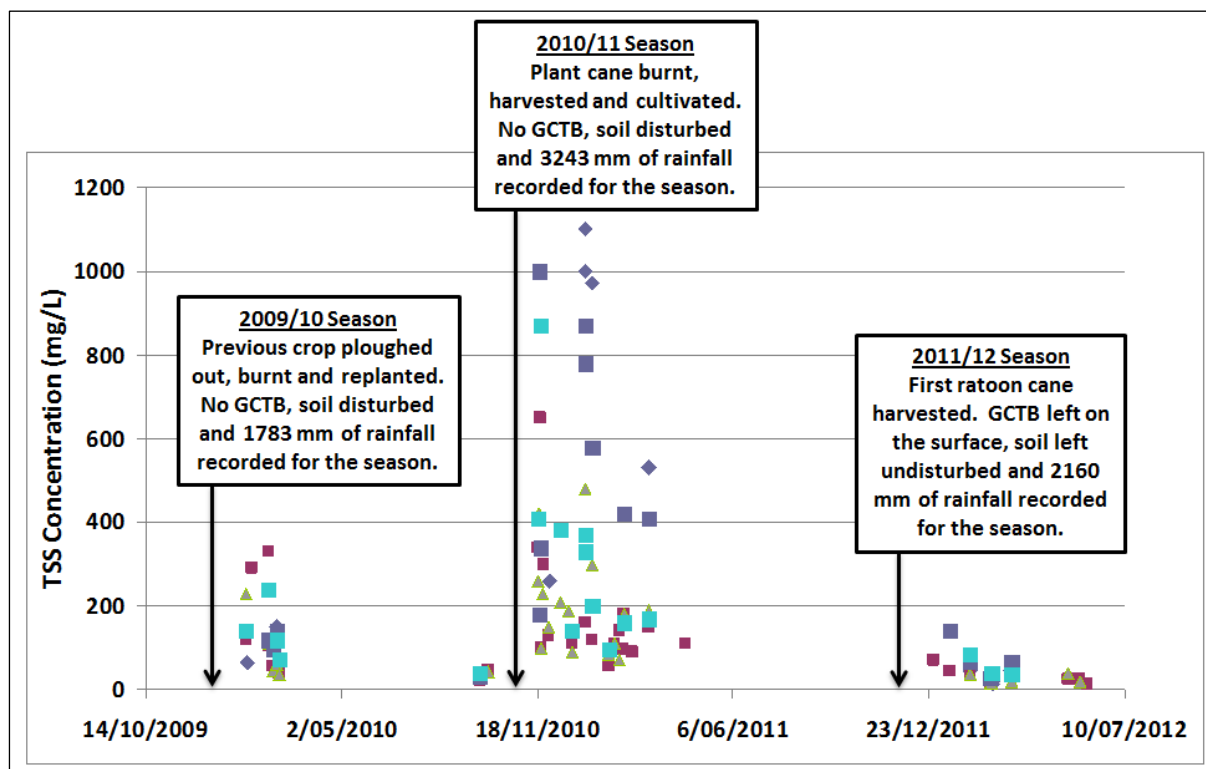


Figure 21 Scatter plot of concentrations of total suspended solids in runoff, Marian site

Similar to TSS concentrations, turbidity showed no obvious treatment effects. When all samples were combined (treatments and seasons), there was a good relationship between TSS concentration and turbidity (Figure 11).

The EC of rainfall runoff water was generally consistent between treatments and seasons; with an overall range of 26-255 $\mu\text{S}/\text{cm}$. These results are much lower than those samples collected from irrigation runoff water on 13th May 2012 (1171 $\mu\text{S}/\text{cm}$ and 1308 $\mu\text{S}/\text{cm}$ for Treatments 2 and 3, respectively), presumably due to groundwater being used for irrigation.

3.4.4.2 Nitrogen

Concentrations of $\text{NO}_x\text{-N}$ (median and maxima) in rainfall runoff were highest in the 2010/11 season (Figure 22) when runoff was first recorded 16 days after nutrient application (102-105 days for other seasons). As previously reported, $\text{NO}_x\text{-N}$ concentrations were highest in the first runoff events after application, and then declined as the season progressed. Across the three seasons, Treatment 5 (1.8 m skip row, Six Easy Steps) had the highest median $\text{NO}_x\text{-N}$ concentration (151 $\mu\text{g N}/\text{L}$; 28 samples). This was thought to be due in part to nutrients being applied to the skip area and no peanut crop planted (although it was planned) to uptake the nutrients and to supply additional nitrogen. The median concentration of other treatments was consistent (80-93 $\mu\text{g N}/\text{L}$), except for Treatment 1 (150 $\mu\text{g N}/\text{L}$; only 18 samples).

In contrast to rainfall runoff, the samples collected from the irrigation runoff on 13th May 2012 had relatively high $\text{NO}_x\text{-N}$ concentrations (4037-4505 $\mu\text{g N}/\text{L}$; 242 days after nutrient application). Although the source water of this irrigation was not sampled, water quality results from a nearby bore (2 km away) sampled in 2006/07 showed relatively high nitrate-N concentrations of 2260 $\mu\text{g N}/\text{L}$ (Masters *et al.* 2008).

In comparison to $\text{NO}_x\text{-N}$ concentrations, urea-N concentrations were low ($<700 \mu\text{g N/L}$), with seasonal median concentrations similar between 2010/11 and 2011/12 (84-122 $\mu\text{g N/L}$; urea-N not analysed in 2009/10). Maximum concentrations were higher in 2010/11 than 2011/12, probably due to the shorter period between application and first runoff (16 days, compared to 102 days in 2011/12).

Similar to $\text{NO}_x\text{-N}$ concentrations, ammonium-N concentrations were highest in the 2010/11 season, when runoff first occurred 16 days after nutrient application. Across all of the samples collected with both TN and ammonium-N results, ammonium-N comprised 5% of the TN (13% for $\text{NO}_x\text{-N}$).

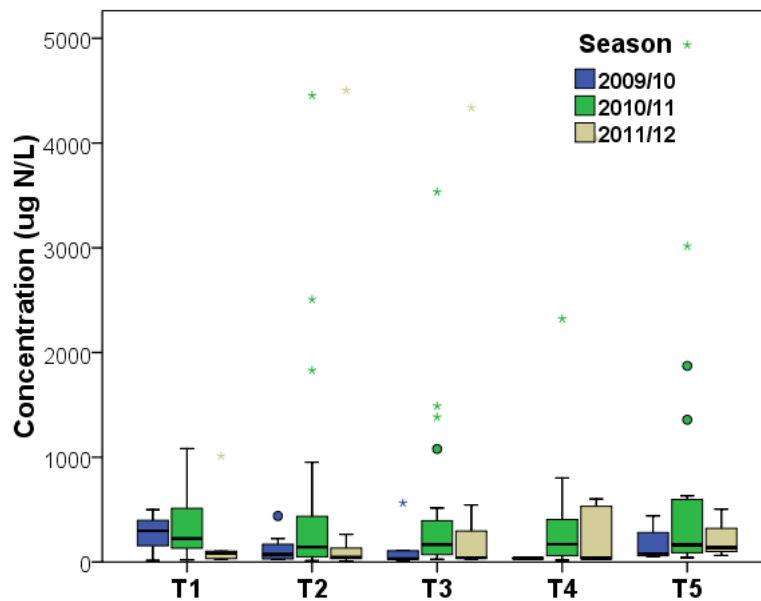


Figure 22 Concentrations of $\text{NO}_x\text{-N}$ in runoff, Marian site

3.4.4.3 Phosphorus

Seasonal median filterable reactive phosphorus (FRP) concentrations (Figure 23) tended to increase for Treatments 1 and 2 (where 20 kg/ha of phosphorus was applied each season) and remained steady for Treatments 3-5 (when no phosphorus was applied other than at cane planting). When data from the three seasons was combined, treatment medians were similar (362-416 $\mu\text{g P/L}$), except Treatment 2 (645 $\mu\text{g P/L}$).

Across all of the samples collected, FRP comprised the majority (median 91%) of the TFP signature. Of those samples with both FRP and TP, FRP comprised 61% (median) of TP.

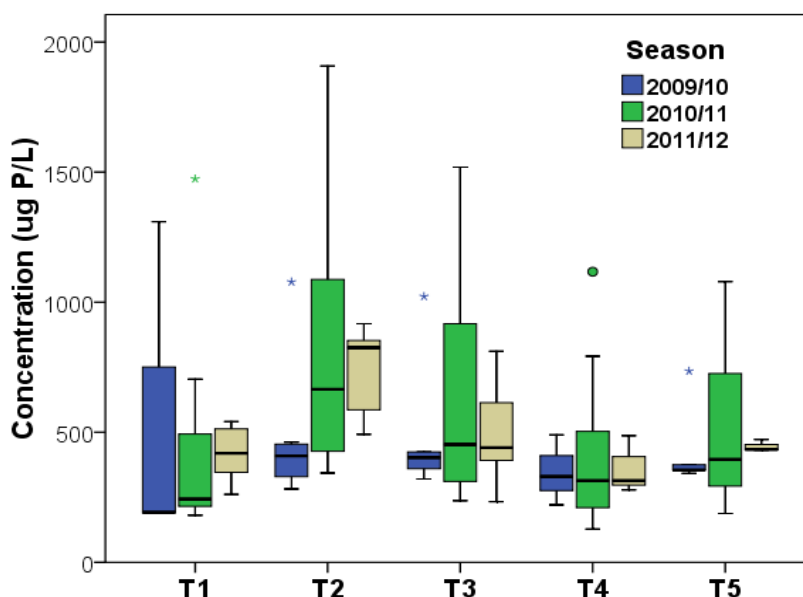


Figure 23 Filterable reactive phosphorus concentrations in runoff, Marian site

3.4.4.4 Herbicides

Interpreting herbicide runoff concentrations across the three seasons is difficult, due to different products used each season (Table 8). However, a number of conclusions can be drawn.

As with the Victoria Plains site, herbicide concentrations were highest in the initial runoff events following application. For example, the first runoff in the 2009/10 season was 88 days after application. Metolachlor concentrations were $<12 \mu\text{g/L}$ in the first runoff event and decreased to $<2 \mu\text{g/L}$ one month later. In contrast, atrazine was $<0.3 \mu\text{g/L}$ in all monitored events.

In the 2010/11 season, the first runoff event was four days after application. Initial atrazine concentrations were $>5 \mu\text{g/L}$, decreasing to $<1 \mu\text{g/L}$ within 20 days. Initial concentrations of 2,4-D were $>50 \mu\text{g/L}$, decreasing to $<1.1 \mu\text{g/L}$ in the following event (10 days after application).

The first runoff event in the 2011/12 season was 30 days after application. Diuron and hexazinone concentrations were low (<0.5 and $<0.3 \mu\text{g/L}$, respectively), and decreased as the season progressed. Isoxaflutole was not detected in any runoff samples ($<1 \mu\text{g/L}$), with samples first collected 48 days after application to Treatment 3.

3.4.5 Drainage water quality

It is suspected that drainage water quality (from soil solution samplers at 0.9 m depth) may be confounded by the presence of a shallow water table, particularly in the 2010/11 season. It is also thought that within and across treatment variability may be also partly due to sample contamination. Due to the low confidence in the data quality, results are not reported.

3.4.6 Agronomic

There was very little difference in the cane yield of Treatments 1-4 during the first two years (plant cane and first ratoon; Table 21). In the third year (second ratoon), the cane yield of

Treatment 4 (N replacement) was reduced due to the low nitrogen application rate. The cane yield of Treatment 3 (Six Easy Steps) was also lower than Treatments 1 and 2, possibly due to the lower nitrogen application rate and/or no phosphorus applied. Treatment 5 (skip row, Six Easy Steps) yielded ~70% of solid plant (Treatment 3) in “reasonable” seasons (plant cane and second ratoon crops), but only yielded 50% in the wet year (first ratoon crop).

Table 21 Machine harvest yield results for each treatment, Marian site

		T1	T2	T3	T4	T5
Plant cane (harvested 29/10/10)	N applied (kg/ha)	191	191	172	97	164
	Cane (t/ha)	135	128	127	122	93
	PRS	11.9	11.9	11.8	11.9	11.0
	Sugar (t/ha)	16.0	15.2	14.9	14.5	10.2
	Net return (\$/ha)	1900	2100	2100	2000	1200
First ratoon (harvested 30/08/11)	N applied (kg/ha)	258	258	220	180	220
	Cane (t/ha)	43	43	41	38	21
	PRS	NS	12.6	13.4	12.7	NS
	Sugar (t/ha)	NS	5.5	5.5	4.9	NS
	Net return (\$/ha)	670	730	840	740	430
Second ratoon (harvested 18/09/12)	N applied (kg/ha)	197	197	159	53	159
	Cane (t/ha)	100	103	83	59	59
	PRS	15.0	14.9	15.6	15.3	15.6
	Sugar (t/ha)	15.0	15.4	13.0	9.0	9.3
	Net return (\$/ha)	2800	3100	2600	1900	1700
Average (of 3 seasons)	N applied (kg/ha)	215	215	184	110	181
	Cane (t/ha)	93	91	84	73	58
	PRS	13.5	13.2	13.6	13.3	13.3
	Sugar (t/ha)	NS	12.0	11.1	9.5	NS
	Net return (\$/ha)	1800	2000	1800	1500	1100

NS – not sampled due to insufficient sample volume

The nitrogen and phosphorus content of the cane stalk prior to harvest showed little difference between seasons, except for a reduction in nitrogen in Treatments 1 and 4 in the second ratoon (Figure 24). The reduction in stalk nitrogen content in Treatment 4 may be due to the lower rate of nitrogen applied and the lower yield (Table 21). Phosphorus content was similar between seasons, and tended to reflect the soil phosphorus concentrations (e.g. Treatment 1 generally had lower surface soil concentrations (Figure 18) and the lowest stalk content). It should also be noted that the stalk phosphorus content at this site (~0.1-0.16% dry matter) is much higher than that of the Victoria Plains site (~0.04-0.06% dry matter). This reflects the much higher soil phosphorus concentrations at the Marian site.

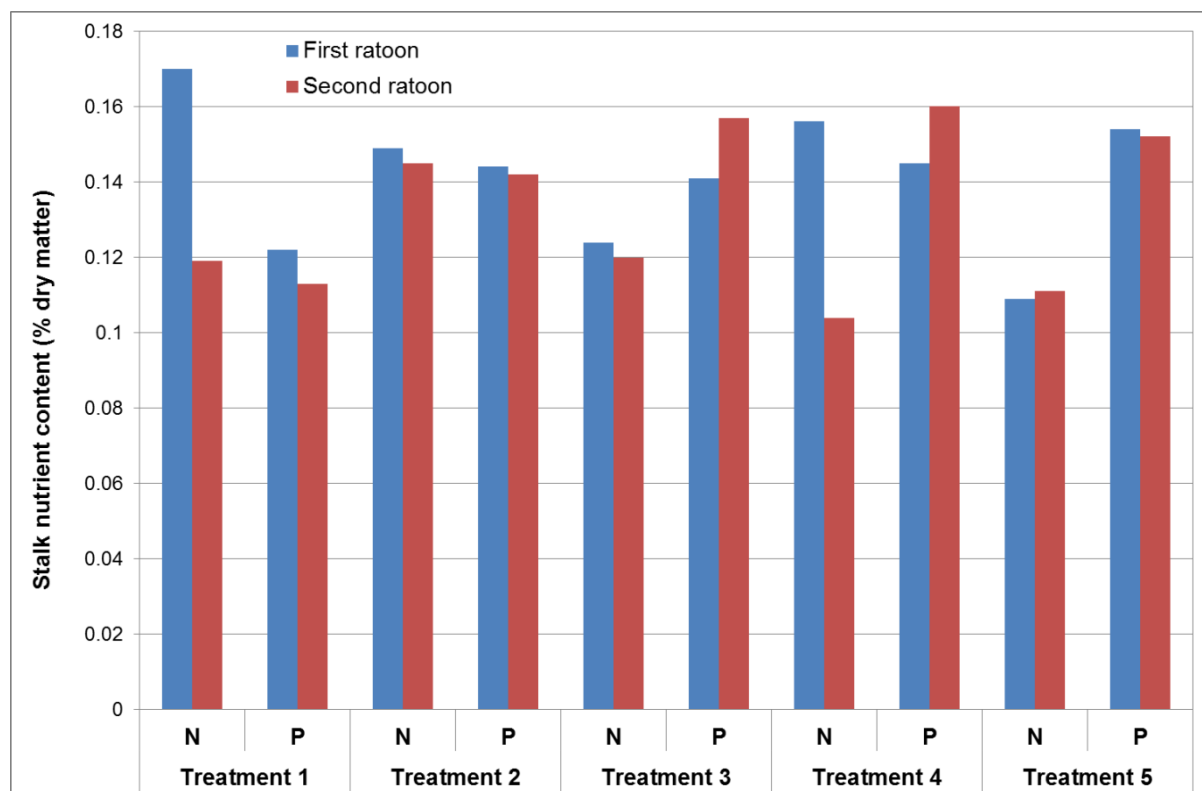


Figure 24 Nitrogen and phosphorus content of the cane stalk prior to harvest of first and second ratoon crops, Marian site

3.5 Multi-block and Multi-farm sites

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 adjacent cane paddocks. During large events, the water depth at the Multi-farm site drain was high enough to flood into the Multi-block drain, further confounding flow estimates. During many flow events (generally late in the wet season), water would back up across the Multi-block weir after the downstream dam and drain filled; causing significant flow rates to be recorded when there was actually very little flow across the weir. **It is therefore not possible to determine accurate flow volumes of runoff for events, and consequently loads could not be calculated for the Multi-block site. Runoff and load calculations for the Multi-farm site should be treated with caution.**

3.5.1 Rainfall and runoff

A total of 7669 mm of rainfall was recorded at the Multi-farm site from October 2009 to September 2012, with 2010/11 being the wettest year (3241 mm). At the Multi-block site, 7170 mm was recorded from October 2009 to June 2012 (equipment removed in early July 2012). All years were above the long-term October-September average of 1679 mm (median 1513 mm) (Te Kowai Research Station, 1889/90-2009/10; data extracted in April 2011 from <http://www.bom.gov.au/climate/data/>).

Total runoff for the three seasons from the Multi-farm site was 2765 mm (Table 22), or 36% of rainfall.

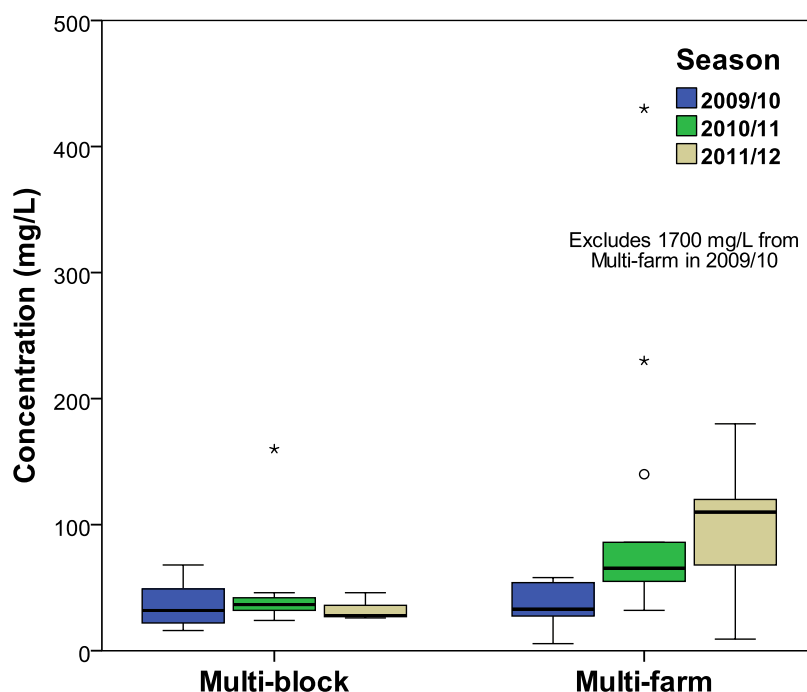
Table 22 Seasonal rainfall, runoff and TSS loads and concentrations during the monitored wet seasons, Multi-farm site

Season	Rainfall (mm)	Runoff (mm)	TSS Load (kg/ha)	EMC (mg/L)
2009/10	2104	752	1218	162
2010/11	3241	1364	1387	102
2011/12	2324	649	779	120
Total	7669	2765	3384	
Annual average	2556	922	1128	122

3.5.2 Runoff water quality

3.5.2.1 Total suspended solids, turbidity and electrical conductivity

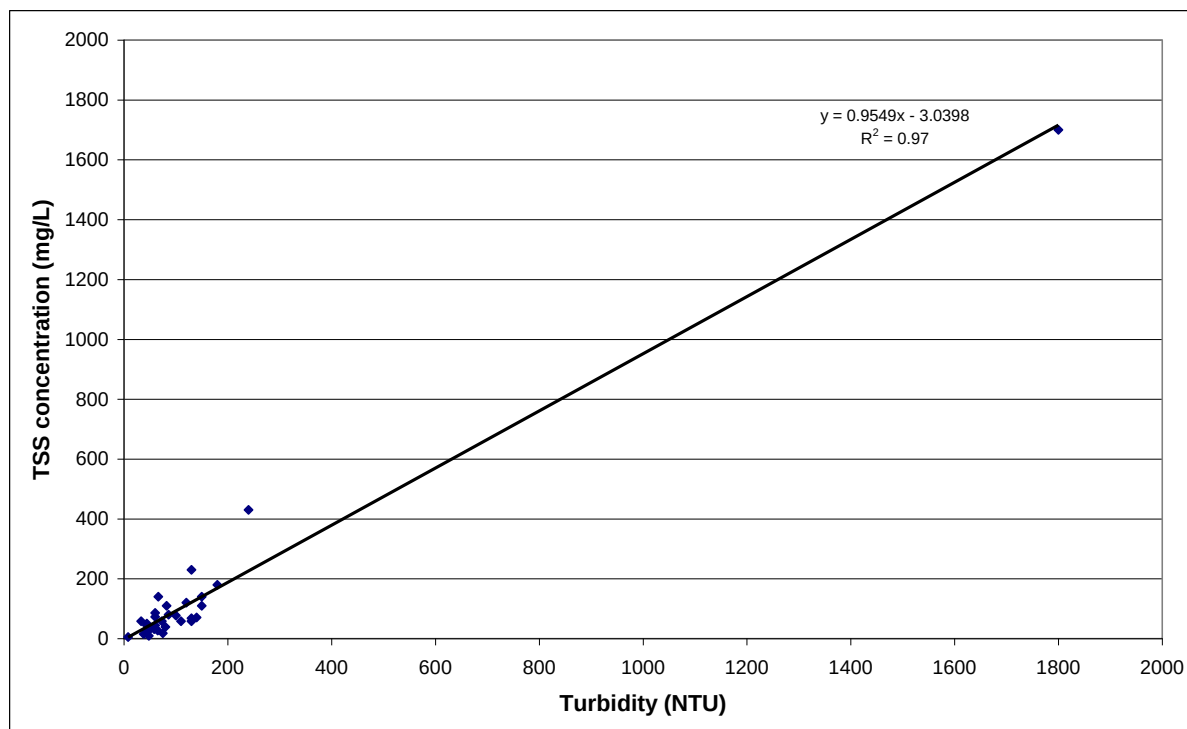
Concentrations of TSS at the Multi-block site were low and consistent across the three monitored wet seasons (Figure 25). The highest concentration (160 mg/L) was recorded in September 2010, the first runoff event of the 2010/11 season. All other concentrations were <70 mg/L. Due to the low range of concentrations, there was no significant relationship with turbidity. Similar to TSS, there was little variability in the electrical conductivity (EC) across the seasons with an overall range of 43-133 μ S/cm.

**Figure 25 Concentrations of TSS in runoff, Multi-block and Multi-farm sites**

At the Multi-farm site, the range of TSS concentrations was much higher than the Multi-block site, with the median concentration increasing each season (Figure 25). This is in contrast to the flow-weighted seasonal event mean concentration (EMC), with the 2009/10 season having the highest concentration (Table 22). This is due to the highest concentration (1700 mg/L in February 2010) producing 82% of the seasonal load from only 11% of the runoff. The average estimated seasonal sediment load was 1128 kg/ha, with a flow-weighted mean concentration of 122 mg/L (Table 22). There was a good relationship between TSS concentration and turbidity (Figure 26). Electrical conductivity values varied little across the seasons (median 48-71 μ S/cm), with a maximum of 277 μ S/cm in January 2010.

Table 23 Calculated loads of nutrients from runoff, Multi-farm site

Season	TKN		NO _x -N		TKP		FRP	
	kg/ha	µg N/L	kg/ha	µg N/L	kg/ha	µg P/L	kg/ha	µg P/L
2009/10	7.0	929	2.1	280	2.8	366	1.0	138
2010/11	12.7	928	2.2	165	4.9	357	1.3	95
2011/12	8.4	1294	1.8	283	2.7	416	1.1	172
Total	28.1		6.1		10.4		3.4	
Average	9.4	1016	2.0	221	3.5	376	1.1	123

**Figure 26 Relationship between turbidity and TSS concentration, Multi-farm site**

3.5.2.2 Nitrogen (NO_x-N)

Concentrations of NO_x-N at the Multi-block site were <2000 µg N/L across all seasons, except for the first sample collected in the 2011/12 season (5520 µg N/L) (Figure 27). The median concentration of the 2010/11 season (76 µg N/L) was lower than the other two seasons (122-149 µg N/L), reflecting the lower application of nitrogen (Table 11) and/or the wetter season and dilution or exhaustion of NO_x-N runoff.

At the Multi-farm site, NO_x-N concentrations were also generally <2000 µg N/L except for the first sample collected every season (2551-5520 µg N/L) (Figure 27). In contrast to the Multi-block site, the highest seasonal median concentration occurred in the 2010/11 season (197 µg N/L), approximately double that of the other seasons (94-105 µg N/L). When the seasonal flow was taken into account, the 2010/11 season had the lowest flow-weighted seasonal concentration (Table 23). The average seasonal NO_x-N load was 2.0 kg/ha, with a flow-weighted seasonal concentration of 221 µg N/L.

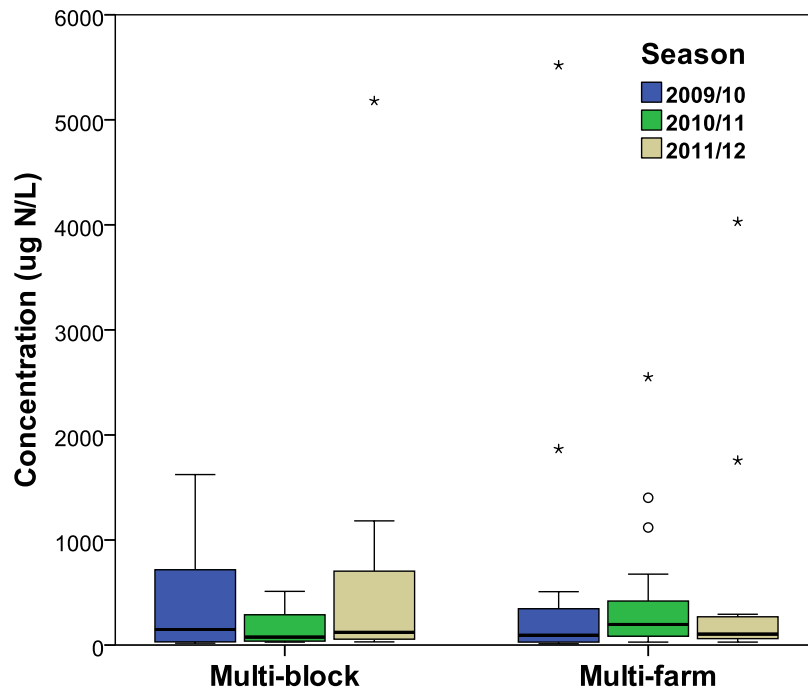


Figure 27 Concentrations of NO_x-N in runoff, Multi-block and Multi-farm sites

3.5.2.3 Phosphorus (FRP)

Seasonal median FRP concentrations at the Multi-block site were approximately three times that of the Multi-farm site (Figure 28). Median concentrations tended to decline each season at the Multi-block site, but were much more consistent at the Multi-farm site. The Multi-block trend may be a result of the slow exhaustion of soil phosphorus (which is known to be high in the area) due to the decreasing application rate across the three seasons (Table 11).

The average seasonal FRP loss in runoff at the Multi-farm site was 1.1 kg/ha, with a flow-weighted seasonal average of 123 µg P/L (Table 23).

Similar to the Marian site, FRP at the Multi-block site comprised the majority (median 88%) of the TFP signature, and 61% of TP. The Multi-block site was similar to the Victoria Plains site: FRP comprised 71% of the TFP signature and one-third of the TP.

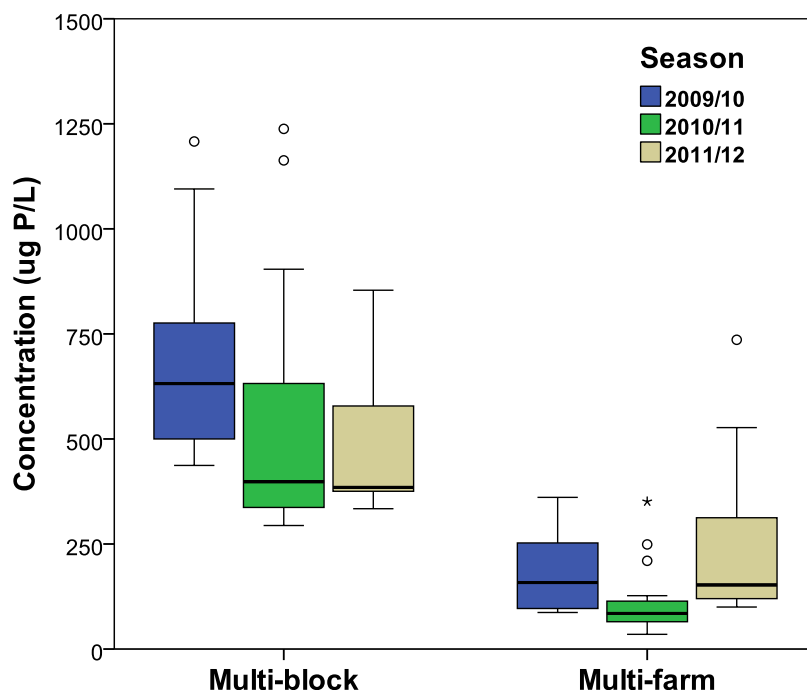


Figure 28 Filterable reactive phosphorus concentrations in runoff, Multi-block and Multi-farm sites

3.5.2.4 Ametryn

Ametryn concentrations at the Multi-block site were highest in the 2010/11 (up to 0.74 µg/L), but was not detected in the majority of samples from the 2011/12 season. At the Multi-farm site, it was detected at higher concentrations than the Multi-block site (Figure 29a), with a maximum concentration detected (1.3 µg/L) in December 2011, the first event of the season. The average seasonal ametryn load was 0.9 g/ha, with a flow-weighted average concentration of 0.10 µg/L (Table 24). Seasonal losses of herbicides in runoff at the Multi-farm site did not reflect the amount of product applied each season. This is likely due to the different timing of application in relation to the first runoff event, and the amount of rainfall during that period.

3.5.2.5 Atrazine

Atrazine concentrations at the Multi-block site were generally <3 µg/L, except for two events in late December 2010 and late January 2011 (10 and 9.4 µg/L, respectively) (Figure 29b). As atrazine had not been applied to this catchment for a number of years prior to the 2010/11 season, the low concentrations detected in the 2009/10 season are likely to be residual from prior applications or as a result of the Multi-farm drain overflowing into the Multi-block drain during high flows. Concentrations of other herbicides were not elevated in these events.

Similarly, concentrations at the Multi-farm site were generally <3 µg/L, except for an event in December 2011 (11 µg/L; the first event of the season) (Figure 29b). Diuron and hexazinone were also elevated in this event. The average seasonal atrazine load was 5.7 g/ha, with a flow-weighted average concentration of 0.61 µg/L (Table 24).

3.5.2.6 Diuron

The highest diuron concentrations at the Multi-block site (32-43 µg/L) were detected in January 2010, the first sampled events of the 2009/10 season. Concentrations declined to be <3 µg/L by February. Concentrations in the following seasons were <7 µg/L (Figure 29c). At the Multi-farm site, diuron concentrations were reasonably consistent across the seasons,

with all concentrations $\leq 10 \mu\text{g/L}$ (Figure 29c). The average seasonal diuron load was 9.0 g/ha, with a flow-weighted average concentration of 0.98 $\mu\text{g/L}$ (Table 24).

3.5.2.7 Hexazinone

At the Multi-block site, hexazinone concentrations followed a similar trend to diuron, with the highest concentrations (13-16 $\mu\text{g/L}$) detected in the initial events of the 2009/10 season (Figure 29d). Concentrations in subsequent seasons were all $<0.1 \mu\text{g/L}$. These herbicides were applied to ~20% of the Multi-block site area prior to the 2009/10 wet season, and have not been applied since.

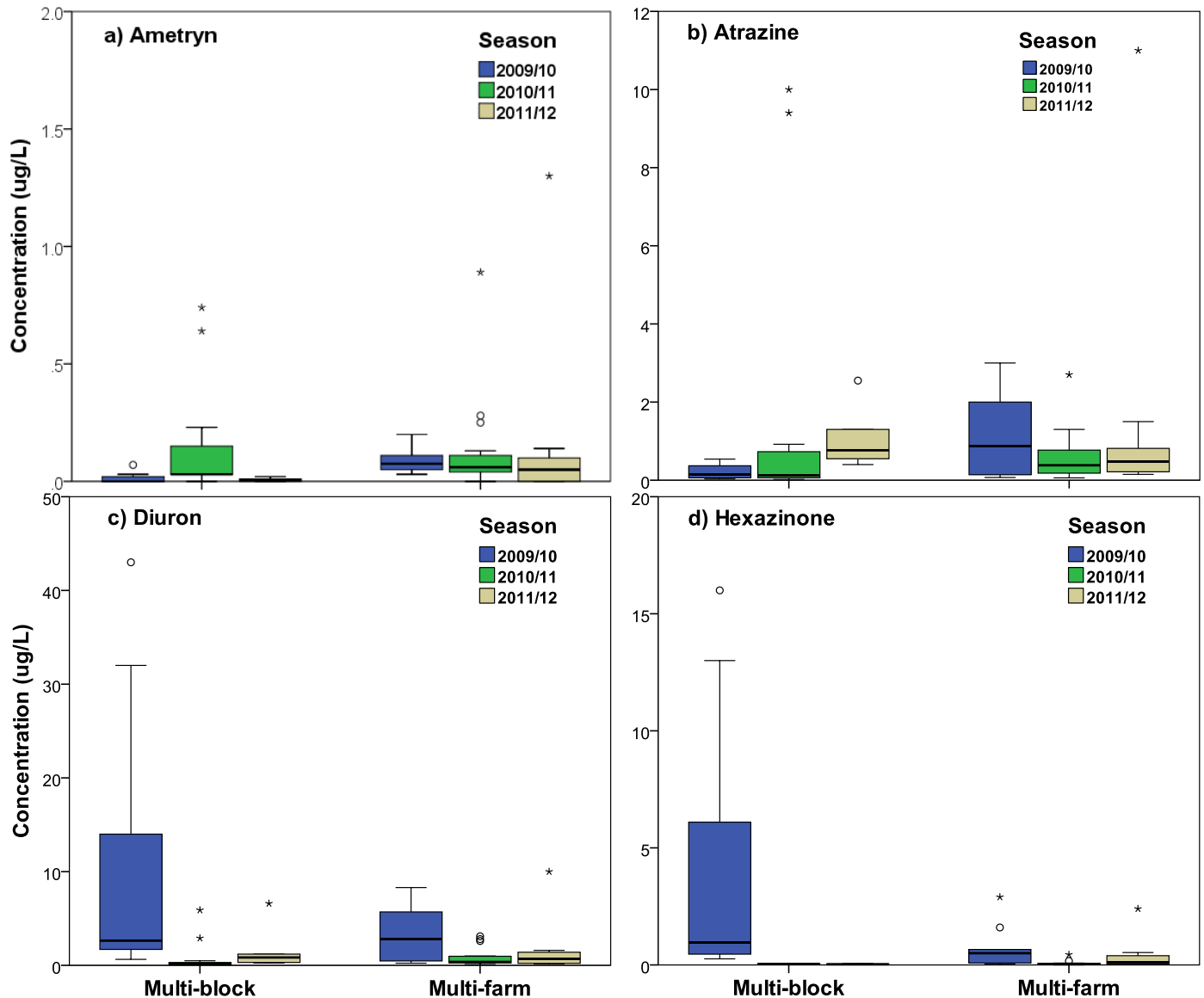


Figure 29 Concentrations of a) ametryn, b) atrazine, c) diuron and d) hexazinone in runoff, Multi-block and Multi-farm sites

Table 24 Seasonal loads and concentrations of herbicides from runoff, Multi-farm site

Season	Ametryn		Atrazine		Diuron		Hexazinone	
	g/ha	µg/L	g/ha	µg/L	g/ha	µg/L	g/ha	µg/L
2009/10	0.40	0.05	3.1	0.41	9.3	1.2	1.7	0.23
2010/11	1.8	0.13	8.3	0.61	12	0.88	1.2	0.09
2011/12	0.60	0.09	5.5	0.82	6.1	0.94	1.4	0.21
Total	2.8		17		27		4.3	
Average	0.9	0.10	5.7	0.61	9.0	0.98	1.4	0.16

Hexazinone concentrations at the Multi-farm site also followed a similar trend to diuron. Concentrations were lowest in the 2010/11 season (Figure 29d), possibly due to the reduced application and/or diluted due to the high rainfall in that season. The average seasonal hexazinone load was 1.4 g/ha, with a flow-weighted average concentration of 0.16 µg/L.

3.5.2.8 Other pesticides

Metolachlor was detected at low concentrations (0.01-0.03 µg/L) in almost half of the samples collected from both the Multi-block and Multi-farm sites in the 2009/10 season. In the 2010/11 season, metolachlor was only detected at the Multi-block site in the initial sample collected (0.01 µg/L) and the Multi-farm site in one sample (0.02 µg/L). In the 2011/12 season, metolachlor was detected in all samples collected for Multi-block (0.03-2.7 µg/L) and in the majority of samples collected from the Multi-farm site (maximum concentration 0.13 µg/L).

Imidacloprid was only detected at the Multi-block site during the 2011/12 season (0.01-0.02 µg/L). At the Multi-farm site, it was detected (0.01-0.07 µg/L) in the majority of samples each season.

At both sites, bromacil was only detected in the 2011/12 season. Concentrations were lower at the Multi-block site (<0.01-0.01 µg/L) than the Multi-farm site (<0.01-0.1 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 a comparison of row spacing/wheel traffic effects on runoff. Due to flooding, this comparison is not possible at the Marian site.

At the Victoria Plains site, Treatment 2 (1.8 m row spacing, controlled traffic) had 14.5% less runoff than Treatment 1 (1.5 m row spacing) across the three monitored wet seasons. This reduction in runoff, presumably due to controlled traffic, has been similar across the seasons, with the 2009/10 season having the largest reduction (18%) (Rohde and Bush 2011). The commencement of runoff was delayed on average by approximately 17 minutes, and peak runoff rates reduced by 18%. These results are comparable to other soil compaction and controlled traffic studies, described below.

Previous studies on a heavy clay soil 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.* 2011). Results from a rainfall simulation study on a Marian soil showed that runoff averaged 43% less from 2 m controlled traffic cane treatments compared to 1.5 m current practice treatments on dry soil, to 30% less on wetter soils (Masters *et al.* 2008, Masters *et al.* 2012). Also, all of these studies support our findings of reduced treatment differences in runoff due to a prolonged wet season and wetter soils.

The reductions in start time to runoff (~17 minutes) and reduced peak runoff rates (average 18%), which were observed in the wider row spacing treatment, were consistent with reduced compaction and improved infiltration. In the rainfall simulation study of Masters *et al.* (2012), they found that the bulk densities of current practice treatments (1.5 m) were significantly higher (and hence more compact) in the top 30 cm of the mid-section of the cane bed. This reflects the straddling effect of wheels in uncontrolled traffic and therefore greater area of compaction under current practice (1.5 m) compared to controlled traffic (2 m). Differences in our bulk density treatment differences (Rohde *et al.* 2011,) were not as evident as those observed in the rainfall simulation study. However, the treatments at the Victoria Plains site had only been in place for three years, 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 reduced each season as the cane cycle progressed from the cultivated plant cane phase (631-826 mg/L in 2009/10) to the green cane trashed blanketed ratoon phase (135-158 mg/L in 2010/11, and

22-24 mg/L in 2011/12). As a result, seasonal soil erosion also reduced from ~ 3t/ha in plant cane (2009/10) to ~0.3 t/ha in 2010/11.

At the Marian site, TSS concentrations varied with cover and cultivation: 36-330 mg/L (average 127 mg/L) in 2009/10 (initially bare plant cane); 23-1100 mg/L (average 289 mg/L) in 2010/11 (burnt cane and one cultivation); and 13-140 mg/L (average 40 mg/L) in 2011/12 (green cane trash blanket). These results are expected, as the main factors found to affect soil erosion are tillage and ground cover (Prove *et al.* 1995, Connolly *et al.* 1997, Silburn and Glanville 2002).

The estimated soil erosion each season (~0.3-3 t/ha) measured from the Victoria Plains site is much lower than that historically recorded. Soil erosion rates of 42-227 t/ha/year have been recorded in the Mackay region under conventional tillage and burnt cane harvesting (Sallaway 1979). With the move to green cane harvesting, trash blanketing and minimum tillage, soil erosion rates have dropped to <5-15 t/ha/year (Prove *et al.* 1995). Although the soil erosion measured in the 2011/12 season is considered low, it is similar to the rate of soil formation (~0.3 t/ha) resulting from basaltic lava flows in semi-arid tropical Australia (Pillans 1997).

Sediment concentration in runoff is driven by peak runoff rate, cover and roughness (surface consistency); while peak runoff is influenced by rainfall intensity, runoff depth and ground cover (Freebairn *et al.* 2009). Freebairn *et al.* (2009) reported 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. 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

Three main factors appear to control nitrogen and phosphorus concentrations in runoff; the period of time between application and the first runoff event, the amount of product applied (fertiliser), and background soil nutrient levels. This makes a direct comparison of nitrogen between seasons difficult, due to the speciation of nitrogen over time. It should also be noted that granular fertiliser was used in the first season, and liquid fertilizer in subsequent seasons.

In the 2009/10 season (following a legume fallow and high soil nitrate-N concentrations) at the Victoria Plains site, the nitrogen concentrations in the first runoff event (176 days after fertiliser application) were dominated by NO_x-N, although urea-N was not analysed. This led to relatively high seasonal nitrogen runoff losses (~5-13 kg/ha of NO_x-N; ~10% of applied nitrogen). The first runoff in the 2011/12 season occurred three days after fertiliser application, and nitrogen loss was dominated by urea-N and therefore the seasonal runoff load was dominated by urea-N (~12-16 kg/ha; ~10% of applied nitrogen), presumably due to the high soil nitrate-N concentrations from the legume fallow. In the 2011/12 season, the first runoff occurred 78 days after application, and nitrogen losses were dominated by NO_x-N and were much lower than previous seasons (~1 kg/ha; ~1% of applied nitrogen). **These losses are an order of magnitude lower than previous seasons**, when runoff occurred within 10 days of application. The relatively low concentrations of nitrogen (particularly urea-N) in the 2011/12 season are encouraging for riverine and marine water quality. Elevated concentrations of urea-N have been shown to be a preferred form of nitrogenous nutrient for many phytoplankton, including some dinoflagellates which form harmful algal blooms (Glibert *et al.* 2005).

In all seasons, Treatment 1 at the Victoria Plains site lost more nitrogen to runoff than Treatment 2 due to the higher application rates, although the percentage loss for each treatment was similar. In 2009/10 (when soil nitrate-N concentrations were high) and 2010/11 (when runoff occurred 3 days after fertiliser application), runoff losses ($\text{NO}_x\text{-N}$ plus urea-N) were ~10% of the applied fertiliser rate. In 2011/12, runoff losses were only ~1% of the applied fertiliser rate due to the lower soil nitrate-N concentrations and extended period between application and first runoff.

A similar cane study near Mossman in far North Queensland also found that the total runoff 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 that losses of 10-15% of applied nitrogen (to surface or sub-surface waters) are regularly recorded in high rainfall areas (or in our case, when runoff occurred soon after application), but can be reduced to 1% when conditions are favourable.

Filterable reactive phosphorus (FRP) concentrations in runoff at the Victoria Plains site were similar between treatments due to similar rates of phosphorus being applied. The median concentration tended to increase each season, as did the soil phosphorus levels. Runoff FRP concentrations (flow-weighted seasonal average concentration 50-65 $\mu\text{g P/L}$) were much lower than those measured at the Marian site (treatment median concentrations of 362-645 $\mu\text{g P/L}$). The difference in runoff concentrations between sites (soils) (~8 times higher at the Marian site) is thought to be associated with the background levels of soil phosphorus. Surface (0-0.1 m) soil phosphorus concentrations at harvest each season at the Marian and Victoria Plains sites were 290-900 $\mu\text{g/kg}$ and 116-288 $\mu\text{g/kg}$, respectively.

4.4 Factors affecting herbicides in runoff

In this study the timing of rainfall after herbicide application greatly influenced the concentrations of herbicides detected in runoff water. At the Victoria Plains site, the first runoff event in the 2011/12 season occurred 128 days after herbicide application (7-8 days in previous seasons).

The total diuron loss for the 2011/12 season (3.0 g/ha) was <0.2% of the applied diuron (11.8% in 2010/11), whereas <0.4% of the applied hexazinone (17.8% in 2010/11) was lost in runoff. Single event runoff losses of herbicides in the range of 1-2% are not uncommon, however losses greater than this are generally considered only to occur as a result of extreme environmental conditions (Wauchope 1978). Wauchope's (1978) study defined runoff events as "critical" if they occurred within a two week period of application and had a runoff volume which was 50% or more of the rainfall.

Initial concentrations of herbicides detected in runoff at the Victoria Plains site in the 2011/12 season (6.9 and 3.8 $\mu\text{g/L}$ for diuron and hexazinone, respectively) were much lower than those detected in previous seasons (240 and 98 $\mu\text{g/L}$ in 2010/11 and 18 and 41 $\mu\text{g/L}$ in 2009/10 for diuron and hexazinone, respectively). Herbicide loss in runoff is strongly influenced by rainfall immediately following herbicide application, and by environmental conditions, such as crop residue cover and soil water content (Smith *et al.* 2002). They showed that in a rainfall simulation experiment, a post-herbicide irrigation ("rain-in" of 4-8 mm) reduced atrazine mass loss by 33% one day after application, largely due to the resulting reduction of the herbicide concentration in the surface soil. In another rainfall simulation study, irrigation substantially reduced the total amount and rate of metolachlor runoff (Potter

et al. 2008). In our study in the 2011/12 season, 22.8 mm of rain was recorded within 10 days of herbicide application, and a further 200 mm fell before the first runoff event. This compares to no rainfall between application and the first runoff event in 2010/11, and 7.6 mm in 2009/10. This rainfall, and the longer period to runoff, has led to lower cane trash and surface soil herbicide concentrations and consequently less herbicide available to be lost in runoff.

In the 2010/11 season, much shorter half-lives (more than half) were measured on cane trash than in the 2011/12 season. This is thought to be due to the higher rainfall (1090 mm within 100 days of application) washing the herbicide from the cane trash into the surface soil much more rapidly than the 2011/12 season when only 98 mm of rain fell within 100 days of application. The study has confirmed that herbicide half-lives are shorter on cane trash than in surface soil.

In contrast to the cane trash results, soil herbicide half-lives were much longer (~1.3-3 times longer) in the 2010/11 season than the 2011/12 season. The extreme rainfall in the 2010/11 season was able to “trickle feed” the surface soil (after being washed from the trash), leading to longer apparent field half-lives. These field based half-lives (74-199 days and 39-53 days for diuron and hexazinone, respectively) are much longer than those generally reported in the literature. For example, Sanchez-Bayo and Hyne (2011) reported half-lives in tropical soils of 15-31 days and 20-21 days for diuron and hexazinone, respectively. Across a number of soil types in the Bundaberg region, Simpson *et al.* (2001) found the dissipation of diuron ranged from 13->250 days.

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 spacing resulted in a reduction in runoff. Specifically:

- Total runoff from individual runoff events from Treatment 2 (1.8 m row spacing) averaged 14.5% less than Treatment 1 (1.5 m row spacing) (3232 mm and 3781 mm, respectively; or 42% and 49% of rainfall). Runoff from Treatment 2 was delayed on average by ~17 minutes compared with Treatment 1, and the peak runoff rate was ~18% lower, all contributing to reduced runoff.
- Total suspended solids (TSS) concentrations were slightly higher in Treatment 2, but concentrations at both sites reduced each season: 631-826 mg/L (excluding 3000 mg/L from Treatment 1) in the plant cane phase (cultivated) to 22-24 mg/L in the second ratoon (green cane trash blanket).
- Excluding 2009/10 (unexplained treatment variability), total estimated wet season soil loss was also slightly higher in Treatment 2, but also reduced from plant cane (~3 t/ha) to second ratoon (~0.3 t/ha).
- Initial nitrogen concentrations in runoff are dependent on the amount applied and period of time between application and first runoff. In the first two seasons, ~10% of the applied nitrogen (as NO_x-N and/or urea-N) was lost in runoff when soil nitrate concentrations were high (2009/10 season), or when runoff occurred within three days of application (2010/11 season). Runoff losses in 2011/12 were much lower (~1% of applied fertiliser) when runoff first occurred 78 days after fertiliser application.
- Filterable reactive phosphorus (FRP) concentrations in runoff were similar between treatments due to similar rates of phosphorus applied. Median concentrations tended to increase each season, reflecting the increasing soil phosphorus levels. However, these concentrations (runoff and soil) are much lower than the Marian site.
- The calculated half-lives of diuron, hexazinone and imazapic varied with each season. In 2010/11, much shorter half-lives (more than halved) were measured on trash when 1090 mm of rain fell with 100 days of application (compared with 98 mm in 2011/12). In contrast, soil herbicide half-lives were much longer (~1.3-3 times), due to the extreme rainfall in the 2010/11 season “trickle feeding” the surface soil (after being washed from the trash).
- Timing of rainfall after herbicide application was a critical factor in seasonal runoff losses of herbicides. In the 2010/11 season, 12% of the applied diuron (and 18% for hexazinone) was lost in runoff when the first event occurred seven days after application. This was reduced to <0.5% in 2011/12 when the first runoff occurred 128 days after herbicide application.
- Imazapic has only been detected in one runoff sample (1 µg/L), although analyses did not occur until part way through the 2010/11 season. As a result, no loads can be calculated.
- Machine harvest yield results show an average 7% lower cane yield from Treatment 2, despite receiving 41% less nitrogen. As a result, there was no difference in net return.

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

- Total suspended solids concentrations varied with cover and cultivation: 36-330 mg/L (average 127 mg/L) in 2009/10 (initially bare plant cane); 23-1100 mg/L (average 289 mg/L) in 2010/11 (burnt cane and one cultivation); and 13-140 mg/L (average 40 mg/L) in 2011/12 (green cane trash blanket).
- Concentrations of $\text{NO}_x\text{-N}$ (median and maxima) in rainfall runoff were highest in the 2010/11 season when runoff was first recorded 16 days after nutrient application (102-105 days for other seasons). Similar to the Victoria Plains site, $\text{NO}_x\text{-N}$ concentrations were highest in the first runoff events after application, and then declined as the season progressed. Across the three seasons, Treatment 5 (1.8 m skip row, Six Easy Steps) had the highest median $\text{NO}_x\text{-N}$ concentration (151 $\mu\text{g N/L}$), thought to be due in part to nutrients being applied to the skip area and no peanut crop planted (although it was planned) to uptake the nutrients and supply additional nitrogen. The median concentration of other treatments were consistent (80-93 $\mu\text{g N/L}$), except for Treatment 1 (150 $\mu\text{g N/L}$). In contrast to rainfall runoff, the samples collected from the irrigation runoff on 13th May 2012 had relatively high $\text{NO}_x\text{-N}$ concentrations (4037-4505 $\mu\text{g N/L}$; 242 days after nutrient application).
- Seasonal median filterable reactive phosphorus (FRP) concentrations tended to increase for Treatments 1 and 2 (where 20 kg/ha of phosphorus was applied each season) and remained steady for Treatments 3-5 (when no phosphorus was applied other than at cane planting). When data from the three seasons was combined, treatment medians were similar (362-416 $\mu\text{g P/L}$), except Treatment 2 (645 $\mu\text{g P/L}$). These concentrations are much higher than the Victoria Plains site due to the higher soil phosphorus concentrations.
- Interpreting herbicide runoff concentrations across the three seasons is difficult, due to the different products used each season. As with the Victoria Plains site, herbicide concentrations were highest in the initial runoff events following application, but maximum concentrations have been lower.
- There was very little difference in the cane yield of Treatments 1-4 during the first two years (plant cane and first ratoon). In the third year (second ratoon), the cane yield of Treatment 4 (N replacement) was reduced due to the low nitrogen application rate. The cane yield of Treatment 3 (Six Easy Steps) was also lower than Treatments 1 and 2, possibly due to the lower nitrogen application rate and/or no phosphorus applied. Treatment 5 (skip row, Six Easy Steps) yielded ~70% of solid plant (Treatment 3) in “reasonable” seasons (plant cane and second ratoon crops), but only yielded 50% in the wet year (first ratoon crop).

At the Multi-block and Multi-farm sites:

- Total runoff for the three seasons from the Multi-farm site was 2765 mm (average 922 mm/year), or 36% of rainfall. Determining accurate volumes of runoff (and therefore water quality loads) at the Multi-block site are not possible due to flooding issues.
- Concentrations of total suspended solids (TSS) were low and consistent across the three seasons (generally <70 mg/L, except for 160 mg/L in the first runoff event of the 2010/11 season). At the Multi-farm site, TSS concentrations were higher and tended to increase each season.
- Average estimated seasonal sediment yield for the Multi-farm catchment was 1128 kg/ha, with a flow-weighted mean concentration of 122 mg/L.

- Similar to the paddock sites, the highest $\text{NO}_x\text{-N}$ concentrations were recorded in the first sample of every season. The average seasonal $\text{NO}_x\text{-N}$ load from the Multi-farm site was 2.0 kg/ha, with a flow-weighted seasonal concentration of 221 $\mu\text{g N/L}$.
- Filterable reactive phosphorus (FRP) concentrations at the Multi-block site were consistently higher (~ 3 times) than those of the Multi-farm site. Similar to the paddock data, this may reflect the variable phosphorus levels in the surface soil. The average seasonal FRP loss in runoff at the Multi-farm site was 1.1 kg/ha, with a flow-weighted seasonal average of 123 $\mu\text{g P/L}$.
- Herbicide residue concentrations were variable between the two sites, which may be a reflection of the different periods of application (and the products applied) between the two catchments.

In summary, results from the three seasons show similar trends between treatments and sites, although concentrations vary (mainly due to the period from application to first runoff). The presence of a green cane trash blanket results in an approximate ten-fold decrease in suspended sediment losses compared to cultivated plant cane. 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.

5.1 Recommendations for further research

Due to on-going seasonal flooding issues, the runoff and water quality monitoring equipment from the Marian and Multi-block sites have already been removed. Given that the Victoria Plains and Multi-farm sites continue to function adequately in the wet seasons experienced, it is recommended that these sites continue to be funded. Other recommendations include the following:

- Continue the agronomic treatments at the Marian site through a full cane cycle to identify continuing treatment responses (or otherwise). No further water quality monitoring will be undertaken at this site.
- Continuing the Victoria Plains site will allow the monitoring of a full cane cycle, and then the opportunity to undertake various fallow management treatments (including presence/absence of legumes and/or cultivation) before entering the next cane cycle. This will include runoff and water quality monitoring, and other data sets for modeling.
- Continued monitoring of water quality at the Multi-farm site and management practice adoption within the catchment over the coming seasons will hopefully identify improved water quality due to improved management within the catchment.
- These sites are all contained within the Sandy Creek catchment, which also contains a catchment monitoring site. If a marine monitoring site was located near the mouth of Sandy Creek, this will allow a nested catchment approach to monitoring management practice adoption and resulting water quality from a paddock to marine scale.

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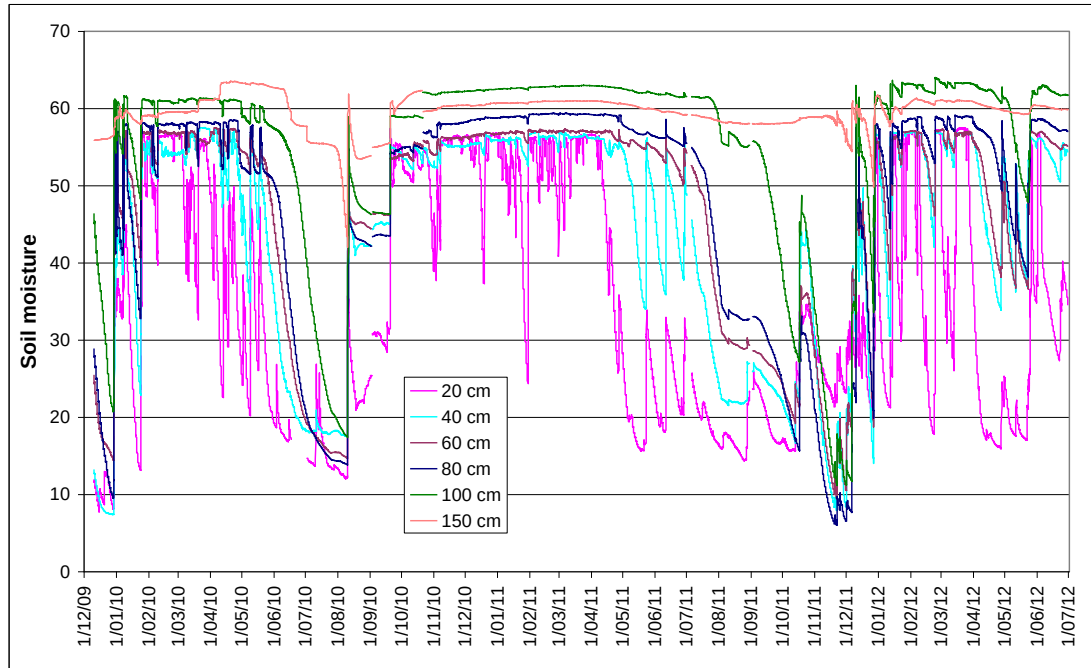
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7 APPENDICES

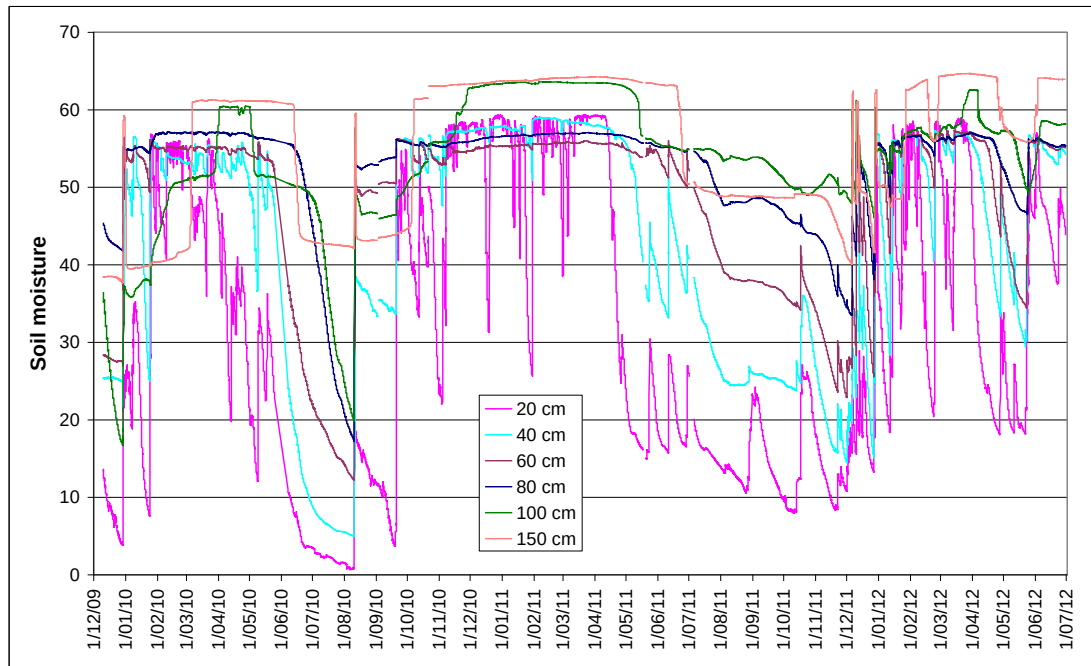
7.1 Soil moisture plots

Soil moisture shown in the plots below are an uncalibrated volumetric water content (no units)

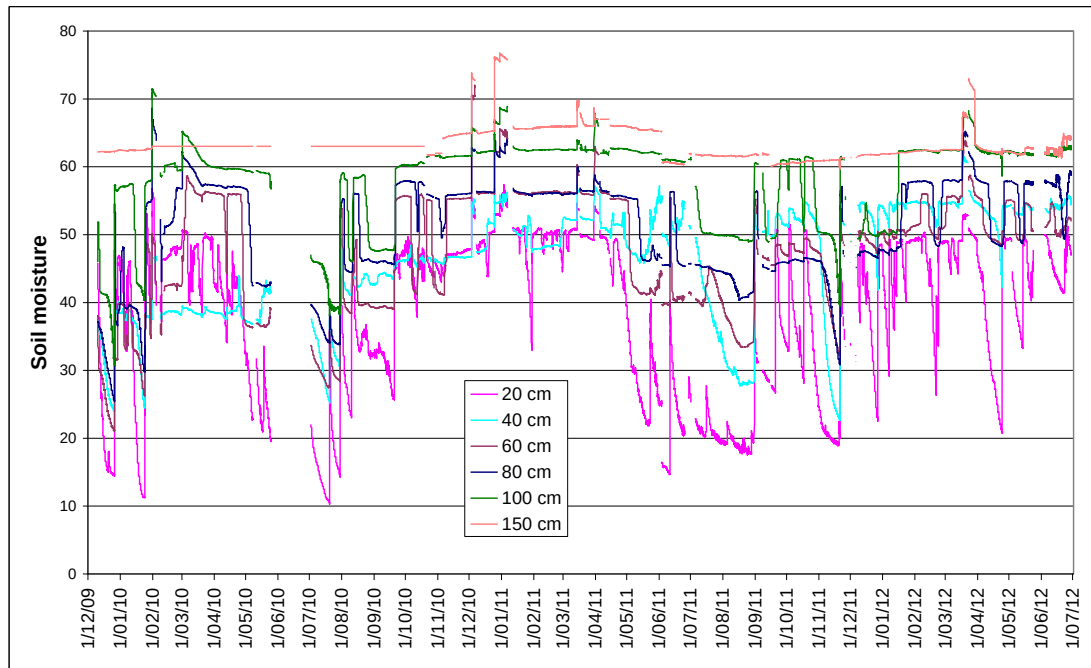
7.1.1 Victoria Plains Treatment 1



7.1.2 Victoria Plains Treatment 2

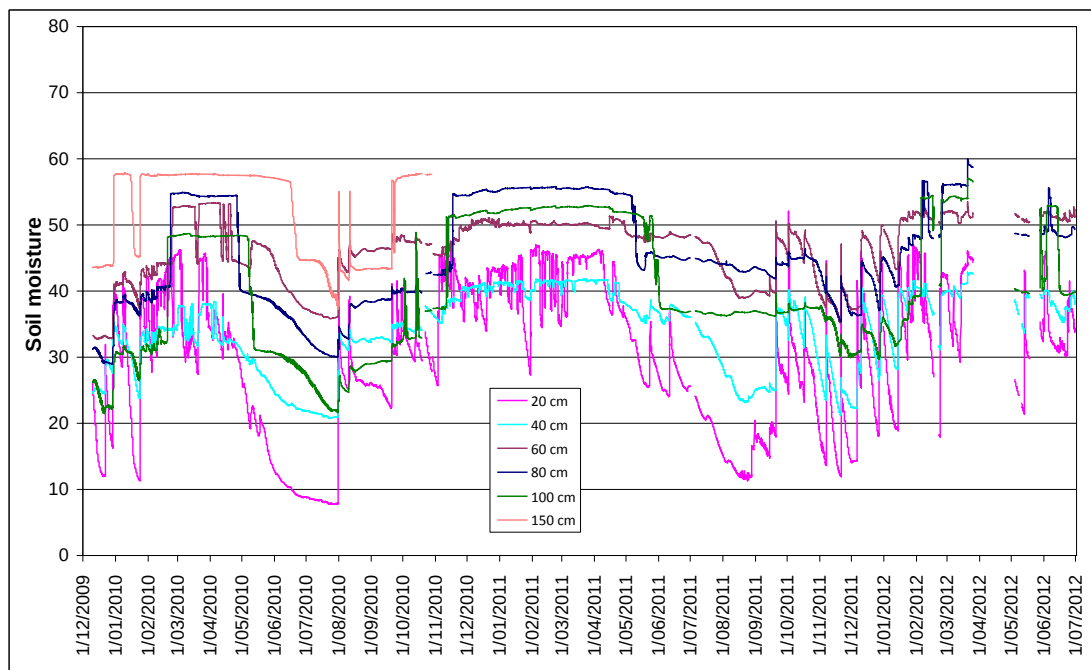


7.1.3 Marian Treatment 1



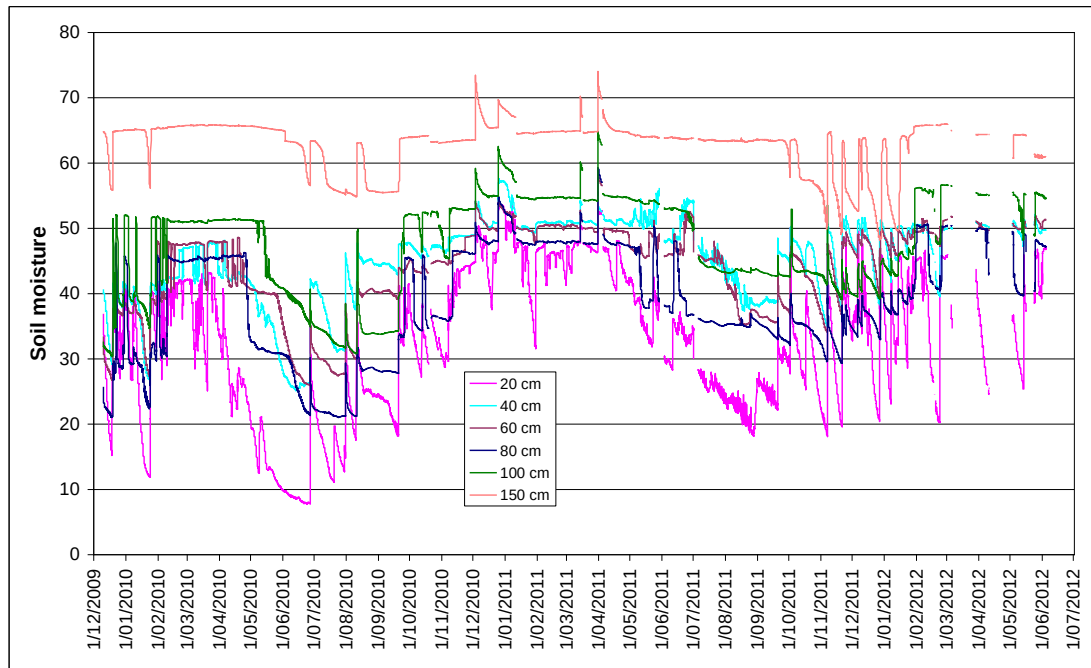
Note: Increases in soil moisture above “normal” values (e.g. December 2010 and March 2011) are when the site flooded and soil moisture sensors were wet. Data gaps are due to equipment failures.

7.1.4 Marian Treatment 2



Note: Sensor at 150 cm stopped working on 28/10/2010 and could not be replaced. Increases in soil moisture above “normal” values (March 2012) are when the site flooded and soil moisture sensors were wet. Data gaps are due to equipment failures.

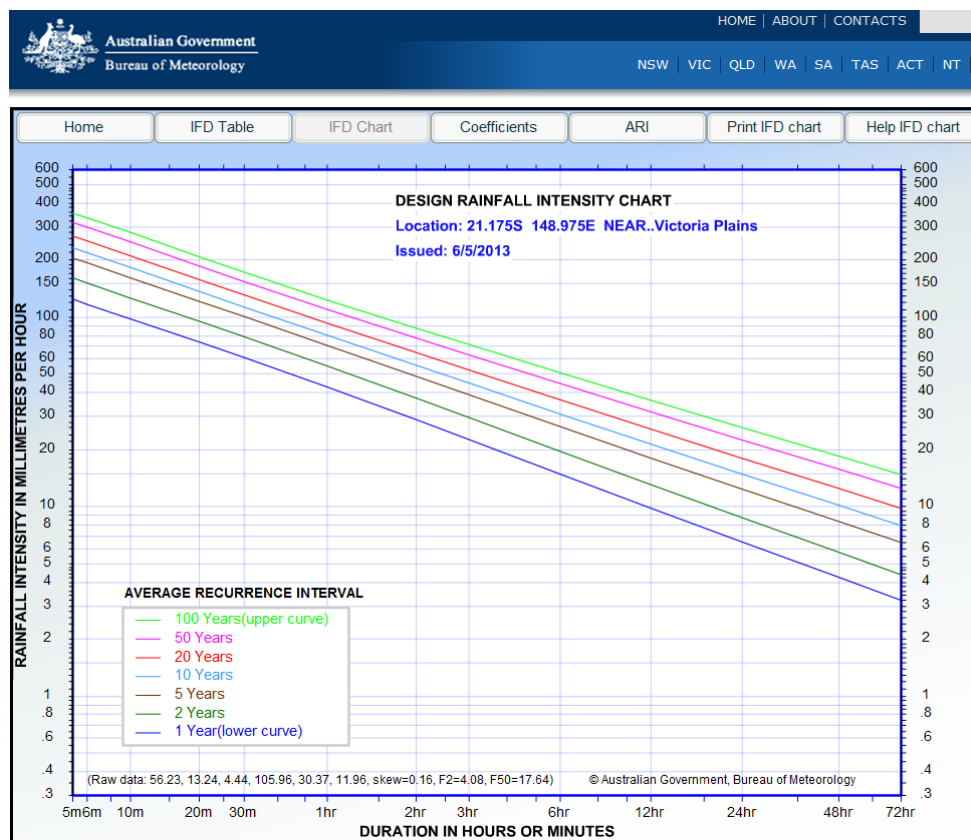
7.1.5 Marian Treatment 5



Note: Increases in soil moisture above “normal” values (e.g. December 2010 and March 2011) are when the site flooded and soil moisture sensors were wet. Data gaps are due to equipment failures.

7.2 Rainfall intensity-frequency-duration graph

Extracted from <http://www.bom.gov.au/water/designRainfalls/ifd/index.shtml> in May 2013.



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