



FINAL REPORT

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Improving the quality of drainage water from NSW canelands

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PUBLICATION DETAILS

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EXECUTIVE SUMMARY

This report describes a participative, 3.5 year Sugar Research and Development (SRDC) / Cooperative Research Centre for Sustainable Sugar Production (CRC Sugar) funded study of surface water quality adjacent to canelands in north-east coastal NSW. Around 35,000 ha of good agricultural land are used for sugar cane production by $\approx$ 600 growers in Australia's most southerly cane growing region, located at downstream ends of the Tweed, Brunswick, Richmond and Clarence River Catchments.

The project targeted six of the many natural and constructed drains in the region, two in each of three mill areas (Condong; Tweed/Brunswick Catchments: Broadwater; Richmond Catchment: Harwood; Clarence Catchment). Growers with farms adjacent to the drains operated as focus groups to discuss and respond progressively to the results from their respective drains, while a range of strategies (media, field days, conference presentations) were used during the study to inform other canegrowers and the wider community of the projects objectives and findings.

The project commenced in July 1999 with six major objectives. These were to create awareness amongst NSW cane growers of relationships between cane growing practices and water quality; to progressively enhance water quality by modifying any practices identified by monitoring to be unsustainable; to inform growers on other drainage systems in NSW of management practices that have improved water quality; to expand the capability of the Broadwater Mill's acid sulfate soils' laboratory to measure nitrate and chloride in water; to assess whether nitrate and chloride pulses in drains were correlated with the off-site movement of herbicides; and to inform the regional community of findings and actions by cane growers to enhance water quality.

Water quality monitoring commenced in November 1999 after appointment of a Project Officer (Mr. B. Green) and continued through to September-October 2002, with the remaining time (April 2003) used to process the water quality and flow data and to communicate the findings.

The drains were numbered 1 to 6 and had the names Bartletts Creek, Mooball / Crabbes Creeks, Empire Vale / Reedy Creek, Dungarubba Drain / Creek, Marsh's Drain No. 2, and Stranger's Drain, respectively. The first two were in the Tweed / Brunswick Catchment, Drains 3 and 4 were in the Richmond Catchment, and Drains 5 and 6 were in the Clarence Catchment. All were under tidal influence and all except Drain 2 were "gated" to restrict the ingress of estuarine water, except that part-way through the study, the "gates" of Drains 5 and Drain 6 were commonly opened to encourage tidal water exchange. Chloride and electrical conductivity (EC) analyses confirmed that all drains were influenced by estuarine water to variable extents. Drain 4 had the lowest (least saline) median EC and Drain 5 the highest (most saline).

Automated water quality "stations" were installed and maintained at the discharge end of the six main drains to continuously measure pH, EC, dissolved oxygen (DO), temperature, stream height and velocity, the latter involving doppler technology. In addition, monthly water samples were collected close by and analysed on-site for DO and in the NATA quality assured laboratory of the Queensland Department of Natural Resources and Mines, Indooroopilly, for suspended solids, pH, EC, chloride, nutrients [totals and components of nitrogen and phosphorus (N and P)] and pesticides (atrazine, diuron, 2,4-D, glyphosate, chlorpyrifos). Additional water samples were collected and analysed from further up selected drains and in other drains for "control" purposes and to better understand the connection between land uses and local water quality.

The water quality data and some relationships between different attributes are presented graphically and/or in tabular formats on a site-by-site basis and/or as an aggregation across all drains. The tabulations typically include the "count", as well as maximum, minimum and median values. Key water quality attributes such as DO, nutrients and pesticide residues were also assessed for the influence of typically wet and dry periods and also on a seasonal (spring, summer, autumn, spring) basis. In most cases concentrations of total nutrients and pesticide residues (atrazine, diuron, 2,4-D) were higher in the "wet" months and during the summer / autumn seasons, while the reverse occurred with DO.

Pulses of strong acidity were similarly detected from time to time by monthly and continuous monitoring, particularly in Drains 2 and 4. There were differences, however, in the median values for DO based on monthly (typically higher values) and continuous sampling. While there were occasions when DO concentrations were very low (undesirable), median DO concentrations from continuous monitoring ranged from 3.6 to 5.2 mg O₂/L, with values between 5 to 10 mg O₂/L preferred. *Identical DO probes are recommended for future in-stream continuous monitoring, which is preferred to periodic monitoring.*

With the exception of the 2001 floods, turbidity in the drains was within ANZECC (2000) guidelines, with medians for the drains ≤ 12 NTU, which are good. Water temperatures ranged from summer maximums of 29.3 to 31.9°C and winter minimums of 8.7 to 13.1°C.

Overall, the median concentrations of total nutrients (N and P) and the corresponding concentrations of ammonium-N and dissolved inorganic P (DIP) exceeded relevant ANZECC 2000 generic guidelines for lowland rivers in NSW on all or most occasions, while median oxidised-N concentrations for five of the six drains (Drain 2 was the exception) easily complied with the locally applicable generic guideline of 0.04 mg N/L. To enhance local confidence in the water quality guidelines for nutrients and ecosystem protection, it is *recommended that a consortium of skilled stakeholders review these water quality criteria as a matter of priority with the aim of replacing them with more realistic criteria for waterways within the fertile, alluvial, sub-tropical coastal plains of NSW.*

Close to 80% of the total N in the drains was water-soluble and around 55% of the total N was present as organic N. In addition, ammonium-N consistently contributed more to dissolved inorganic N (DIN) across all drains than did oxidised-N for reasons thought to be associated with the suppression of nitrification from strong acidity in soils and drainwaters. *These N sources and their transformations need to be better understood, with process studies recommended that include the use of isotopic tracers. These studies should be given priority, as the present concentrations of ammonium-N may still exceed locally relevant water quality criteria when they are developed.*

Across all drains, 50% of the total P (median percentage) was organic, while the corresponding median total inorganic P was 33% of total P. It was unexpected to record relatively high percentages of DIP compared to total P in Drains 5 and 6 (24.6% and 28.7%; versus 10% for all drains combined), when local growers had reported no unusual use of P fertilisers. Four plausible scenarios to explain the findings have been postulated. To resolve the uncertainty, it is *recommended that the forms of P in these drains and in the adjoining Clarence estuary be assessed, probably by a PhD student, in order to understand how the P is cycling (transported) and how it might be managed.*

The six key points to emerge from the monitoring of pesticides in the drainwaters were firstly, the failure to detect during over one year of monthly monitoring any residues of the herbicide glyphosate and the insecticide chlorpyrifos. Secondly, median concentrations of atrazine, diuron and 2,4-D were mostly low or non-detectable and, with the exception of diuron on 6.6% of all (198) sampling occasions, were always within Australian water quality guideline values for moderately disturbed systems and the protection of 90% of species. Thirdly, the patterns of off-site pesticide movement differed from drain to drain, despite similar sugar cane cultural practices, indicating that low-density monitoring could lead to erroneous conclusions on pesticide environmental risk. Fourthly, the levels of residues in Drain 6 declined to inconsequential levels following initiatives of the local advisor and growers to replace problem formulations with alternative products. Fifthly, at no time did any pesticide residue exceed Australian drinking water or recreational use guidelines. Sixthly, the concentrations of the pesticide residues studied were unrelated to the concentrations of anions in the water at the same time, indicating that anion concentrations (nitrate, chloride, phosphate) cannot be used to predict pesticide concentrations in NSW cane drains. *It is recommended that any future monitoring for pesticide residues include drain-bottom sediments, which were not considered in this study.*

Another important finding was the small volumes of water (0.006% to 0.04%) discharged from the drains relative to mean annual flows in the river systems. For example, for the 68 drains in lower reaches of the Richmond River, the volume discharged from Drain 4 would scale up to approximately 2.7% of the total annual average river discharge, if equal volumes of water were regularly discharged from all other cane drains in that catchments. The flow data for Drains 1, 4 and 5 allowed estimates to be made of nutrient and pesticide fluxes from cane drains for the first time.

Pre- and post-project attitudinal surveys revealed cane growers adjacent to the selected main drainage systems were interested in water quality and its links to land use practices. Their understanding and knowledge of water quality was enhanced by the project. Other canegrowers were kept informed as was the local community and scientists associated with CRC Sugar. The initiative and some of the findings were also presented and discussed at national and international conferences on sugar and natural resource management.

Information gained from the monitoring was used to assemble an empirical report card for the six drains. The tests considered were pH, EC, water temperature, turbidity, DO, total-N, ammonium-N, oxidised-N, total-P, DIP, and pesticide residues. Numeric “scores” from 1 (worst) to 11 (best) were allocated and averaged to give an overall score. All drains rated as fair across the three-year period of active monitoring but at the extremes, Drain 5 just

achieved the rating while the drains with the best numeric scores were Drain 1, closely followed by Drain 3.

The NSW sugar industry is committed to continue with water quality monitoring, using the equipment already in place and by equipping and training growers on other drains. The study has served as a model that others might adopt.

Finally, the authors endorse a local initiative to compile and consolidate water quality data for rivers, creeks and drains on the north coast of NSW.

1. INTRODUCTION

1.1 BACKGROUND

Water quality was rated among the highest of the environmental issues confronting the NSW sugar industry (August 1998). It also attracted attention during the 1998 strategic planning process of the Cooperative Research Centre for Sustainable Sugar Production (CRC Sugar).

The NSW Government had a ‘Key Sites Program’¹ and a ‘Storage Monitoring Program’ but all of the ‘key sites’ in the Tweed (one site), Richmond (two sites) and Clarence (three sites) were upstream of sugar-growing areas and away from zones of tidal influence. Median concentrations of total P in 1993/94 at these sites were known to range from 0.015 to 0.135 mg P/L.

In addition, academics, local authorities and River Care groups in northeast NSW were engaged in or planning to monitor water quality in major streams close to canelands². To participate from a position of strength in these studies, NSW Sugar Industry needed to be aware of its impacts on water quality. It also needed to know how changes to on-farm management might impact on water quality in adjacent drainage canals, which are unique and valuable features of the NSW sugar industry.

The CRC Sugar audit of fertiliser and pesticide use in northern NSW cane lands³ had provided an important foundation for a water quality-monitoring program, which had hitherto been lacking in the eastern Australian sugar industry. Locally there was a prerequisite that such a program had to be participatory with growers, a research methodology that proved highly successful in resolving the acid sulfate soil (ASS) problem in the region, particularly via the interactive farm-scale survey of ASS in NSW canelands in which every grower participated. The wide network of natural and constructed waterways in the region provided an opportunity to undertake water quality monitoring in micro-catchments surrounded almost exclusively by cane farms. This CRC Sugar 3.5 year project “*Improving the quality of drainage water from NSW canelands*” was jointly funded by the Sugar Research and Development Corporation (SRDC) and CRC Sugar, the latter through the NSW Sugar Milling Co-operative Limited, (Sunshine Sugar), the Qld Department of Natural Resources and Mines (NR&M), and the Bureau of Sugar Experiment Stations (BSES). The water quality monitoring commenced in November 1999 and continued through to September – October 2002.

1 Daly, H., Martin, V. And Bales, M. (1995) “Window on Water, the state of water in NSW - 1993/1994”. Dept. Land and Water Conservation (Water Resources), Water Resources Div., Parramatta, NSW.

2 Eyre, B.D. and Pepperell, P. (1999). A spatially intensive approach to water quality monitoring in the Rous River catchment, NSW, Australia. J. Env. Management 56, 97-118.

3 Hamilton, D. and G. Haydon (1997). Final Report. Pesticides and fertilisers in the New South Wales sugar industry - estimates of usage and likely environmental fate. Vol. 1. Pesticides. (Dept. Natural Resources and CRC for Sustainable Sugar Production, Brisbane.)

1.2 PROJECT INFORMATION

<u>Project Title:</u>	Improving the quality of drainage water from NSW canelands.
<u>Duration:</u>	1 st July 1999 to 30 April 2003
<u>Research Organizations:</u>	BSES; CRC Sugar; SRDC; NR&M and NSW Sugar Milling Co-operative Ltd.
<u>Chief Investigators:</u>	George Rayment (Natural Resources and Mines, Qld); Rick Beattie (NSW Sugar Milling Co-operative) and Bryan Green (BSES).
<u>Other Investigators:</u>	Bob Aitken (BSES Harwood) and Peter McGuire (BSES Condong)

Project Objectives:

1. Create awareness amongst NSW cane growers of relationships between cane growing practices and water quality (pesticides, nutrients, etc.) in main drainage systems and in subsidiary drains through interactive processes which build on the award winning, interactive acid sulfate soils initiative in NSW canelands.
2. Enhance water quality by assisting growers to benchmark their cane farming practices, to modify any practices identified by monitoring to be unsustainable, and to record and encourage adoption of good practices.
3. Inform growers on other drainage systems in NSW of management practices that have improved water quality in the monitored drainage systems.
4. Expand the capability of the Broadwater Mill's ASS laboratory to measure nitrate, and chloride in water.
5. To assess whether nitrate and chloride pulses in drains reflect seasonal off-site movement of herbicides.
6. Inform the regional community of findings and actions by cane growers to enhance water quality.

1.3 THE NSW SUGAR INDUSTRY

Hildebrand (2002)⁴ provided a recent summary of the NSW sugar industry located on NSW's northern coastal floodplains of the Tweed, Brunswick, Richmond and Clarence River Catchments (Figure 1.3–1). That report noted there were 600 cane farmers and that the industry made an important contribution to the region's economy, including 2,200 jobs.

Focal points of the local industry are its three mills. Two of these produce raw sugar (Condong and Broadwater; Tweed / Brunswick and Richmond catchments, respectively), while Harwood, the most southerly of the mills located in the Clarence Catchment, produces raw and refined sugar.

Expansion of the area under cane and in milling capacity were features of the local industry in the final quarter of the 20th century, particularly since the formation of the NSW Sugar Milling Cooperative in 1978 (Figure 1.3–2. Even with this expansion, the “footprint” of the industry in the catchments is highly visible yet minor, comprising a little over one percent of the combined area of the four catchments (total area of 3.095 million ha).

The same period saw changes in the amounts of nitrogen (N), phosphorus (P) and potassium (K) fertiliser used, and changes in the proportion of N relative to P and K. For example, the elemental ratio of N:P:K increased from 5.4:1:2 in 1940 to 12.5:1:2.2 in 1995, when the annual inputs were approximately 4015, 320 and 705 tonnes of N, P and K, respectively, and increasing.

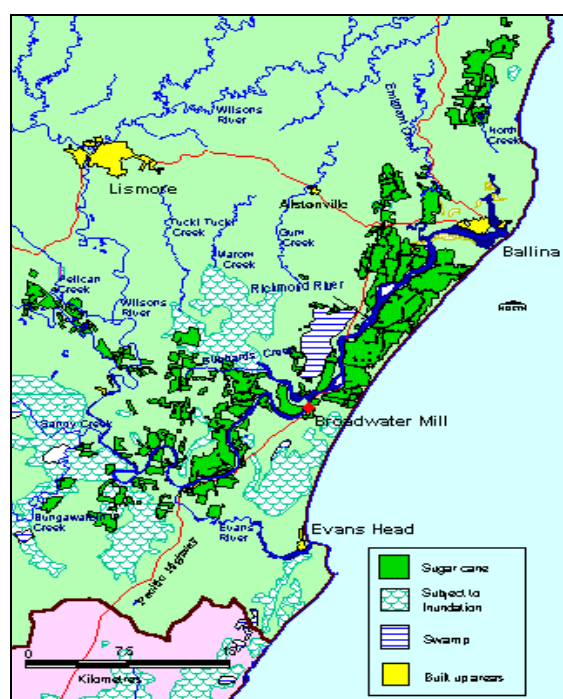


Figure 1.3–1 Example of the distribution of sugar growing areas in northern NSW

⁴ Hildebrand, C. (2002). Independent Assessment of the Sugar Industry. Agriculture, Fisheries and Forestry Australia, Canberra. 178 pp.

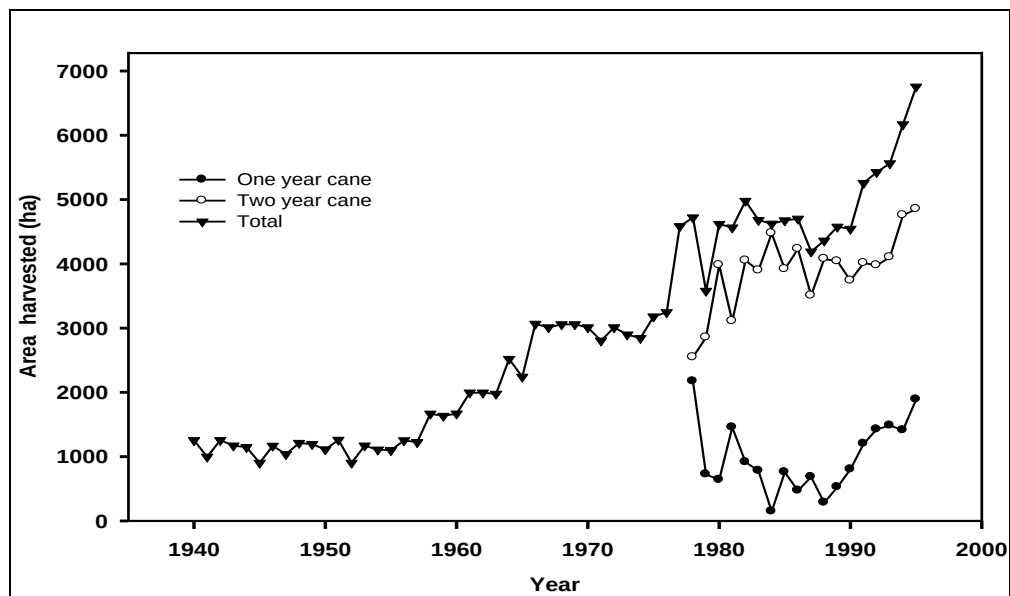


Figure 1.3–2 an example from the Richmond Catchment of the growth in the area of cane harvested from 1940 to 1995/6 (data of Bloesch and Rayment).

1.4 CATCHMENT CHARACTERISTICS

Summary details of the four catchments most relevant to this study are summarised in Table 4.1 – 1. Brief descriptive details are provided in Sub-sections 1.4.1 to 1.4.3.

1.4.1 Tweed and Brunswick Catchments

The Condong Sugar Mill receives around 64% of its cane supply from the Tweed Catchment; (108,400 ha); the remainder is drawn from the smaller Brunswick Catchment (51,260 ha).

The Tweed Catchment has an average yearly discharge of 540 000 ML. The catchment has three major tributaries: the Rous, Oxley and Tweed Rivers. The Tweed River originates near the Loft's Pinnacle in the south-west part of the catchment and flows in a north-easterly direction. The upper catchment is characterised by mountainous terrain, while above Murwillumbah it flows through narrow alluvial flats. Below Murwillumbah, the terrain becomes broad open valleys, with abrupt changes, from rich alluvial flats and red clay loam soils to sandy heath and dune with cane being the dominant crop grown in the middle to lower reaches of the Tweed River. Finally, the flow is parallel to the coast before discharging at Tweed Heads⁵. Cane within the Tweed Catchment is 8220 ha, or 7.4 % of the area.

Table 1.4–1 Characteristics of the four major “cane” catchments (Resource and Conservation Assessment Council, 1996)⁵.

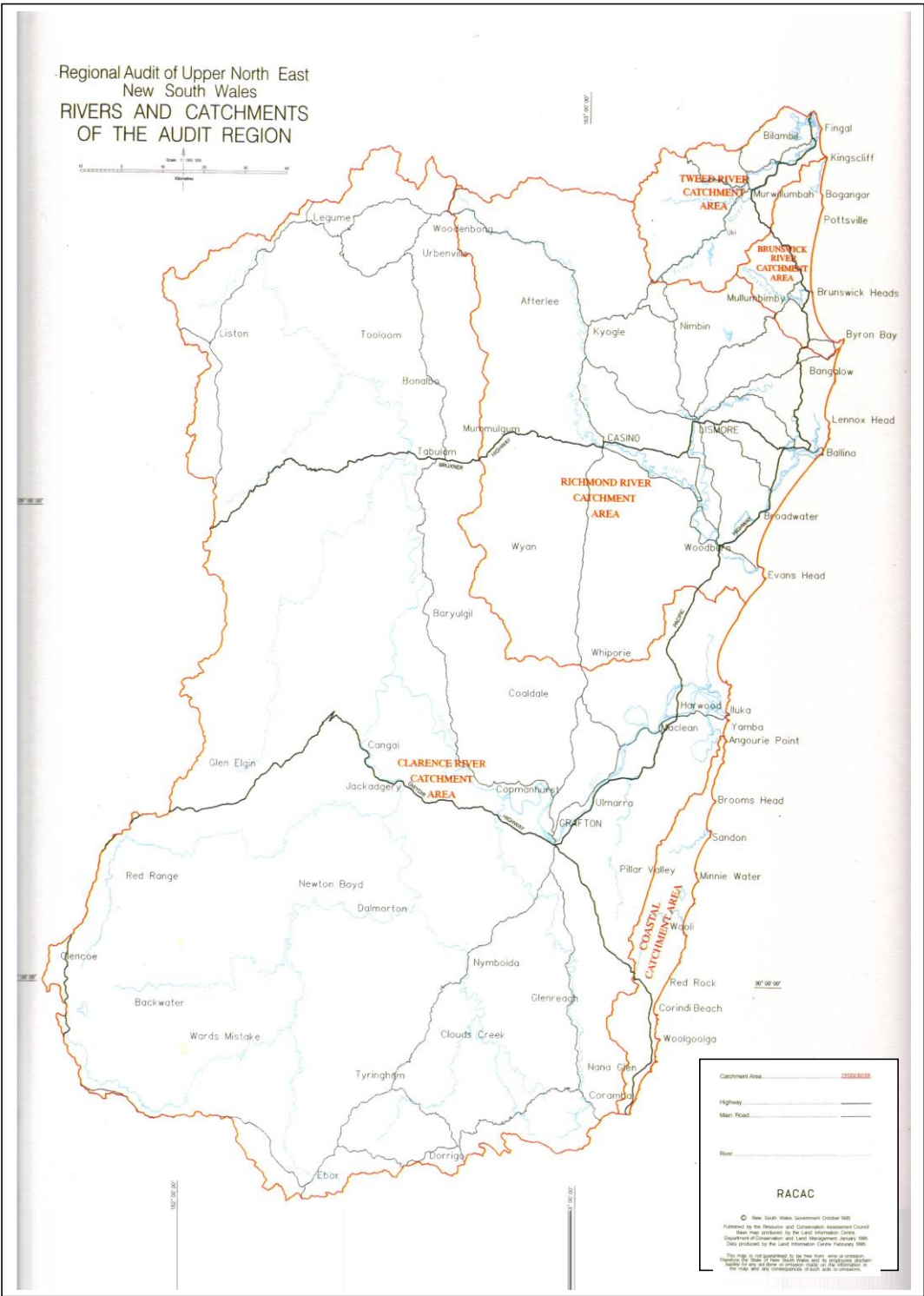
Catchment	Area (ha)	Length of River (km)	Average annual discharge (X 10 ³ ML)	Average annual runoff (mm)	Average annual rainfall (mm)	Runoff as a percentage of rainfall
Tweed	108,400	80	540	492	1650	30
Brunswick	51,260	23	246	500	1730	29
Richmond	704,400	80	2390	344	1525	23
Clarence	2,231,000	394	5000	220	1070	21

1.4.2 Richmond Catchment

The Broadwater Sugar Mill receives 100% of its cane supply from the Richmond Catchment. The Richmond River rises in the McPherson Range near Mount Lofty and flows south towards Casino. In the lower catchment, the Richmond travels in a north-easterly direction entering the South Pacific Ocean at Ballina. There are also several coastal streams: Emigrant, Tuckean, North Creek that drain directly into the estuarine section of the lower Richmond River. In the upper catchment, about one fifth of the catchment is mountainous, while the remainder of the catchment comprises steep to undulating hills as well as flat country. In the middle to lower reaches of the river catchment, much of the original vegetation has been removed, particularly where topography and soil have favoured pastoral land use, while in the rich, alluvial soils of the coastal plains sugar cane occupies 14 798 hectares or 2.1% of the catchment.

⁵ Resource and Conservation Assessment Council (1996).

Figure 1.4 –Rivers and Catchments of the study area.



The Richmond has two main tributaries: the Wilson and Bungawalbyn Creeks. The Wilson drains the southern part of the catchment and joins the Richmond at Coraki. The Wilson River drains a steep and deeply dissected plateau from the main McPherson's Range through Loft's Pinnacle and Mount Mathieson to near the coast at Byron Bay. The Bungawalbyn Creek originates from the southern end of the Richmond Range, with the main tributaries being Myall and Myrtle Creeks⁶.

1.4.3 Clarence Catchment

The Harwood Sugar Mill receives 100% of its cane supply from the Clarence Catchment. The catchment is bounded to the west by the Great Escarpment and consists of undulating or hilly country. To the east of the divide, the tablelands extend for some distance before falling away to steep dissected valleys, leading to the Clarence River. From the New England Tablelands many of the streams initially flow north/north east parallel to the Great Dividing Range, then turn east to the coast. An eastward spur of the Great Dividing Range forms the southern boundary of the catchment, while the eastern boundary consists of relatively low range of hills, which are known as The Coast Range. The McPherson Range and part of the Great Dividing Range make up the northern boundary of the catchment.

The Clarence River has many tributaries. The northern tributaries of the Upper Clarence River flow southwards and have wide valleys resulting in large areas of arable land. The streams flowing east from the New England Tablelands, from the Maryland River in the north to the Sara River in the south, enter very rugged country after leaving the plateau. The Guy Fawkes and Nymboida Rivers both drain the southern end of the catchment, also entering very rugged dissected country. The Orrara River is characterized by broader and flatter valleys and hence floodplains that are adjacent to the main stream.

The Clarence River flows through some rugged country as far as Copmanhurst. Downstream from Copmanhurst, the river is influenced by tides and the catchment opens out to large alluvial plains and undulating country between Copmanhurst and the coast. Intensive agriculture makes up most of this part of the Clarence Valley, with cultivated cane occupying 12 200 hectares or 0.55% of the catchment.

⁶ Resource and Conservation Assessment Council, (1996)

2.0 METHODOLOGY

2.1 Site locations

Six main drainage systems, two each in cane-growing areas of the Tweed, Richmond and Clarence Catchments were chosen because they were broadly representative of the region. While dominated by sugar cane farms, these micro-catchments mostly had areas committed other primary pursuits (particularly horticultural). Other features included road-ways and lanes, rural dwellings, farm sheds and natural areas such as wetlands and marsh's. All but one drain (Mooball / Crabbes Ck) contained structures (flood-gates or similar) to limit and/or manage estuarine / tidal water exchange into the drainage systems.

Another feature of the drain-selection process was that all six had multiple growers willing to form “focus” groups prepared to participate in the water quality monitoring and improvement process. Summary details of the drainage systems, included the numbers of members of each focus group are given in Table 2.1-1. A region and site location map is included as Figure 2.1-1. Physical descriptions and pictorial examples of each of the main drainage systems are given in following Sub-sections.

Table 2.1-1 Summary details of the six drainage systems / creeks

Drain No.	Drainage systems	Location (and number of participants in each focus group)	Catchment	Mill Area
1	Bartletts Ck	Condong (20)	Tweed	Condong
2	Mooball / Crabbes Ck	Wooyung (14)	Brunswick	Condong
3	Empire Vale / Reedy Ck	South Ballina (10)	Richmond	Broadwater
4	Dungarubba Drain / Ck	Dungarubba (17)	Richmond	Broadwater
5	Marsh's Drain No. 2	South Bank Rd., Palmers Channel (11)	Clarence	Harwood
6	Stranger's Drain	Chatsworth Island East (9)	Clarence	Harwood

Drain 1 Bartletts Creek

Bartlett's Creek monitoring station was located about 5 km north of the Condong Sugar Mill adjacent to the old Pacific Highway (Plate 2.1). Bartletts Creek has four pipes (1.8 m diameter) running under the old Pacific highway and flood gated on the Tweed River side. Tweed Shire Council's landfill (Stotts Creek Landfill) is located approximately 7 km south east of the monitoring station. Stotts Creek runs around the base of the landfill site and enters Bartletts Creek approximately 4 km upstream (east) of the monitoring station.

Ledday's and O'Donald's Creeks are located north of Bartletts Creek. Leddays, Bartletts and O'Donald's Creeks are inter-connected and form an extensive drainage network that flows out into the Tweed River.

Details of in-stream monitoring equipment (instrumentation) installed at this and other main-drain sites are described in more detail in Sub-section 2.2.3. Installation of the equipment for this drain (also referred to as site/s) was completed in August 2000 and commissioned on the 15 August 2000. Initially, flow was the only parameter monitored, based on doppler technology. In addition, from installation date to 23 March 2001, one TPS 90 FL data logger was shared between this site and Site 2 (Mooball Creek). Continuous data logging of pH, DO, temperature and electrical conductivity (EC) with a dedicated TPS 90 FL data logger commenced on 23 March 2001 and continued until 20 December 2001.

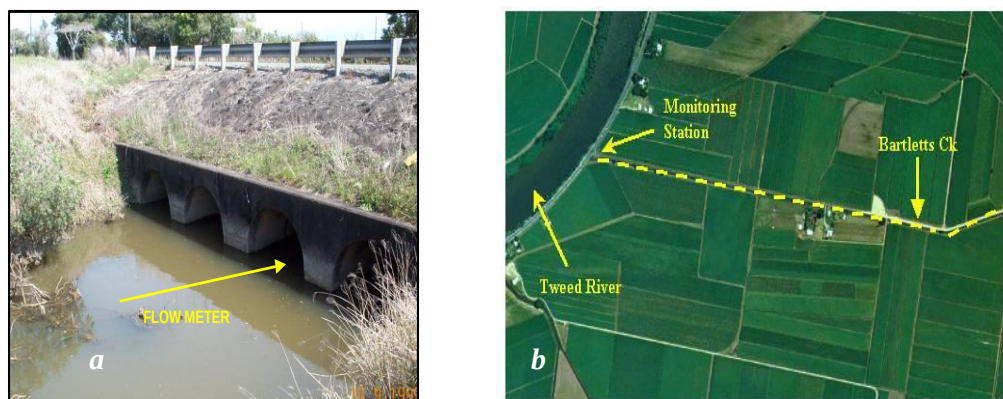


Plate 2.1 Bartletts Creek (Site 1) monitoring station, drain side of old Pacific Highway (a) and aerial view (b).

Drain 2 Mooball Creek

Mooball Creek has a catchment area of 125 km⁷. Mooball Creek drains the north-eastern portion of the Brunswick Catchment and has its origins in the Billinudgel Nature Reserve. Mooball Creek flows north, parallel to the coast, and drains a mixture of marshy wetlands and coastal heath. The Creek has two main tributaries: Crabbes Creek, which drains from Chinaman’s Hill area, adjacent to the village of Crabbes Creek, parallel with the Wooyung Road and into Mooball Creek approximately 4 km upstream from the monitoring station. In the upper catchment, a variety of small plot, horticultural crops are grown, while in the upper / middle to lower reaches cane is dominant, with a few areas of potato and other small crops. In addition, there are two nurseries in the middle section of Crabbes Creek.

Burringbar Creek has it origins in the Burringbar Range and flows in a south-easterly direction towards Burringbar village, running under the old Pacific Highway, changing course to the east, parallel to Wooyung Road and north of Crabbes Creek, until entering Mooball Creek about 2 km upstream of the gauging station.

The monitoring station was located about 5 km upstream from the township of Pottsville where Mooball Creek finally breaks into the Pacific Ocean. Mooball Creek is a natural waterway (i.e. non-gated), approximately 20 metres wide at the monitoring station. The galvanised box housing the instrumentation was on the western bank of the creek, while the TPS 90FL probes and doppler cable were housed in a 100 mm conduit laying perpendicular to the bank and in mid-stream. The doppler system to measure water flow was installed on 21 August 2000. From this installation date to 23 March 2001, one TPS 90 FL data logger was shared with Site 1. Continuous data logging of pH, DO, temperature, electrical conductivity with a dedicated TPS 90 FL data logger commenced on 8 November 2000 and continued until 20 June 2002.

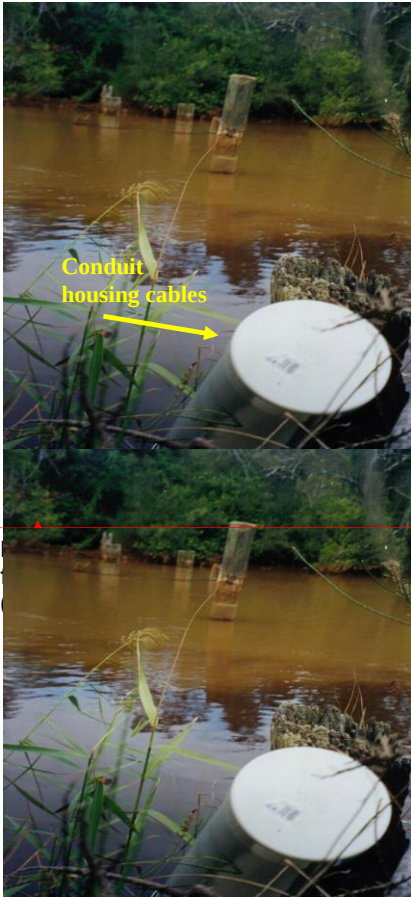


Plate 2.2 (a).Mooball Creek (Site 2) from eastern side of creek (Wooyung Rd.).

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⁷ Resource and Conservation Assessment Council, (1996)

Drain 3 Empire Vale

Empire Vale Creek (Plate 2.3) is a tributary to the Richmond River, joining the river about 7 km south of the Ballina township. Empire Vale mainly supports sugar cane, other agricultural, and rural dwellings. It drains a low-lying coastal floodplain with some significant tracts of coastal heath vegetation. Empire Vale Creek also drains coastal dunes and flows in a westerly direction towards the Richmond River. It is fed by Reedy Creek that runs parallel to the coastline and two major drains, Moylans and Sneesby's.

The study's monitoring station was located on the most westerly point of Empire Vale Creek corner of Empire Vale Road and River Drive. The galvanised box housing the instrumentation was located on a four-culvert (each culvert is 1.52m wide) bridge, adjacent to River Drive, crossing Empire Vale Creek. The site was commissioned on the 1 December 2000 following the installation of a doppler flowmeter. From this date to 6 July 2001 one TPS 90 FL data logger was shared with Site 4. Continuous logging of pH, DO, temperature and electrical conductivity commenced on 6 July 2001.

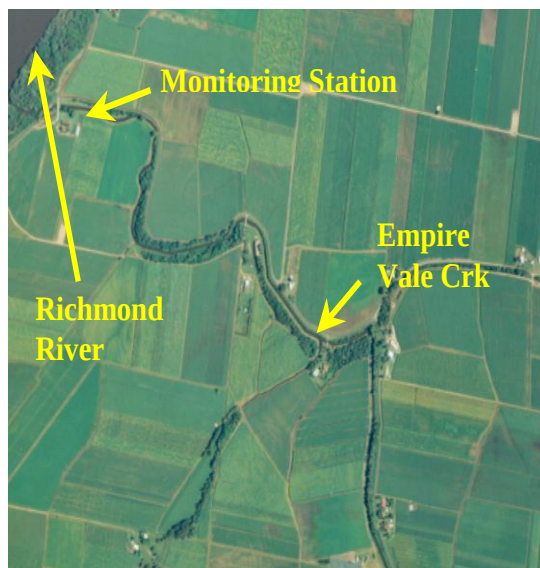


Plate 2.3 Empire Vale (Sire 3) aerial View



Plate 2.4 Empire Vale Creek (Site 3) from floodgate (Richmond River) side.



Plate 2.5 Empire Vale Creek (Site 3) looking upstream.

Drain 4 Dungarubba Drain

Dungarubba Drain (Plate 2.6) enters the Richmond River about 7 km upstream from the Broadwater Sugar Mill. The Dungarubba drainage system drains a vast floodplain and links up with the Richmond River in the Buckendoon area. The drainage system follows the original Dungarubba Creek but was diverted in the late 1960 about 2 km upstream from where the drain enters the Richmond River. An extensive wetland area, known locally as Dungarubba wetland, is situated on Dungarubba Drain about half way between Kilgin Rd and Wyrallah Rd. The wetland is a well known ASS “hotspot”.

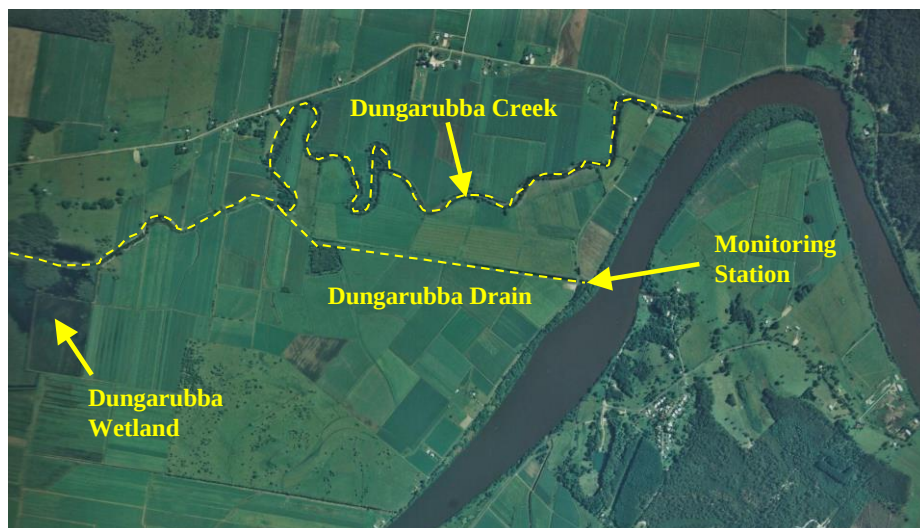


Plate 2.6 Key features of the Dungarubba Drainage basin, Richmond Catchment.

The monitoring station (Plate 2.7) is situated on a five-culvert (each culvert is 2.12m wide) bridge that crosses the Dungarubba Drain on Kilgin Rd.



Plate 2.7 Location of TPS data logger probes and doppler at the discharge zone of Dungarubba Drain

Installation of logging instrumentation was completed in November 2000 and commissioned on the 15 November 2000. Of the 4 gauging stations that monitored the floods in the Richmond Catchment in February / March 2001.

Dungarubba was the only station to successfully collect flow and dissolved oxygen (DO) data. This was a notable achievement for the sugar industry, because not only did it highlight the local sugar industry's initiative towards environmental care but also had the water quality data to support the view that major fish kills in the lower Richmond River were not due to the water discharging from the sugar cane drain. That is, the cause/s was/were generated further upstream.

Drain 5 Marsh's Drain

Marsh's Drainage (Plate 2.8) system drains a complex network of cane drains and floodplains at the foot of an escarpment to the east / south east of Palmers Channel and north of Wooloweyah Lagoon. Marsh's Drain is connected to Wooloweyah Lagoon via the Ring Drain. Reedy Creek drains a substantial swamp to the south east of the monitoring site and flows into Marsh's drain where Gardiners Rd crosses the drain. Marsh's catchment is dominated by sugar cane with some cattle on the escarpment.

The monitoring station is located on Palmers Channel South Bank Rd, approximately 5 km from the junction of Yamba Rd and Palmers Channel South Bank Rd. The discharge is by way of two concrete pipes (Plate 2.9), 1.52 m diameter each and flows into Palmers Channel. The southern end of Palmers Channel is connected to Wooloweyah Lagoon, while the northern end is connected to the main arm of the Clarence River.

Site 5 was commissioned on the 15 November 2000, minus the TPS 90 FL data logger. Continuous monitoring of physical chemical parameters commenced in June 2001, when funding permitted an additional TPS 90FL data logging unit for this site. Active floodgate management commenced in May 2002. This involved landholders opening the floodgates on incoming tides for several hours to assist in buffering sulphidic acidity and improving DO levels.

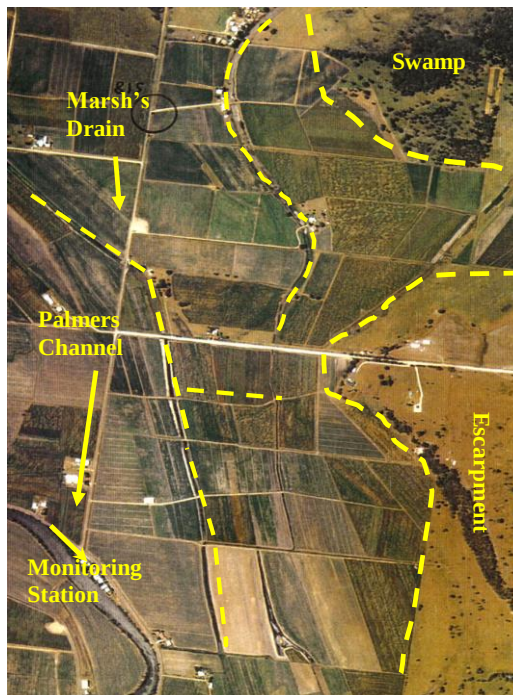


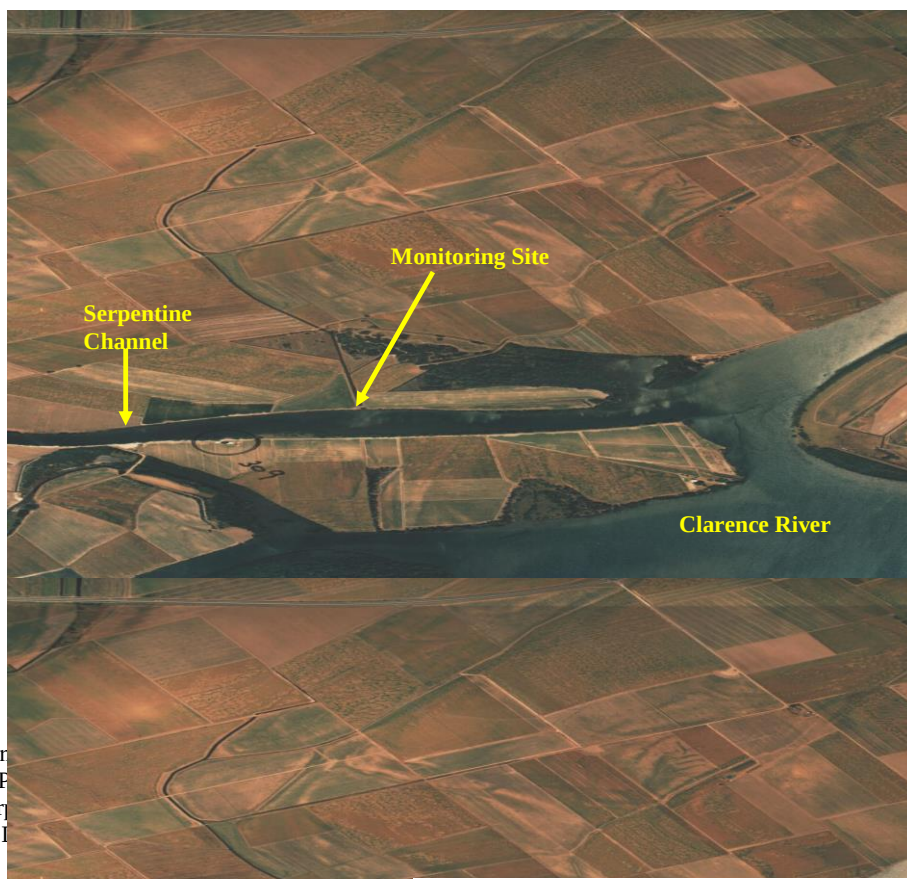
Plate 2.8 Aerial view of Marsh's Drain



Plate 2.9 Marsh's Drain (Site 5) from drain (southern) side

Drain 6 Strange's Drain

Strange's drain (Plate 2.10) monitoring site was chosen because of its proximity to sugar cane being the only agricultural crop grown in this micro-catchment. Strange's drain flows into the Serpentine Channel, approximately 2 km upstream from where the Serpentine flows into the north arm of the Clarence River. A small wetland (approximately 2 ha) lies to the north-east of the monitoring station and flows into Strange's drain about 300 m upstream from the monitoring site.



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Plate 2.11 Strange's Drain (Site 6) galvanised box to house loggers, and solar panel



Plate 2.12 Strange's Drain looking downstream towards Serpentine Channel



Figure 2.1-1 A region and site location map showing the approximate location in northern NSW of the drains, water quality monitoring sites, canelands and other local features.

2.2 Monitoring Program, Equipment and Methods

2.2.1 Monitoring Program

Flow gauging via doppler technology, automated logging of physico-chemical parameters, and monthly water sampling were arranged to occur at the downstream – exit ends of each of the main drains between the last junction and the main floodgate (if present).

Components of the main water quality monitoring program are summarised in Table 2.2-1 and described in the following sub-sections.

Water samples were collected initially monthly by the Project Officer from each "key" sampling site and analysed on a purchaser/provider basis in a National Association of Testing Authorities (NATA) quality assured laboratory (Queensland Department of Natural Resources and Mines, Indooroopilly). Laboratory tests on unfiltered waters were pH, electrical conductivity (EC), total N and total P, plus the pesticides atrazine, diuron, chlorpyrifos, and 2,4-D. In addition, chloride plus total N and mineral N (ammonium and nitrate/nitrite) and total P and reactive (orthophosphate) P were determined on filtered (0.7 µm glass-fiber filter paper) samples to comprehensively characterise the N and P composition of the water samples. Additional sampling for nitrate, chloride, etc (including event sampling) occurred throughout the drainage systems by the Project Officer / growers.

Table 2.2-1 Summary details of the main water quality monitoring program in cane drains of northern NSW.

Category	Parameter	When
Physico-Chem.		
	DO	Continuous and monthly
	pH	Continuous and monthly
	Temperature	Continuous and monthly
	Electrical conductivity (EC)	Continuous and monthly
	Chloride	Monthly
	Turbidity	Monthly
	Suspended Solids	Monthly
Nutrients		
	Total nitrogen (plus all major components, including mineral N)	Monthly at monitoring station; occasional at up-drain locations
	Total phosphorus (plus all major components, including reactive P)	Monthly at monitoring station; occasional at up-drain locations
Pesticides		
	Selected herbicides (atrazine, diuron, 2,4-D, glyphosate) and the insecticide chlorpyrifos	Monthly at monitoring stations; occasional at up-drain locations; glyphosate and chlorpyrifos only for the first 15 months.

Sample collection and handling

Ambient surface water samples were collected monthly from November 1999 through to September-October 2002 by the Project Officer from key sites (one composite each time from each of the six drain systems). Water samples were also collected less systematically at other locations and times (see later).

The sampling regime for the six drainage systems was typically conducted over a 3-day period, since tidal cycles and distances between the various sites made same-day sampling of all sites impossible. Monthly (unfiltered) samples were taken at the discharge end of drains, while the event-based samples (unfiltered) were collected in the upper, middle and discharge section of the drain. All six main sampling sites were tidally influenced. Our sampling protocol required that these samples were taken on an out-going tide to capture possible surface water run-off and groundwater movement from the cane paddocks, as well as other diffuse and/or point sources. Limited event-based sampling was conducted by Peter McGuire (BSES – Condong), Bob Aitken (BSES – Harwood) and Bryan Green (BSES / CRC Sugar – Broadwater) at selected locations along the relevant drainage systems (data included in Appendix 1).

The water samples for nutrients were transported in pre-cleaned, cold, insulated polyethylene containers kept cold with dry-ice. Water samples for pesticide residues were transferred to the laboratory in solvent pre-cleaned, glass containers kept ice-cool ($<4^{\circ}\text{C}$) in insulated plastic containers. Each water sample bottle was identified by a unique number listed as “sample ID” and included in the results table. Seals on the bottles used for nutrients were polyethylene, while those for pesticides were lined with clean aluminum foil. Typically, samples were transported to the Indooroopilly laboratory without delay by road transport. where portion of those for nutrients / major ions were filtered ($0.7\ \mu\text{m}$). The filtered and unfiltered water samples were either analysed immediately or otherwise held in refrigerated storage ($<5^{\circ}\text{C}$) until thawed for analysis.

2.2.2 Analytical Methods

Pesticide Analysis

Approximately 500 mL of unfiltered water sample was extracted with organic solvent (liquid-liquid; water to DCM) followed by analysis of the extract using gas chromatography for atrazine, chlorpyrifos and 2,4-D (after esterification). Diuron was analysed by HPLC with UV detection. Glyphosate was determined by HPLC with fluorescence detection after post column derivitisation.

Identification of pesticide residues (except diuron and glyphosate) detected in samples were confirmed with a high degree of confidence by selected ion monitoring using a mass spectrometer. Methods follow those of Graves (1989)⁸, except that the final exchange solvent was hexane and the finish was via GC/MS rather than GC/ECD or NPD. More details are given in the laboratory’s Pesticide Residue Chemistry Method Manual Issue No. 3, 1998. Limits of reporting are summarised in Table 2.2-2.

Nutrients and related parameters

Table 2.2-3 provides a summary of the nutrient types and forms monitored, including abbreviations and brief details of their chemical or physical properties.

Table 2.2-2 Limits of reporting (LOR) for pesticides covered by monitoring, all expressed as $\mu\text{g/L}$.

Pesticide	LOR
Atrazine	0.05
Diuron	0.3
2,4-D	0.2
Glyphosate	50
Chlorpyrifos	0.05

8 Graves, R.L. (1989). “Methods for the Determination of Organic Compounds in Drinking Water”, EPA Methods 507 & 508: Rev 3

Table 2.2-3 Inorganic indicators, abbreviations, limits of reporting (LOR) and a summary description of the parameter / test.

Forms	Abbreviation	LOR mg/L	Description
Total nitrogen (N)	total-N	0.0014	All N in the water sample (includes N on/in particles as well as the N dissolved in the water).
Ammonium	ammonium-N	0.0014	Reported as N, the measure includes ammonium ions (NH_4^+) and free ammonia (NH_3 ; if any). Ammonium is a reduced form of mineral N and consumes oxygen if transformed during nitrification to nitrate-N.
Nitrate	nitrate-N	0.001	Reported as N, nitrate (NO_3) is one of the oxidised forms of mineral N that is highly water soluble and reactive.
Oxidised N	oxidised-N	0.001	Reported as N, the measure includes NO_3 and any nitrite (NO_2) that may be present.
Mineral N or Dissolved inorganic	DIN	≈ 0.001	The sum (as N) of $\text{NO}_3 + \text{NO}_2 + \text{NH}_4/\text{NH}_3$.
Total insoluble N	Total N Insoluble or TIN	0.0014	Reported as N, the measure includes organic and/or other forms of N associated with particles $>0.7 \mu\text{m}$. Calculated as the difference between total Kjeldahl N (unfiltered sample) minus total Kjeldahl N (filtered sample).
Total organic N	TON	0.0014	Reported as N, the parameter quantifies the organic N associated with particles $>0.7 \mu\text{m}$ and in solution. Calculated as total Kjeldahl N (unfiltered sample) minus ammonium-N.
Dissolved organic N	DON	0.0014	Reported as N, the measure includes water soluble (or particles $<0.7 \mu\text{m}$) organic substances such as amines and amino acids that contain N. Calculated as total Kjeldahl N (filtered sample) minus ammonium-N.
Total soluble N	Total N Soluble or TSN	0.0014	Mineral N + DON, calculated as total Kjeldahl N (filtered sample) plus oxidised-N.
Total phosphorus (P)	total-P	0.015	All P in the water sample (includes P on/in particles as well as the P dissolved in the water), measured as total Kjeldahl P.
Total insoluble P	TP Insoluble or TIP	0.015	Reported as P, the test includes organic and/or other forms of P associated with particles $>0.7 \mu\text{m}$. Calculated as total Kjeldahl P (unfiltered sample) minus total Kjeldahl P (filtered sample).
Total soluble P	TP Soluble or TSP	0.015	Reported as P, the test includes organic and/or other forms of P in solution or present as particles $<0.7 \mu\text{m}$. Measured as total Kjeldahl P (filtered sample).
Dissolved inorganic P	DIP	0.001	Reported as P, this test measures orthophosphate-P plus other “reactive” forms of P either dissolved or present on particles $<0.7 \mu\text{m}$ that react with the molybdenum blue reagent of Murphy and Riley (1962) ⁹ .
Dissolved organic - P	DOP	0.015	Reported as P, this test quantifies the total water soluble P not classed as “reactive” P. It includes the P in cells such as in DNA. It is calculated as total Kjeldahl P (filtered sample) minus DIP.
Acidity	pH	0.01	An expression of the active (disassociated) hydrogen ions present in the water.
Dissolved oxygen	DO	0.1	A measure of the dissolved oxygen (plus any free oxygen) in the water. Oxygen in water is essential for the survival of aquatic fauna and flora. NOT ANALYSED I’PILLY
Turbidity and Suspended solids	Turbidity or SS	SS – 1 TURB –10 NTU	Qualitative (via an Horiba U10 portable instrument) and quantitative (laboratory) measures, respectively, of turbidity, reflecting the quantities of soil particles suspended in the water column at the time of sampling.
Electrical conductivity	EC	1 $\mu\text{S}/\text{cm}$	An electrical measure of dissolved ions present in the water. The higher the EC the higher the salinity.
Water soluble chloride	Cl	0.5	The concentration of free chloride ions present in the water sample.

⁹ Murphy, J. and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27, 31-6.

Suspended solids

A measured volume of homogeneous sample was filtered through a pre-rinsed, oven-dried (105-110°C) and weighed glass fibre filter disc. The filter disc (0.7µm) with the residue was oven dried and weighed. The increase in weight (i.e., the oven-dry weight of the residue) represents the total suspended solids content of the measured volume of sample.

Total nitrogen and total phosphorus

These analyses were undertaken on unfiltered and filtered samples. A Kjeldahl digestion procedure with sulfuric acid / red mercuric oxide was used to digest and solubilise N compounds as ammonium and the P as orthophosphate. After quantitative dilution, digest solutions were analysed colorimetrically. Samples outside the working range were further diluted with digest-blank and re-analysed. Standards and samples were quantified on a Skalar segmented flow analyser; the Skalar turbo-matrix photometers have a capability of adjusting for differing matrices. Brief details are:

Nitrogen in the diluted digest was determined using the Berthelot indophenol reaction reviewed by Searle (1984)¹⁰, in which an emerald-green colour is formed by the reaction of ammonia, sodium salicylate and sodium dichloroisocyanurate, catalysed by sodium nitroprusside, in a buffered alkaline medium at a pH of 12.8-13.0. The absorption of the indophenol complex was read at 660 nm, with a correction filter of 525 nm. Total N is the result from this Kjeldahl digestion plus oxidised-N.

Phosphorus in the Kjeldahl digest solution was determined by the reaction of orthophosphate in an acid medium with ammonium molybdate to form phosphomolybdic acid that was subsequently reduced by ascorbic acid, with potassium antimony tartrate as catalyst, to a phosphomolybdic blue complex. The absorption of the phosphomolybdic blue complex was measured at 880 nm, with a correction filter of 1010 nm.

Ammonium-N

Ammonium-N in filtered water samples was determined by an automated colorimetric method based on the Berthelot indophenol reaction described earlier for total-N.

Nitrate-N (plus any nitrite)

A variation of the automated cadmium reduction method was used on filtered water samples. In the method, nitrate (NO_3^-) is reduced to nitrite (NO_2^-) in the presence of cadmium as a catalyst. The method therefore quantitatively measured NO_3^- plus any NO_2^- , although little (if any) NO_2^- was likely to be present. An intensely coloured azo dye proportional to concentration formed when NO_2^- reacted with a combination of sulfanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride in an alkaline medium (the Griess-Ilosvay reaction). The absorbance of the azo dye coloured solution was read at 540 nm, with a correction filter of 620 nm.

Dissolved inorganic P (reactive phosphate – P)

An automated variation of the phosphomolybdic/ascorbic acid method of Murphy and Riley (1962)¹¹ was used to determine P as orthophosphate or similar in filtered water samples. Orthophosphate was reacted in an acid medium with ammonium molybdate to form phosphomolybdic acid that was subsequently reduced by ascorbic acid, in the presence of potassium antimony tartrate as catalyst, to a phosphomolybdic blue complex. The absorption of the phosphomolybdic blue complex was measured at 880 nm, with a correction filter at 1010 nm.

Total insoluble N, Total organic N, Total inorganic P and Total organic P

These were derived from other laboratory measurements on the same sample/s as defined in Table 2.2-2.

Local laboratory analyses

10 Searle, P.L. (1975). Automated colorimetric determination of ammonium ions in soil extracts with 'Technicon Autoanalyzer II equipment'. New Zealand Journal of Agricultural Research 18, 183-7.

11 Murphy, J. and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analytical Chim. Acta. 27, 31-6.

High Pressure Liquid Chromatography (HPLC) equipment in the ASS laboratory at the Broadwater Sugar Mill was refitted with funding from the project by the manufacturer's agent (Geoff Brimms of GBC) and configured to measure anions (particularly nitrate, chloride and sulfate) in natural waters. The HPLC was used when warranted. However, it was more cost efficient for the water samples to be sent the NR&M laboratories, Indooroopilly.

2.2.3 Field Instrumentation

Six Starflow Loggers and six TPS 90 Field Labs (Table 2.2–4; Appendix 2 has details of instrument specifications) were installed at the six monitoring stations. Starflow loggers are an ultrasonic doppler type instrument measuring velocity, depth and temperature, while the TPS 90 FL data logger measures pH, DO, EC and water temperature (Table 2.2–1). Both instruments were programmed to record data at prescribed scan intervals. A Horiba U10 was used as a portable recording instrument to record pH, DO, turbidity, EC, salinity and water temperature.

In addition, a pumping auto sampler was purchased to move from drain to drain. However, the auto sampler was of limited use due to tidal influence at all sites. Auto samplers rely on either a change in depth, conductivity or flow to trigger the sampler. All three parameters were influenced by tidal movement, thereby triggering the auto sampler during tidal action.

The installed field recording equipment was and remains housed in 1 m² galvanised boxes (Plate 2.11 and 2.13) located adjacent to the drains. The data loggers stored averaged one minute data at 10 minute intervals. These data were downloaded manually on a weekly basis to a field laptop PC.

The dopplers were installed to ensure they collected flow data typically 30 to 40cm below the surface of the water column. These and other sensors were serviced/cleaned and calibrated on-site on a needs' basis. Specifically, the dopplers measured velocity acoustically by recording the doppler shift from suspended particles and air bubbles, and water depth by a pressure transducer. These data allowed discharge to be estimated when consistent readings of flow and height were integrated with the known cross-section areas of the entry / discharge zone of each of the drains. Where the discharge was via circular pipes, the relevant parameters to calculate discharge (cumsec) and volume (ML) included depth (m), velocity (m/sec), radius – depth (m), sector angle, sector area, and wetted area. In the event, only the doppler data from Drains 1, 4 and 5 were of sufficient quality and period to be used with confidence.

Table 2.2-4 Instrumentation installed and used to monitor flow and other water quality parameters.

Instruments	Location	In - Situ	Rotation	Notes
Flow Meter	6 sites	Yes	No	Commonly referred to as dopplers
Auto Sampler		No	Planned	Little used due to difficulties of “triggering” the sampling to respond to run-off rather than to tidal flows.
TPS 90 FL data loggers	6 sites	Yes	Briefly yes; subsequently dedicated to individual drains.	See text for dates of commissioning.
U10 Horiba	6 sites	No	Portable	Calibrated before use.

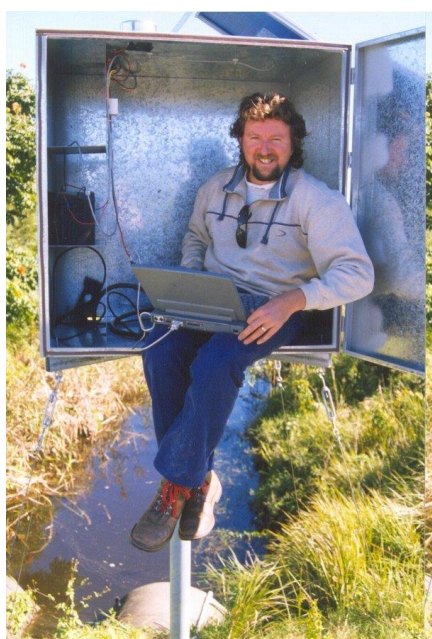


Plate 2.13 Galvanised box located at Marsh’s Drain (Site 5) to house data loggers, solar panels and batteries. These were all elevated above expected flood height at locations readily accessible to permit easy downloading to PC.

2.3. ANZECC Guidelines for Fresh and Marine Water Quality

Elevated concentrations of nutrient elements such as N and P may be beneficial when present in irrigation water but are undesirable for ecosystem protection and for the health of estuaries off-shore ecosystems.

Contemporary ANZECC Water Quality Guidelines apply the concept of trigger levels for assessing the possible risk of adverse effects of nutrients and toxicants in different ecosystem types (ANZECC 2000)¹². The ecosystems most applicable to this study are lowland rivers that discharge into estuaries. Generic trigger levels for nutrients (N and P) for these environments, which changed during the conduct of this monitoring study (Table 2.3-1), are summarised in Table 2.3-2 to Table 2.3-5

Table 2.3-1 Superseded ANZECC Guidelines for N and P (ANZECC 1992)¹³

WHERE	PARAMETER	RANGE	PARAMETER	RANGE
Rivers & streams	Total P (µg /L)	10 - 100	Total N (µg /L)	100 - 750
Lakes & reservoirs	Total P (µg /L)	5 - 50	Total N (µg /L)	100 - 500
Estuaries	PO ₄ -P (µg /L)	5 - 15	NO ₃ -N (µg /L)	10 - 100
			NH ₄ -N (µg /L)	<5
Coasts	PO ₄ -P (µg /L)	1 - 10	NO ₃ -N (µg /L)	10 - 60
			NH ₄ -N (µg /L)	<5

Table 2.3-2 Contemporary ANZECC Generic Guidelines for Total N (µg N /L) and Total P (µg P /L) in waterways and water bodies. Data for N sourced from Part of Table 8.2.2, ANZECC (2000); corresponding P data sourced from Table 8.2.3, ANZECC (2000)¹⁴.

ECOSYSTEM TYPE	TOTAL N - NSW	TOTAL N - QLD SOUTH EAST	TOTAL P - NSW	TOTAL P - QLD SOUTH EAST
Upland River	200	215	20	35
Lowland River	600 350 ^a	500	50 25 ^a	55
Estuaries	350	310	35	35
Marine	110	120 ^b	25	20

a = value for coastal rivers

b = offshore values

¹² ANZECC (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000). (ANZECC and ARMCANZ, Canberra.)

¹³ ANZECC (1992). Australian Water Quality Guidelines for Fresh and Marine Waters. National Water Quality Management Strategy. (ANZECC, Canberra.)

¹⁴ ANZECC (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000). (ANZECC and ARMCANZ, Canberra.)

Table 2.3-3 Contemporary ANZECC Generic Guidelines for Ammonium ($\mu\text{g N/L}$) and Oxidised N (mainly nitrate) in waterways and water bodies. Data for NH_4 was sourced from Table 8.2.7 and from Table 8.2.6 for Oxidised N (ANZECC 2000).

ECOSYSTEM TYPE	NH_4 - NSW	NH_4 - QLD SOUTH EAST	OXIDISED N - NSW	OXIDISED N -QLD SOUTH EAST
Upland River	40	6		20
Lowland River	30 15 ^a	12	5 40 ^a	65
Estuaries	20	19	10	17
Marine	20	14	25	3

a = value for coastal rivers

Table 2.3-4 Contemporary ANZECC Generic Guidelines for Filterable Reactive Phosphorus ($\mu\text{g P/L}$) sourced from Table 8.2.5 (ANZECC 2000).

ECOSYSTEM TYPE	NSW	QLD - SOUTH EAST
Upland River	15	20
Lowland River	15 8 ^a	25
Estuaries	4	
Marine	10	

a = value for coastal rivers

Dissolved Oxygen

ANZECC (2000) guidelines (generic trigger values) recommend the use for rivers and streams of median DO concentrations measured under low flow conditions. Specifically, lowland rivers in NSW should have a lower limit of 85% DO saturation and an upper DO saturation of 110%. Corresponding values for estuaries are 80 and 110%. It is generally accepted that DO concentrations below 5 mg O_2/L are stressful to many species of fish under southern Australian conditions.

Turbidity and Suspended Solids

ANZECC (2000) guidelines suggest that NTU values for turbidity for lowland rivers should be in the range 6-50, with lowest values expected in rivers flowing through well vegetated catchments and at low flows.

Electrical Conductivity / Salinity

Preferred ANZECC (2000) levels in lowland rivers not influenced by estuarine inputs are preferred to be in the range 125 – 2200 $\mu\text{S/cm}$, equivalent to dS/m.

pH

ANZECC (2000) generic guidelines for lowland rivers in south-east Australia (includes northern NSW) are 6.5 (lower limit) to 8.0 (upper limit).

Pesticides

ANZECC (2000) generic guidelines for pesticide toxicant trigger values for 90% and 80% species protection plus some others are summarised in Table 2.3-5 for the pesticides monitored.

Table 2.3-5 Guideline values for pesticide residues, including toxicant trigger values (µg/L)

PESTICIDE	GUIDELINE CATEGORIES			
	DRINKING WATER HEALTH VALUE OF NHMRC (1996-2001) ^{15, A}	Aquatic Ecosystem Protection ^{b, c}	Primary Industries ^b	Recreation ^b
Atrazine	20	13 (45)	N	ND ^d
Diuron	30	0.2	2 ^e	40
2,4-D	30	280 (450)	N ^f	100
Glyphosate	1000	(2000)		
Chlorpyrifos	10	(0.11 ^g)		

^a Health value based upon 10% of Acceptable Daily Intake;

^b ANZECC (2000)

^c Trigger value for toxicants for protection of 95% of species in slightly-moderately disturbed systems; figure in brackets shows trigger values for protection of 90% of species

^d ND = indicates guidelines are not available due to insufficient data

^e N = Guidelines are not available except for a general limit in irrigation waters of 10 µg/L for all herbicides in New South Wales; for livestock drinking water, the human drinking water guidelines are recommended (NHMRC 1996-2001)

^f Interim guideline only

^g This value may not protect key test species from chronic and acute toxicity

3. RESULTS AND DISCUSSION

This study generated much water quality data on main drains of northern NSW canelands via a combination of monthly monitoring, continuous in-stream monitoring and a lesser amount of *ad hoc* assessments.

To facilitate information exchange, the data and their implications for sustainable sugar production have been grouped and considered under six major sub-headings (physiochemical properties, nutrients, pesticides, nutrient/pesticide relationships, “control” sites, and raising awareness).

3.1 PHYSIOCHEMICAL PROPERTIES

3.1.1 Drain water pH

The results from continuous in-stream monitoring of pH for the two drainage systems in the Condong mill area (Drains 1 and 2) are shown in Figure 3.1-1. At Drain 1 pH values were always >5.5 . At Drain 2, while pH values were mostly >6 , there were several occasions when water pH values dropped to around 4.5 to 5.0, suggesting the entry of strong acid drainage, probably from ASS known to exist in the area. Indeed, Rayment *et al.* (2000)¹⁶ reported that around 70% of canelands in the Condong Mill Region were underlain by pyritic minerals. This was the highest percentage for mill regions of northern NSW.

Continuously monitored water pH values for Empire Vale Creek (Drain 3) and Dungarubba Drain (Drain 4) are presented in Figure 3.1-2. At Drain 3, pH values were always >6 except for a brief period in April 2002, when the pH dropped to around 4.5. In contrast, monitoring at Drain 4 indicated the entry of strongly acidic drainage on multiple occasions, particularly in early 2001. Given the reappearance of a period of strong acidity in August-September 2002 and the considerable efforts of NSW cangrowers to control strong ASS acidity in their cane drains, it is likely that the Dungarubba Wetlands (see Plate 2.6 for their location) could be the source of much of the unwanted acidic drainage. Sampling along the drain and water pH values in the swamp (Michael Wood, personal communication) support this contention.

Figure 3.1-3 contains continuously monitored pH data for Drains 5 and 6 in the lower Clarence River system. The absence of any water acidity problems during the period of monitoring of both drains is an encouraging finding, given the local industry’s effort to better manage their ASS. It is noteworthy that water pH at Drain 6 [Figure 3.1-3 (b)] remained around 6 during the February and March 2001 floods of the Clarence River.

Water pH sampled on a monthly basis (see Figure 3.1-4) added to the awareness of acidity and alkalinity in NSW main cane drains. When assessed as the negative log (base 10) of the hydrogen ion concentration, the arithmetic average pH across all six drains for the entire period of monitoring (count of 196 samples) was 5.54 ± 4.7 . The arithmetic average was 7.03 ± 0.86 when pH values rather than negative log (base 10) of the hydrogen ion concentration were used. Independent of method of assessment, the maximum pH recorded was 8.6, the minimum 3.74, and the median 7.2. Of interest, the highest and lowest pH values occurred in Drain 4.

¹⁶ Rayment, G.E., Balakrishnan, T., Nielsen, P. and Raymond, M. (2000). Identifying acid sulfate soils in NSW canelands to minimise strong acid discharge. In “Proc. Aust. Soc. Sugarcane Technologists”. (Ed. D.M. Hogarth.) p 513. (22nd Conference, Bundaberg.)

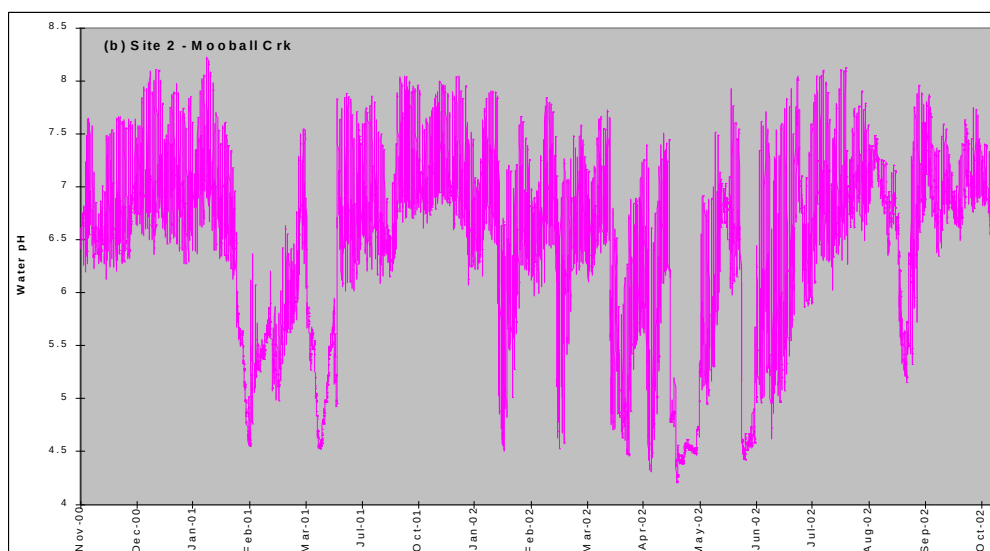
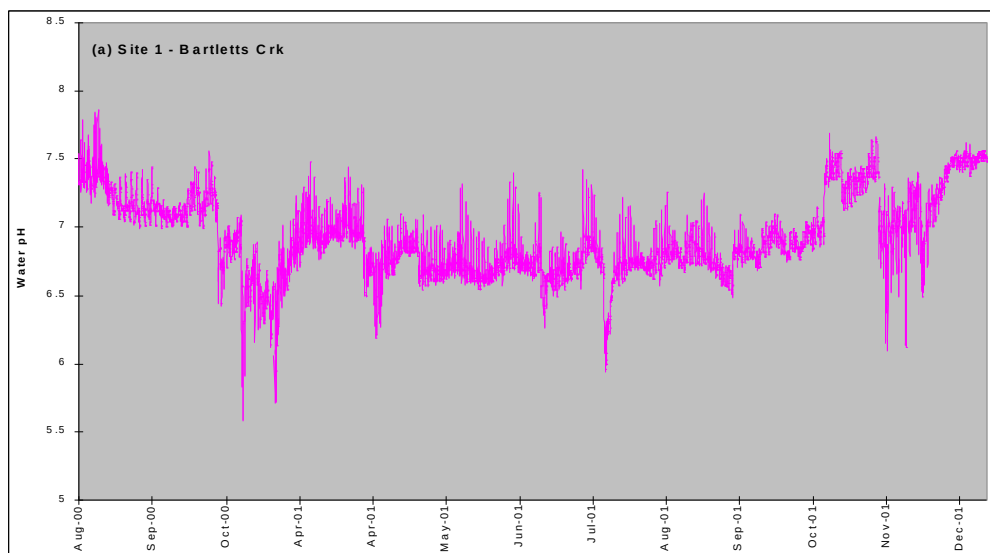


Figure 3.1-1 Drain water pH continuously logged for various periods at (a) Drain 1 and (b) Drain 2.

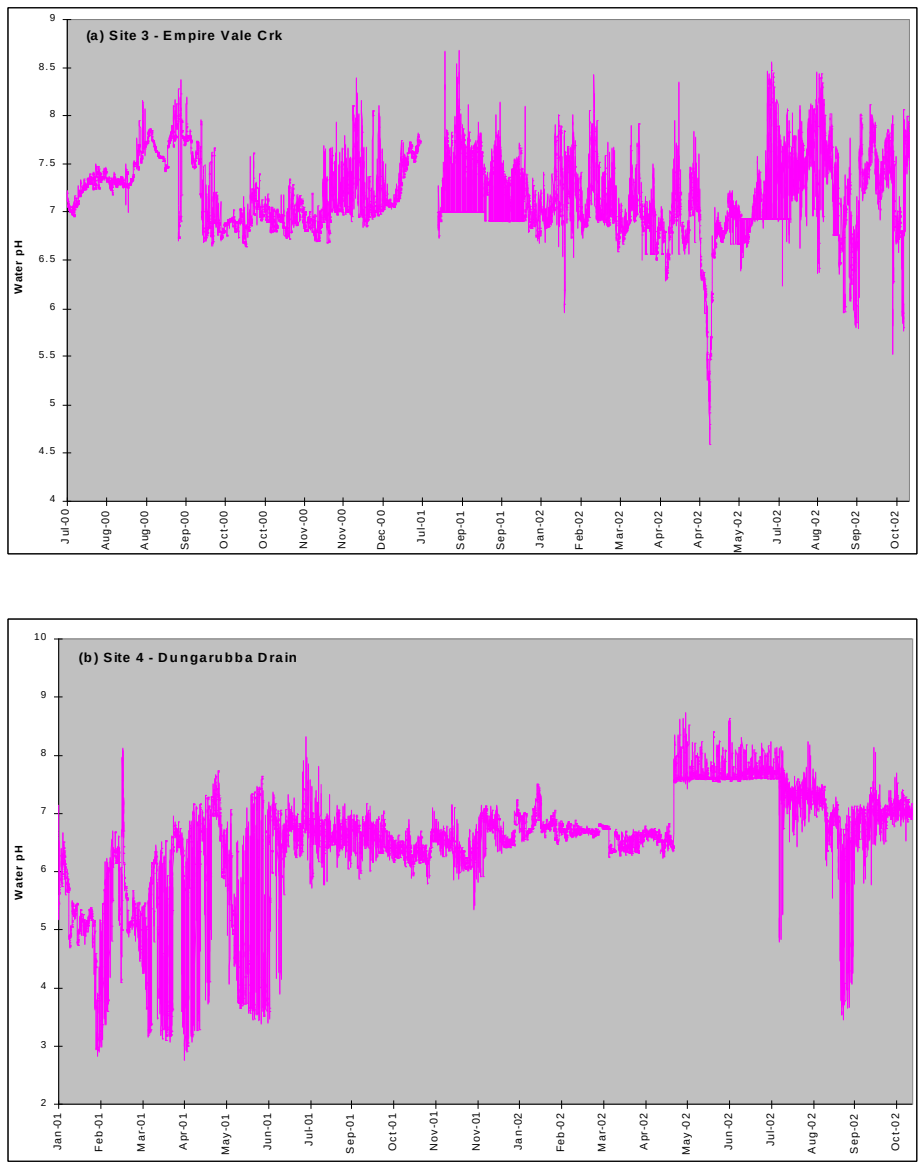


Figure 3.1-2 Drain water pH continuously logged for various periods at (a) Drain 3 and (b) Drain 4

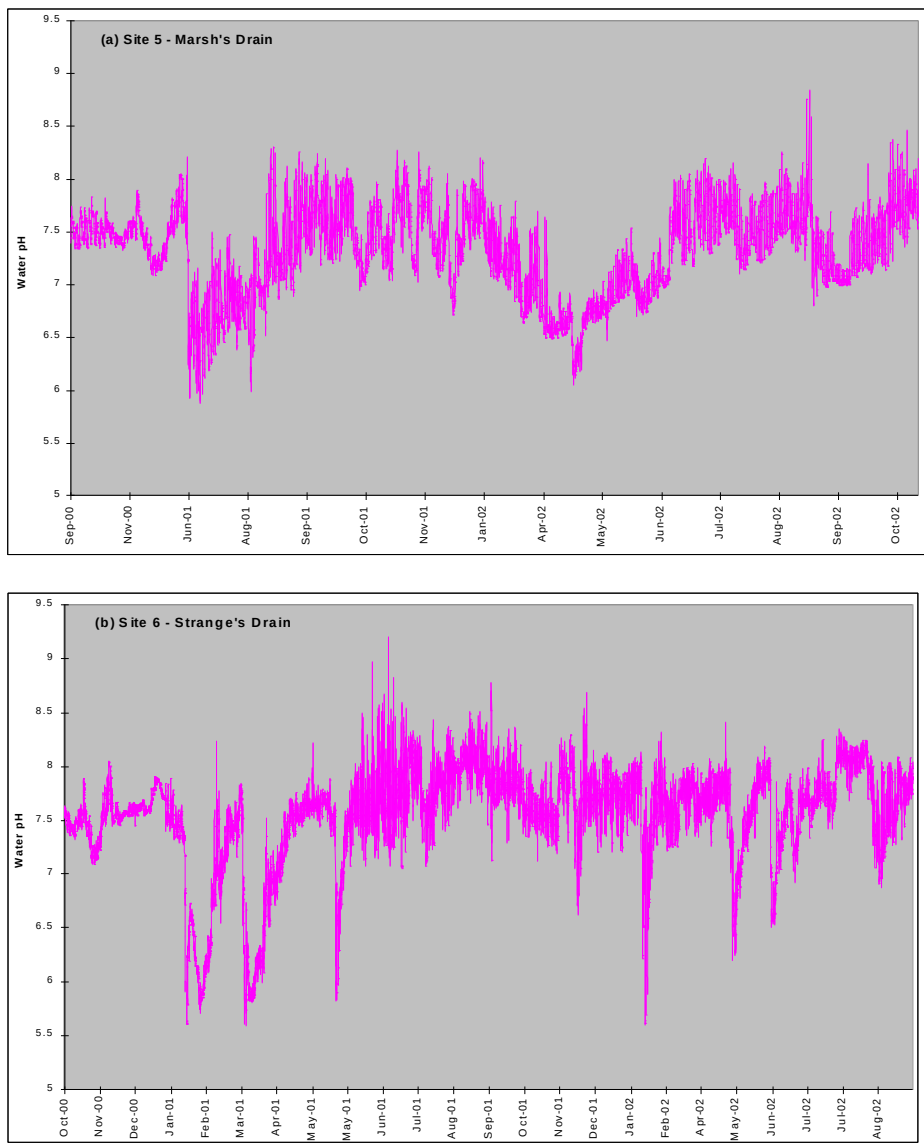


Figure 3.1-3 Drain water pH continuously logged for various periods at (a) Drain 5 and (b) Drain 6.

In all, 90.6% of the monthly samples from all six drains combined had pH values >6.0, the most to least frequently acidic being, in order of decreasing acidity, Drain 2 (84.8% of samples >6.0), Drain 4 (66.7% of samples >6.0), Drains 1 and 5 (each with 97% of samples >6) and Drains 3 and 6 (100% of samples >6.0). On these findings, most local effort to limit acid discharge to water needs to occur throughout the catchments of Drains 2 and 4, not just in cane growing areas.

Water pH data for Drain 5 are in agreement with previous monitoring of water around Palmers Channel and Wooloweyah Lagoon. Specifically, Woodhouse (2001)¹⁷ reported pH data collected over an 11 month period in 1999 (above average rainfall year) from 14 drains in the area. At Marsh's Drain there was little difference in pH between Palmers Channel and inside the drain with pH ranging from 6.3 to 7.8 in that dataset. During the present study (November 1999 – September 2002) pH values inside the drain were all >6 except for the first sampling in November 1999, when the pH was 5.2.

With respect to monitoring technique, continuous monitoring and monthly monitoring provided broadly similar information on drain water acidity / alkalinity. This supports the actions of a number of NSW canegrowers who are now undertaking their own monitoring of water pH and EC using portable meters (typically fortnightly readings).

Interrelationships between physiochemical parameters, tidal influence and rainfall are discussed in Sub-section 3.1.6.

¹⁷ Woodhouse, S. (2001), *Wooloweyah Lagoon Yamba, NSW Management Strategy*, Volume 1, NHT Project No. 14988, Natural Heritage Trust/Clarence River County Council.

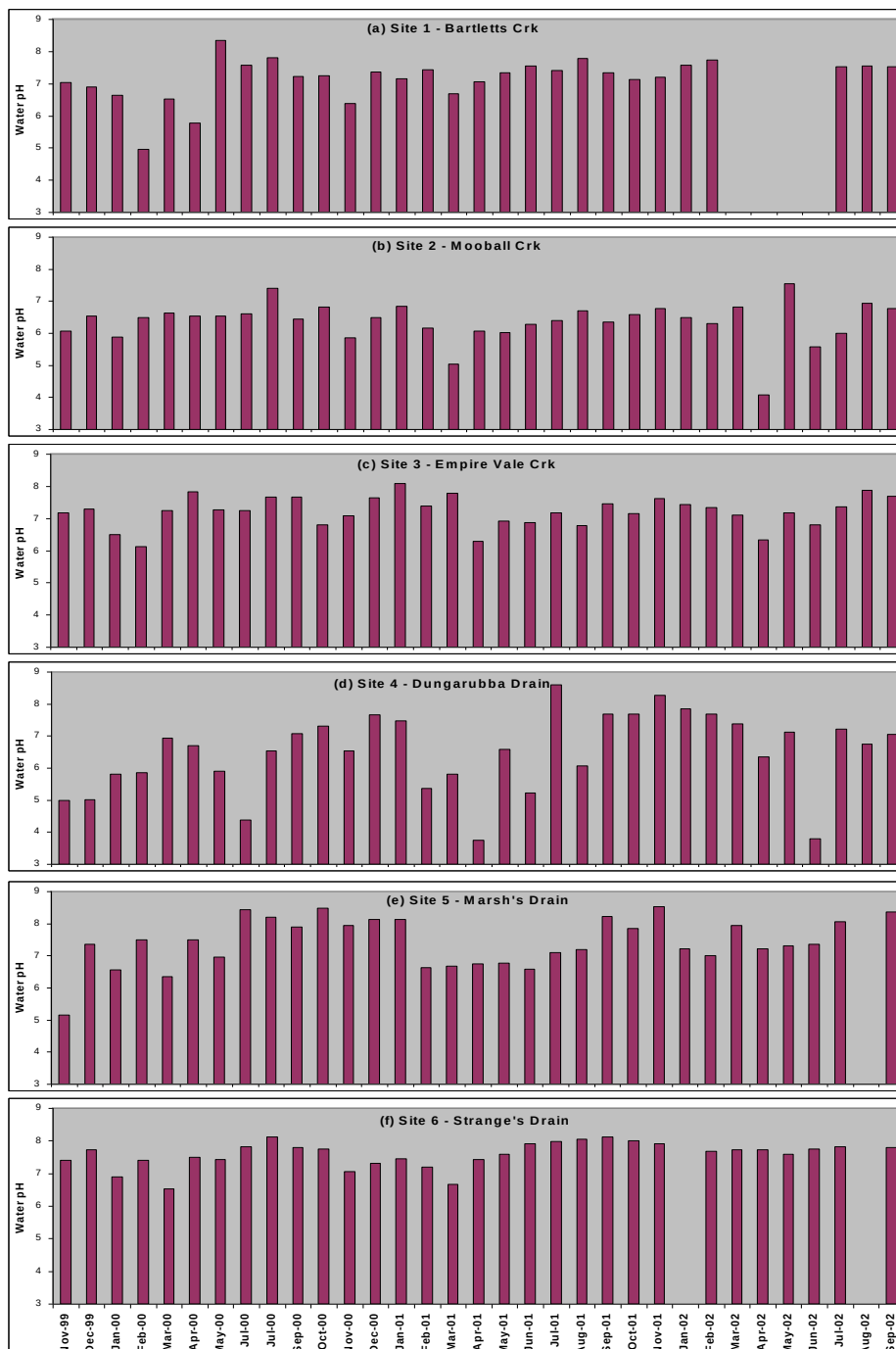


Figure 3.1-4 Monthly pH values for drain water in each of six drain systems

3.1.2 Dissolved oxygen

Waterways provide critical habitat in the life cycles of many fish and other important aquatic species. All need DO in the water to remain healthy and productive. It follows that low DO concentrations have adverse effects on many aquatic organisms (e.g., fish, invertebrates, and micro-organisms) that rely on DO for efficient functioning and survival (Hunt and Christiansen 2000)¹⁸. Supersaturation of the water with oxygen, often via gaseous trapping from photosynthetic activity, may also be harmful if sustained over extended times. Water quality criteria on DO for ecosystem protection (see Sub-section 2.3) recognize these two extremes. The difficulty with DO is that it only needs to be in short supply (or gross oversupply) for a matter of minutes to severely disadvantage aquatic fauna such as fish.

Water temperature and chlorinity affect how much oxygen can dissolve in water. For example, water at 20°C with zero chlorinity and with 6.0 mg O₂/L of DO is 67% saturated. Zero chlorinity water at 25°C at the same DO concentration is ≈ 72% saturated (Rayment and Bohl 2002)¹⁹. In addition, concentrations of DO vary with the time of day (usually lowest around dawn and at low tide), particularly when the water is slow moving or still, such as in storages, lakes and lagoons. Also, water bodies are prone to stratify into distinct layers, separated during warm weather by a shear-plane called a thermocline. “Bottom” waters typically contain less DO than surface waters.

Ultimately, the amount of oxygen dissolved in the drainwater is influenced by all of the above, plus the variable presence of other oxygen depleting substances. Those that create a biological oxygen demand (BOD) include organic matter derived from cane fields (eg. cane trash and sugar juice) and from sources further upstream (eg. litter and manure from pastures, sewage effluent, etc). Chemical oxygen demand (COD) usually acts more rapidly and involves the consumption of DO by chemical reaction, commonly when substances such as dissolved ferrous iron is oxidized to ferric iron.

As with water pH, the study undertook monthly monitoring at defined sampling points near the outlet of each main drain as well as periods of continuous in-stream monitoring at close to the same locations. Including four samples from a second site in Drain 1 when the main site was inaccessible due to road works, there were 196 monthly readings (see Figure 3.1-5). These covered the range 0 – 13.2 mg O₂/L, with a population median of 6.7, a 10th percentile of 3.9, and a 90th percentile of 9.9 mg O₂/L. That is, most of the monthly DO readings were within or close to the present generic ANZECC water guidelines for lowland rivers in NSW. Median DO values for Drains 1 to 6 were 7.7, 6.1, 6.7, 8.5, 6.0 and 7.1 mg/L, respectively. However, median values of DO from 16,609 to 32,443 separate continuously monitored readings from each drain were always lower (56.8 to 77.7% relatively to the monthly value) than their corresponding monthly counterparts.

Summary data for continuously-monitored DO are summarised in Table 3.1-1, while graphical presentation of the continuously monitored DO data from each drain are recorded in Figure 3.1-6 (a) and (b), Figure 3.1-7 (a) and (b), and Figure 3.1-8 (a) and (b). Because of the need to rotate the DO sensing equipment, particularly early in the study, and also because of fouling of sensors and the like, the DO data partly cover different seasonal conditions and have periods of discontinuity, apparent from dates given on the relevant “X” axes. These “gaps” differ from drain to drain and in the case of Drain 1, the continuous monitoring spanned only a few months of 2000. In 2001, the continuous monitoring commenced in March-April and continued through into December. The lowest DO concentrations in this drain (values < 2 mg O₂/L) mostly occurred in the spring – early summer periods.

¹⁸ Hunt, R.J. and Christiansen, I (2000). Understanding Dissolved Oxygen in Streams – Information. CRC Sugar Technical Publication. (CRC Sugar, James Cook University, Townsville).

¹⁹ Rayment, G.E. and Bohl, H. (2002). Dissolved oxygen in waterways of sugar catchments. In. Managing Soils, Nutrients and the Environment for Sustainable Sugarcane Production, Course Manual”. (Ed. R.C. Bruce). pp. 15-23. (CRC for Sustainable Sugar Production, Townsville.)

Table 3.1-1 Number of recordings (count), maximum, minimum and median values from continuous monitoring of dissolved oxygen, electrical conductivity and temperature and monthly monitoring of NTU of six main drains in canelands of northern NSW.

D.O (mg/L)

	Drain 1	Drain 2	Drain 3	Drain 4	Drain 5	Drain 6
Count	16609	21817	28616	27360	19283	32443
Max	12	14.59	13.88	14.78	11.68	13.84
Min	0.11	1.06	0.93	0	1	0
Median	5.15	4.74	4.94	4.83	3.58	5.11

EC (mS/cm)

	Drain 1	Drain 2	Drain 3	Drain 4^A	Drain 5	Drain 6
Count	16609	21817	28095	27268	19250	28877
Max	36.1	55.6	49.9	38.2	54.6	44.3
Min	0.291	0.059	0.080	0.080	1.23	0.162
Median	22.02	22.5	14.96	7.5	35.6	28

^A Excludes 92 data with EC values > 200 milliS/cm, thought to be due to a corrupted sensor

Temperature (°C)

	Drain 1	Drain 2	Drain 3	Drain 4	Drain 5	Drain 6
Count	16609	21817	28616	27360	19283	28877
Max	29.3	32.8	32.5	32.8	30	31.9
Min	12.5	13.1	8.7	11.3	11.7	10.5
Median	20.8	22.7	21.4	22.1	20.2	21.2

NTU (Monthly)

	Drain 1	Drain 2	Drain 3	Drain 4	Drain 5	Drain 6
Count	24	27	27	27	27	28
Max	87	61	201	118	84	182
Min	1	1	1	0	0	0
Median	12	6	8	8	5	4

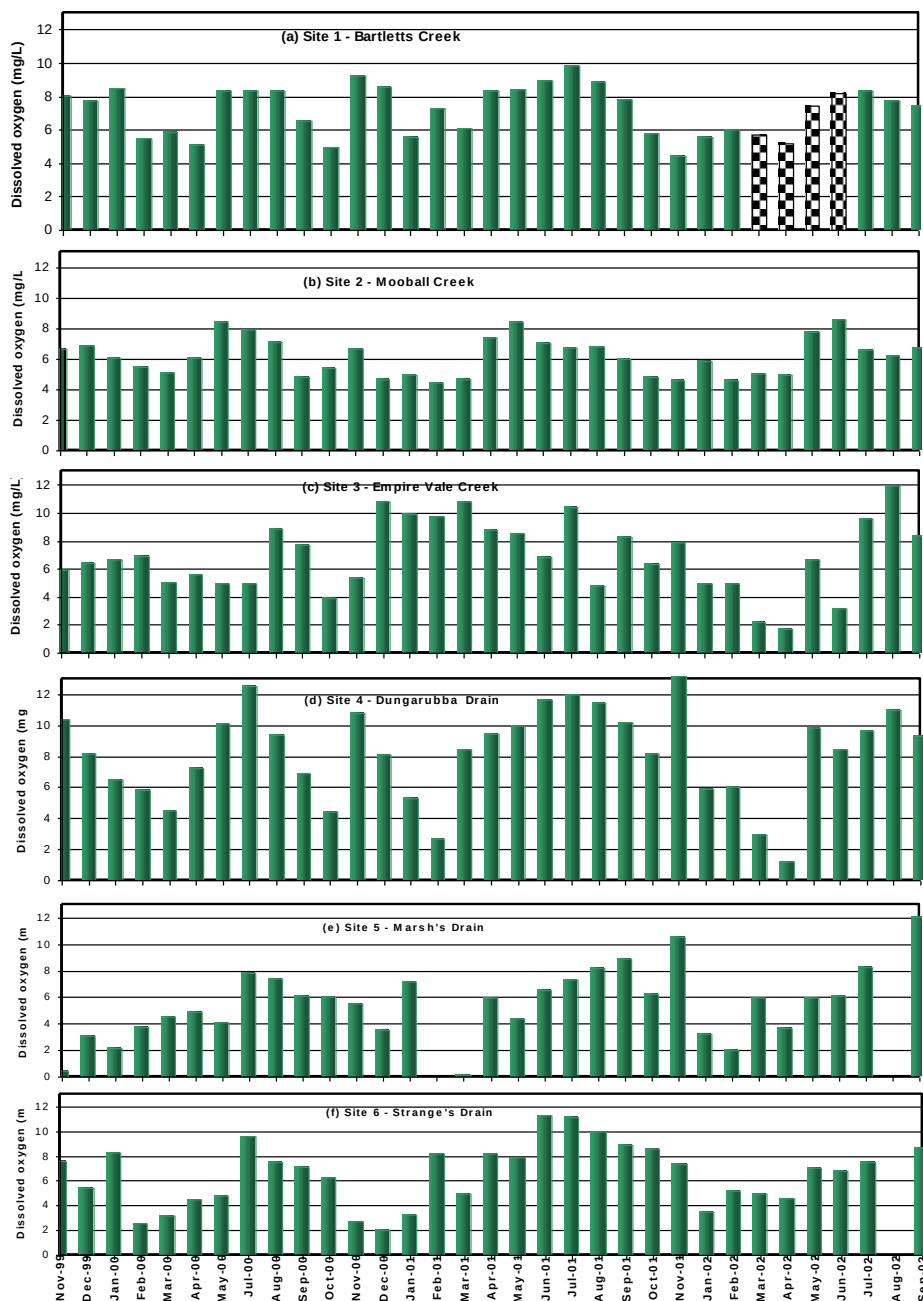


Figure 3.1-5 Monthly dissolved oxygen values for drain water in each of six drain systems. The four hatched 'bars' in Drain 1 were from a similar site as the original site was not accessible at the time due to road works.

A feature of the continuously monitored data were the wide ranges in DO values in all drains, particularly 1, 3, 4, 5 and 6. However, consistent patterns when DO levels were depressed and when they were elevated to the point of apparent supersaturation were elusive, except for a tendency for minimum values to be higher in 2002 than they were in the same month in a prior year or years. Drain 3 shows this pattern better than most. That is, there were many very low DO levels in that drain prior to March 2002 and very few from then through to termination of monitoring in October 2002.

To examine the possibility that seasonal conditions were implicated in the above observations, the DO concentrations from monthly samplings from each of the six drains were “pooled”, then partitioned into quarterly and half-yearly periods, respectively, the latter to broadly reflect “wet season” and “dry season” conditions. Quarterly grouping (spring, summer, autumn, winter) were also assessed, with summary data for both data sets provided in Table 3.1-2.

Table 3.1-2. The effects of typically “wetter” and “drier” months and also the effect of season (spring, summer, autumn, winter) on maximum, minimum and median monthly concentrations of dissolved oxygen (mg O₂/L) across all six main drains in NSW canelands.

WATER QUALITY ATTRIBUTE	“WET” MONTHS	“DRY” MONTHS	SPRING	SUMMER	AUTUMN	WINTER
Count	102	96	48	53	49	48
Maximum	10.8	13.2	13.2	10.8	10.1	12.5
Minimum	ND ^A	0.4	0.4	ND	0.1	3.2
Median	5.7	7.7	6.8	5.5	6.0	8.2

^A ND = not detected

Based on the median values in Table 3.1-2, the typically wetter and warmer seasons had lower median DO concentrations than did corresponding data for drier / cooler months. While in part these findings may simply reflect oxygen’s higher solubility in cool water than in warmer water, the differences in the medians seem too large for this to be solely responsible. A plausible explanation is that the elevated runoff and drainage volumes typically of wetter periods probably transported greater quantities of oxygen depleting substances into the drains.

It was expected Mooball Creek, as an ungated drain, would have been influenced more than the others by ingress of typically oxygen-rich estuarine water due to tidal flows. In practice, this drain had the second-lowest median DO concentration from monthly and continuous monitoring (6.1 and 4.7 mg O₂/L) and had the lowest spread of DO levels from continuous monitoring [Figure 3.1-6 (b)]. The possibility exists that the drain suffers from the presence of a chronic COD associated with the acidity known to be entering this drainage system. In general, the greater the sulfidic acidity the greater the chance a significant COD could develop.

The generally higher DO levels at Drain 6 [Figure 3.1-8 (b)] from mid 2001 onwards compared to late 2000 through to the early 2001 period may be associated with the installation of floodgate winches and regular opening of the gates by the landholder at this site (gates opened regularly from early August 2001 onwards). Similarly, at Drain 5, a marked improvement in DO levels after June 2002 is evident from Figure 3.8 (a). Here the DO increased from a low of 1.0 mg O₂/L to between 3 to 4 mg O₂/L. Landholders commenced periodic opening of this drain’s floodgates in May 2002. The increase then decrease in DO in late August - early September 2000 is most likely related to an 80 mm rainfall event following a period of 52 days when only 9 mm was recorded.

It warrants noting that the in-stream DO sensors associated with our 90 FL TPS data loggers were not identical in all cases, and this may have had some influence on the findings. At Drain 1, for example, the DO probe had a stirrer, agitating the water to aerate the probe membrane. Drain 2 relied primarily on water passing through the conduit housing the probe, thereby agitating the water. Identical DO probes, recommended for future in-stream monitoring, would have provided greater certainty that differences between the drains were real.

We are unable from the design of the study to resolve unequivocally why median monthly DO data were typically $\geq 25\%$ higher than their continuously monitored counterparts. A likely contributing factor is that monthly samples were always collected in daylight hours, when DO concentrations tend to be higher due to photosynthetic activity by aquatic flora in the drains. While continuous monitoring of in-stream DO is recommended for future studies, comparative assessments between drainage systems can only be undertaken with confidence if the sampling periods are identical, which was not possible on this occasion due to funding constraints early in the life of the study.

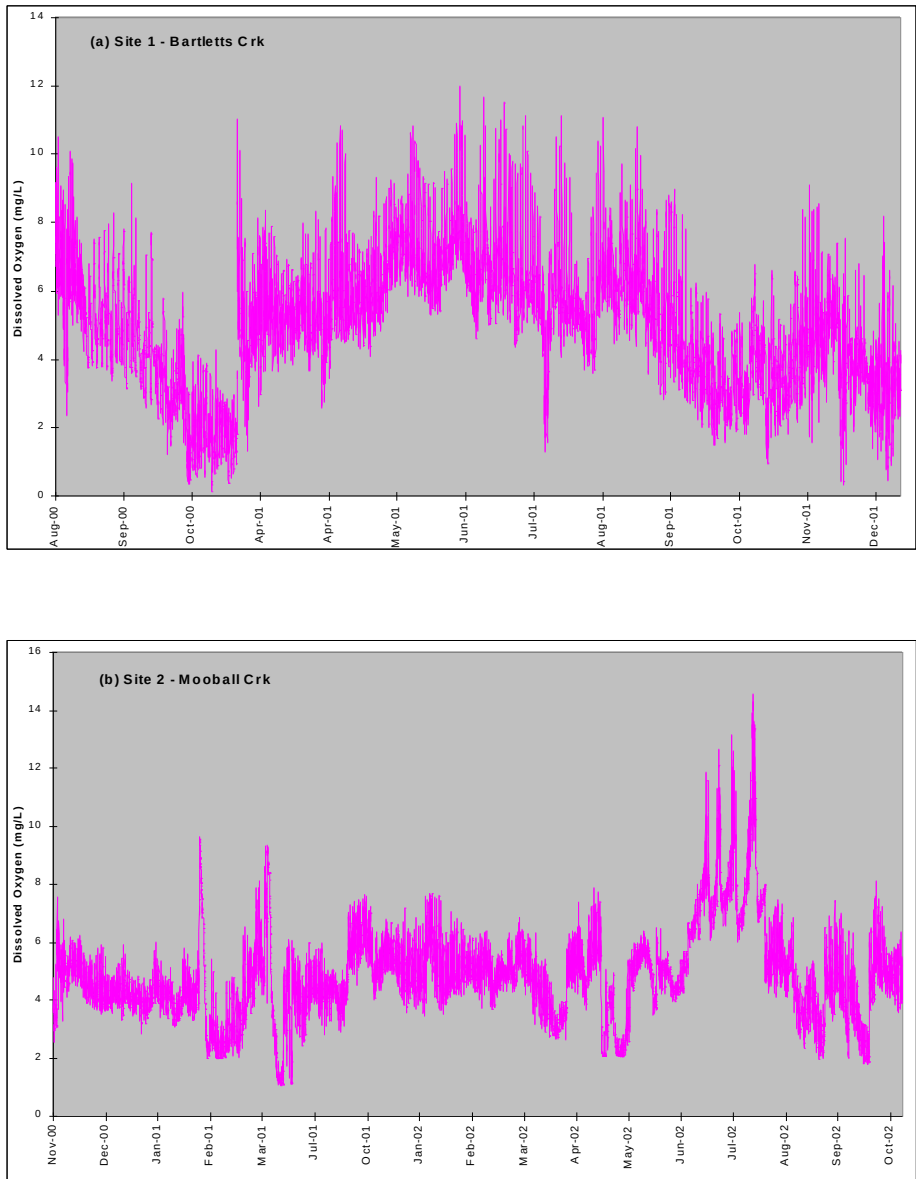


Figure 3.1-6 Dissolved Oxygen in drain water continuously logged at each of (a) Drain 1 and (b) Drain 2.

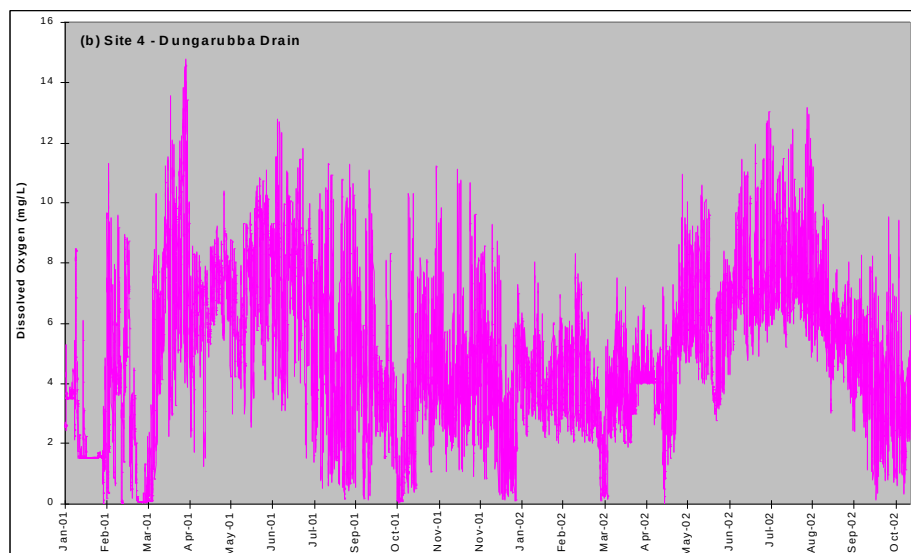
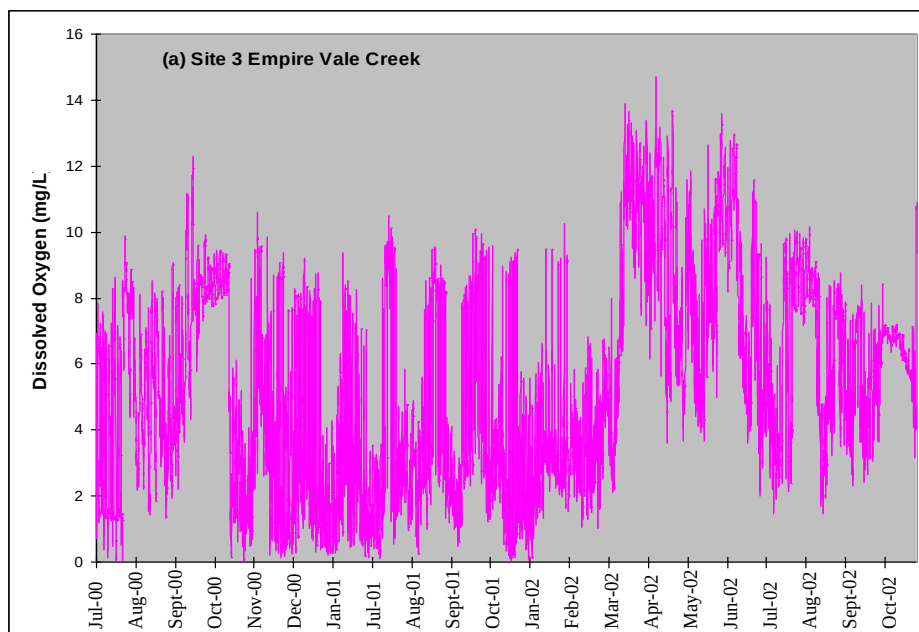


Figure 3.1-7 Dissolved Oxygen in drain water continuously logged at each of (a) Drain 3 and (b) Drain 4.

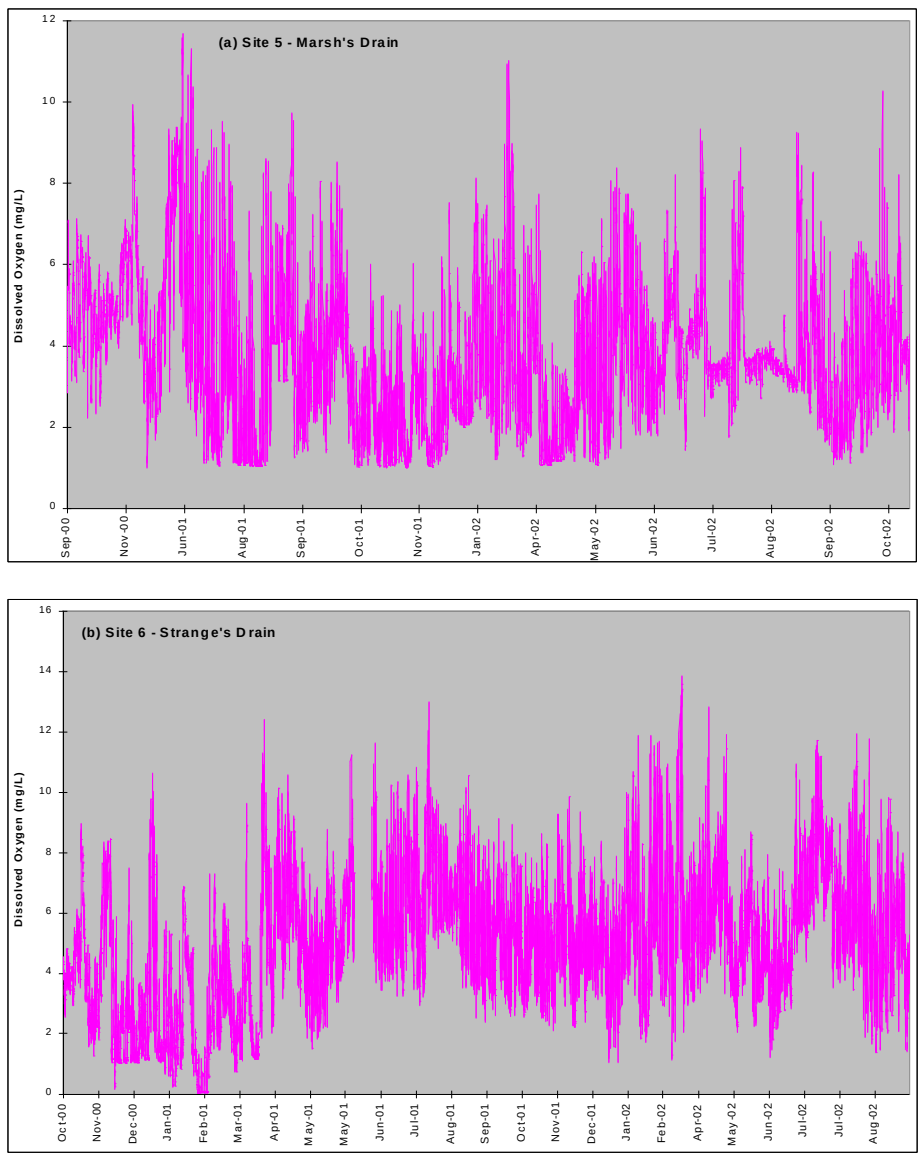


Figure 3.1-8 Dissolved Oxygen in drain water continuously logged at each of (a) Drain 5 and (b) Drain 6.

3.1.3 Electrical conductivity (EC)

The ability of water to conduct an electrical current is influenced by the concentration and nature of the ions present, as well as the temperature of the water. Most soluble inorganic compounds dissociate in solution to produce ions. The EC of water therefore reflects the concentration of dissolved inorganic salts such as sodium chloride and gypsum.

The EC of the water is measured relative to that of standard potassium chloride solution using a conductivity cell and a meter to measure / record the EC. Corrections are made for temperature at the time of measurement (standardised at 25°C)²⁰ and the results are reported as milli Siemens per centimetre (milliS/cm), equivalent to deciSiemens per metre (dS/m) at 25°C. The EC of natural “fresh” waters in Australia range typically from 0.05 to 10 milliS/cm (Rayment and Higginson, 1992)²¹.

There was one ungated and 5 gated drains. Moreover, on most of the gated drains there was leakage through the gates at high tide, which had an influence on EC values. Also, floodgate management (namely opening of the gates to allow estuarine water into the gated drains) commenced during the course of the project, mostly affecting Drains 5 and 6.

Summary data on EC, derived from continuous monitoring for each drain are presented in Table 3.1-1. On these data, the drain that was least saline most often was No. 4 (Dungarubba Drain; median EC of 7.5 milliS/cm). At the other extreme, Drain 5 had the highest median EC at 35.6 milliS/cm.

In all cases, median ECs from monthly monitoring (median values of 14.6, 10.2, 8.39, 4.57, 12.65, and 23.9 milliS/cm) were lower than corresponding medians from monthly monitoring (Table 3.1-1) by from 117 to 221%, calculated relative to the monthly data. The trend of least to most saline median values also differed, apart from the least saline drain. Likely reasons for the inconsistencies include: a) the dates covered by monthly monitoring were wider than those for continuous monitoring; and b) monthly monitoring occurred at the bottom third of the tide, making it more likely to intercept fresh runoff rather than water influenced by estuarine inputs.

3.1.4 Turbidity

Turbidity is a measurement used to quantify the degree to which light is scattered by suspended particles when traveling through the water column. Increased turbidity reduces the ability of light to penetrate the water column, limiting the ability of plants to photosynthesize. If turbidity is mainly caused by organic particles, there is a high risk of oxygen depletion (ANZECC 2000²²).

Monthly turbidity measurements for each site are presented in Figure 3.1-9 and summarised in Table 3.1-1. The flood events in February and March 2001 in the Richmond (Drains 3 and 4) and Clarence (Drains 5 and 6) are evidenced by high turbidity values. With the exception of the 2001 flood events, turbidity did not generally exceed 50 NTU. Indeed, median values for all drains were ≤ 12 . The low turbidity values from mid 2001 to September 2002 are consistent with the very dry conditions during this time period. The majority of cane fields in the floodplains of northern NSW have very low slopes and therefore soil erosion is not a major issue.

²⁰ An approximate correction can be made by increasing the values by 2% for each degree that the ambient temperature is below 25°C, and decreasing them when the temperature is above 25°C.

²¹ Rayment, G.E. and Higginson, F.R., (1992). Australian Laboratory Handbook of Soil and Water Chemical Methods, Waters Method B, 217-218 (Inkata Press, Melbourne).

²² ANZECC (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000). (ANZECC and ARMCANZ, Canberra.)

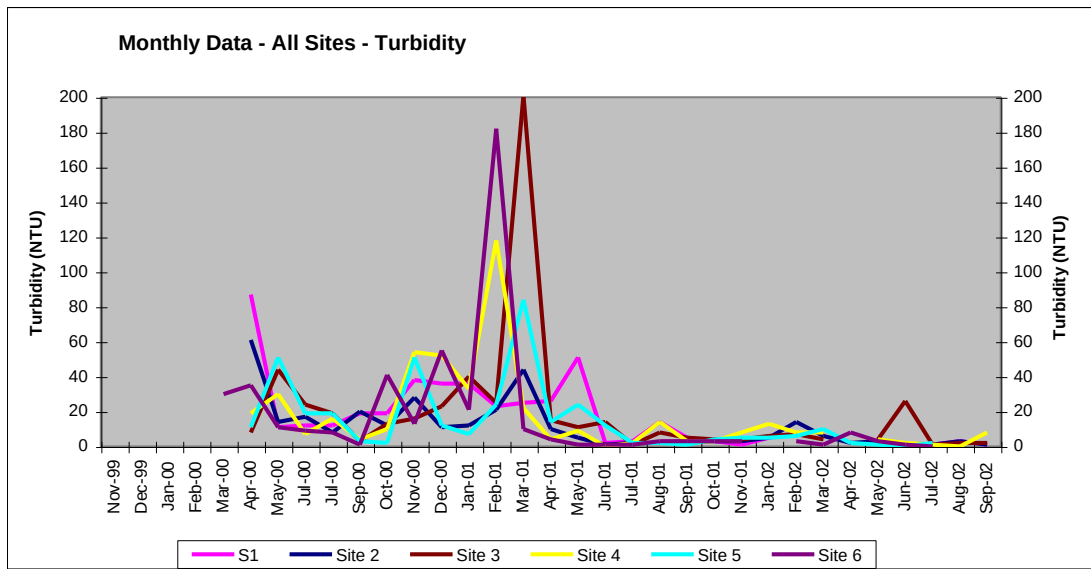


Figure 3.1-9 Drain water turbidity recorded at monthly intervals in six drainage systems in NSW.

3.1.5 Temperature

As expected, drain water temperature at each site showed distinct seasonal trends (Figure 3.1-10). There were no major differences between the various drains (see Table 3.1-1 for summary data from continuous monitoring), with all drains having maximums from 29.3 to 31.9 °C in summer and minimums of from 8.7 to 13.1 °C in winter. These temperatures would be expected to support saturated DO concentrations of around 6 to 8 mg/L assuming chlorinity levels of 20 mg/L (Rayment and Bohl 2002)²³.

²³ Rayment, G.E. and Bohl, H. (2002). Dissolved oxygen in waterways of sugar catchments. In. Managing Soils,Nutrients and the Environment for Sustainable Sugarcane Production, Course Manual” . (Ed. R.C. Bruce). pp. 15-23. (CRC for Sustainable Sugar Production, Townsville.)

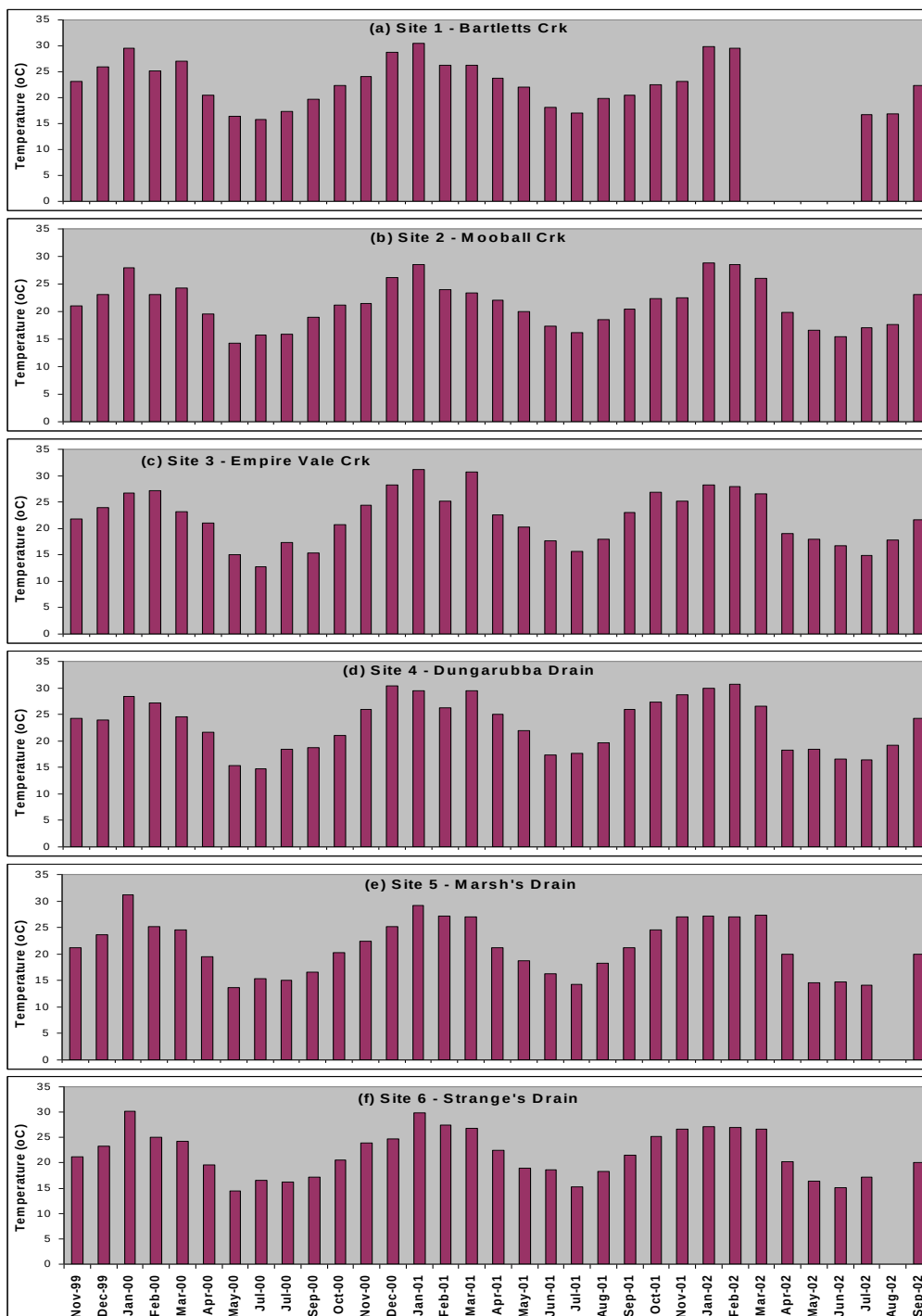


Figure 3.1-10 Monthly temperature values for drain water in each of six drain systems

3.1.6 Interrelationships between physiochemical properties, tidal influences & rainfall.

It was difficult from separate plots of the continuously monitored data for pH, DO, EC and temperature to discern the presence (if any) of any continuous relationships between the magnitudes of the various measurements across the full periods of monitoring. The same comment applies equally to the monthly-monitored data.

In the event, few meaningful associations could be found. For example, there was no continuous relationship between EC levels and DO concentrations, based on pooling all the monthly data for all drains (n=195). On this finding, suggestions that estuarine water had a significant and enduring influence on in-drain DO concentrations across the entire period of monitoring must be dismissed. That said, there were occasions, such as at Drain 2, when both parameters were inclined to increase as high tides maximised water depth at the logger site. This effect was less obvious in drains further up the river relative to the ocean discharge point and was not apparent at other times and places.

The effects of tides as well as dry and wet periods on physiochemical properties (DO, EC, water depth, rainfall) at Drain 2 and Drain 4 are shown in Figures 3.1-11 to 3.1-14. As expected, both DO and EC decreased following major runoff events. The initial increase in DO sometimes associated with significant rainfall may have been due to high DO in rainfall and increased turbulence due to wind and high flow rates.

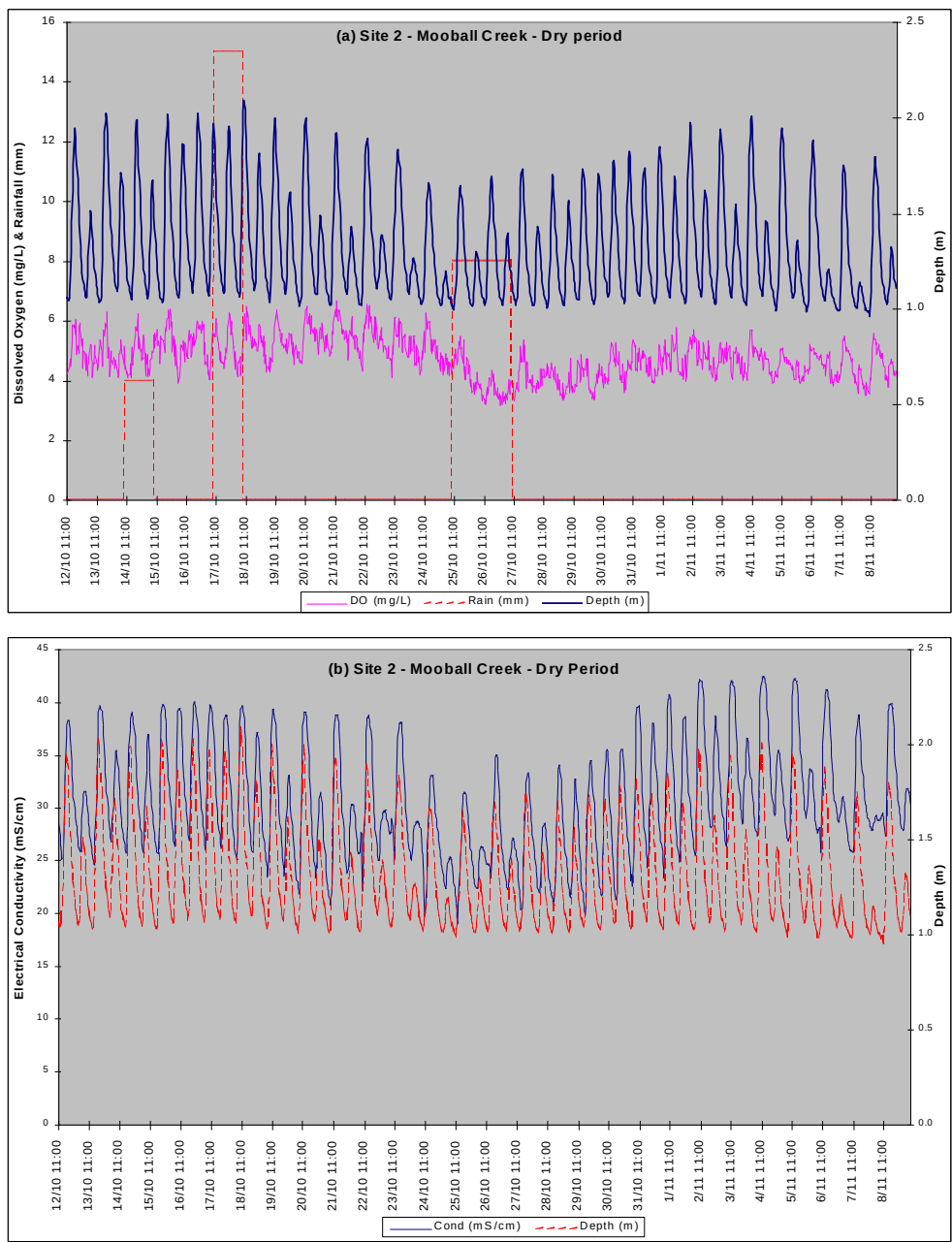


Figure 3.1-11 Interrelationship between physicochemical properties, tidal influences and rainfall during a dry period at Drain 2 (a) and (b).

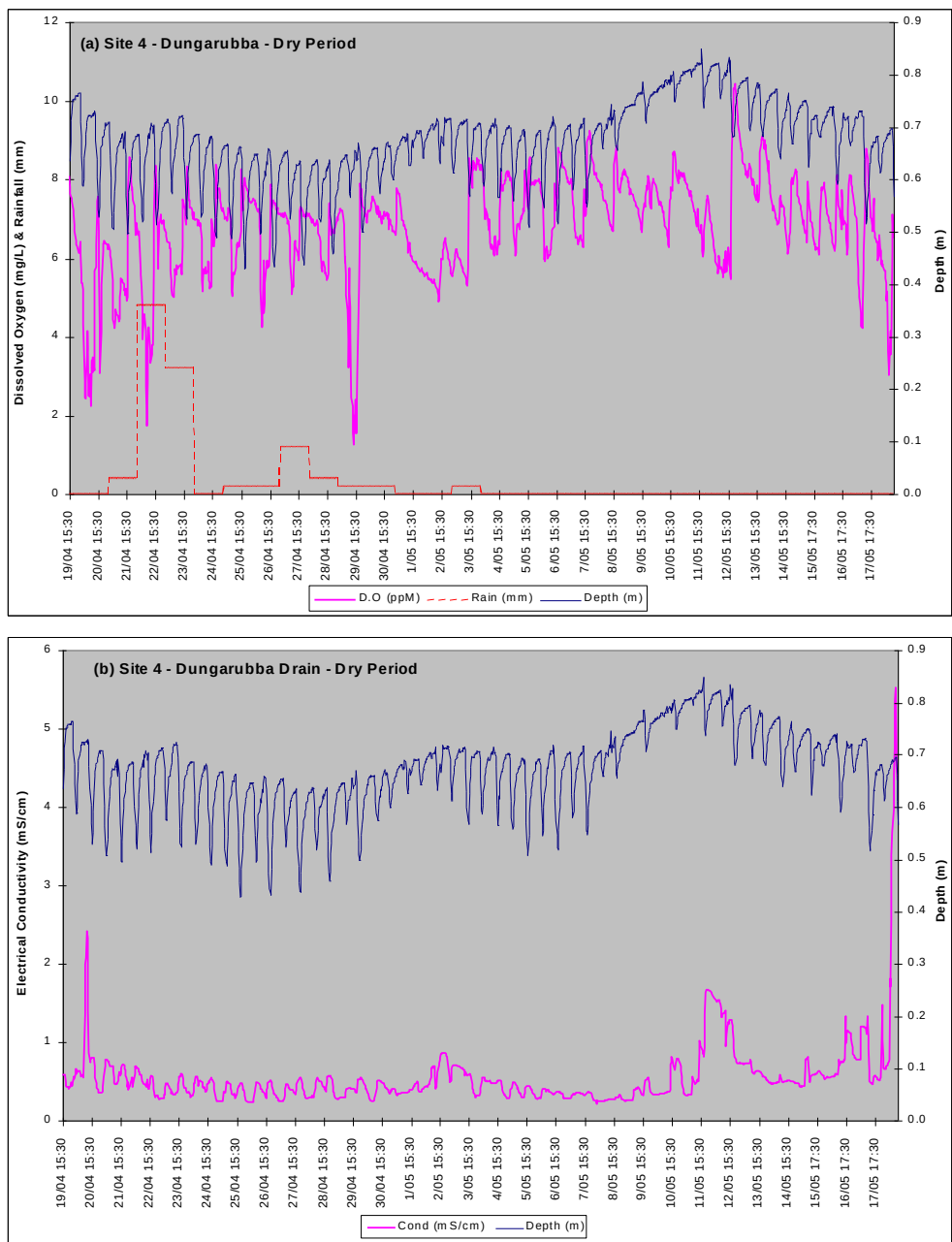


Figure 3.1-12 Patterns among physicochemical properties, tidal influences and rainfall during a dry period at Drain 4 (a) and (b).

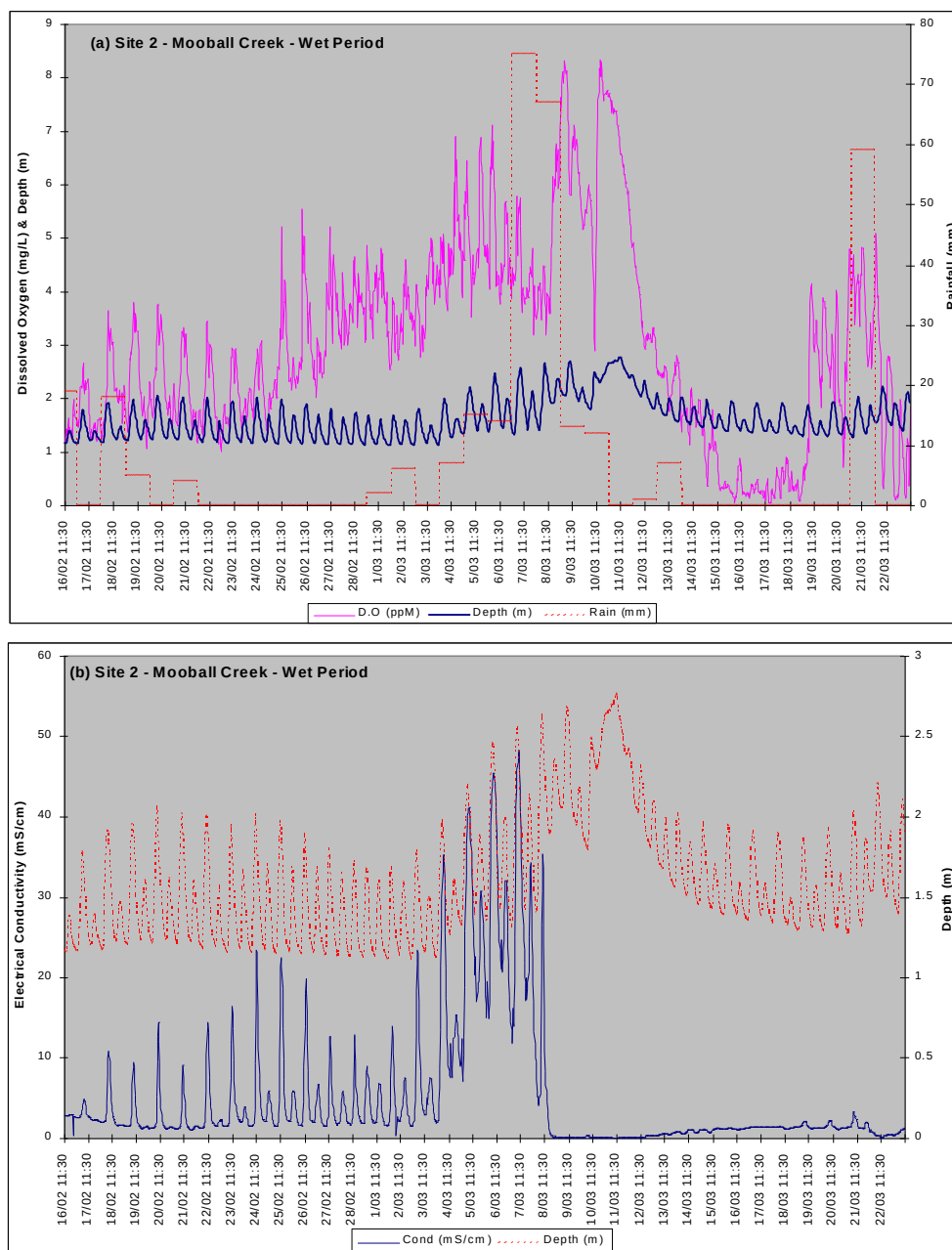


Figure 3.1-13 Patterns among physicochemical properties, tidal influences and rainfall during a wet period at Drain 2 (a) and (b).

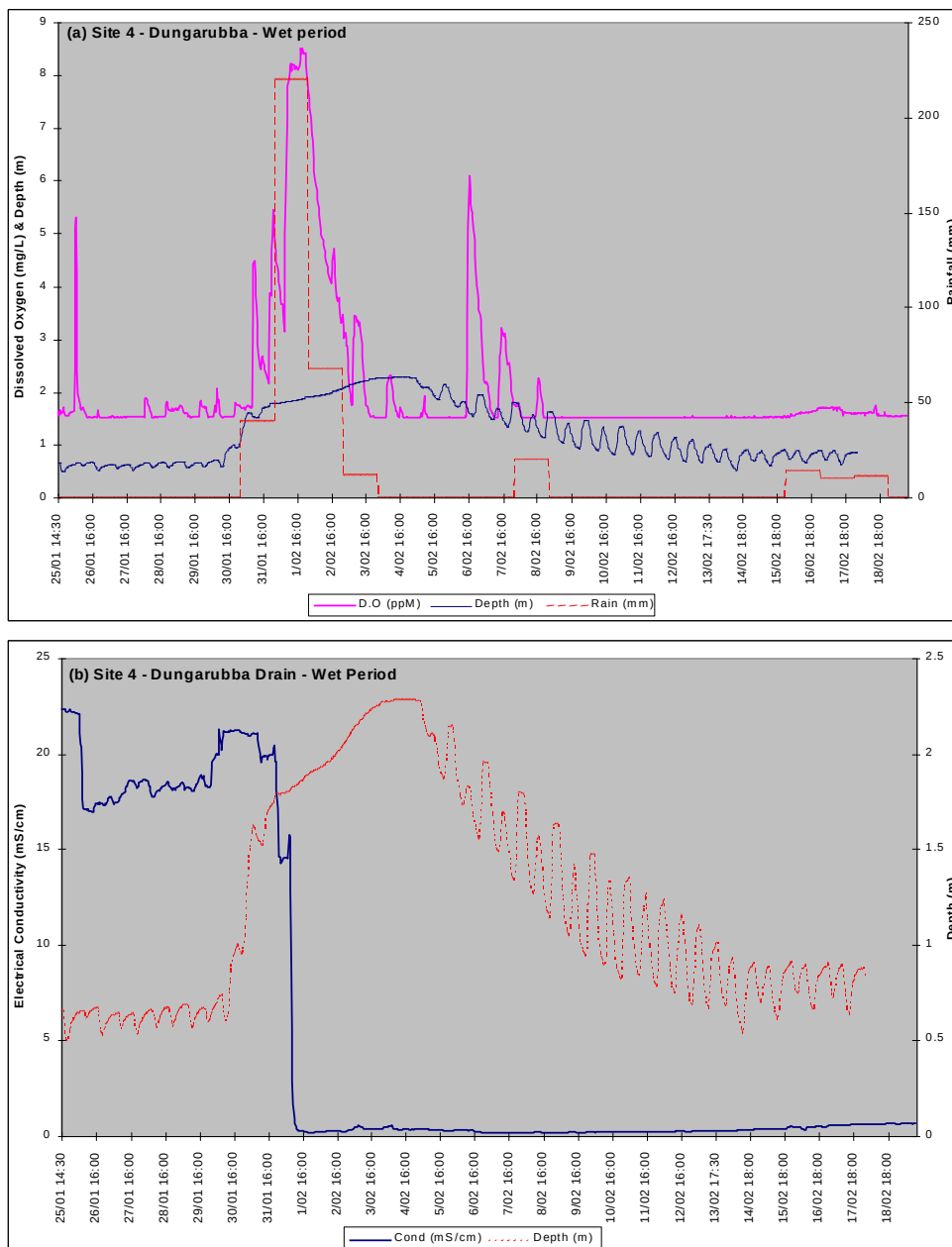


Figure 3.1.14 Interrelationship between physicochemical properties, tidal influences and rainfall during a wet period at Drain 4 (a) and (b).

Correlation matrix plots for the interrelationships between pH, DO, turbidity, EC and temperature for Drains 2 and 6 are presented in Figures 3.1-15 and 3.1-16, respectively. Similar plots for the other 4 sites are shown in Appendix 3. Although correlation coefficients were generally very low (data not shown), there was a trend for DO to decrease with increasing temperature at each site. The increase in pH with increasing EC is attributed to the higher pH (alkalinity) of saline estuarine waters entering the drains via leaky floodgates (Figure 3.1-16, Drain 6), floodgate management, or on incoming tides (Figure 3.1-15, Drain 2). Although turbidity data were not normally distributed (Figures 3.1-15 and 3.1-16), the trend for decreasing turbidity with increasing EC at most sites is consistent with clearer estuarine waters entering the drain systems or causing flocculation of suspended colloids. When data for all sites were combined (plots not shown) there was a trend for decreased DO with increasing temperature (weak) and a positive relationship between EC and pH.

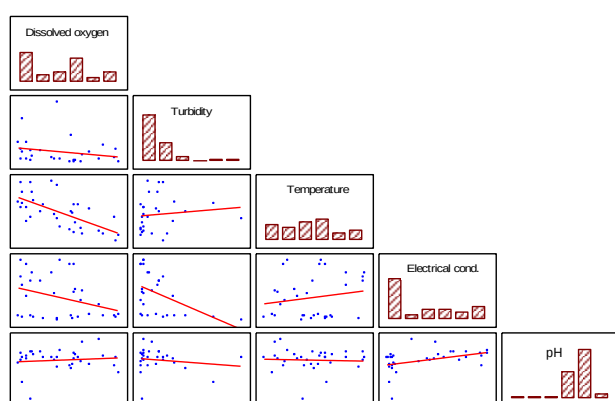


Figure 3.1-15 Matrix correlation plot for physiochemical properties of drain water at Drain 2. All plots in the column below the property have that property plotted on the x axis with the y axis property shown at the end of each row. Bar charts show the frequency distribution of each physiochemical property.

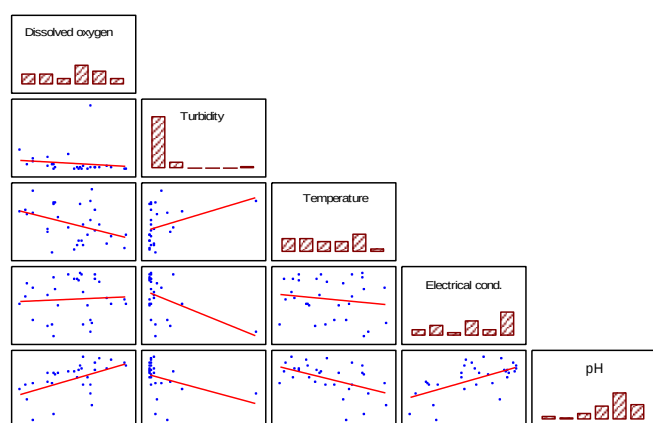


Figure 3.1-16 Matrix correlation plots for physiochemical properties of drain water at Drain 6. All plots in the column below the property have that property plotted on the x axis with the y axis property shown at the end of each row. Bar charts show the frequency distribution of each physiochemical property.

3.2 NUTRIENTS

Many reports^{24 25 26 27 28} have confirmed positive relationships between the use of fertilisers and consequential nutrient enrichment of waterways, stream sediments and groundwaters adjacent to and downstream of agricultural lands. Unfavorable consequences include a greater likelihood of algal blooms and unwelcome changes to ecosystem composition and health. As sugarcane is a significant user of fertilisers, particularly N, P and potassium (K), it was appropriate to include nutrients (N and P) in the suite of water quality parameters examined on a monthly basis. This was done in the knowledge that almost all growers in the NSW sugar industry use subsurface placement of fertilizer (mostly in the October to January period) to minimise or eliminate N volatilization and to maximize crop utilization of the added nutrients. A pre-project survey indicated 76% of growers placed their fertilizer as a subsurface band.

Given the soil types in the drainage catchments monitored²⁹, it was thought unlikely that significant leaching of P to the water table would occur due to the dominance of fine textured soils in cane-growing areas of NSW³⁰.

3.2.1 Nitrogen

Other than under very strongly acidic and waterlogged conditions, most fertiliser N applied to soils is rapidly converted to nitrate. If not utilised by the crop, it has the potential to be lost in runoff and/or leached below the root zone. The extent to which this occurs is influenced by N application rate (the higher the rate the more likely the chance of loss), crop requirement, soil type, soil N transformations, and the amount of water percolating within the profile.

Ammonium N may also be lost in runoff but is rarely leached. However, it is vulnerable to loss by volatilisation, and may return to the drainage basin dissolved in rainwater. Accordingly, both nitrate and ammonium forms of mineral N (these forms are soluble in water) were expected to be encountered in all of the drains. The unknowns were at what concentrations relative to national water quality guidelines for ecosystem protection, whether concentrations varied with seasonal conditions, and the proportions of mineral N relative to other forms of N in the drains, including total N concentrations.

In all there were around 195 monthly samples on which a suite of N determinations were made in the laboratory, corresponding to from 31 to 33 samples from each main drain. Summary data from all sites individually and combined are presented in Table 3.2-1, including the median percentages of ammonium-N and oxidised-N [nitrate + nitrite (if any)] relative to total N. The drain data are presented graphically in Appendix 4.

The tabulated data show median concentrations of total N in individual drains ranged from 0.33 mg N/L (Drain 1) through to 0.94 mg N/L (Drain 5), with a grand median (calculated from the combined raw data) of 0.50 mg N/L. This value would conform to year 2000 ANZECC generic guideline concentration for coastal rivers in south Queensland and is lower than the guideline for lowland rivers in non-coastal NSW. However, it exceeds by 0.15 mg N/L the generic guideline concentration for lowland rivers in coastal NSW. Drain 1 was the only drain where the median total N concentration was lower than the coastal NSW water quality guideline for total N. All drains had at least some monthly concentrations below the guideline concentration, while water in all drains at least at one monthly sampling tested at least six times higher than the NSW generic guideline for total N.

DIN and its components (oxidised-N and ammonium/ammonia-N) attracted close attention due to their connection with land management practices. Across all drains DIN was less than 10% of the total N concentration. In every drain,

24 Addiscott, T.M., Whitmore, A.P. and Powlson, D.S. (1991). "Farming, Fertilisers and the Nitrate Problem". (C.A.B. International, Wallingford).

25 Anon. (1995). "Nutrient Management in Irrigated Agriculture, Research and Implementation". Proceedings of a Conference June 19-20, 1995, Echuca. 139 pp. (Agriculture Victoria, ISIA).

26 Garman, D.E.J. and Sutherland, P.D. (1983). Pesticides, fertilisers, heavy metals and salinity - an assessment of the non-point source problems in Australia. In: "Workshop on Non-point Sources of Pollution in Australia Proceedings. Aust. Water Resources Council Conference Series No. 9. pp. 27-47. (AGPS, Canberra).

27 Walker, W.J. and Branham, B. (1992). Environmental impacts of turfgrass fertilisation . Ch. 3. In "Golf Course Management and Construction - Environmental Issues". Eds J.C. Balogh and W.J. Walker. (Lewis Publishers, USA.).

28 Rayment, G.E., Kuhn, G. and Pulsford, J.S. (1996). Fertiliser options and improved nutrient management practices. In "Downstream Effects of Land Use". (Eds. H.M. Hunter, A.G. Eyles and G.E. Rayment). pp. 227-34. (Department of Natural Resources, Queensland: Brisbane.)

29 Soils' map produced by W.J. Vivian for J. W. McGarity, University of New England, Armidale, June 1961; map silk screened by Mick Allsopp, Tamworth.

30 Rayment, G.E., Raymond, M. and Balakrishnan, T. (2001). Quick field test for lime rates of pyritic drain-spoil in NSW canelands. In "Proc. Aust. Soc. Sugarcane Technologists". (Ed. D.M. Hogarth.) pp. 58-63. (23rd Conference, Mackay.)

the median concentration of ammonium-N exceeded the median concentration of oxidised-N by at least a factor of 2 and usually more. The exception was Drain 2, where ammonium-N was 1.3 times higher but both water-soluble N components were higher than in any other drain, for no certain reason. It is noteworthy, however, that Drain 2 contained more land use diversity than the others. For example, the drainage basin has significant areas of banana production, nurseries, and villages with septic systems.

In well oxygenated water with a pH around 7.0 or slightly less, ammonium ions are rapidly oxidised by nitrifying bacteria to nitrite and then to nitrate, which is well tolerated by most fish at concentrations up to several hundred mg/L. Conversely, microorganisms can reduce nitrate back to ammonium ions and eventually to atmospheric nitrogen (N_2) when waters are depleted of DO. Given that the waters in the drains were reasonably well oxygenated most of the time, the most likely reasons for higher concentrations of ammonium-N were: (a) traces of ammonium forms of fertiliser may have moved to the drains via runoff; and (b) strong acidity present some of the time in most drains (or in the soils adjacent to the drains) may have suppressed nitrification of ammonium-N to oxidised-N.

As the median concentration of ammonium-N in all of the drains, particularly in Drain 2, Drain 5 and Drain 6 exceeded the year 2000 ANZECC generic guideline for lowland rivers in NSW (0.015 mg N/L), the cause or causes plainly require elucidation. That said, it is not clear why this generic guideline concentration for ammonium-N is half of that applicable to non-coastal lowland rivers in NSW.

It is noteworthy that ammonium ions are not easily transported across cell membranes and therefore do not usually pose a major toxicity threat to aquatic organisms. The un-ionised form (NH_3) is the “villain”, as it easily crosses cell membranes, but usually only becomes prevalent and therefore an environmental issue in alkaline natural waters. At pH 9.0 and over, most of the ammonium-N would be present as un-ionised ammonia, which at concentrations >0.02 mg N/L (un-ionized) can cause problems for fish.

In all drains with the exception of Drain 2, median concentrations of oxidised-N were well below the generic guideline concentration for lowland rivers in coastal NSW of 0.04 mg N/L (Table 2.3-3), mostly contributing <2% on a mass basis of the corresponding total N concentration (Table 3.2-1).

Table 3.2-1 Summary statistics for monthly sampling on up to 33 sequential occasions for nitrogen concentrations (totals and fractions; mg N/L) and suspended solids (mg/L) in six NSW main cane drains, inclusive of percentages relative to total N of ammonium and oxidised N (median values).

Statistic	Total N	Total N Insoluble	Total N Soluble	Total Organic N	NH ₄ -N	NH ₄ -N as % of total N	OxidisedN (NO ₃ -N)	NO ₃ -N as % of total N	Suspended Solids
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Drain 1

Count	31	31	31	31	31		31		31
Maximum	2.55	0.42	2.43	0.56	0.45		1.64		25.00
Minimum	0.10	0.00	0.02	0.01	0.00		0.00		2.00
Median	0.33	0.11	0.23	0.19	0.02	5.15	0.01	2.12	8.0
Geomean	0.40	0.09	0.25	0.17	0.02		0.02		7.41

Drain 2

Count	33	33	33	33	33		33		33
Maximum	2.25	0.34	2.18	0.62	0.23		1.69		57.00
Minimum	0.10	0.01	0.09	0.03	0.01		0.01		2.00
Median	0.38	0.04	0.33	0.17	0.07	18.7	0.05	13.9	6.00
Geomean	0.39	0.04	0.32	0.15	0.07		0.07		6.64

Drain 3

Count	33	33	33	33	32		33		32
Maximum	2.36	1.30	1.88	0.88	0.64		1.21		31.00
Minimum	0.01	0.01	0.01	0.01	0.00		0.00		1.00
Median	0.55	0.18	0.39	0.30	0.03	5.18	0.01	1.82	9.50
Geomean	0.56	0.15	0.38	0.26	0.03		0.01		8.58

Drain 4

Count	32	32	32	32	32		32		33
Maximum	2.33	0.80	2.22	1.21	0.18		1.41		55.50
Minimum	0.13	0.00	0.04	0.03	0.00		0.00		1.00
Median	0.44	0.12	0.29	0.27	0.02	3.40	0.01	1.13	9.00
Geomean	0.45	0.08	0.30	0.25	0.02		0.01		8.53

Drain 5

Count	33	33	33	33	33		33		33
Maximum	3.35	1.41	2.35	1.90	1.60		1.12		57.80
Minimum	0.32	0.02	0.19	0.13	0.00		0.00		1.00
Median	0.94	0.15	0.81	0.59	0.05	5.41	0.02	1.91	6.00
Geomean	1.03	0.16	0.81	0.63	0.05		0.02		6.52

Drain 6

Count	33	33	33	33	33		33		33
Maximum	3.30	1.65	1.65	1.11	0.50		0.76		55.00
Minimum	0.08	0.01	0.05	0.02	0.00		0.00		1.40
Median	0.56	0.14	0.40	0.32	0.05	9.29	0.01	1.79	10.60
Geomean	0.55	0.12	0.40	0.28	0.04		0.01		8.34

Table 3.2-1. (cont.)

Statistic	Total N	Total N Insoluble	Total N Soluble	Total Organic N	NH ₄ -N	NH ₄ -N as % of total N	Oxidised N (NO ₃ -N)	NO ₃ -N as % of total N	Suspended Solids
All drains combined									
Count	195	195	195	195	194		195		194
Maximum	3.35	1.65	2.43	1.90	1.60		1.69		77.00
Minimum	0.01	0.00	0.01	0.01	0.00		0.00		1.00
Median	0.50	0.12	0.38	0.28	0.03	6.90	0.01	2.40	8.00
Geomean	0.53	0.10	0.38	0.26	0.03		0.00		7.98

To better understand factors that might be contributing to the N concentrations found in the six drains, the N (and P) data were “pooled” across drains then partitioned into quarterly and half-yearly periods, respectively, the latter to broadly reflect “wet season” and “dry season” conditions. Likewise, the quarterly grouping (spring, summer, autumn, winter) could be visualized into different periods of the crop production and harvesting system. Summary statistics for these groupings (N as well as P) are provided in Table 3.2-2.

Table 3.2-2 The effects of typically “wetter” and “drier” months and also the effect of season (spring, summer, autumn, winter) on median total nitrogen and phosphorus concentrations across all six main drains in NSW canelands, together with corresponding medians for suspended solids and certain water soluble concentrations and their percentages of corresponding total concentrations.

Water quality attribute	“Wet” months	“Dry” months	Spring	Summer	Autumn	Winter
Count	97-98	95	48	48-49	51	47
Total N (mg N/L)	0.66	0.42	0.41	0.60	0.72	0.42
Ammonium-N (mg N/L)	0.05	0.03	0.04	0.04	0.05	0.02
Ammonium-N as % of total N	6.9	6.9	9.4	5.9	7.1	4.3
Oxidised-N (mg N/L)	0.02	0.01	0.01	0.01	0.05	0.01
Oxidised-N as % of total N	2.9	2.1	2.1	1.8	7.2	2.9
DIN (mg N/L)	0.07	0.04	0.05	0.05	0.10	0.03
DIN as % of total N	9.8	9.1	11.5	7.8	14.3	7.1
Total P (mg P/L)	0.10	0.05	0.07	0.14	0.07	0.04
DIP (mg P/L)	0.01	< 0.01	0.01	0.01	0.01	<0.01
DIP as % of total P	12.0	8.0	7.1	10.4	12.9	10.0
N:P ratio (totals)	7.0	7.0	6.2	5.5	8.6	8.1
Suspended solids (mg /L)	8.0	7.0	9.0	11.6	8.0	5.0

Mitchell and Furnas (1997)³¹ examined the influence of “wet” and “dry” seasonal conditions on nutrient concentrations in river waters from the wet and dry tropics of Queensland. They reported seasonal peak concentrations of DIN (and less often DIP) typically occurred during the first significant flow event of each summer wet season, with “first-flush” peak concentrations of DIN as high as 0.56 mg N/L. They considered these “peaks” reflected the mobility of oxidised N (and to a lesser extent P) stocks built up in catchment soils during the dry season. Thereafter, DIN (and DIP) concentrations in the Queensland coastal river waters progressively declined over the course of the “wet” season, a finding Mitchell and Furnas attributed to a run-down of leachable N and P stocks.

While there were insufficient nutrient data in the present study to confirm the “first-flush” observations, it was considered likely that at least DIN concentrations might trend higher in what are historically the wetter months in northern NSW, which were taken as December to May, inclusive. Indeed, median concentrations of DIN for the “wet” period were close to double those for the “dry” grouping (Table 3.2-2), although the percentage contributed by “wet” months’ DIN to the total median N concentration (9.8%) was slightly lower than for the “dry” months (9.1%). The higher concentrations of suspended solids in the “wet” months relative to the “dry” months help explain these findings, which have support from water quality monitoring data of Mitchell and Furnas from north Queensland. Median ammonium-N and total N concentrations were also higher in the “wet” months’ grouping.

In addition, median concentrations of total N and other forms of N also varied among the quarterly seasonal groupings. Specifically, median concentrations of total N were highest in autumn and summer and lowest in winter and spring, but there were differences for water soluble forms of N and suspended solids. Median concentrations of suspended solids were highest in summer, followed by spring, autumn and winter months, whereas ammonium-N and particularly oxidised-N were highest in autumn. This latter finding may be due in part to contributions to baseflow in the drains from inputs of local groundwater enriched with oxidised-N, even though the finding was not sustained through the winter months (Table 3.2-1).

It is of interest to note that for four months after the February-March 2001 flood of the Clarence River, Drain 5 continued to record relatively high TN values (APPENDIX 4 -). There is a large melaleuca swamp in this drain system (Plate 2.8) and landholders report ‘blackwater’ draining from this swamp after significant rainfall/flood events. Analysis of N forms indicated that this water had elevated organic N concentrations (Appendix 4).

3.2.2 Phosphorus

Phosphorus is strongly implicated with eutrophication of water (Viets 1970)³². The conflict with water soluble P is that it can increase the economic production of fish and other aquatic biota. There is also a close relationship between total P concentrations in natural waters and algal blooms, which deplete DO, causing fish kills (Sharpley and Menzel 1987)³³.

There has been widespread use of P fertilisers in Australia to increase crop and pasture production, with approximately 106,600 tonnes of P used throughout NSW in 2002. This has arisen as most Australian soils have low natural reserves of plant-available P. Despite inputs of P fertilisers, it is unusual for large quantities of P to leach from the profile of “earthy” soils. This is because the majority of soils, with exceptions such as deep sands, can rapidly “fix” soluble P. Surface soils typically contain significantly greater levels of “plant available” P than do associated sub-soils, a situation known to be true for the canelands of NSW (Rayment *et al.*, unpublished data).

From international studies reviewed by Sharpley and Menzel (1987), P concentrations transported in surface runoff from unfertilised and fertilised sites have ranged from zero to 3.7 mg P/L, the high concentration occurring at a heavily fertilised site in Canada. Desorption of P from eroded soils and dead vegetation can also be important contributors, while discharges from municipal sewage plants and other non-agricultural sources are known to be responsible for some relatively high total P concentrations found in surface waters of Queensland (Anon 1986)³⁴.

As with N, there were around 195 monthly samples on which a suite of P determinations were made in the laboratory, corresponding to from 31 to 33 monthly samples from each main drain. Summary data (individual drains and combined) are presented in Table 3.2-3, including the median percentages of DIP relative to total P. The drain data are presented graphically in Appendix 4.

31 Mitchell, A.W. and Furnas, M.J. (1997). Terrestrial inputs of nutrients and suspended sediments to the GBR lagoon. . In “The Great Barrier Reef - Science, Use and Management”. Proceedings of a National Conference, Townsville 25-29 November 1996. pp. 59-71. (Reef CRC, GBRMPA and James Cook Univ., Townsville).

32 Viets, F.G. Jr. (1971). Water quality in relation to farm use of fertilizer. *Bioscience* 21, 460-467.

33 Sharpley, A.N. and Menzel, R.G. (1987). The impact of soil and fertiliser phosphorus on the environment. *Advances in Agronomy* 41, 297-324.

34 Anon (1986). The Water Quality Council of Queensland - Data Supplement to the Fourteenth Annual Report, 30th June, 1986.

Across the sampling period, median concentrations of total P in individual drains ranged from 0.04 mg P/L (Drain 2) through to 0.13 mg P/L (Drain 5), with a grand median (calculated from the combined raw data) of 0.07 mg P/L. This value exceeds the year 2000 ANZECC generic guideline concentration for coastal rivers in NSW of 0.025 mg P/L, and also exceeds the guideline for lowland rivers in non-coastal NSW and south-east Queensland. That said, all except Drain 5 had one or more monthly concentrations below the relevant guideline concentration, which appears to be a “tough” water quality criterion to apply to drainage canals in fertile alluvial landscapes in northern NSW.

With the exceptions of Drain 5 and Drain 6 that were higher, median concentrations of DIP (Table 3.2-3) were within the range found in most natural waters (0.005 – 0.02 mg P/L³⁵) and always below the ANZECC guideline of 0.008 mg P/L for lowland rivers in coastal NSW. These correspond to 5.0 – 8.3% of the total P in the same drains (median concentrations), whereas DIP expressed as a percentage of total P in Drains 5 and 6 were 24.6 and 28.7%, respectively. That is, waters in the two drainage systems in the Clarence River Catchment are clearly behaving differently to waters in the drains of the Richmond and Tweed.

Reasons for these differences were sought, despite the focus of the study’s design on condition and trend monitoring. It was known, for example (Bloesch and Rayment, unpublished data) that the elemental ratio of N:P:K supplied as commercial fertilisers to cane-growing areas of northern NSW had increased from 5.4: 1:2 in 1940 to 12.5:1:2.2 in contemporary times. That is, the proportion of P fertiliser relative to N fertiliser had been declining for many years. Moreover, a survey of the P nutrient status of NSW canelands summarised in Table 3.2-4 indicates a higher likelihood of elevated soil P in canegrowing areas of the Tweed / Brunswick catchment (Condong) relative to the Richmond (Broadwater) and Clarence (Harwood) catchments. In addition, cane farming practices in northern NSW are not sufficiently different to suggest that farming practices alone were a major explanation. Plausible reasons are offered in the general discussion and conclusions’ section.

35 Chapman, D. and Kimstach, V. (1997) ‘Selection of Water Quality Variables’ in Water Quality Assessments, 2nd edn, ed. D. Chapman, E & FN Spon, London.

Table 3.2-3 Summary statistics for monthly sampling on around 33 continuous occasions for phosphorus concentrations (totals and fractions; mg P/L) and suspended solids (mg/L) in six NSW main cane drains, inclusive of percentages of dissolved inorganic P (DIP) relative to Total P (median values).

Statistic	Total Phosphorus	TP Soluble	TP Insoluble	Organic Phosphorus as P	DIP	DIP as percent of total P
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Drain 1

Count	31	31	31	31	31	
Maximum	0.24	0.09	0.18	0.08	0.03	
Minimum	0.01	0.01	0.00	0.00	0.00	
Median	0.06	0.03	0.03	0.030	0.005	8.3
Geomean	0.07	0.03	0.03	0.03	0.01	

Drain 2

Count	33	33	33	33	33	
Maximum	0.14	0.12	0.09	0.12	0.01	
Minimum	0.00	0.00	0.00	0.00	0.00	
Median	0.04	0.03	0.01	0.04	0.002	5.0
Geomean	0.04	0.03	-	-	0.00	

Drain 3

Count	33	33	33	33	33	
Maximum	0.31	0.14	0.30	0.12	0.03	
Minimum	0.02	0.00	0.00	0.00	0.00	
Median	0.08	0.04	0.03	0.04	0.006	7.5
Geomean	0.08	0.04	-	0.03	0.01	

Drain 4

Count	33	33	33	33	32	
Maximum	0.68	0.23	0.45	0.23	0.05	
Minimum	0.01	0.01	0.00	0.00	0.00	
Median	0.06	0.04	0.02	0.03	0.005	8.3
Geomean	0.06	0.03	-	-	0.01	

Drain 5

Count	33	33	33	33	33	
Maximum	0.68	0.56	0.37	0.20	0.43	
Minimum	0.03	0.01	0.00	0.01	0.00	
Median	0.13	0.09	0.03	0.05	0.032	24.6
Geomean	0.12	0.08	0.03	0.04	0.03	

Drain 6

Count	33	33	33	33	33	
Maximum	0.59	0.23	0.47	0.10	0.20	
Minimum	0.02	0.01	0.00	0.00	0.00	
Median	0.08	0.06	0.02	0.03	0.023	28.7
Geomean	0.09	0.06	-	-	0.02	

All drains

Count	195	195	195	195	194	
Maximum	0.68	0.56	0.47	0.23	0.43	
Minimum	0.00	0.00	0.00	0.00	0.00	
Median	0.07	0.05	0.02	0.04	0.01	10.0
Geomean	0.07	0.04	0.00	0.03	0.00	

Table 3.2-4 Mean dry weight levels of total soil P and acid-extractable soil P [method of Kerr and von Stieglitz (1938)³⁶] in surface soils (0-10 cm) from a random survey of soils of NSW canelands in 1996-1997 (Rayment et al., unpublished data).

MILL REGION	TOTAL P %	ACID EXTRACTABLE P mg P/kg
Condong	0.140	176.4
Broadwater	0.118	56.6
Harwood	0.084	76.3
All NSW cane regions	0.111	99.1
All Queensland cane regions	0.078	125.1

As for total-N, the flood events in February - March 2001 were evident, particularly for Drains 3-6. In addition, there was an obvious seasonal trend (higher median concentration) in summer (Appendix 4) and to a lesser extent in spring and autumn: i.e., total P concentrations were lower in winter months, as were median concentrations of suspended solids.

3.2.3 Interrelationships between nutrients and with suspended solids

Simple linear regression confirmed that total-N concentrations could explain just over 27% of the variability in total P across all sites combined, suggesting different pathways of movement to the drains were occurring. Suspended sediments were one such pathway, but across all drains there were very weak linear associations between this water quality parameter and total N concentrations ($r^2=0.14$) and total P concentrations ($r^2=0.11$). There were, however, reasonable linear correlations across all sites combined between total N and total particulate N ($r^2=0.51$) and between total P and total particulate P ($r^2=0.67$), which probably reflects the greater ability of chemical tests to detect changes in nutrient concentrations.

While there was a stronger correlation between total particulate P and total P than the corresponding correlation for N, the reverse was true for soluble nutrients (includes particles below 0.7 microns). In this case, total water soluble N explained 86% of the variability in total N across all drains, while total water soluble P explained 63% of the variability in total P concentrations. It follows that management practices to improve drain water quality will need to significantly embrace movement via water, which would include runoff, movement of shallow groundwater, and movement up the drain from the river or estuary. There were, however, no correlation between nitrate-N and DIP and a very weak correlation (3% explained linear variance) between ammonium-N and nitrate-N. Clearly, complex variables have operated over the past few years in the nutrient delivery area, and a “fix” for drainage systems in the Tweed and Richmond drainage basins may not have the same effect in the drains of the Clarence, where it is possible that greater than average up-drain movement of P may have occurred. There is support for this contention in the findings of De Jong and Villierius, as cited Ormaza-Gonzalez and Statham (1991)³⁷. These researchers suggested that calcite derived from the more saline waters can act as a carrier phase for adsorbed P, but once transported upstream and reaching lower pH environments in fresher water, decomposition and hence release of the adsorbed P can occur.

³⁶ Kerr, H. W. and von Stieglitz, C. R. (1938). The laboratory determination of soil fertility. Tech. Commn. No. 9, BSES, Qld.

³⁷ Ormaza-Gonzalez, F. and Statham, P. (1991). The occurrence and behaviour of different forms of phosphorus in waters of four English estuaries, In: Estuaries and Coasts: Spatial and Temporal Inter-comparison.

3.2.4 Event Sampling

Levels of the various N forms in samples collected during runoff events in each drain system are shown in Appendix 1. As expected, mean and median levels of suspended solids and TN during runoff events were typically higher (approximately double) than those recorded monthly. Suspended solids were, on average across all sites and sampling times, three times higher during runoff events (33 mg/L) compared to the average of the monthly samplings (11 mg/L).

Drain 2 (Mooball Creek) was the only site where the catchment could be clearly divided into cane and no cane areas with the upper reaches of Mooball Creek not draining any cane land. During a rainfall event of 19 mm at Drain 2 (16/02/01) the TN value downstream of caneland was 0.33 mg/L compared to TN levels of 0.39, 0.47 and 0.69 mg/L for three in-drain sites above cane growing areas. However, there was little difference in TN values between cane and non-caneland for a rainfall of 12 mm on the 27/11/01, while an upstream site had lower TN levels compared to caneland sites for an event on 3/04/02. When averaged across all events at Drain 2, the levels of oxidized-N were slightly higher for water sampled in caneland (average of 0.19 mg N/L) compared to waters upstream of caneland (average of 0.12 mg N/L). The results for similar monitoring of total-P and selected components are given in Table 3.2-5.

Overall, there was insufficient event and upstream sampling to draw firm conclusions on the nutrient contributions made by up-stream land uses and different weather conditions on monthly, end-of-drain results.

Table 3.2-5 Effect of sampling location on the concentrations (mg/L) of various phosphorus forms and suspended solids in Mooball Creek averaged across rainfall events (data from Appendix 3).

PHOSPHORUS FORM (mg/L)	SAMPLING LOCATION	
	UPSTREAM OF CANE	END-OF- CANE DRAIN
Total P	0.043	0.036
Total soluble P	0.026	0.018
Orthophosphate	0.0045	0.0138

3.3 PESTICIDES

3.3.1 Residues and their occurrences

The year 2000 ANZECC generic guidelines use different trigger values for toxicants at alternative levels of protection. These provide for four species protection levels, corresponding to 99%; 95%; 90% and 85% for three different ecosystem types - high conservation value, slightly to moderately disturbed ecosystem & highly modified ecosystem. A 90 % species protection level has been applied for the drainage systems covered by this study, which are considered as highly disturbed ecosystems. However, this will require on-going consultation with local catchment groups, government departments, local industry, and the general public.

Given that the chemical properties of pesticides used in the local sugar industry are all different³⁸, it was appropriate to consider each of the pesticides sequentially, noting the choice of pesticides monitored were guided by the recommendations of Hamilton and Haydon (1997). In all, four of those monitored monthly were herbicides (atrazine, diuron, 2,4-D and glyphosate) and one was an organo-phosphate insecticide (chlorpyrifos).

In the event, the first 15 months of monthly monitoring for glyphosate and chlorpyrifos failed to detect measurable quantities of both pesticides. As a consequence, monthly monitoring of these was terminated after January 2001. This decision was taken in the knowledge that chlorpyrifos was only applied to canelands when planting cane setts, which are placed underground, thereby restricting any opportunity to migrate to drains. As for glyphosate, it is used on fallow-cane blocks and to control weeds on headlands, but is rarely used within fields of established cane. In addition, it is strongly adsorbed to soil at which time it loses its herbicidal activity, even if the soil moves to water.

Table 3.3-1 has summary statistics for the three remaining herbicides (atrazine, diuron and 2,4-D) from all monthly samplings and sites combined, while data for all drains are provided graphically by sampling occurrence in Figure 3.3-1. Median and minimum concentrations were mostly low or non-detectable. These findings indicate that pesticides were present as occasional pulses rather than as chronic loadings, with only diuron exceeding (6.6% of all sampling occasions) the water quality guideline values documented for pesticide residues in Australia relevant to moderately disturbed systems for protection of 90% of species. For diuron, these exceeded the interim trigger concentration of 2 µg/L on 4 occasions in Drain 1, 2 in Drain 2, 1 in Drain 5 and 6 in Drain 6, suggesting that the off-site movement of this herbicide differs from drain to drain. Moreover, most of the exceedences occurred in the early months of the study. It is noteworthy that at no time did diuron residues (or any other pesticide residue tested) exceed Australian drinking water or recreational use guidelines.

Median concentrations of the three herbicides also provided a rapid way of assessing whether “wet” periods were more influential than “drier” months on contributing to the likelihood of detecting measurable residues. Inspection of the summary data in Table 3.3-2 provides support for this contention, with seasonal data in the same table showing that median concentrations were higher in summer and autumn months. These data, coupled with the findings that pesticide residues did drop to undetectable levels in all drains, highlight the need for most vigilance with respect to pesticide use practices from late spring through to and including all autumn months.

38 Hamilton, D. and Haydon, G. (1997). Final Report. “Pesticides and fertilisers in the New South Wales sugar industry - estimates of usage and likely environmental fate. Vol. 1: Pesticides”. (QDNR and CRC for Sustainable Sugar Production, Indooroopilly.)

Table 3.3-1 Summary statistics for monthly sampling on 33 occasions for concentrations of atrazine, diuron and 2,4-D (µg/L) in six NSW main cane drains covering the period November 1999 to September 2002

STATISTIC	ATRAZINE	DIURON	2,4-D	ATRAZINE	DIURON	2,4-D
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Drain 1				Drain 2		
Maximum	9.9	10.4	0.6	1.0	22.0	12.3
Minimum	NDR ^A	NDR	NDR	NDR	NDR	NDR
Median	0.09	NDR	NDR	NDR	NDR	NDR
Average	0.93	0.80	0.05	0.04	1.46	0.67

Drain 3				Drain 4		
Maximum	6.0	1.6	4.7	2.80	1.50	13
Minimum	NDR	NDR	NDR	NDR	NDR	NDR
Median	0.17	NDR	NDR	0.01	NDR	NDR
Average	0.49	0.28	0.19	0.21	0.15	0.53

Drain 5				Drain 6		
Maximum	9.1	4.40	0.40	27	8.20	5.6
Minimum	NDR	NDR	NDR	NDR	NDR	NDR
Median	0.1	NDR	NDR	0.05	0.40	NDR
Average	1.08	0.37	0.05	2.74	1.55	0.45

All drains combined			
	Atrazine	Diuron	2,4-D
Maximum	27.0	22.0	13.0
Minimum	NDR	NDR	NDR
Median	0.05	NDR	NDR
Average	0.92	0.77	0.32

^A NDR = no detectable residue, and were taken as zero for calculation purposes.

Table 3.3.2 The effects of typically “wetter” and “drier” months and also the effects of season (spring, summer, autumn, winter) on median concentrations (µg/L) of atrazine, diuron and 2,4-D across six main drains in NSW canelands.

WATER QUALITY ATTRIBUTE	“WET” MONTHS	“DRY” MONTHS	SPRING	SUMMER	AUTUMN	WINTER
Count	102	96	48	49	52	48
Atrazine	0.15	NDR ^A	NDR	0.27	0.08	NDR
Diuron	0.30	NDR	NDR	0.4	NDR	NDR
2,4-D	NDR	NDR	NDR	NDR	NDR	NDR

^A NDR = no detectable residue, and were taken as zero for calculation purposes.

Finally, it is apparent from Figure 3.3-1, particularly for Drain 6, that the number of times pesticide residues reached prominent concentrations declined as the study progressed, especially for atrazine. This is discussed further in Section 3.4 (Raising awareness). Indeed, this downward trend was visible in the combined data for all drains, although the linear time trend was not significant. *It is recommended that any future monitoring for pesticide residues include drain-bottom sediments, which were not considered in this study.*

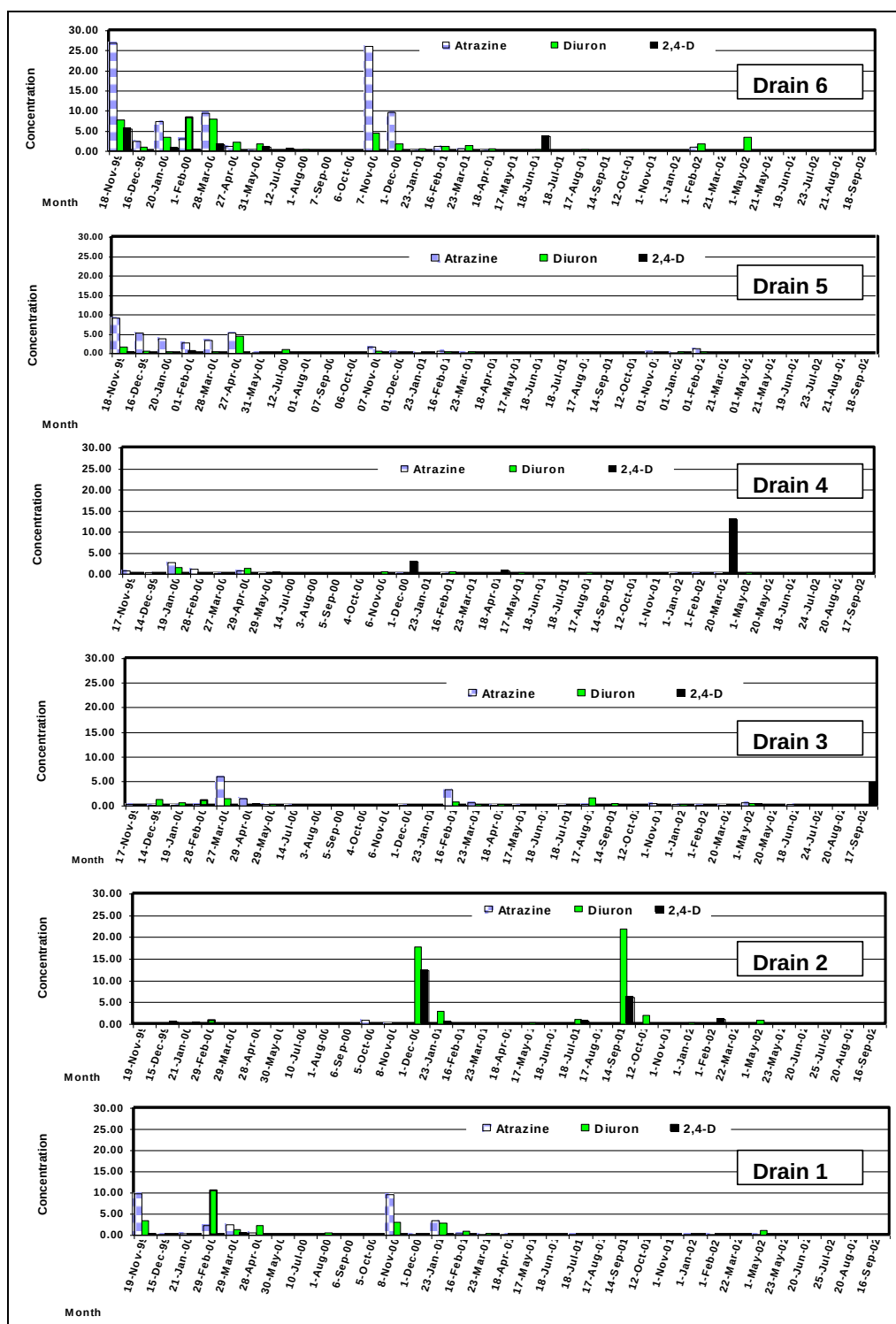


Figure 3.3-1 Monthly monitoring data ($\mu\text{g/L}$) for three herbicides at the discharge end of six main drains in NSW canelands from November 1999 to September 2002.

3.3.2 Correlations between herbicides and anions in the water

Up to 156 sets of data were used to determine from if concentrations of atrazine or diuron could be predicted from oxidised-N concentrations in the drain water at the same time. Comparisons were made using the combined data from all six sites (11/1999 to 02/2002), which had an oxidised-N range of undetectable to 1.64 mg N/L and a median value of 0.01 mg N/L. Corresponding median values of atrazine and diuron in the same data set were 0.09 and zero $\mu\text{g/L}$, respectively. Scatter plots of the data are shown in Figure 3.3.2.

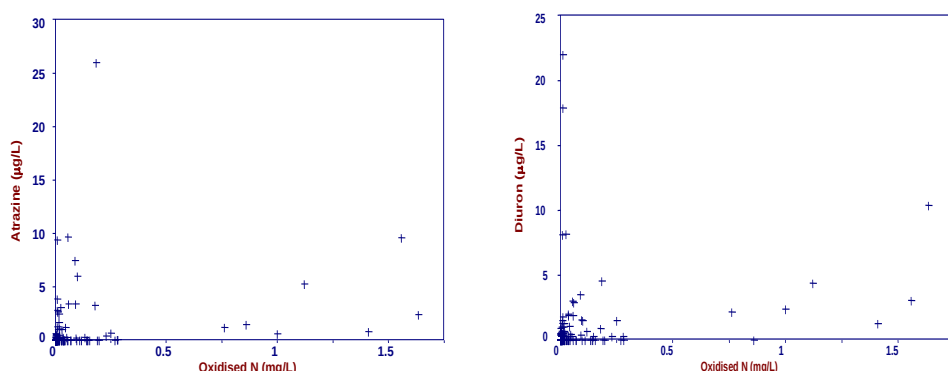


Figure 3.3-2 Scatter plot for the association between oxidised-N and atrazine ($\mu\text{g/L}$) and oxidised-N and diuron ($\mu\text{g/L}$) in the same water at the same time for six NSW main drains (n = 156).

Relationships between oxidised N and atrazine were also explored with a large number of linear models, on data from individual drains (Figure 3.3-3) and separately for the late spring-summer months of the year (October to February) on individual drains (data not presented). None of the correlations were significant.

It follows from the above that the likely presence and concentrations of atrazine and diuron in NSW cane drains cannot be reliably predicted from corresponding concentrations of oxidised N. For example, there were many detects of oxidised N without any measured herbicide residue. Since there was no meaningful correlation (>20 models examined) between concentrations of atrazine in the drainwater (all six sites combined) and corresponding concentrations of diuron, these herbicides each need to be monitored to reflect the true situations, which vary between drains.

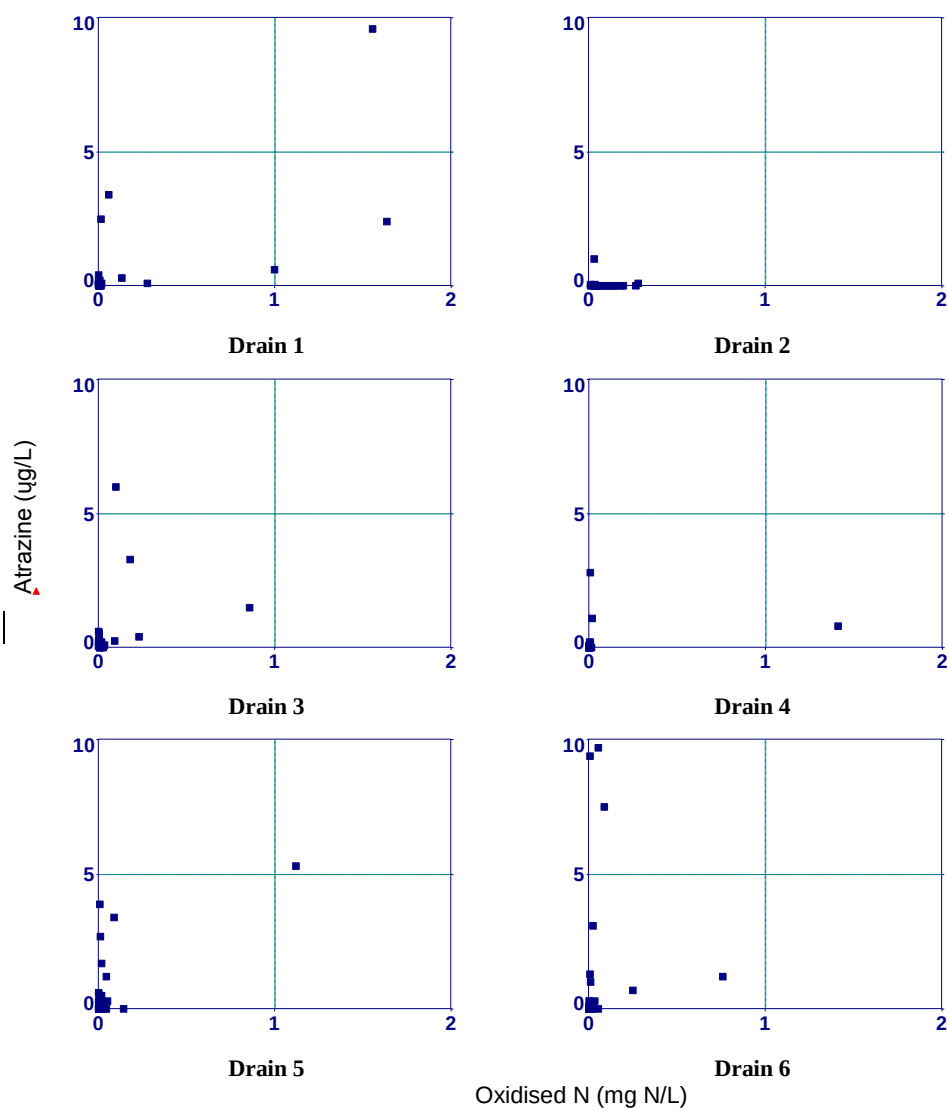


Figure 3.3-3 Scatter plots on a drain by drain basis for the association between oxidised N (mg N/L) and atrazine (µg/L) in the same water at the same time for six NSW main drains covering the sampling period November 1999 to February 2002, inclusive. None have predictive value.

For water-soluble chloride and the same two herbicides, 132 comparisons were assessed (all sites combined to 9/2001) using the same wide selection of linear models. Again, none were significant, with chloride concentrations explaining less than five percent of the variance in concentrations of both atrazine and diuron. Fluctuating chloride concentrations due to tidal influences was undoubtedly one of the factors influencing the poorness of fits. The range in water-soluble chloride concentrations across the six drains was 40-24,000 mg/L in the data set used, with a median of 3,700 mg/L. Corresponding median values for atrazine and diuron were 0.10 and zero µg/L, respectively (11/1999 to 09/2001). Concentrations of DIP also showed no meaningful relationships with atrazine and diuron.

3.4 NUTRIENTS AND PESTICIDE FLUXES

Interpretation of the absolute values of the fluxes presented in this section requires extreme caution since they were calculated from continuously monitored flow data and a single nutrient concentration obtained from the monthly sampling.

3.4.1 Nutrient fluxes

Annual fluxes of various forms of N and P and suspended solids calculated from measurements at Drains 1, 4 and 5 for the periods 6/12/00 – 10/1/02, 6/9/00 – 18/9/01 and 14/8/00 – 15/8/01, respectively, are presented in Table 3.4-1. Concentrations and fluxes for each month at each of Drains 1, 4 and 5 are given in Appendix 5.

Table 3.4-1 Total fluxes for Total-N, P and Suspended Solids at Drain 1 (Bartletts Crk), Drain 4 (Dungarubba Drain) and Drain 5 (Marsh's Drain).

Drain No	TN Flux (kg-N/yr)	Org-N (kg/yr)	NOx Flux (kg-N/yr)	TP Flux (kg-P/yr)	Org-P (kg/yr)	DIP (kg-P/yr)	N:P Ratio	S/S (t/yr)	Total discharge per year from drains (ML)	Proportion of main river flows
1	905	495	100	193	82	17	4.7:1	22	2526	0.04% (Tweed)
4	4348	3056	20	924	465	54	4.7:1	88	7456	0.03% (Richmond)
5	3699	2657	76	630	120	158	5.9:1	30	3067	0.006% (Clarence)

The study found for the first time that the discharge from an individual NSW cane drain constitutes a very small proportion of the main river flow (Table 3.4-1). However, given the number of drains across a mill area (eg. 68 modified or constructed drains enter the Richmond River Estuary between Ballina and Coraki³⁹) there is the potential for relatively small but measurable nutrient loadings to the applicable river system, in addition to inputs to the drains at high tides. The total discharges for the sites are in proportion to the catchment areas and drain sizes with Dungarubba Drain (Drain 4) being the largest catchment (about twice the size of Marsh's Drain catchment).

Although the total N fluxes at Drains 4 and 5 were around 4 t N/yr, the bulk of this N was organic. At Drain 1 organic N was 55% of the annual total N flux whereas at Drains 4 and 5 organic N was around 70% of the annual total N flux. The higher total N fluxes and elevated contributions of organic N to total N at Drains 4 and 5 may be associated with the existence of large wetlands located in these drainage systems. For example, McKee and Eyre (1997)⁴⁰, in their study of nutrient fluxes of the Richmond River in the mid-1990s, found that water coming from the Tuckean wetland area was high in dissolved organic N and made up the majority of the total N in the Richmond River Estuary.

McKee and Eyre (1997) found for the Richmond what many others had reported for other rivers⁴¹. That is, the majority of nutrients were transported during floods. This was also true for this study, where over 8952 kg of total N/yr was exported collectively from Drains 1, 4 and 5 (Table 3.4-1), including 3644 kg N (41%) during the February and March 2001 floods. Across the three drains the proportion of total N exported during the floods was reasonably similar at 48%, 46% and 34%, respectively. The marked effect of a flood on the quantities of nutrients and solids exported is shown in Table 3.4-2.

39 McKee, L.J. and Eyre, B.D. (1997). A nutrient budget for the Richmond River Estuary, northern NSW. "The Coastal Zone – Beyond Beaches. 7th Annual NSW Coastal Conference, 12-14 November, 1997. pp. 136-142. (Ballina Shire, COuncil, Ballina.)

40 McKee and Eyre (1997)

41 Meybeck, M. (1982). Carbon, nitrogen and phosphorus transport by world rivers. *[American] Journal of Science*, **282**: 401-450.

Table 3.4-2 Effect of a flood year (February/March 2001) on the export of N, P and suspended solids from Drain 5 (Marsh's Drain).

TIME	TN FLUX (KG- N/YR)	NOX FLUX (KG- N/YR)	TP FLUX (KG- P/YR)	REACTIVE- P (KG-P/YR)	N:P RATIO	S/S (TONNES/YR)	TOTAL DISCHARGE PER YEAR FROM DRAINS (ML)
14/08/00 – 15/08/01	3699	76	630	158	5.9:1	30	3067
15/08/01 – 18/09/02	773	57	98	45	7.9:1	8	710

The quantities of oxidized N (predominantly oxidised-N) moving out of the drains were small (≤ 100 kg N/yr) and these would represent an extremely small proportion of the fertilizer N applied to cane in these catchments.

A similar analogy can be made with total P. Of the 1712 kg-P/yr total-P flux from all three sites (Table 3.4-1), DOP contributed 650 kg-P/yr or 38%, while reactive-P contributed 13 % of the annual TP flux.

3.4.2 Pesticide Fluxes

Annual quantities of pesticide exported from three of the drainage systems monitored are shown in Table 3.4-3. The amounts exported via the drains were quite small and represent less than 1% of the amount applied, which is in keeping with the research findings of Simpson *et al.* (2002)⁴². This rough estimate is based on the approximate cane areas in the drainage basins and “best-bet” estimates of areas receiving herbicide application as well as the rates of application. Unlike nutrient fluxes, there was no obvious relationship between total discharge volumes and herbicide amounts exported (Table 3.4-3). This possibly reflects the varying proportions of cane in each of the drainage basin. This also suggests the amounts of nutrient (N and P) exported are mainly governed by catchment size rather than the proportion of cane in the areas being drained.

⁴² Simpson, B., Ruddle, L., Hagreaves, P., Ham, G., Cavanagh, J., and Rayment, G. (2002). 7.Pesticides and water quality. In: Water in the Australian Sugar Industry. Eds. K.L. Bristow and D.J. Popham. .CRC Sugar Technical Publication, ISBN 1 876679 19 0. pp. 49-55. (CRC for Sustainable Sugar Production, Townsville.)

Table 3.4-3 Annual pesticide fluxes for Drains 1 (Bartletts Creek), 4 (Dungarubba Drain) and 5 (Marsh's Drain).

DRAIN #	DATE	TOTAL DISCHARGE (ML)	ATRAZINE (KG/YR)	DIURON (KG/YR)	2,4-D (KG/YR)
1	6/12/00 – 10/1/02	2526	3.1	1.66	0.09
4	6/9/00 – 18/9/01	7456	0.23	1.8	1.3
5	14/8/00 – 15/8/01	3067	1.54	0.89	<0.01

3.5. “CONTROL” SITES

Two sites considered as “controls” were chosen for their topography and locality to sugarcane growing areas. One was Jerusalem Creek, located in the Bunjalung National Park, NSW. The majority of the catchment had good vegetation cover, no cane, and was mostly located within the national park. The second “control” site, Uppers Crabbes Crk, was located in the Crabbes Creek catchment. Here again, there was no cane in the upper catchment; only a variety of horticultural crops and small farms were operating. The sampling point was in the upper section of the creek before it enters the floodplain where cane is grown.

Sampling from the control sites occurred at low flow (base flow), when there was little runoff. Atrazine, diuron and 2,4-D were analysed for their presence in these samples. No detections were reported. Similarly, total-N, oxidised-N, total-P and DIP were below the 2000 ANZECC generic guidelines concentrations. The results were included in the Mid-Project Data Report supplied to SRDC in January 2002.

3.6 RAISING AWARENESS

3.6.1 Growers on Monitored Drains

Across all mill areas the total number of cane growers on the drain systems monitored was 81 representing approximately 12% of all NSW growers. Prior to the commencement of the project in 1999, growers on each drain system were contacted, the aims of the project explained and unanimous agreement obtained. These growers then received regular updates of water quality data via shed meetings on the drain system. The results were discussed in relation to current management practices and how management practices could be altered.

Four shed meetings (July 1999, December 2000, March/December 2001) were conducted with the growers on each of the drainage systems over the period of the project. (Table 3.6-1) These meetings were held to provide timely feedback of water quality information. Regular contact with the growers on the drains was also maintained over the life of the project through discussions while water sampling and maintaining the equipment at the sites.

Table 3.6-1 Group meetings at the six drainage systems / creeks.

DRAIN NO.	DRAINAGE SYSTEMS / CREEKS	LOCATION (AND NUMBER OF PARTICIPANTS IN EACH FOCUS GROUP)	MILL AREA	NUMBER OF MEETINGS HELD
1	Bartletts Ck	Condong (20)	Condong	4
2	Mooball / Crabbes Ck	Wooyung (14)	Condong	4
3	Empire Vale / Reedy Ck	South Ballina (10)	Broadwater	4
4	Dungarubba Drain / Ck	Dungarubba (17)	Broadwater	4
5	Marsh's Drain No. 2	Palmers Channel (11)	Harwood	4
6	Stranger's Drain	Chatsworth Island East (9)	Harwood	4

During the first 14 months of the project, elevated levels of atrazine were brought to the attention of growers at Drains 1, 5 and 6 during shed meetings. This information generated considerable discussion and there was a concerted effort to investigate and use alternatives to atrazine. The efficacy of these changes can be seen in the marked reduction in atrazine concentrations in these drains for the remainder of the project (Figure 3.6-1).

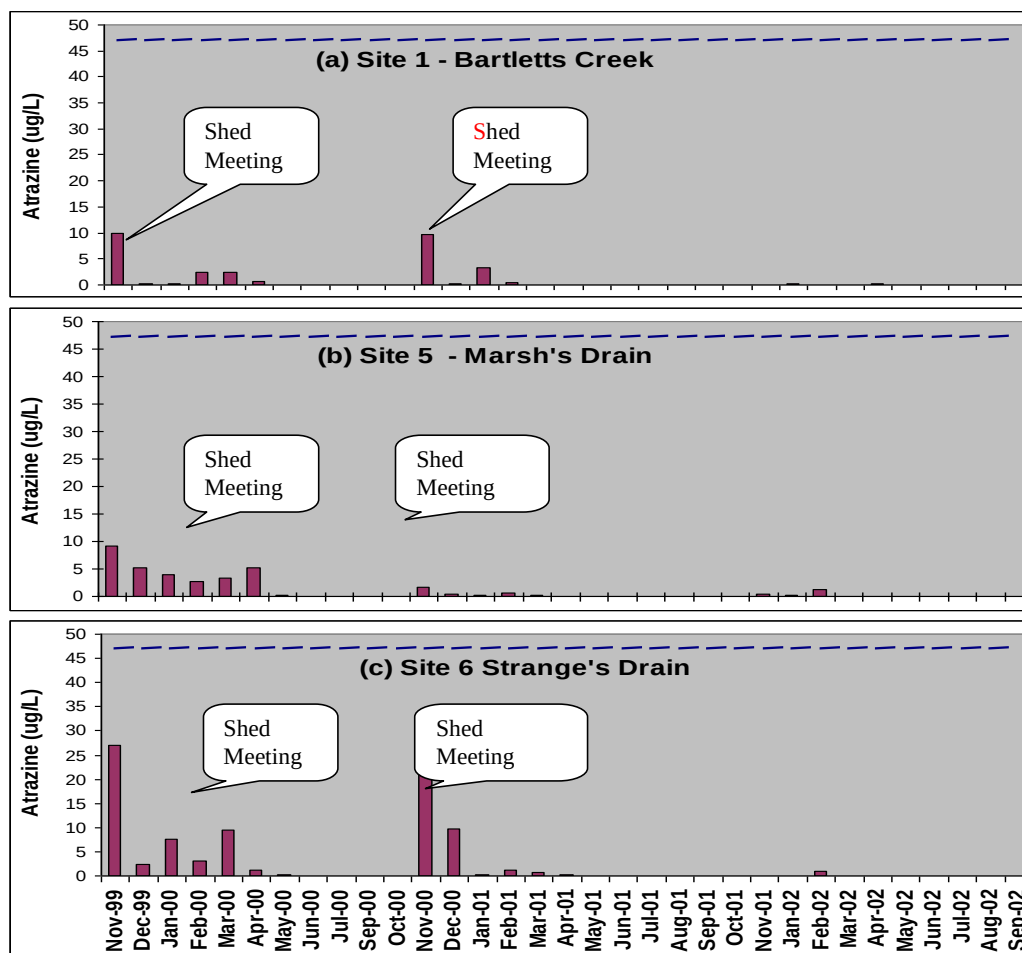


Figure 3.6-1 Graphs illustrating the use of shed meetings as an important tool in either reducing the use of the water-mobile pesticide atrazine or using alternative pesticide. The relevant ANZECC is shown as a dashed line.

3.6.2 Changes in Attitude and Practices

A survey of growers in the main drainage systems being monitored was conducted during September 2000. This formed part of a benchmark survey to gather data to assess the current level of knowledge or awareness of the cane growers involved on the six drainage systems being monitored. The survey had a good response rate with 63% (51 returned from the 81 growers in the drainage systems) of growers responding. All of the growers who responded regarded water quality as moderately or very important within the local catchment. None of the growers surveyed said water quality was not important in their local catchment. Furthermore, 93% of respondents indicated that water quality issues were important for their farm planning and management. This demonstrated the growers' commitment to the project and their concern for the environment.

A post project survey was conducted to assess issues of awareness and understanding of water quality issues and to determine any farm practice changes that have occurred over the three years of the project as result of improved knowledge of the impact of farm management on water quality.

A sample of 25% (21) of the growers in the drainage systems was surveyed. All of the growers responded they had become more aware of the impact pesticides and fertilisers can have on water quality. Similarly 90% of respondents indicated they had gained a better understanding and knowledge of water quality within their drainage system over the past 3 years, due to their association with the study.

In terms of herbicides, 81% of the respondents indicated they had made changes to their herbicide program that would have a positive effect on water quality. Over half of the growers had reduced the rate of atrazine applied and nearly 40% had used the new generation herbicides Flame and Balance. Recent NSW sugar industry herbicide use figures indicate that 27% of the area treated with pre-emergent herbicides was with the new products Flame and Balance. Field results from these products have been excellent and it is expected these products will gain greater acceptance over out-of-patent herbicides such as atrazine, due to their better environmental performance.

For fertilizer use, 43% of respondents indicated that they had made some changes to their fertilizer program that would have a positive effect on water quality. Practices changed were:

- using soil tests for developing a fertiliser program
- earlier application of fertilizer to avoid heavy rain and potential losses
- changing to more subsurface application and deeper placement to avoid losses.

Forty three (43%) percent of respondents also indicated they had made other changes to their farm practices to enhance water quality. Some of these changes included:

- opening floodgates to allow tidal water exchange
- less deep ripping
- increased farm area with minimum/zero tillage
- laser leveling and liming fallow ground
- maintaining wide grassy headlands and vegetation on drain banks to reduce slumping and erosion
- using spray hoods to minimize herbicide movement
- establishing wetland areas.

The pre- and post-project survey information revealed that the growers in the main drainage systems had a high initial awareness and concern for water quality issues within their catchment. Furthermore, as a result of the project, there has been an improved understanding and knowledge of water quality and the impacts that farm practices may have on water quality. Pleasingly, there has been a positive response to changes in herbicide and fertiliser use that will result in improved water quality.

3.6.3 Direct Participation by NSW Growers

A key objective of the project was to raise awareness amongst all NSW canegrowers of the relationships between canegrowing practices and water quality. Information transfer to growers outside of the main drainage systems over the project occurred through a wide range of opportunities such as bus tours to the monitoring sites, breakfast/shed meetings, newsletters and field days.

Bus tours

Grower bus tours to the sites were very successful in exposing a large number of NSW growers to the sites and explaining the monitoring that was occurring and providing a snapshot of the results and actions needed to enhance water quality. Grower bus tours involving around 120 growers at each mill visited the sites separately in May 2000 and over 150 growers visited a site in a combined three-mill bus tour in May 2001.



Plate 3.1 Bus tour at Empire Vale (Drain 3)

Media

Articles were written for local mill newsletter and a regular “*What is*” column was provided to the internal newsletter of the NSW sugar industry the Sunshine Sugar News. These articles covered topics explaining various water quality parameters such as pH, DO, salinity as an example and also covered issues dealing with pesticides and nutrients. This regular information provided all NSW growers with information on water issues and raised awareness of the importance that farm practices may have on water quality.

Formal grower meetings

Regular updates were provided at annual breakfast/shed meetings convened in each mill area as well as Canegrowers and Productivity Board Annual General Meetings (2001 and 2002). More than half of all NSW growers have had exposure to the project and the results.

3.6.4 Wider Community Awareness

Public meeting

A public meeting was conducted in June 2001 at Ballina. The meeting was designed to inform local stakeholders on the project activities, review results to date and discuss related sugar industry initiatives in water quality involving CRC Sugar. This meeting was the first forum where information on the project and results were shared with other resource managers in the north coast of NSW. Generally the participants appreciated the opportunity to hear more of the local activity and of the sugar industry’s efforts in other water quality areas.

The second (final) project public meeting was held on March 21, 2003 at Ballina to present project activities, results and plans for future monitoring. A range of local resource managers, university academics and community group representatives attended and questioned the three technical presenters (Green, Beattie, Rayment). The forum was opened by Mr. G. Messiter, CEO NSW Sugar Milling Co-operative, which was a public statement from the industry leadership of its commitment to be a good neighbor.

CRC Sugar

Annual presentations in 2001, 2002 and 2003 were made at the CRC Sugar Annual Review and Planning Meetings in Townsville (March of each year). This was an opportunity to discuss and critically review the data with a wide range of industry researchers. Attractive, informative posters were produced for each of these occasions. Indeed, the poster presented in 2002 won the CRC Sugar award from the best of 22 posters on display on that occasion. The oral presentation in 2003 (Beattie *et al.*) was a joint recipient of the CRC Sugar “best oral presentation” award, which was judged against 21 competing presentations on method, manner, materials and responses to questions.

Community field tours

In November 2000 a field tour was conducted as part of a Coastal Management Conference held at Yamba. Great exposure for the project and the initiative generally was achieved due to a wide variety of government departments, local and other councillors, a state MP, general community members and aboriginal elders from the local clan attending the bus tour. Feedback was very encouraging.

The Project officer also hosted an onsite information day for students from the Marine Studies course at Ballina High School (4th May 2001).

More recently, the study formed part of the Australian Cane Farmers Association / BSES / CRC Sugar Workshop on “Profitable Cane Farm Management in a Regulated Environment”, Ballina RSL (8/04/2002).

National and international conferences

Pesticide data from the project was used generically at the 24th International Sugar Congress, Brisbane in the oral presentation “Rayment G.E. (2001). Minimising environmental risks from metals, pesticides, waste recycling and acid sulphate soils. Ed. D.M. Hogarth. 24th International Society of Sugar Cane Technologists Congress Proceedings – Vol II, pp. 123-126. ASSCT, Mackay, Australia.” In addition, details of the study were presented as a poster paper to the 2nd National Conference of “Sustaining our Aquatic Environments – Implementing Solutions, 20-23 November, 2001, Townsville. The poster was well received and in keeping with modern trends in water quality assessment.

Media

Press releases were sent to and articles published in the following media outlets.

- The ‘Northern Star’;
- ‘The Land’;
- ‘Queensland Country Life’;
- ‘ASSAY’ (a widely circulated NSW acid sulphate soil newsletter);
- Sugar industry magazines (‘Australian Canegrower’ and ‘Australian Sugarcane’)

Further, press releases were sent to approximately 35 media outlets including print, radio and television. Interviews on the project were also conducted on local Rural ABC radio.

3.6.5 Code of Practice

The Code of Practice for Sustainable Cane Growing for Queensland and New South Wales is being revised and updated and is currently with industry for comment and review. Information learnt through the project has been used to build the Code with information on enhancing water quality in NSW catchments. The code will cover issues affecting water quality such as nutrient application/crop uptake, use of mill by products, pesticide application, riparian zones and wetlands, acid sulfate soil management and will provide best practice recommendation for enhancing water quality. The Code of Practice will go through a period of industry review and consultation and is expected to be formally launched in late 2003. In the meantime a simple fact sheet on the project has been produced. It is reproduced as APPENDIX 6

The fact sheet was distributed at the public meeting held on March 21 2003 as a simple summary of the project findings, changes in practice as a result of project activities, and recommendations for the enhancement of water quality in NSW canelands. The fact sheet was designed to be easily readable by NSW growers and is being distributed with local newsletters to all members of the NSW Sugar Milling Co operative.

4.0 GENERAL DISCUSSION AND CONCLUSIONS

In less than four years, the NSW sugar industry has emerged from having little direct awareness of DO, nutrient and pesticide water quality in major drains adjacent to canelands to a position of strength. It has in the intervening period, in partnership with parties within CRC Sugar, acquired good quality equipment for automatic and periodic water quality monitoring, developed its own skills in water quality monitoring, involved 81 local canegrowers directly, outreached to many more, engaged the wider local community, and compiled an impressive array of water quality data for resource condition and trend assessment. The participative nature of the study helped to raise awareness and change practices that subsequently led to measurable improvements in water quality, particularly for pesticide residues. To our knowledge, this is the first occasion in Australia that a regional group within the sugar industry has undertaken a water quality monitoring study across multiple years to a technical standard at least equivalent to ambient water quality monitoring networks operated by state governments.

In the three drains (1, 4, 5) where doppler instrumentation functioned well over meaningful periods, it was established that individual drains contributed very little to total river flows (0.006% in the Clarence to 0.04% in the Tweed). Even if equal volumes of water were regularly discharged from all other cane drains in the river catchments, the total volumes involved (and therefore the quantities of pollutants potentially discharged) would be quite small. For example, for the 68 drains in lower reaches of the Richmond River, the volume would scale up to approximately 2.7% of the total annual average river discharge. In that catchment, McKee and Eyre (1996)⁴³ had already reported that a variety of land uses (grazing, orchard fruits, bananas, macadamias, state forests / national parks and urban areas) were mobilising quite large quantities of nutrients, particularly during wet seasons. Moreover, export coefficients of both total-N and total-P ($\text{kg km}^{-2} \text{mm}^{-1}$, equivalent to kg/ML) in the upper Richmond and Wilsons sub-catchments were higher than corresponding values for the Johnstone and South Pine Rivers.

The present study provided the NSW sugar industry with the information to construct a report card on local water quality across a three-year period, based on different intensities of monitoring (continuous, monthly and *ad hoc*). This report card, provided as Table 4-1, is based on an empirical “ranking” for key water quality parameters for each of the six drains, as well as an overall ranking, derived as the arithmetic average of the numeric scores allocated to each key water quality attribute. The numeric scores ranged from 1 (worst) to 11 (best), to encompass text ratings for water quality condition used by the NSW Resource and Conservation Assessment Council⁴⁴.

On average, water quality in all drains rated as fair across the three year period of active monitoring. At the extremes, Drain 5 just achieved the rating despite low numeric scores for DO, total-P and DIP, while the drains with the best numeric scores were Drain 1, closely followed by Drain 3. It is stressed that all of the numeric ratings were influenced by generic year 2000 ANZECC water quality criteria for lowland rivers of coastal NSW, which for nutrients are thought to warrant serious review. Indeed, to enhance local confidence in the water quality guidelines for nutrients and ecosystem protection, it is *recommended that a consortium of skilled stakeholders review these water quality criteria as a matter of priority with the aim of replacing them with more realistic criteria for waterways within the fertile, alluvial, sub-tropical coastal plains of NSW.*

Technically, the study permitted comparisons of monthly versus in-stream continuous monitoring of parameters such as pH and DO. For pH, the two techniques returned much the same information, such as the presence of pulses of strong acidity in most drains at least on occasions, both day and night. However, the diurnal fluctuations known to affect DO concentrations clearly influenced the results for this water quality attribute. Importantly, the continuously measured median DO concentrations were numerically lower than their monthly monitored equivalents sampled only in daylight hours. While periodic DO monitoring one to two hours after dawn may have provided more relevant data, *we recommend that future monitoring for DO should be undertaken continuously, supported by random early-morning checks at other locations by local cane growers using reliable, well calibrated, hand-held equipment.* In addition, between drain comparisons can only be made with confidence if the times of monitoring correspond, and the DO sensors are of similar construction and quality.

While surveys were conducted of cane growing practices along each of the drains, it was mainly with herbicides that conscious efforts to modify practices resulted in apparent improvements in water quality, measured as lower or non-

43 McKee, L. and Eyre, B. (1996). Nutrient export in a large rurally diverse northern NSW coastal catchment: a preliminary assessment. In “Downstream Effects of Land Use”. (Eds. H.M. Hunter, A.G. Eyles and G.E. Rayment). pp. 65-72. (Department of Natural Resources, Queensland: Brisbane.)

44 Resource and Conservation Assessment Council (1996). Regional Report of Upper North East New South Wales. Vol. 3. (Resource and Conservation Assessment Council, April 1996.)

detectable levels of residues of atrazine and diuron. The use of shed meetings and field days at monitoring sites to provide cane farmers with regular feedback regarding the results contributed to this success. Undoubtedly, the local industry's participative approach to its management of ASS helped to lessen the amount of acidity entering the drains, even though there was evidence that acid discharges are still occurring on occasions, particularly in the Tweed and Richmond catchments.

Apart from establishing that close to 80% of the total N in the drains was water soluble and around 55% of the total N was present as organic N, it was unusual to find consistently that ammonium-N contributed more to DIN across all drains than did oxidised-N. In the absence of isotopic tracers, it is speculative to suggest the main source/s of the ammonium-N, but this may be linked to commercial fertilisers and industry by-products, along with the suppression of nitrification due to the presence from time to time of strongly acidic drainwaters. In addition, it is known from a survey of 59 farms across the region⁴⁵ that median soil pH (1:5 soil/water) values in each mill region were sufficiently acidic (from 5.1 to 5.4) to slow biologically mediated nitrification reactions. *These N sources and transformations need to be better understood, with process studies recommended that include the use of isotopic tracers. These studies should be given priority, as the present concentrations of ammonium-N may still exceed locally relevant water quality criteria when they are developed.*

With respect to P, Bloesch *et al.* (1997)⁴⁶ concluded it would take time for soil P levels in Queensland cane lands to fall, even if P fertiliser inputs were to decline abruptly. As an analogous situation would likely apply in NSW, the project team did not expect to see startling improvements in P water quality within the period of monitoring. Nevertheless, it was a surprise to consistently record relatively high percentages of DIP compared to total P in Drains 5 and 6 (24.6% and 28.7%; versus 10% for all drains combined), when local growers had reported no unusual use of P fertilisers.

Non-cane sources of water soluble P, probably from the estuary (eg. sewage/septic and domestic / industrial discharges) could explain these findings. Another possibility is that the P reported as DIP was present as micro-particulates, able to pass through the filter papers used during sample preparation. Indeed, the mostly-alkaline waters of the two drains plus the presence of calcium ions from the estuary would favor the formation of basic forms of calcium phosphate, which have very low water solubility. A third possibility is that cane growing soils of the Clarence may have lower P sorption capacities than those further north and/or significant preferential flow of P due to macroporosity, a mechanism confirmed elsewhere^{47 48}. Alternatively, the "soluble" P in the water column (inclusive of particles <0.7 microns) of Drains 1 to 4 may have been organically bound to a greater extent than in Drains 5 and 6. Indeed, the median concentrations of dissolved organic-P (monthly data from Drains 1 to 4, inclusive), when expressed as a percentage of total P in the same samples, was 62.5%, compared to 43.3% for Drain 5 and Drain 6, lending some support to this suggestion. However, the median percentage for Drain 1 was lower (38.5%) than both the percentages for Drain 5 (40%) and Drain 6 (46.7%), suggesting factors other than DOP were operating. To resolve this uncertainty, it is recommended that the forms of P in these drains and in the adjoining Clarence estuary be assessed, probably by a PhD student, in order to understand how the P is cycling (transported) and how it might be managed. Across all drains, 50% of the total P (median percentage) was organic, while the corresponding median total inorganic P was 33% of total P.

Finally, the authors endorse a local initiative to compile and consolidate water quality data for rivers, creeks and drains on the north coast of NSW. The main participants in the project are Southern Cross University and the Richmond Estuary Ecological Health Monitoring Study (REEHMS). The RHEEMS concept was developed to enhance awareness and to prevent a reoccurrence of the failure of most local groups to collect water quality data during the February / March 2001 flood of the Richmond River. Strategies are being put in place to monitor and collect fish and water samples during future floods in the catchment. As it was, our study provided the only continuously monitored DO data from the recording station at Dungarubba Drain, which was a strong positive for the project.

⁴⁵ Unpublished data of Rayment *et al.*

⁴⁶ Bloesch, P.M., Rayment, G.E. and Pulsford, J.S. (1997). Regional total phosphorus budgets for sugar production in Queensland. In "Proc. Aust. Soc. Sugarcane Technologists". (Ed. B.J. Egan.) pp. 213-20. (Watson Ferguson and Company, Brisbane.)

⁴⁷ Akhtar, M.S., Richards, B.K., Medrano, P.A., deGroot, M. and Steenhuis, T.S. (2003). Dissolved phosphorus from undisturbed soil cores: related to adsorption strength, flow rate, or soil structure? *Soil Sci Soc. Am. J.* 67: 458-470.

⁴⁸ Preferential flow through the soil profile may also explain at least part of the movement of water mobile pesticides to adjacent drains.

Table 4-1 Empirical “ratings” for key water quality parameters (November 1999 to September 2002) for each of six NSW cane drains, plus an overall ranking that integrates empirically the various attributes into a single rating. The ratings apply to ecosystem protection and are categorised numerically (unweighted) across an 11 point scale as good (9,10,11), fair (6,7,8), poor (3,4,5), very poor (0,1,2), which correspond to text ratings used by the NSW Resource and Conservation Assessment Council⁴⁹.

DRAIN	1	2	3	4	5	6
pH	5	4	8	3	8	9
EC	7	7	8	9	7	8
Temp	10	7	9	8	10	9
Turbidity	9	10	9	9	10	10
DO	6	4	5	4	2	6
Total-N	9	8	6	7	4	6
Ammonium-N	8	2	7	8	4	4
Oxidised-N	10	6	10	10	8	10
Total-P	4	5	3	4	2	3
DIP	10	11	9	9	2	3
Pesticide residues	7	6	9	8	7	6
Overall rating	8 (Fair)	6 (Fair)	8 (Fair)	7 (Fair)	6 (Fair)	7 (Fair)

⁴⁹ Resource and Conservation Assessment Council (1996). Regional Report of Upper North East New South Wales. Vol. 3. (Resource and Conservation Assessment Council, April 1996.)

APPENDICES

APPENDIX 1 EVENT BASED FROM ALL SITES (ADDITIONAL DATA)

Date	Sampling Site	Rain	TN	TN-insol	TN-sol	Org-N	NH4	NOx	TP Sol	TP Insol	Org-P	Ortho-P	Susp solids
SITE 1 – BARTLETTS DRAIN													
9 Mar 01	Bartletts Crk	45	3.86	1.08	0.54	0.54	0.06	2.78	0.08	0.17	0.03	0.05	0.25
11 Nov 01	Bartletts Crk	46	2.70	0.45	2.25	0.24	0.31	1.70	0.03	0.21	0.02	0.02	0.24
12 Nov 01	Bartletts Crk	58	3.16	0.39	2.77	0.18	0.42	2.17	0.12	0.01	0.09	0.03	0.12
7 Dec 01	Stotts Crk		2.53	0.60	1.93	0.62	1.18	0.13	0.07	0.09	0.06	0.01	0.16
6 Feb 02	Ledday's Crk		1.90	0.88	1.00	0.60	0.02	0.39	0.14	0.09	0.10	0.04	0.23
22 Mar 02	Ledday's Crk		0.8	0.54	0.26	0.223	0.027	0.006	0.02	0.07	0.016	0.004	0.09
22 Mar 02	Ledday's Crk-Middle		1.61	1.18	0.43	0.4	0.025	0.007	0.04	0.15	0.02	0.018	0.19
29 Mar 02	Ledday's Crk		2.50	0.10	2.40	0.47	0.83	1.10	0.07	0.02	0.03	0.04	0.09
4 Apr 02	O'Donalds		1.26	0.52	0.74	0.20	0.49	0.06	0.06	0.01	0.05	0.01	0.06
4 Apr 02	Ledday's Crk		1.40	0.10	1.30	0.60	0.60	0.10	0.03	0.01	0.03	0.00	0.04
4 Apr 02	Upper O'Donalds		1.94	0.20	1.74	0.92	0.68	0.14	0.05	0.01	0.05	0.00	0.06
17 Apr 02	Ledday's Crk		0.44	0.31	0.13	0.10	0.03	0.00	0.01	0.01	0.01	0.00	0.01
17 Apr 02	Stotts Crk		0.37	0.23	0.14	0.08	0.05	0.01	0.01	0.05	0.01	0.01	0.05
SITE 2 – MOOBALL DRAIN													
12 Jul 00	Upper Burringbar Crk	0	0.48	0.27	0.06	0.21	0.059	0.205	0.01	0.01	0.01	0.004	
12 Jul 00	Upper Crabbes Crk	0	0.48	0.27	0.01	0.26	0.042	0.211	0.02	0	0.02	0.002	
8 Nov 00	Upper Burringbar Crk	21	0.45	0.23	0.01	0.24	0.032	0.22	0.06	0.01	0.06	0.001	3
8 Nov 00	Upper Crabbes Crk	21	0.64	0.44	0.01	0.48	0.001	0.204	0.06	0.01	0.06	0.005	45
16 Feb 01	Upper Crabbes Crk	19	0.39	0.36	0.05	0.31	0.008	0.028	0.01	0.05	0.01	0.005	
16 Feb 01	MUCCrk	19	0.33	0.26	0.01	0.27	0.024	0.07	0.01	0.02	0	0.006	8
16 Feb 01	Pacific Highway	19	0.47	0.25	0.01	0.28	0.023	0.216	0.01	0.03	0.01	0.004	
16 Feb 01	Upper Burringbar Crk	19	0.69	0.58	0.01	0.59	0.117	0.108	0.01	0.01	0.01	0.003	
9 Mar 01	Mooball Crk	33	1.19	0.77	0.33	0.44	0.036	0.423	0.06	0.06	0.04	0.016	
2 Nov 01	Upper Crabbes Crk	0	0.29	0.15	0.14	0.12	0.014	0.007	0.05	0.05	0.05	0.003	3.7
19 Nov 01	Mooball Crk	5	0.15	0.15	0.05	0.05	0.013	0.003	0.01	0.03	0.01	0.002	6.2
27 Nov 01	Mooball Crk	12	0.27	0.02	0.25	0.1	0.114	0.037	0.02	0.01	0.02	0.002	2.7
27 Nov 01	Upper Crabbes Crk	12	0.34	0.18	0.16	0.15	0.012	0.002	0.02	0.08	0.01	0.009	19.8
27 Nov 01	Upper Burringbar Crk	12	0.21	0.07	0.14	0.1	0.02	0.018	0.03	0.01	0.02	0.006	5.3
22 Mar 02	Mooball Crk	27	0.63	0.23	0.4	0.17	0.181	0.048	0.01	0.06	0.01	0.002	4
22 Mar 02	Upper Crabbes Crk	27	0.61	0.3	0.31	0.28	0.018	0.008	0.01	0.12	0.01	0.002	6.5
3 Apr 02	Mooball Crk	22	1.14	0.35	0.79	0.17	0.441	0.178	0.01	0.03	0.01	0.002	
3 Apr 02	Upper Crabbes Crk	22	0.49	0.13	0.36	0.29	0.008	0.06	0.01	0.02	0.01	0.007	0.2
3 Apr 02	L/M BCrk	22	0.73	0.1	0.63	0.2	0.222	0.206	0.01	0.01	0.01	0.002	3.3
3 Apr 02	Lower Burringbar Crk	22	0.94	0.1	0.84	0.27	0.175	0.4	0.01	0.01	0.01	0.002	5.6
4 Apr 02	Mooball Crk	22	0.79	0.17	0.62	0.26	0.182	0.182	0.01	0.01	0.01	0.002	6.9
20 Aug 02	Upper Crabbes Crk		0.11	0.07	0.08	0.08	0.008	0.017	0.02	0.01	0.02	0.003	2

SITE 3 – EMPIRE VALE DRAIN													
29 May 00	Site 3 URCrk	16	1.78	1.44	0.63	0.81	0.11	0.341	0.11	0.12	0.06	0.05	25
6 Nov 00	Site 3 URCrk	3	0.21	0.21	0.01	0.24	0.002	0.001	0.08	0.02	0.06	0.022	18
14 Aug 01	Site 3 a	30	0.804	0.71	0.38	0.33	0.022	0.094	0.004	0.056	0.004	0.002	12
14 Aug 01	Site 3 b	30	0.26	0.26	0.09	0.17	0.002	0.002	0.005	0.015	0.005	0.002	38
14 Aug 01	Site 3 c	30	1.44	0.96	0.53	0.43	0.002	0.48	0.093	0.137	0.028	0.065	89
14 Aug 01	Site 3 d	30	0.76	0.54	0.19	0.35	0.008	0.22	0.018	0.022	0.018	0.002	
14 Aug 01	Site 3 e	30	0.53	0.38	0.11	0.27	0.013	0.15	0.007	0.023	0.007	0.002	48
14 Aug 01	Site 3 f	30	0.59	0.44	0.17	0.27	0.012	0.15	0.007	0.043	0.007	0.002	23
14 Aug 01	Site 3 g	30	1.79	1.2	0.58	62	0.19	0.59	0.028	0.172	0.017	0.011	68
14 Aug 01	Site 3 h	30	0.412	0.37	0.13	0.24	0.005	0.042	0.008	0.052	0.008	0.002	9
14 Aug 01	Site 3 i	30	1.16	0.83	0.27	0.56	0.004	0.33	0.035	0.045	0.033	0.002	69
14 Aug 01	Site 3 j	30	0.376	0.29	0.06	0.23	0.006	0.086	0.023	0.017	0.023	0.02	13
14 Aug 01	Site 3 k	30	0.54	0.37	0.04	0.33	0.004	0.17	0.015	0.025	0.015	0.002	18
28 Nov 01	Site 3 a	9	7.24	0.05	7.24	0.86	1.037	5.34	0.06	0.22	0.05	0.012	29
28 Nov 01	Site 3 b	9	6.01	0.7	5.31	0.87	0.733	3.71	0.07	0.31	0.03	0.037	51.2
28 Nov 01	Site 3 c	9	5.17	0.1	5.07	1.18	0.417	3.47	0.03	0.23	0.02	0.013	38.9
28 Nov 01	Site 3 d	9	6.8	0.7	6.1	0.98	0.823	4.3	0.22	0.28	0.09	0.127	105.4
18 Jun 02	Site 3 a	32	1.8	1.3	0.52	0.21	0.19	0.12	0.01	0.3	0.01	0.015	31
18 Jun 02	Site 3 d	32	3	1.4	1.6	0.71	0.69	0.16	0.08	0.41	0.04	0.041	16
22 Aug 02	Site 3 a	25	0.3	0.29	0.3	0.29	0.007	0.003	0.04	0.01	0.03	0.008	5
22 Aug 02	Site 3 b	25	0.63	0.36	0.31	0.56	0.054	0.024	0.03	0.17	0.19	0.013	13
22 Aug 02	Site 3 c	25	0.93	0.15	0.67	0.57	0.21	0.15	0.03	0.11	0.13	0.012	8
22 Aug 02	Site 3 d	25	0.29	0.07	0.24	0.25	0.04	0.003	0.09	0.13	0.13	0.091	4
27 Aug 02	Site 3 a	45	2.7	1.4	1.3	1.9	0.009	0.76	0.04	0.39	0.4	0.035	110
27 Aug 02	Site 3 b	45	1.6	0.56	1	1.1	0.007	0.48	0.08	0.14	0.17	0.049	67
27 Aug 02	Site 3 c	45	1.6	0.53	1.1	1.2	0.007	0.39	0.1	0.34	0.37	0.074	56
27 Aug 02	Site 3 d	45	2.5	1.1	1.3	1.7	0.064	0.65	0.03	0.19	0.2	0.023	49
27 Aug 02	Site 3 e	45	1.3	0.4	0.89	0.95	0.035	0.31	0.04	0.12	0.13	0.03	58
SITE 4 - DUNGARUBBA DRAIN													
29 May 00	Site 4 Upper	20	1.23	1.22	0.34	0.88	0.01	0.006	0.22	0.03	0.09	0.131	18
06 Nov 00	Site 4 Upper	0	0.91	0.91	0.17	0.74	0.001	0.001	0.112	0.04	0.09	0.026	1
16 Aug 01	Dungarubba Crk	22	1.2	1.2	0.75	0.45	0.002	0.002	0.017	0.123	0.015	0.002	44
16 Oct 01	Dungarubba Crk	17	0.63	0.33	0.3	0.27	0.021	0.009	0.13	0.06	0.03	0.105	10.2
12 Nov 01	Dungarubba Crk	13	1.16	0.51	0.65	0.63	0.022	0.003	0.35	0.12	0.06	0.287	7.4
23 Jan 02	Dungarubba Crk	0	0.9	0.54	0.36	0.24	0.099	0.019	0.11	0.23	0.02	0.093	6.6
01 Mar 02	Site 4 Gate	0	1.7	1.3	0.41	0.27	0.13	0.01	0.1	0.22	0.02	0.084	25.3
01 Mar 02	Site 4 Mole Drain	0	14	2.5	11	1.1	0.518	9.57	0.19	0.91	0.01	0.196	155.4
01 Mar 02	Site 4 Upper	0	0.67	0.23	0.44	0.4	0.031	0.012	0.04	0.01	0.01	0.028	11.1
18 Jun 02	Dungarubba Crk	32	1.9	1.3	0.61	0.6	0.012	0.002	0.08	0.25	0.04	0.045	70
18 Jun 02	Site 4 Upper	32	0.86	0.07	0.85	0.57	0.037	0.24	0.02	0.02	0.01	0.009	13
27 Aug 02	Site 4 X	13	4	1.5	2.5	2	0.03	2	0.03	0.68	0.68	0.03	280

SITE 5 – MARSHS DRAIN													
30 May 00	Site 5 Upper	0	1.2	1.19	0.3	0.89	0.011	0.007	0.07	0.05	0.04	0.035	5
07 Nov 00	Site 5 Upper	26	1.34	1.34	0.31	1.03	0.051	0.001	0.13	0.06	0.08	0.054	2
05 Feb 02	Site 5 Gate	26	18.58	1.90	16.68	0.05	1.40	15.28	0.34	0.14	0.05	0.29	44
06 Feb 02	Site 5 Gate	91	12.49	0.30	12.19	0.16	1.94	10.09	0.34	0.06	0.06	0.28	16
03 May 02	Site 5 Gate	17	1	0.05	1	0.3	0.59	0.11	0.03	0.01	0.01	0.021	2.9
03 May 02	Site 5 Middle	17	1.27	0.47	0.8	0.18	0.6	0.024	0.03	0.03	0.01	0.021	6.3
03 May 02	Site 5 Upper	17	0.49	0.14	0.35	0.27	0.075	0.012	0.01	0.03	0.01	0.003	4.5
23 Aug 02	Site 5 Mole Drain	40	13	8.2	4.8	13	0.007	0.002	2.1	3.2	5.2	0.068	180
23 Aug 02	Site 5 Middle	40	0.49	0.09	0.4	0.44	0.03	0.015	0.05	0.03	0.048	0.032	13
23 Aug 02	Site 5 Gate	40	0.55	0.09	0.46	0.45	0.057	0.039	0.05	0.02	0.043	0.027	6
SITE 6 – STRANGERS DRAIN													
30 May 00	Site 6 Upper	0	1.11	1.08	0.38	0.7	0.006	0.028	0.11	0.31	0.04	0.074	98
07 Nov 00	Site 6 Upper	24	1.2	1.16	0.37	0.79	0.001	0.044	0.13	0.23	0.1	0.031	63
15 Aug 01	Site 6 Gate	5	0.47	0.47	0.05	0.42	0.002	0.002	0.025	0.005	0.023	0.002	1
15 Aug 01	Site 6 Middle	5	0.53	0.53	0.1	0.43	0.002	0.002	0.057	0.003	0.016	0.041	6
15 Aug 01	Site 6 Upper	5	0.79	0.79	0.3	0.49	0.002	0.002	0.073	0.057	0.012	0.061	11
13 Nov 01	Site 6 Gate	25	0.71	0.16	0.55	0.5	0.051	0.003	0.1	0.05	0.07	0.034	20.5
13 Nov 01	Site 6 Middle	25	1.08	0.05	1.03	0.96	0.062	0.005	0.32	0.02	0.11	0.206	10.1
13 Nov 01	Site 6 Upper	25	2.54	0.42	2.12	2.07	0.039	0.007	0.49	0.25	0.13	0.358	18.1
12 Dec 01	Site 6 Gate	10	0.71	0.16	0.55	0.5	0.051	0.003	0.1	0.05	0.07	0.034	20.5
12 Dec 01	Site 6 Middle	10	1.08	0.05	1.03	0.96	0.062	0.005	0.32	0.02	0.11	0.206	10.1
12 Dec 01	Site 6 Upper	10	2.54	0.42	2.12	2.07	0.039	0.007	0.49	0.25	0.13	0.358	18.1
03 Apr 02	Site 6 Gate	16	1.61	0.2	1.41	1.38	0.019	0.012	0.03	0.01	0.02	0.006	10.1
03 Apr 02	Site 6 Middle	16	0.55	0.04	0.51	0.44	0.061	0.014	0.1	0.02	0.06	0.042	4.2
03 Apr 02	Site 6 Upper	16	0.34	0.08	0.26	0.16	0.066	0.033	0.17	0.08	0.12	0.051	6.9
03 May 02	Site 6 Middle	33	0.47	0.1	0.37	0.16	0.201	0.013	0.07	0.07	0.01	0.058	15.6
03 May 02	Site 6 Upper	33	1.06	0.26	0.8	0.72	0.01	0.068	0.35	0.15	0.2	0.154	46.8
09 May 02	Site 6 Gate	37	0.61	0.19	0.42	0.13	0.225	0.065	0.04	0.03	0.01	0.026	10.6
19 Jun 02	Site 6 Middle	8	0.98	0.39	0.59	0.33	0.24	0.024	0.08	0.05	0.01	0.067	6
19 Jun 02	Site 6 Upper	8	2.4	0.4	2	2	0.017	0.006	0.17	0.17	0.13	0.04	9

KEY:

Site 2 L/M BCrk = Lower/Middle Burringbar Creek
MUCck = Middle Upper Crabbes Creek

Site 3 URCrk = Upper Reedy Creek

Site 4 X = 100 m north of Broadwater bridge on western side of Richmond River

APPENDIX 2 INSTRUMENT SPECIFICATIONS

UNIDATA STAR FLOW

Mechanical

Size:	290mmL x 70mmW x 25mmH
Weight:	850g (2kg with 15m cable)
Material:	PVC body, Stainless steel mounting plate
Cable:	15 metre, 9 way vented cable <SQL> Compatible

Micrologger

Storage Memory:	100Kbyte, CMOS RAM
Log Interval:	Programmable 5 seconds to 1 week
Communication:	RS-232, 300-38400 BAUD
SDI-12:	1200 BAUD, instrument channel
Flow computation:	Flow Rate, Totalised Flow
Control:	CMOS output trigger
Operating Temperature:	0°C to 60°C water temperature
Compatibility:	STARLOG compatible

Velocity

Range:	21mm/s to 4500mm/s bi-directional
Resolution:	1mm/s
Accuracy:	2% of measured velocity
Signal Path:	30° above horizontal

Depth

Ranges:	Model 6526-21	0 to 2m	
	Model 6526 - 51	0 to 5m	
Resolution:	Model 6526-21	1 to 1m1mm	
		1 to 2m2mm	
	Model 6526-51	0 to 2.5m	2.5mm
		2.5 to 5m	5mm
Accuracy:	±0.25% of calibrated lower range		
Type:	Hydrostatic pressure sensor vented to atmosphere		

Temperature

Range:	-17°C to 60°C
Resolution:	0.1°C

Power

Battery:	External 12VDC
Voltage:	11.5V to 15VDC
Current:	50µA standby, 90mA during communication 299mA during measurement
Average Power:	0.3W (1 min scan rate)

HORIBA U-10

pH

Principle:	Glass electrode
Range:	pH0-14
Resolution:	Standard: 0.1pH Expanded: 0.01pH

Repeatability: $\pm 0.05\text{pH}$
 Temperature compensation: $0\text{-}50^{\circ}\text{C}$
 Readout: LCD
 Calibration: 1-point auto (Zero)
 Manual 2-point

Temperature

Principle: Thermistor
 Range: $0^{\circ}\text{-}50^{\circ}\text{C}$
 Resolution: Standard: 1°C
 Expanded: 0.1°C
 Repeatability: $\pm 0.3^{\circ}\text{C}$
 Temperature compensation: -
 Readout: LCD
 Calibration: -

DO

Principle: Membrane galvanic cell
 Range: $0\text{-}19.\text{pmg//}$
 Resolution: Standard: 0.1mg//
 Expanded: 0.01mg//
 Repeatability: $\pm 0.1\text{mg//}$
 Temperature compensation: $0^{\circ}\text{-}40^{\circ}\text{C}$
 Readout: LCD
 Calibration: 1-point auto (Span)
 Manual 2-point

Conductivity

Principle: 4-electrode
 Range: $0\text{-}100\text{ms/cm}$
 Resolution: Standard: $0\text{-}1\text{mS/cm}$: 0.01mS/cm
 $0\text{-}10\text{mS/sc}$: 0.1mS/cm
 $10\text{-}100\text{mS/cm}$: 1mS/cm
 Expanded: $0\text{-}1\text{mS/cm}$: 0.01mS/cm
 $0\text{-}10\text{mS/sc}$: 0.1mS/cm
 $10\text{-}100\text{mS/cm}$: 1mS/cm
 Repeatability: $\pm 1\%\text{F.S.}$ within each measurement range
 Temperature compensation: $0^{\circ}\text{-}50^{\circ}\text{C}$
 Readout: LCD
 Calibration: 1-point auto (Span)
 Manual 2-point

Turbidity

Principle:	Scattered/Transmitted light
Range:	0-800 NTU
Resolution:	Standard: 10 NTU Expanded: 1 NTU
Repeatability:	±3%/F.S.
Temperature compensation:	-
Readout:	LCD
Calibration:	1-point auto (Zero) Manual 2-point

Salinity

Principle:	Conversion based on conductivity
Range:	0-4%
Resolution:	Standard: 0.1% Expanded: 0.01%
Repeatability:	±0.1%
Temperature compensation:	0°-30°C
Readout:	LCD
Calibration:	—

TPS 90-FL

DO

Range:	0 to 32.00 ppm
Resolution:	0.01 ppm
Accuracy:	±0.2% of full scale
Sensor Type:	Clark type polarographic sensor with in-built ATC
Salinity Correction for ppm:	0 to 50.0ppK, automatic using conductivity /TDS reading
Temperature Compensation:	Automatic for membrane permeability Automatic for Dissolved Oxygen solubility in ppm mode
Calibration:	Automatic zero and span calibration
Sensor Span Range:	65 to 200%

Conductivity

Ranges:	0 to 200.0 μS/cm
	0 to 2000 μS/cm
	0 – 20.00 mS/cm
	0 – 200.0 mS/cm
Resolution:	0.1 μS/cm
	1 μS/cm
	0.01 mS/cm
	0.1 mS/cm
Accuracy:	±0.5% of full scale of selected range at 25°C
Sensor Type:	Ryton® plastic body with two platinised platinum plates with in-built ATC.
Temperature Compensation:	Automatic, 0 to 100°C (standard Conductivity sensor is limited to 60°C)
Calibration:	Automatic zero and span calibration
Sensor Span Range:	±25% of nominal k factor

PH

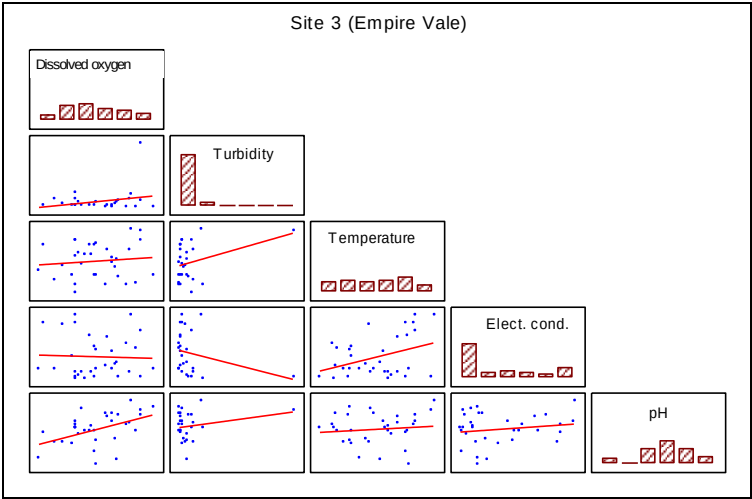
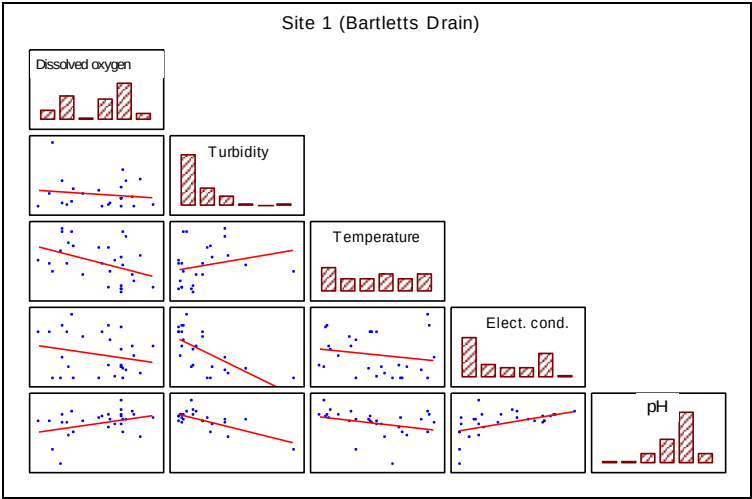
Range:	0 to 14.00 pH
Resolution:	0.01 pH
Accuracy:	±pH
Sensor Type:	Glass bulb pH sensor, combination or half cell
Input Impedence:	>3 x 10 ¹² Ohms
Temperature Compensation:	Automatic, 0 to 100°C
Calibration:	Automatic asymmetry and slope calibration
Automatic Buffer Recognition:	PH4.00, pH6.88, pH7.00, pH9.23 & pH10.06. Any other can be entered during calibration
Sensor Asymmetry Range:	-1.00 to 1.00 pH
Sensor Slope Range:	85.0 to 105.0%

Temperature

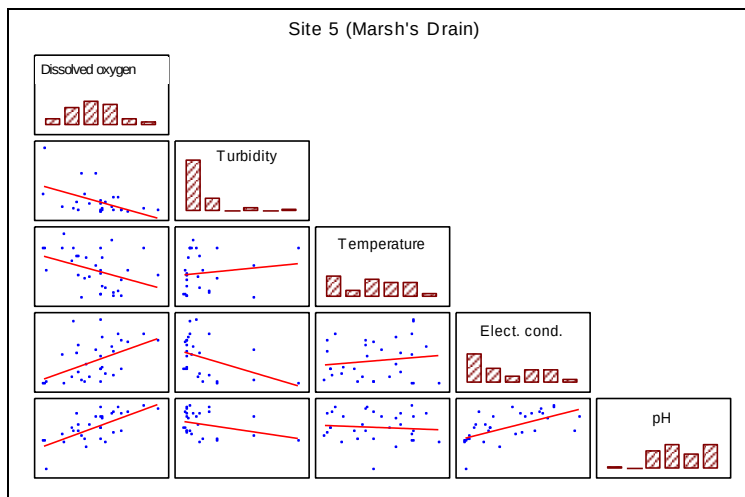
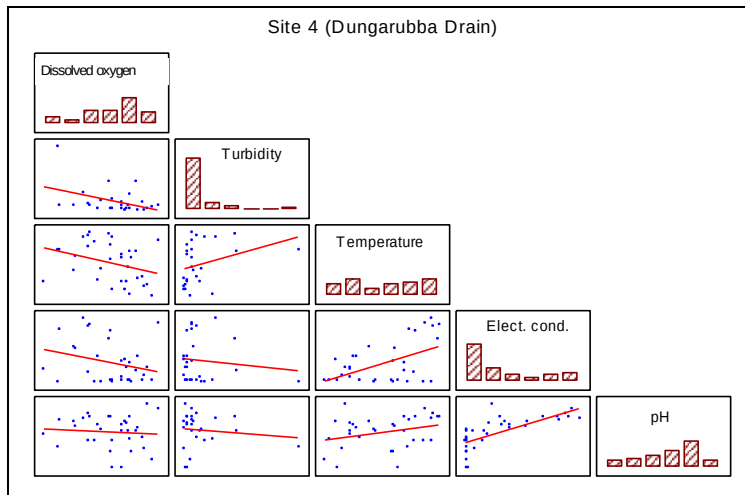
Range:	-30.0 to 110.0°C
Resolution:	1.0°C
Accuracy:	±0.2°C
Sensor Type:	Silicon transistor built into tip of Conductivity / TDS sensor, or separate Temperature sensor if Conductivity / TDS sensor is not in use.
Calibration:	Automatic offset and span calibration
Sensor Offset Range:	-15.0 to 15.0°C
Sensor Span Range:	93 to 107%
Memory:	2032 readings including date and time with A&B function disabled
Automatic Logging:	Rate per Day 1 to 288 readings per day Time of Day 1 to 12 discrete times of the day, in 24 hour format Sampling Period and Duration One reading every 1 to 300 seconds for a duration of 1 to 720 minutes or continuous
RS232 Port:	300, 9600 & 19200 baud 8 bits, no parity, 1 stop bit, XON/XOFF Protocol
Clock:	Calendar clock displays date, month, hours, minutes & seconds. Year is Y2K compliant and is attached to all stored data.
Power:	7.2V, 1300mAH NiCad battery built in. Battery charger for country of destination is included. Solar panel and external battery clip lead optionally available

APPENDIX 3 MATRIX CORRELATION PLOTS FOR PHYSIOCHEMICAL PROPERTIES AT EACH OF SITES 1, 3, 4 AND 5.

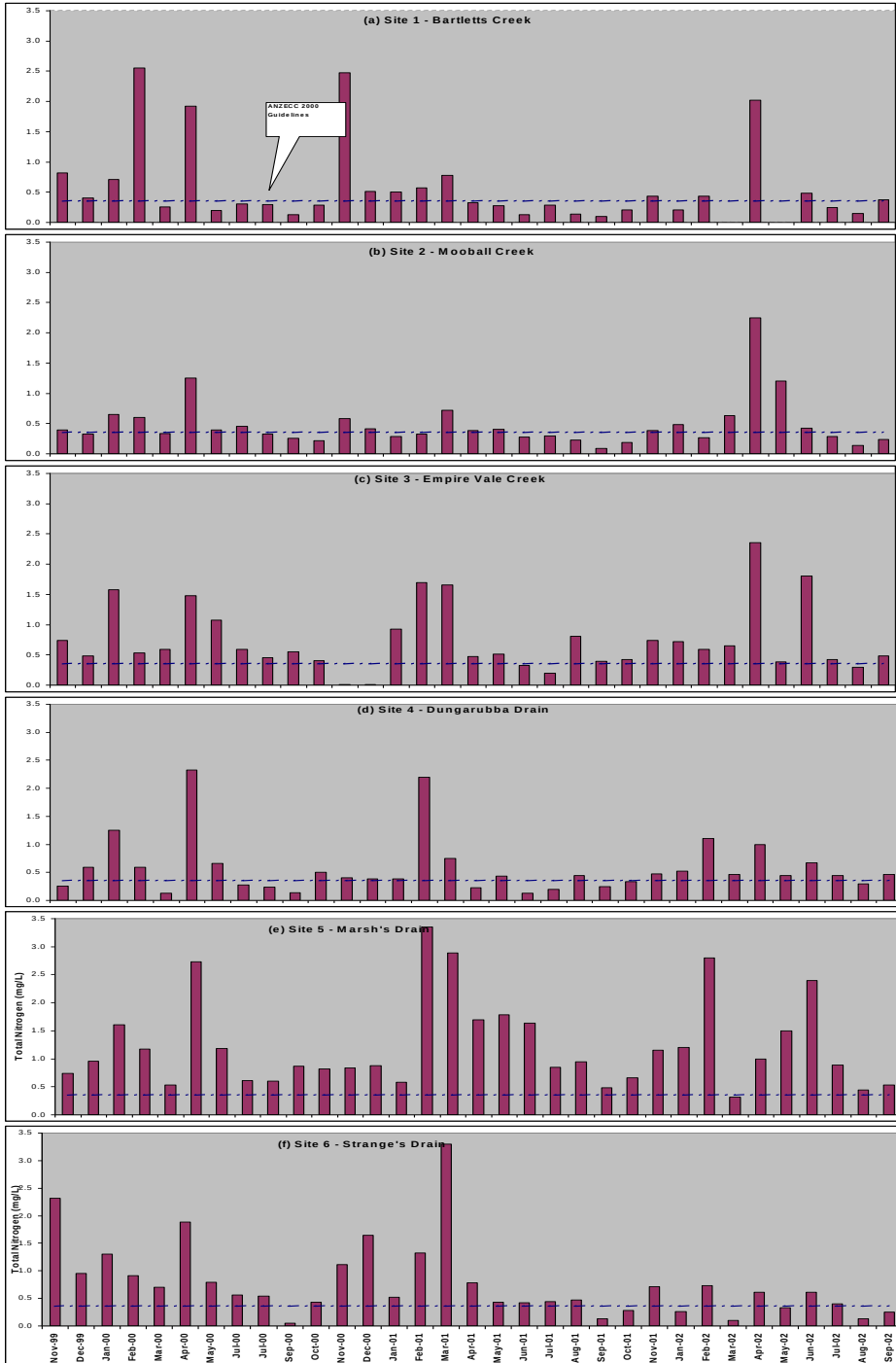
All plots in the column below a property have that property plotted on the x axis with the y axis property shown at the end of each row. Bar charts show the frequency distribution of each physiochemical property.



Appendix 3 (continued).



APPENDIX 4 GRAPHS OF Total N (All Drains)



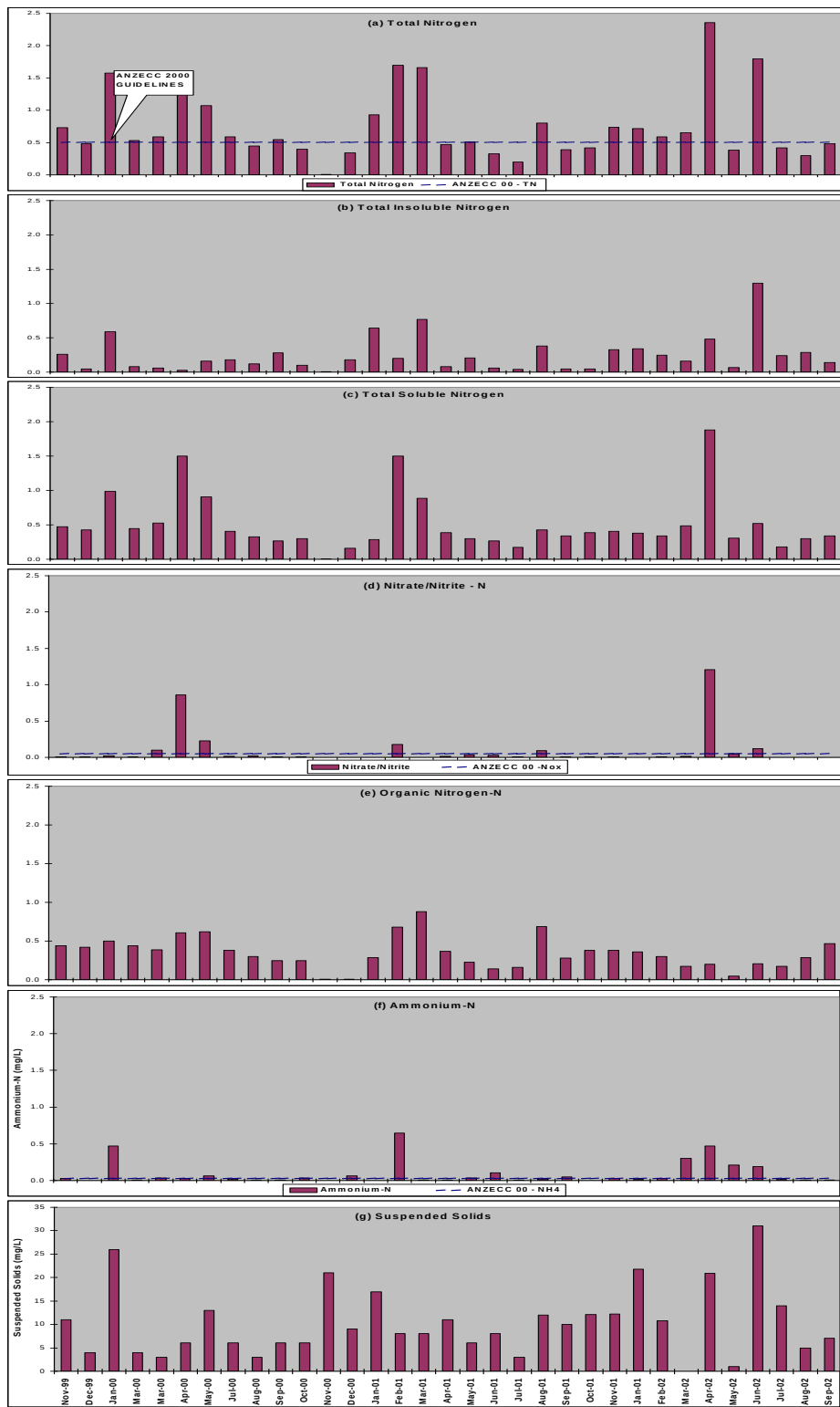
Monthly Nitrogen-N values for drain water in each of the six drain systems



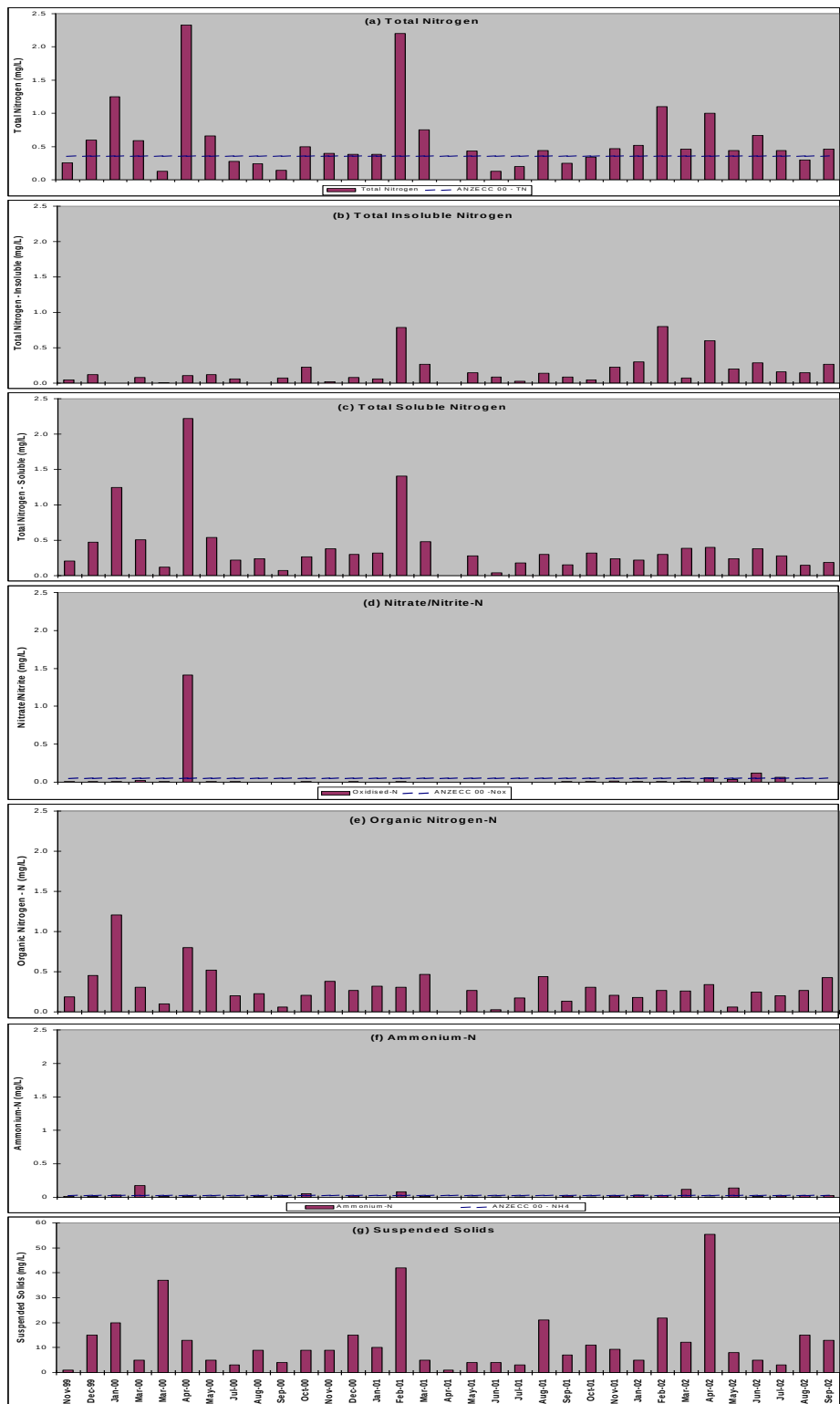
Monthly values of all forms of Nitrogen-N and Suspended Solids from Site 1(Bartletts Creek



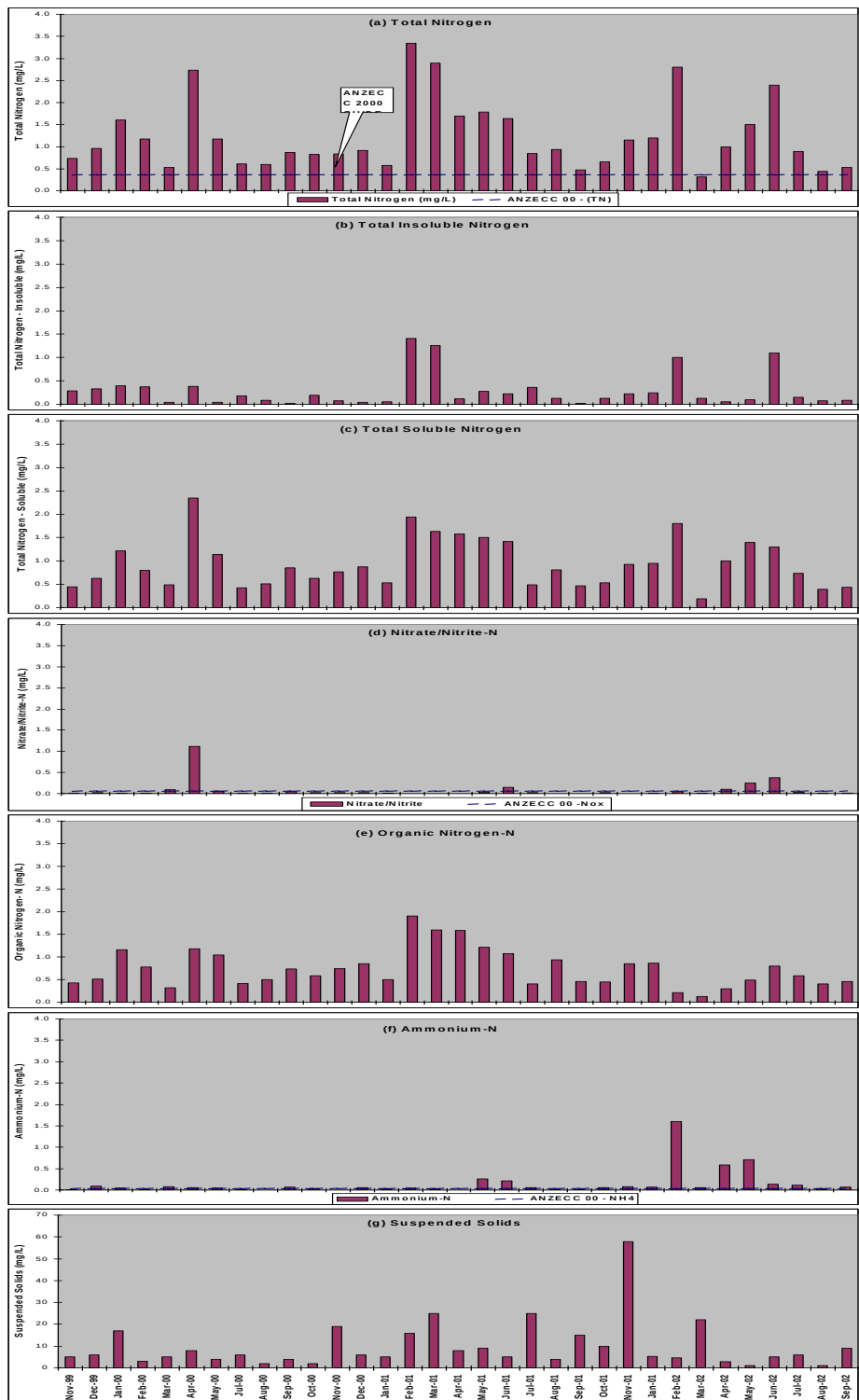
Monthly values of all forms of Nitrogen-N and Suspended Solids for Site 2 (Mooball Creek).



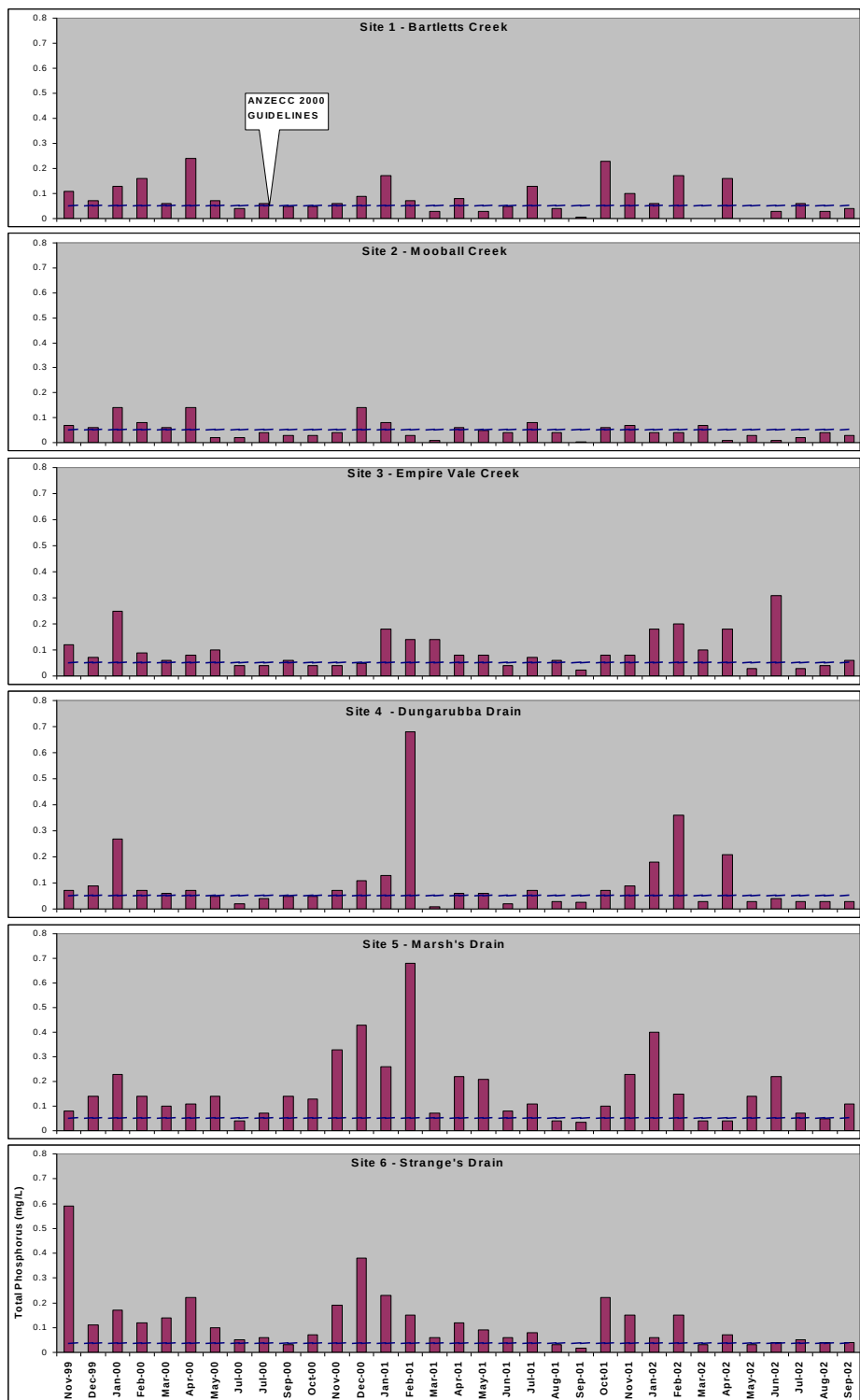
Monthly values of all forms of Nitrogen-N and Suspended Solids for Site 3 (Empire Vale Creek).



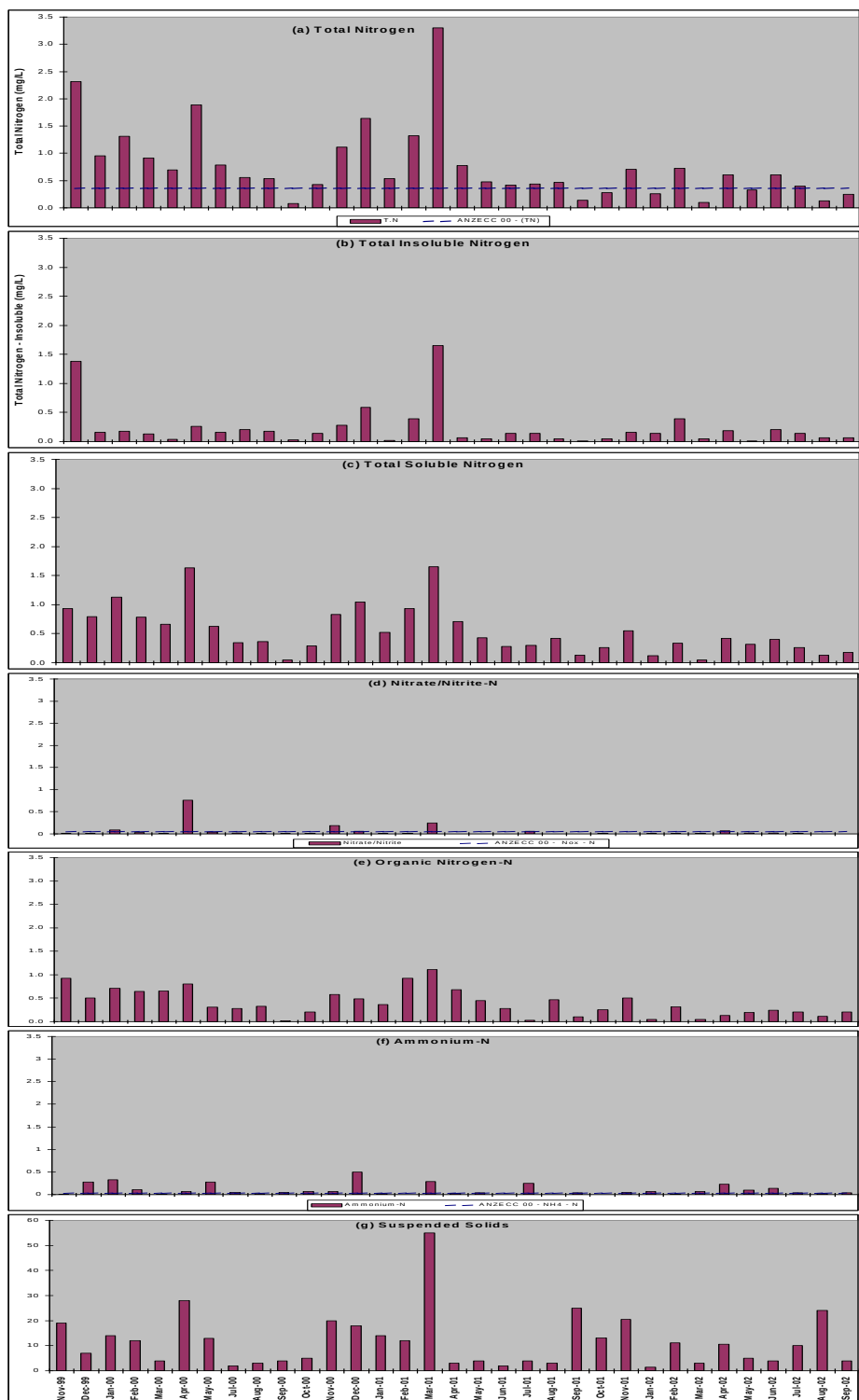
Monthly values of all forms of Nitrogen-N and Suspended Solids for Site 4 (Dungarubba Drain).



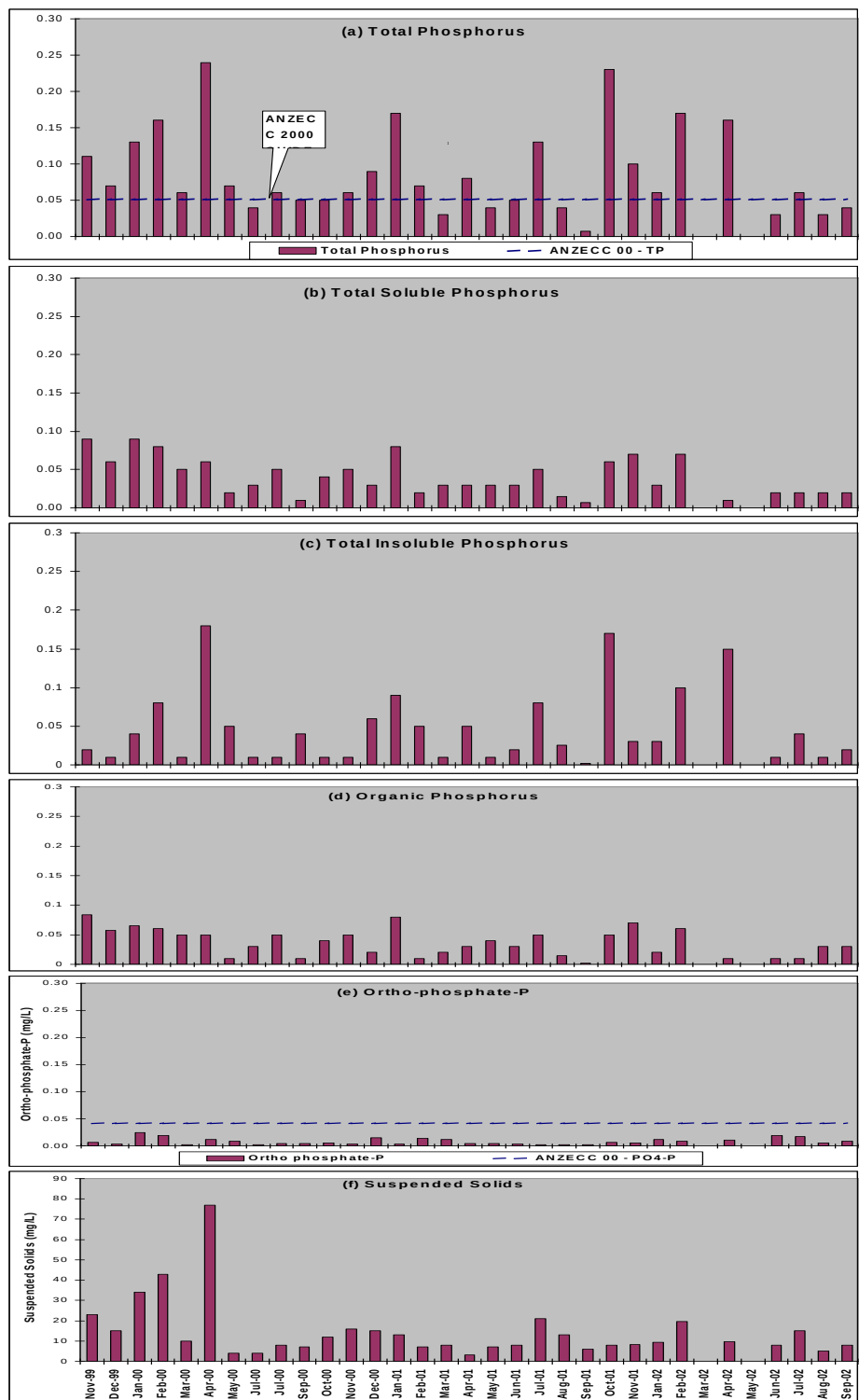
Monthly values of all forms of Nitrogen-N and Suspended Solids for Site 5 (Marsh's Drain).



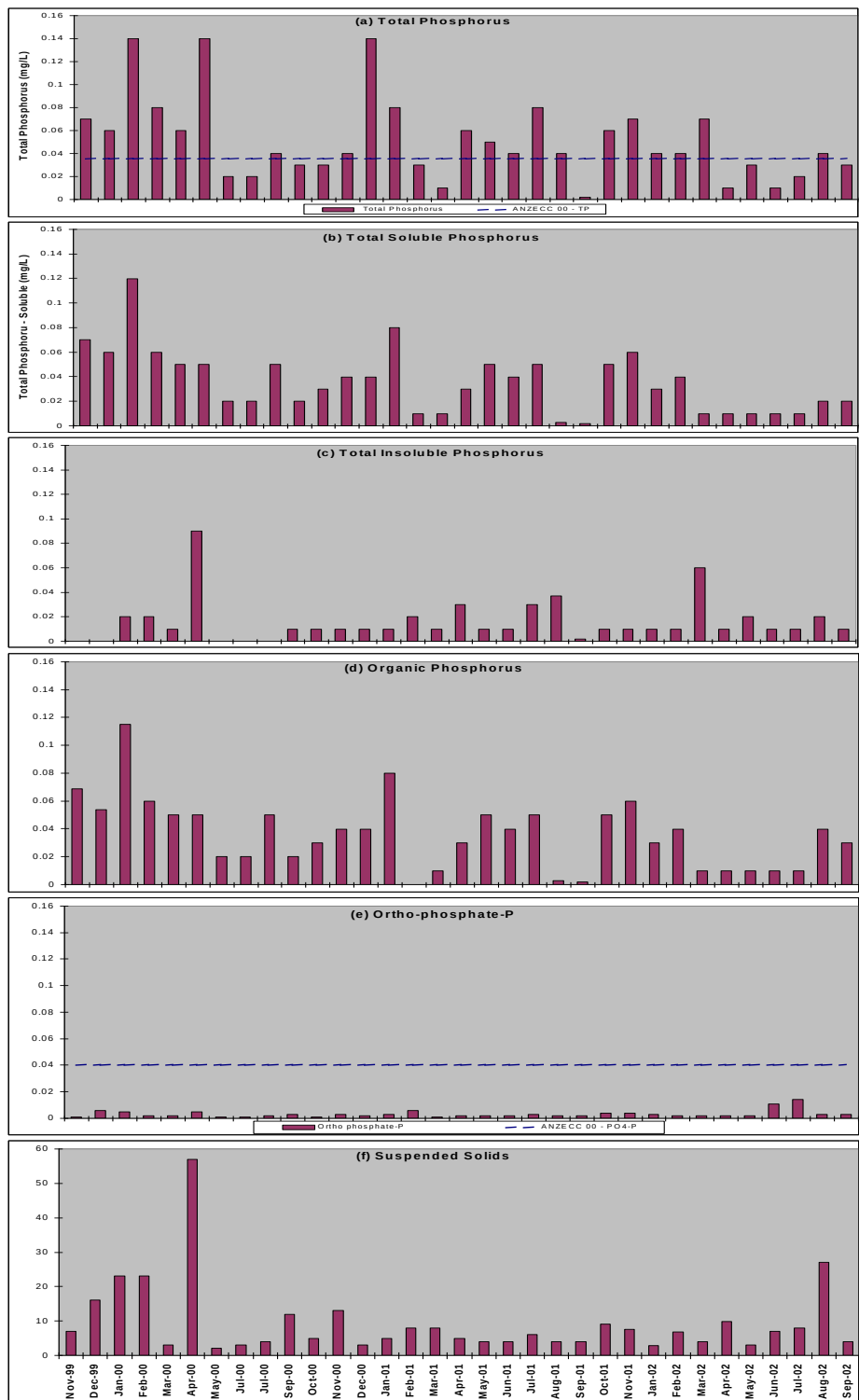
Monthly Total Phosphorus-P values for drain water in each of the six drain systems



Monthly values of all forms of Nitrogen-N and Suspended Solids for Site 6 (Strange's Drain).



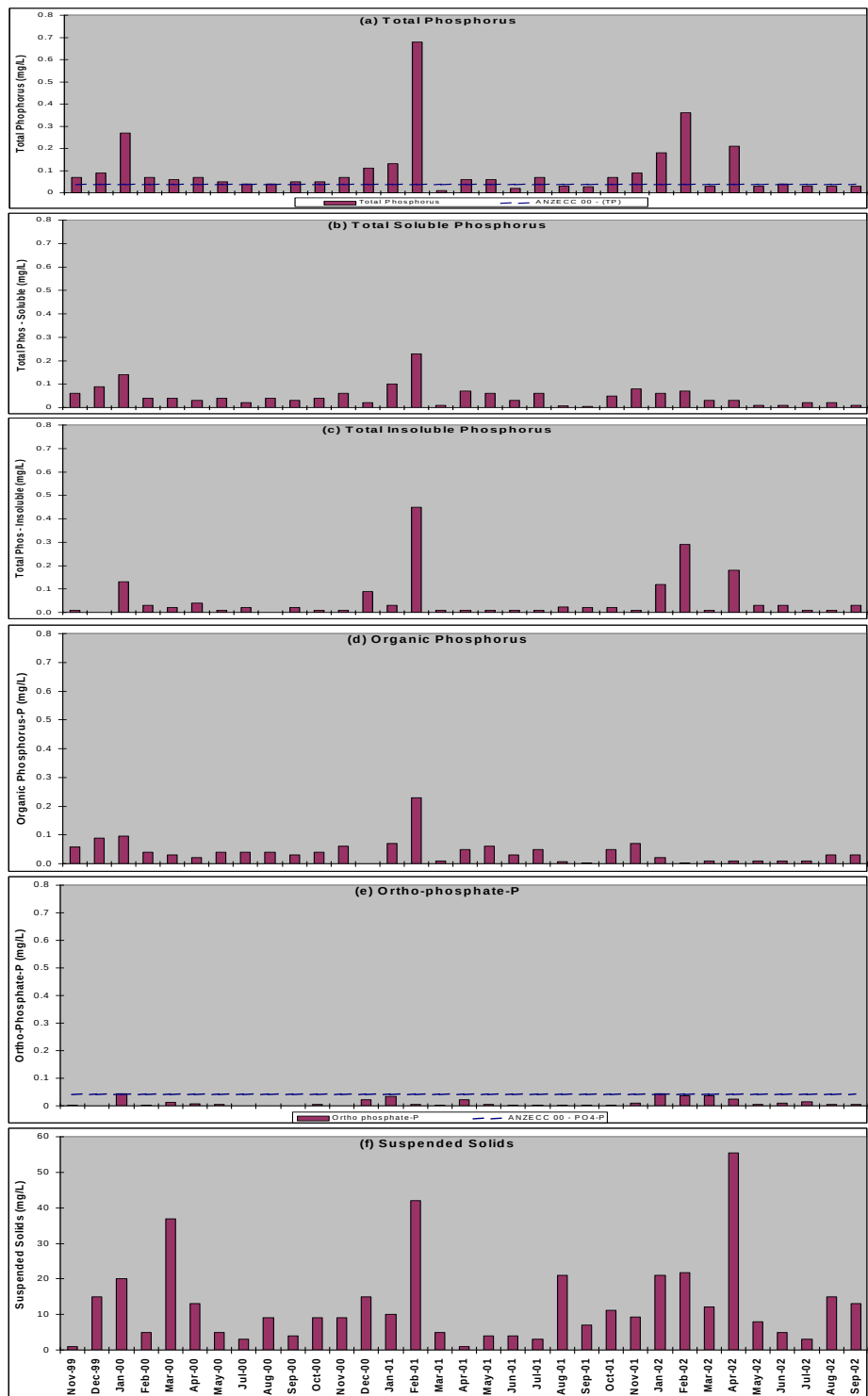
Monthly values of all forms of Phosphorus-P and Suspended Solids from Site 1 (Bartletts Creek).



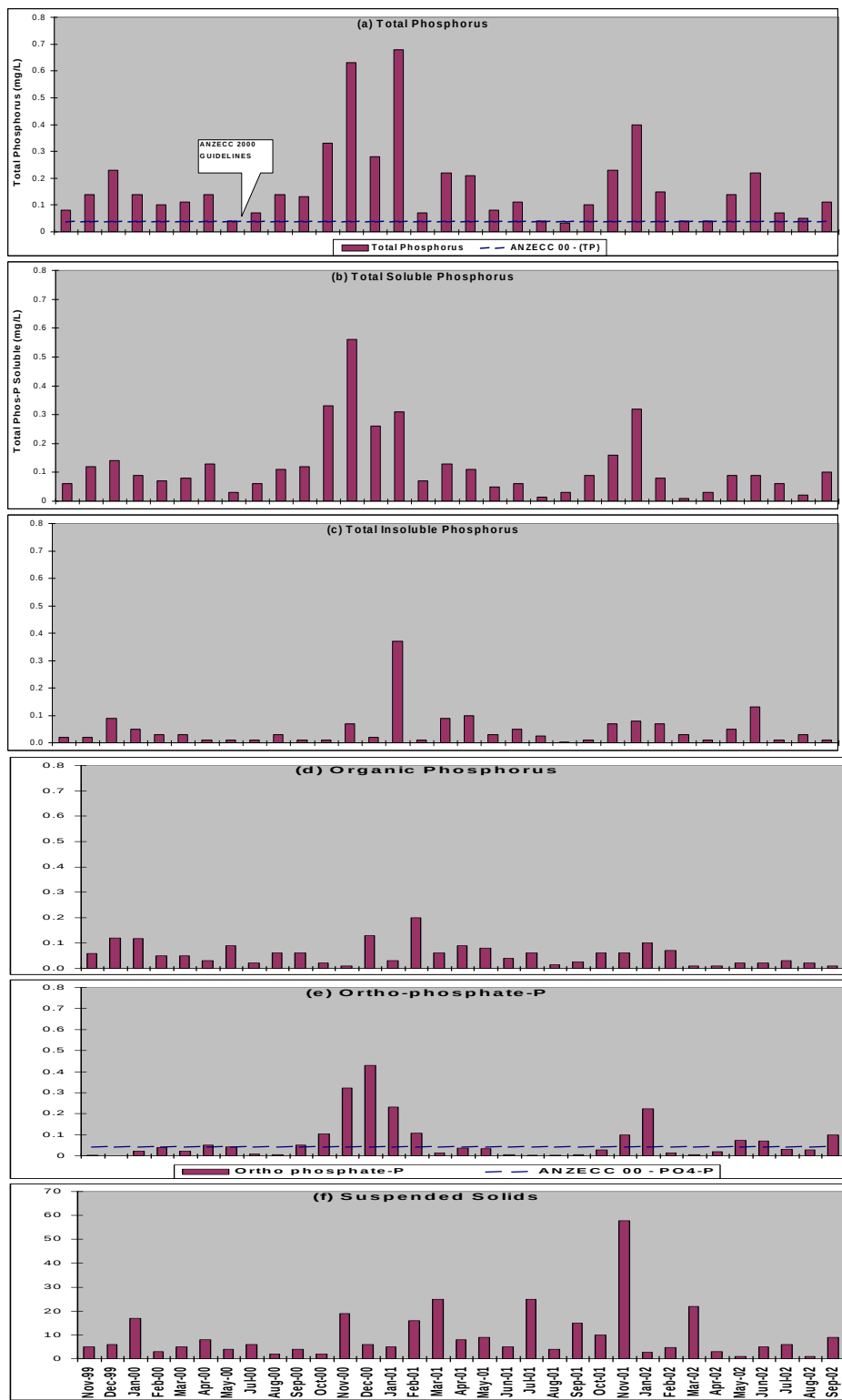
Monthly values of all forms of Phosphorus-P and Suspended Solids from Site 2 (Mooball Creek)



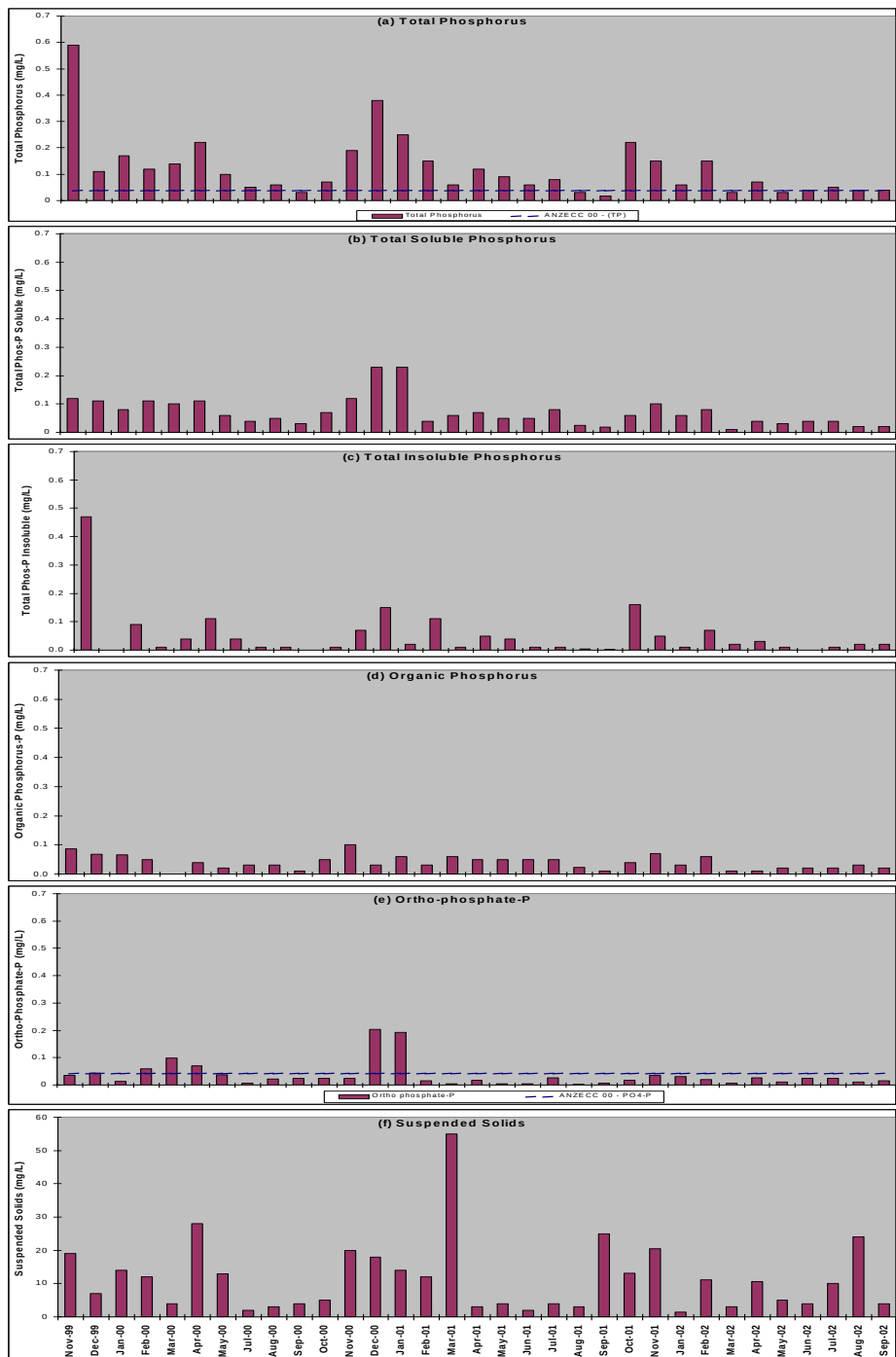
Monthly values of all forms of Phosphorus-P and Suspended Solids from Site 3 (Empire Vale Creek)



Monthly values of all forms of Phosphorus-P and Suspended Solids from Site 4 (Dungarubba Drain).



Monthly values of all forms of Phosphorus-P and Suspended Solids from Site 5 (Marsh's Drain).



Monthly values of all forms of Phosphorus-P and Suspended Solids from Site 6 (Strange's Drain).

APPENDIX 5 NUTRIENT & PESTICIDE FLUXES

Date	Total Vol ML	TN (mg/L)	TN Flux (kg-N)	Org-N (mg/L)	Org-N (s) Flux (kg-N)	NOx-N (mg/L)	NOx-N Flux (kg-N)	TP (mg/L)	TP Flux (kg-P)	Org-P (s) (mg/L)	Org-P (s) Flux (kg-P)	Reactive-P (mg/L)	Reactive-P Flux (kg-P)	S/S (tonnes)
6/12/00-23/1/01	209.6	0.5	104.80	0.3	62.88	0.06	12.58	0.17	35.63	0.08	16.77	0.003	0.63	2.72
23/1 - 14/2/01	339.43	0.57	193.48	0.39	132.38	0.02	6.79	0.07	23.76	0.01	3.39	0.014	4.75	2.38
19/2 - 19/3/01	243.11	0.78	189.63	0.31	75.36	0.278	67.58	0.03	7.29	0.02	4.86	0.012	2.92	1.94
19/3 - 18/4/01	263.79	0.33	87.05	0.21	55.40	0.02	5.28	0.08	21.10	0.03	7.91	0.004	1.06	0.79
18/4 - 17/5/01	235.81	0.28	66.03	0.24	56.59	0.003	0.71	0.03	7.07	0.04	9.43	0.004	0.94	1.65
17/5 - 18/6/01	219.86	0.13	28.58	0.05	10.99	0.003	0.66	0.05	10.99	0.03	6.60	0.003	0.66	1.76
18/6 - 18/7/01	150.27	0.29	43.58	0.07	10.52	0.001	0.15	0.13	19.54	0.05	7.51	0.002	0.30	3.16
18/7 - 17/8/01	133.32	0.14	18.66	0.14	18.66	0.002	0.27	0.04	5.33	0.015	2.00	0.002	0.27	1.73
17/8 - 14/9/01	143.43	0.1	14.34	0.06	8.18	0.006	0.86	0.007	1.00	0.002	0.29	0.002	0.29	0.86
14/9-12/10/01	117.62	0.21	24.70	0.17	20.00	0.016	1.88	0.23	27.05	0.050	5.88	0.006	0.71	0.94
12/10-9/11/01	159.57	0.43	68.62	0.10	15.96	0.012	1.91	0.1	15.96	0.070	11.17	0.005	0.80	1.28
12/11-10/1/02	310	0.21	65.1	0.09	27.9	0.003	0.93	0.06	18.60	0.020	6.20	0.012	3.72	2.79
Total Flux - kg/yr	2526		905		495		100		193		82		17	22

Site 4 - Dungarubba Drain

Date	Total Vol (ML)	TN (mg/L)	TN Flux (kg-N)	Org-N (s) (mg/L)	Org-N (s) Flux (kg-N)	NOx-N (mg/L)	NOx-N Flux (kg-N)	TP (mg/L)	TP Flux (kg-P)	Org-P (s) mg/L	Org-P (s) Flux (kg-P)	Reactive-P (mg/L)	Reactive-P Flux (kg-P)	S/S (tonnes)
6/9 - 4/10/00	1013.5	0.5	507	0.21	213	0.004	4.05	0.05	50.68	0.04	40.54	0.005	5.07	9.12
4/10 - 15/11/00	2501.6	0.4	1001	0.38	951	0.002	5.00	0.07	175.11	0.06	150.10	0.001	2.50	22.51
15/11 - 7/12/00	351.3	0.38	133	0.27	95	0.005	1.76	0.11	38.64	0	0.00	0.023	8.08	5.27
7/12 - 25/1/01	707.8	0.38	269	0.32	226	0.001	0.71	0.13	92.01	0.07	49.55	0.034	24.07	7.08
25/1 - 18/2/01	725	2.2	1595	1.31	950	0.005	3.63	0.68	493	0.23	166.75	0.005	3.63	30.45
19/2 - 26/3/01	538.14	0.75	404	0.47	253	0.001	0.54	0.01	5.38	0.01	5.38	0.003	1.61	2.69
25/3 - 18/4/01	250.2	0.23	58	0.4	100	0.001	0.25	0.06	15.01	0.05	12.51	0.021	5.25	0.25
19/4 - 18/5/01	244	0.43	105	0.27	66	0.003	0.73	0.06	14.64	0.06	14.64	0.004	0.98	0.98
18/5 - 21/6/01	358.1	0.13	47	0.03	11	0.002	0.72	0.02	7.16	0.03	10.74	0.002	0.72	1.43
21/6 - 19/7/01	245.5	0.2	49	0.17	42	0.001	0.25	0.07	17.19	0.05	12.28	0.002	0.49	0.74
19/7 - 16/8/01	265.5	0.443	118	0.438	116	0.003	0.80	0.03	7.97	0.007	1.86	0.002	0.53	5.58
16/8 - 18/9/01	255.5	0.25	64	0.132	34	0.005	1.28	0.027	6.90	0.002	0.51	0.003	0.77	1.79
	7456		4348		3056		20		924		465		54	88

Site 5 - Marsh's Drain

Date	Total Vol (ML)	TN (mg/L)	TN Flux (kg-N)	Org-N (s) (mg/L)	Org-N (s) Flux (kg-N)	NOx-N (mg/L)	NOx-N Flux (kg-N)	TP (mg/L)	TP Flux (kg-P)	Org-P (s) mg/L	Org-P (s) Flux (kg-P)	Reactive-P (mg/L)	Reactive-P Flux (kg-P)	S/S (tonnes)
14/8 - 6/9/00	581.8	0.87	506	0.73	425	0.045	26.18	0.14	81	0.06	34.91	0.05	29.09	1.16
6/9 - 5/10/00	839.58	0.82	688	0.58	487	0.019	15.95	0.13	109	0.02	16.79	0.105	88.156	15.95
5/10 - 7/11/00	786.08	0.84	660	0.75	590	0.018	14.15							0.00
15/11 - 5/12/00	29.6	0.92	27	0.85	25	0.02	0.59		0		0		0	0.18
5/12 - 24/1/01	70.63	0.58	41	0.5	35	0.006	0.42	0.26	18	0.05	3.53	0.232	16.39	0.35
24/1 - 13/2/01	140.98	3.35	472	1.9	268	0.001	0.14	0.68	96	0.2	28.20	0.107	15.08	2.26
15/2 - 22/3/01	273.29	2.89	790	1.6	437	0.001	0.27	0.07	19	0.06	16.40	0.013	3.55	6.83
22/3 - 16/4/01	87.2	1.7	148	1.58	138	0.004	0.35	0.22	19	0.09	7.85	0.037	3.23	0.70
16/4 - 15/5/01	63	1.78	112	1.21	76	0.029	1.83	0.21	13	0.08	5.04	0.033	2.08	0.57
16/5 - 20/6/01	104.4	1.64	171	1.07	112	0.143	14.93	0.08	8	0.04	4.18	0.007	0.73	0.52
20/6 - 17/7/01	38.93	0.85	33	0.4	16	0.028	1.09	0.11	4	0.06	2.34	0.002	0.08	0.97
17/7 - 15/8/01	51.93	0.943	49	0.932	48	0.003	0.16	0.04	2	0.015	0.78	0.002	0.10	0.21
Total Fluxes (kg/yr)	3067		3699		2657		76		371		120		158	30

FACT SHEET

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