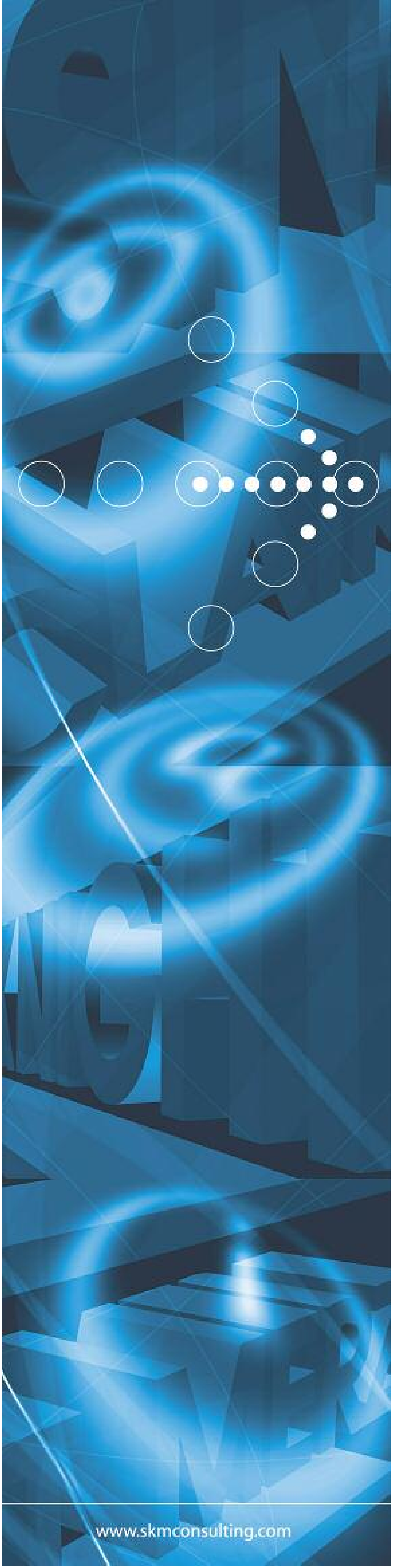

Goulburn-Murray Water

Land & Water Australia Project GMW6

D118 – Nutrient Removal from Rural Drainage Systems Using Wetlands

Final Report on Nutrient Removal from Rural Drainage Systems using Wetlands

December 2002

SINCLAIR KNIGHT MERZ

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1. Executive Summary

In 1996, the Goulburn Broken Catchment Water Quality Strategy identified irrigation drainage as contributing 47% of the total catchment phosphorus loads to the Murray River each year. EPA Guidelines for managing the environmental impacts of construction projects, in this case controlling the mobilisation and transport of sediments in both new and old drainage systems, also highlighted the need for more appropriate drain construction and maintenance techniques.

In response to these issues, the D118 project, "Nutrient Removal from Rural Drainage Systems using Wetlands", was commissioned to investigate the potential of reducing nutrients in irrigation drainage systems using in-line wetland technology and batter stabilisation and to test the design suggested by Breen and Craigie(1997) and Craigie & Breen. There were two components to the investigation: Drain Batter Stabilisation and Nutrient Removal from Rural Drainage Systems using Wetlands. This report details the second of these two components. The results from the drain batter stabilisation investigations have been reported in *"D118 – Nutrient Removal from Rural Drainage Systems using Wetlands – Final Report on Drain Batter Stabilisation Trials."*

A trial site was established in November 1999 in a 1600m length of Shepparton Drain 8/1A/12 which has a capacity of 100ML/d. The upstream half of the drain (800m) acts as a 'control' section and is subject to traditional drain management practices. The 'trial' section covers the remaining 800m and has been modified with the inclusion of aquatic plants in the bed of the drain for filtration and nutrient removal purposes. Batter stabilisation works have also been implemented in the trial section.

The objectives of the project were:

1. To investigate the potential of reducing nutrients in irrigation drainage systems using wetland technology and batter stabilisation.

2. To determine the effectiveness of wetland technology within drainage systems with respect to:
   - nutrient removal;
   - construction and maintenance costs;
   - impacts of measures on drain operation;
   - other practical problems associated with construction and maintenance.

3. To recommend further design and implementation of nutrient mitigation measures within the Shepparton Irrigation Region, with the potential to retrofit existing drains and modify design of new drains.

Please note two aspects of nutrient removal were to be explored:

- stabilisation of the drainage cross section and prevent drainage infrastructure from contributing to drainage sediment and nutrient loads.
- Using in-line aquatic plants to remove nutrients from the drainage water (biological and physical processes)

Flow monitoring stations were installed upstream and downstream of each section to collect water quality data. Water samples were collected manually once per fortnight, while automatic samples were taken every 12 hours. Of the two sampling techniques, data from the manual samples was preferred as the automatic samples were influenced by an external source of nutrients. The samples were analysed for TN, TKN, NH_4, NO_x, TP, PO_4, suspended solids. Turbidity, temperature, pH and EC and stage height were monitored continuously and flow was calculated using a stage/ discharge relationship.

By the conclusion of the nutrient removal trial in March 2002, two and a half years of data had been collected, covering three irrigation seasons. The manual sampling results of the trial section relative to the control section show that the aquatic plants in 800m of Shepparton Drain 8/1A/12 produce:

- an average reduction in TP concentrations of 23%;
- an increase in TP loads across the trial section of 4%;
- an average reduction in TN concentrations by 6%;
- an average reduction in TN loads of 3%;
- an average reduction in turbidity of 31%;
- an average reduction of suspended solids concentrations of 6% and loads by 11%.

All these results were tested for statistical significance at a 95% confidence and only the phosphorus concentrations and turbidity were significantly lower due to the trial section.

Investigation of the components of the nitrogen and phosphorus revealed the majority of the reduction was due to the insoluble portions of the nutrients and the processes involved were physical processes such as sedimentation and filtration. A second important contributor to nitrogen concentration reduction was the process of nitrification.

The trial section of the drain did achieve the first aspect of the project objectives as nutrient and sediment generation from the drain infrastructure was prevented. Only minor erosion was detected during inspections and turbidity and suspended solid measurements showed a reduction across the trial even immediately following construction.

The second aspect to the objectives was to assist with nutrient removal from the catchment. The results indicated that in-line wetlands in irrigation drains would be unsuited for this purpose. However the trial showed that in-line wetlands may be of greater value to reduce turbidity and suspended solids, both of which were removed by the trial. Where there is bed or bank erosion or a turbidity concern, in-line wetlands have potential to ameliorate these impacts.

The in-line wetland showed indications that as installed in this trial it could reduce the level of service to irrigators in regard to drainage capacity during runoff events. However due to the lack of high flows during the trial period this hypothesis could not be confirmed.

More importantly, the results indicated that if constructed off-line to the drains, wetland systems could offer significant benefits for nutrient reduction. A review of nutrient removal performance of the trial section for low flows (less than 2.5 ML/d) showed that nutrients were removed from the trial section relative to the control with a catchment nutrient reduction of between 10 and 29% achieved through this one small trial section. The results show that strategically located offline wetlands protected by suitably scaled inlet flow controls (in this case diverting flows with a velocity greater than 0.035 m/s) would provide a valuable part of an integrated nutrient removal strategy. The balance of nutrient loads being reduced through re-use, diversion and batter stabilisation.

2. Introduction

2.1 Background

In 1996, the Draft Goulburn Broken Catchment Water Quality Strategy identified irrigation drainage as contributing 47% of the total catchment phosphorus loads to the Murray River each year. EPA Guidelines for managing the environmental impacts of construction projects, in this case controlling the mobilisation and transport of sediments in both new and old drainage systems, also highlighted the need for more appropriate drain construction and maintenance techniques.

In response to these issues, the D118 project, "Nutrient Removal from Rural Drainage Systems using Wetlands", was commissioned to investigate the potential of reducing nutrients in irrigation drainage systems using in-line wetland technology and batter stabilisation and to test the design suggested by Breen and Craigie (1997) and Craigie and Breen (1997). Two aspects of reducing nutrients were to be explored:

- Using aquatic plants to remove nutrients from the drainage water (biological and physical processes); and,
- Stabilising the drain cross section to minimise the drain's contribution to poor water quality through erosion and nutrient export.

The project was co-funded by Goulburn-Murray Water, the Shepparton Irrigation Region Implementation Committee and Land and Water Australia (formerly LWRRDC).

2.2 Project Objectives

The objectives of the project were:

1. To investigate the potential of reducing nutrients in irrigation drainage systems using in-line wetland technology and batter stabilisation.

2. To determine the effectiveness of in-line wetland technology within drainage systems with respect to:
   - nutrient removal;
   - construction and maintenance costs;
   - impacts of measures on drain operation;
   - other practical problems associated with construction and maintenance.

3. To recommend further design and implementation of nutrient mitigation measures within the Shepparton Irrigation Region, with the potential to retrofit existing drains and modify design of new drains.

2.3 Project Establishment

The trial site consisted of a 1600 m continuous length of drain (Shepparton Drain 8/1A/12) with a capacity of 100 ML/d. Diagrams of the site are provided in **Figure 2.1** and **Figure 2.2** and a locality plan is included in **Appendix A**

The upstream half of the drain (800 m) acts as a 'control' section and was subject to traditional drain management practices such as weed spraying. The 'trial' section covers the remaining 800 m and was modified with the inclusion of aquatic plants in the bed of the drain for filtration and nutrient removal purposes. Batter stabilisation works have also been implemented in the trial section.

Flow monitoring stations have been installed upstream and downstream of each section to collect water quality data. The numbers of these stations from upstream to downstream are 405759, 405760, 405761.

Figure 2.1 Plan View of the Trial, Shepparton Drain 8/1A/12

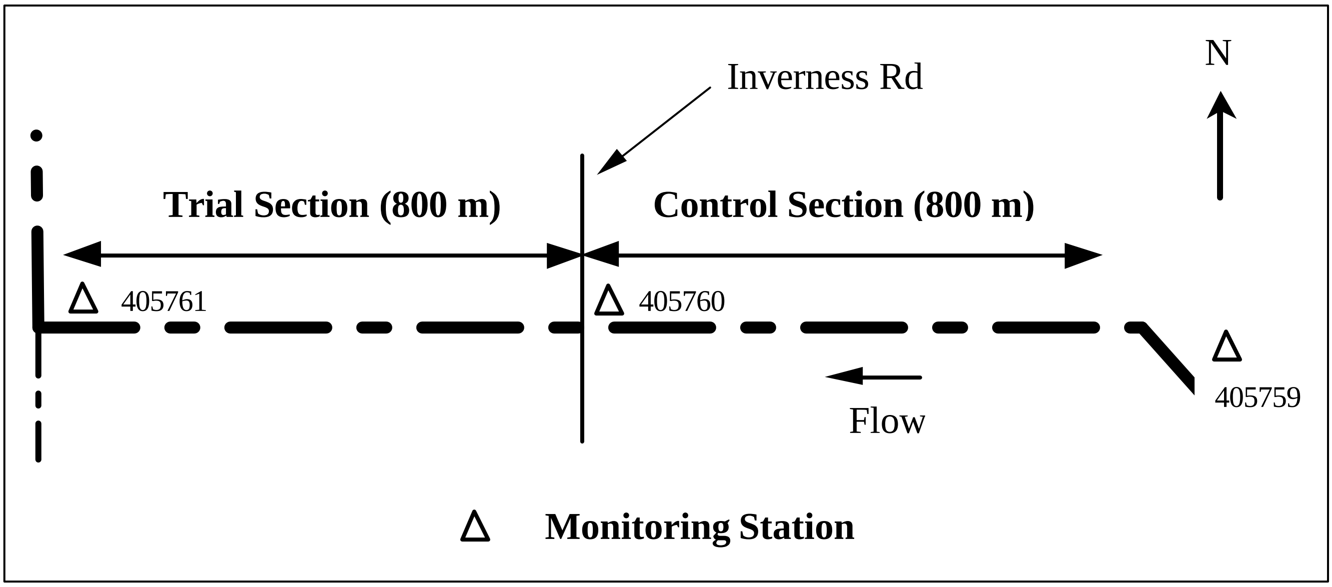
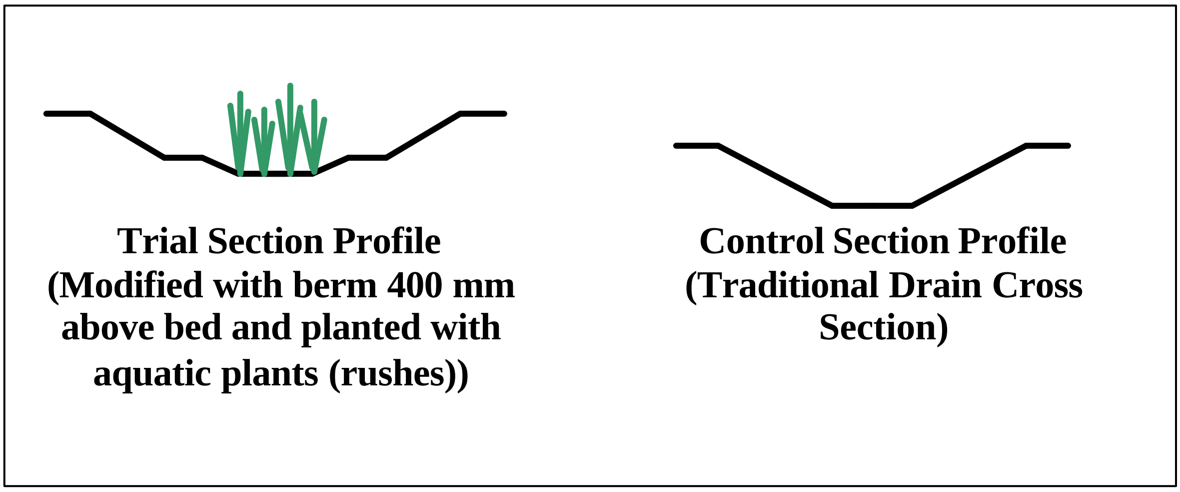


Figure 2.2 Cross Sections of the Trial and Control Sections



Note: See Appendix F for surveyed dimensions

Figure 2.3: Invergordon Trial Site Cross Section; 28 July 2000

Figure 2.3 shows the northern batter of the drain. Note the grass on the batter due to the hydromulching and rushes in the bed of the drain.

2.4 Drain Revegetation

2.4.1 In-line Vegetation

Four aquatic rush species were selected for the trial, based on their indigeneity to the area, their nutrient removal/filtration characteristics, and their practicality for inclusion into an operating drainage system. They are:

- *Schoenoplectus validus* (River Club Rush);
- *Eleocharis acuta* (Spike Rush);
- *Juncus usitatus* (Common Rush);
- *Carex appressa* (Common Sedge).

An initial planting was attempted in October/November 1998. Unfortunately, the success rate was estimated at only 5%, primarily due to the immature "viro-cells" (plant seedlings) being unable to withstand varying drain flow depths and velocities. This delayed the commencement of the project by 12 months as additional plants for immediate re-planting could not be sourced.

The trial section was successfully vegetated with more developed plants in tubestocks in November 1999, and water quality monitoring subsequently commenced.

2.4.2 Batter Stabilisation

The drain batters at the site were treated with a process called ‘hydromulching’, a slurry of paper mulch and seed, to facilitate vegetation cover on the batters to prevent and reduce erosion. This technique had limited initial success in 1998 but a subsequent attempt in 1999 provided good grass coverage, particularly of the northern batter. Other sites and other revegetation techniques have also been very encouraging, as documented in the report "D118 – Nutrient Removal from Rural Drainage Systems using Wetlands – Final Report on Drain Batter Stabilisation Trials” (SKM, 2002)

3. Methodology

3.1 Method of Measurement

In order to measure the nutrients in the drain, water samples were taken automatically and manually at all three stations.

An automatic sample was composed of a mix of four samples taken every 12 hours over a two day period. The automatic sample was tested for Total Nitrogen and Total Phosphorus only. Total Nitrogen was calculated through the measurement of Total Kjeldahl Nitrogen and NO_x.

Manual sampling involved regular sampling once per fortnight and intensive sampling for one week each month. The intensive sampling consisted of daily sampling for five continuous days. The manual samples at each of the three monitoring sites were tested for the concentrations of the following water quality parameters:

- Total Phosphorus;
- Filterable Reactive Phosphorus;
- Total Nitrogen (calculated from NO_x and TK-N);
- Total Kjeldahl Nitrogen (TK-N);
- Nitrates and Nitrites (NO_x);
- Ammonia (NH_4);
- Suspended Solids.

The turbidity, EC, temperature, pH and stage were measured by an automatic probe with a data logger. Manual measurements of each of these parameters were taken approximately every two weeks.

The sites were monitored and maintained by Thiess Environmental Services, Tatura. Water quality analysis of the samples were undertaken by the Chemistry Laboratory at the Institute for Sustainable Irrigated Agriculture (ISIA), Tatura.

3.2 Laboratory Analysis Methods

All samples were processed “as received”. The code numbers below refer to the method numbers in “Australian Laboratory Handbook of Soil and Water Chemical Methods” by G.E Rayment and F.R. Higginson.

Total – P: analysis performed by automated ICP-OES. Conc. HNO_3 was added to samples to give acid concentrations of 4%. Samples were then stood for at least two hours before measurement to allow any sediment to settle. Readings were made at 214.91nm.

PO_4 – P : H2B Automated Colour

TK-N: automated version of G1b manual colour method (Similar to the automated soils method 7A2)

NH_4 – N: modified version of the soils method 7A2 (no digestion)

NO3 – N: G2b automated colour

NO2 – N: G3b automated colour

3.3 Data Modification

The water quality data required some formatting and screening to enable direct and accurate comparisons between monitoring stations. The issues considered in the data formatting or removal can divided into three main factors and are discussed below:

- Drainage inlet flows
- "Cease to flow" events (only applicable to 1999/2000 data)
- One or more of the stations did not sample on that particular day

3.3.1 Drainage Inlet Flows

As shown on Drawing Number 448077 in **Appendix A**, four farm drainage inlets and one road drainage inlet are located within the control section. Works were undertaken to limit flows into the drain at these points by redirecting or blocking flows. However one of the farm inlets, just upstream of monitoring station 405760, has discharged water into the drain on a regular basis. This inlet drains water from a property owned by Geoff Teague and is referred to as Teague's Inlet in this report.

Inflows from Teague's inlet had a direct impact on the nutrient balance within the control section and this became apparent during the first year's analysis of the data. The following alterations were made to the project monitoring in an attempt to reduce the inlet's influence in following seasons:

- Installation of a height recorder at Teague's inlet to monitor the occurrence of inflows;
- Additional manual water sampling of all the drainage inlets and significant drainage flow events.

The data was processed in several ways to remove the influence of the inlet:

- If it was noted by Thiess that there was flow through the inlet, either a manual sample of the inlet water was taken or the drain samples from that day were removed from the dataset;
- Once the inlet flows were monitored, data was removed from the analysis when the inlet was contributing more than 10% of the drain flow.

See also Section **5.1.1** for further details.

3.3.2 "Cease to Flow" Events

A "cease to flow event" is said to occur when the automatic samplers stop taking samples due to a lack of flow in the drain. Cease to flow events may occur at different times at each of the monitoring stations depending on downstream conditions, water back up from aquatic vegetation, or fouling of the float switch which triggers the automatic samplers. Estimates are made of sampling dates during these times based on stage height data from the middle monitoring station. However, where dates can not be determined with reasonable confidence, the data is excluded from the analysis. This problem only occurred in the first year of sampling as the automatic samplers recorded the time a sample was taken in the following years.

3.3.3 Station sample missing

If a sample from one station is missing, the calculation of nutrient change across either the control or the trial section cannot be completed. Therefore if one or more of the sampling stations did not sample (mainly due to mechanical failure) then the whole dataset for that particular day was removed.

3.4 Data Analysis

The effectiveness of the aquatic plants on nutrient removal was assessed by comparing the nutrient changes in the control section with the nutrient changes in the trial section. The aim of the analysis was to produce conclusions in relation to whether:

- the trial section reduced nutrient concentration and loads relative to the control section
- the trial section reduced nutrient concentration and loads in isolation

The methodology used to determine if the trial section reduced nutrients relative to the control section involved the following steps:

1) calculate the average of the water quality data sets from monitoring stations 405759, 405760 and 405761;
2) determine the average change across the control (the station 405760 average minus station 405759 average) and the average change across the trial (the station 405761 average minus the station 405760 average). A negative result indicates nutrient reduction.
3) subtract the average change of the control section from the trial section. Again if the result is negative then it can be concluded that a relative reduction has occurred as result of the wetland.

Two indicators of the reliability of the data analysis, T tests and confidence limits have been employed. Both indicators can be used to assess whether the sample averages are a good representation of the actual processes occurring in the drain.

3.4.1 T-Tests and Confidence Limits

T-tests and confidence limits both provide an indication of the reliability of a sample mean. At a set confidence level, the t-tests provide an indication whether a result is significant and confidence limits provide an interval which includes the true mean.

The value of the t-test can be illustrated by investigating the phosphorus concentrations from the manual sampler. The average of the samples from station 405760 is 1.89 mg/L and the average at the downstream station 405761 is 1.71 mg/L. The difference of the average phosphorus concentrations is -0.18 mg/L. This indicates a reduction of approximately 10% across the trial section. By considering the standard deviation of the data and the number of samples, the t-test can indicate if a result is statistically significant at a certain confidence. A 95% confidence level has been selected throughout the analysis. In this case the concentration at Station 761 was significantly lower and the confidence interval indicated the true average change could be –0.01 mg/L to –0.35 mg/L or –1 % to –19 %.

All the parameters have been tested to indicate if a nutrient reduction is a statistically significant conclusion. Once a result is known to be significant, the confidence interval is determined.

4. Results

4.1 Introduction

The results from the trial have been detailed in the following four sections. **Section 4.2** provides background information about the general nutrient levels relative to other drains. **Section 4.3** details the results over the whole three years of the trial and **section 4.4** looks at the various stages of the trial. An objective of the project was to determine the impact the aquatic plants had on the operation of the drain and **section 4.5** shows the results of this investigation. The analysed data from the trial is presented in **Appendix B**.

4.2 Typical Nutrient Levels

Harrison (1994) defined low, medium and high concentration ranges for water quality parameters which provide a useful guide to assessing the quality of irrigation drainage water. These criteria are shown in **Table 4.1**.

Table 4.1: Criteria Selected for Nutrients in Irrigation Drains (Harrison 1994)

Criteria	NOx (mg/L)	TN (mg/L)	FRP (mg/L)	TP (mg/L)
Low	<0.5	<1	<0.01	<0.1
Medium	0.5-2.5	1-5	0.01-0.05	0.1-0.5
High	>2.5	>5	>0.05	>0.5

Table 4.2 and **Table 4.3** provide a summary of the parameters from the middle site during the period from the November 1999 to March 2002 for both the manual and automatic samples, to give an indication of the level and range of nutrient levels in Shepparton Drain 8/1A/12. According to Harrison's classification the Shepparton Drain 8/1A/12 has a high level of phosphorus and a medium level of nitrogen.

Table 4.2: Water Quality Parameters Station 405760 - Manual Samples (1999 - 2002) Manual Samples

	NOx (mg/L)	NH_4 (mg/L)	TKN (mg/L)	TN (mg/L)	Soluble TN %	FRP (mg/L)	TP (mg/L)	Soluble TP %	SS (mg/L)
Min.	0.02*	0.10	0.42	0.54	2%	0.10	0.34	0%	0
Average	0.30	0.46	3.31	3.62	20%	1.05	1.89	55%	142
Median	0.17	0.20	3.15	3.26	16%	0.96	1.62	60%	105
Max.	1.77	4.75	8.28	8.33	86%	3.38	5.77	90%	542

* NB: Lowest limit of detection

Table 4.3: Water Quality Parameters Station 405760 - Automatic Samples (1999 - 2002)

	TN (mg/L-N)	TP (mg/L-P)
Min.	0.16	0.26
Average	3.16	2.09
Median	2.82	1.80
Max.	12.25	10.5

Details of nutrient levels in other drains within the Shepparton Irrigation Region (detailed in **Table 4.4**) also show that TP and TN levels are relatively higher in Shepparton Drain 8/1A/12.

Table 4.4: Nutrient Levels in Drains

Drain	Catchment Size	TN (mg/L)		TP (mg/L)	
	(ha)	Average	Median	Average	Median
Deakin Main Drain	74054	2.66	2.41	0.80	0.71
Rodney Main Drain	19836	1.34	1.13	0.24	0.20
Murray Valley Drain 6	16392	2.00	1.64	0.65	0.71
Shepparton 8/1A/12	860	3.62	3.26	1.89	1.62

Source: Review of Data for the Shepparton Irrigation Region Drain Water Quality Monitoring Programs, May 1990 – June 1999 (SKM 2000).

4.3 Nutrient Removal: Analysis of Total Data Set

4.3.1 Introduction

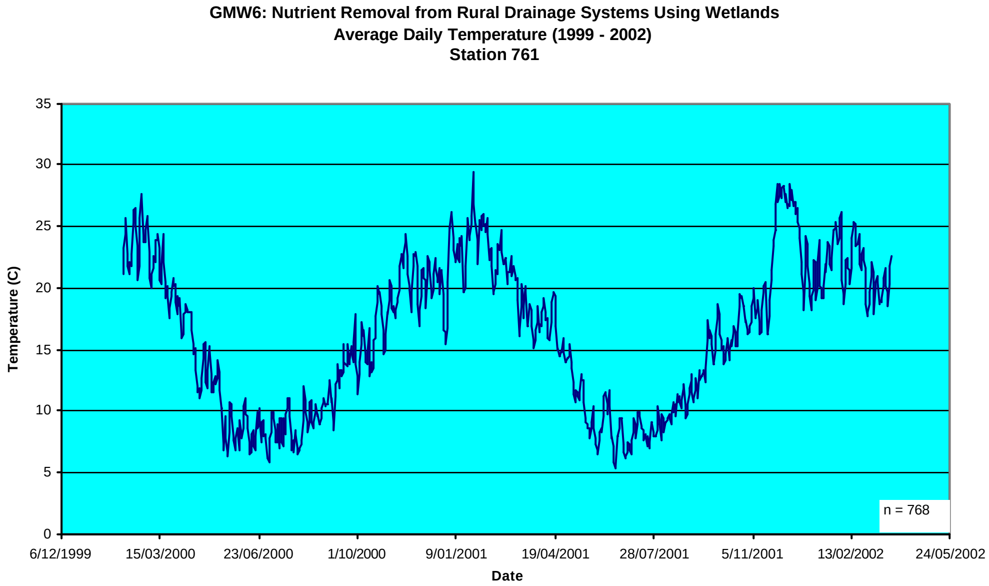
There are two reasons for analysing all the data as one set:

- To provide an indication of the long term effectiveness of the aquatic plants;
- To provide more confidence in the sampling results as a larger dataset will more accurately represent the true behaviour of the drain.

4.3.2 Temperature, EC and pH

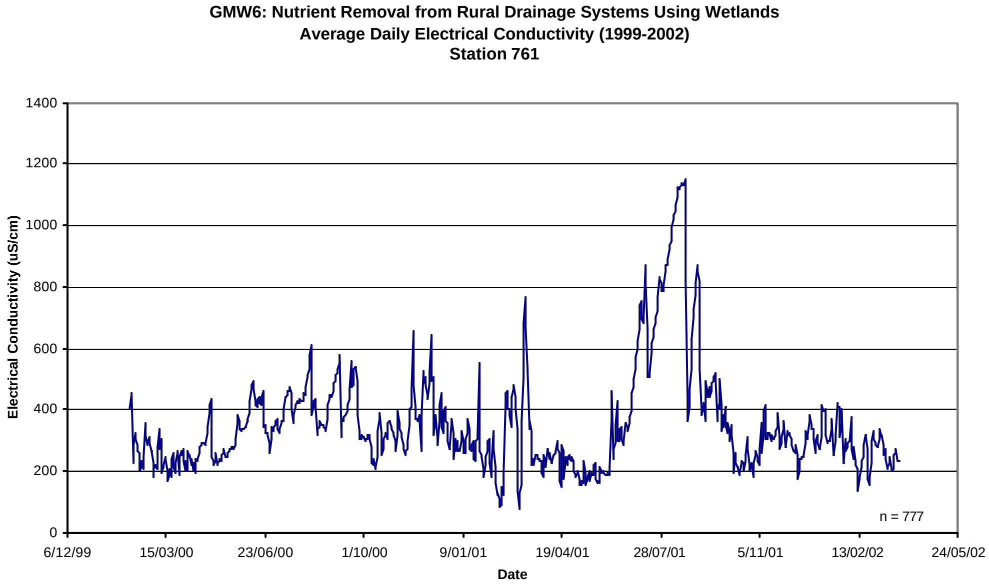
Plots of average water temperature, EC, pH and flowrate for the entire trial period are shown in **Figure 4.1**, **Figure 4.2**, **Figure 4.3** and **Figure 4.4** respectively. The automatic data has been presented in the report for these parameters. This is because the automatic measurements were more frequent and therefore a better representation of the behaviour in the drain. Please note that the values measured at station 405761 have been included to provide a more complete dataset as the instruments at Station 405760 were defective at times.

Figure 4.1 Average Daily Temperature 1999 - 2002



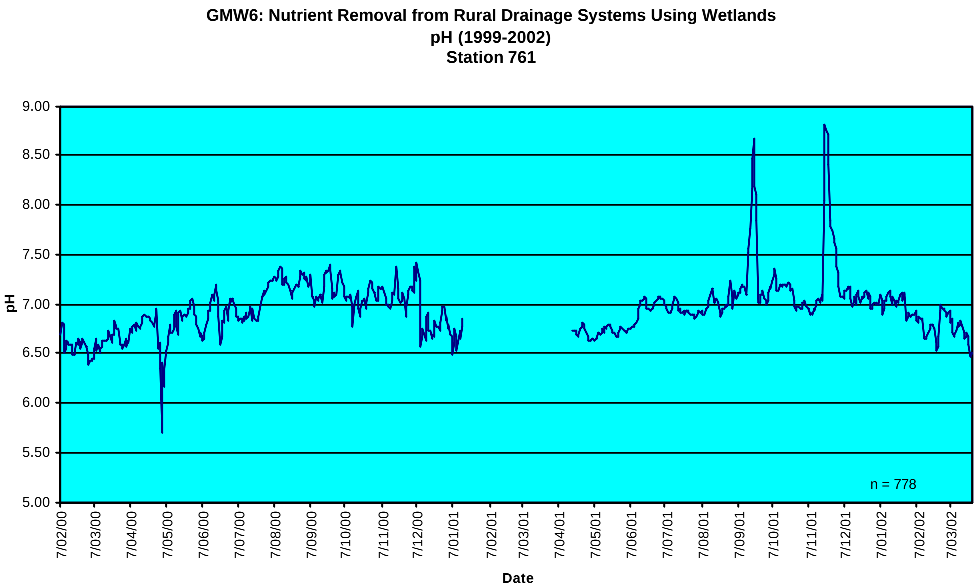
Please note the temperature in the drain followed a similar pattern for all three stations. There was no indication that temperature influenced nutrient removal of the treatment.

Figure 4.2 Average Daily EC 1999 – 2002



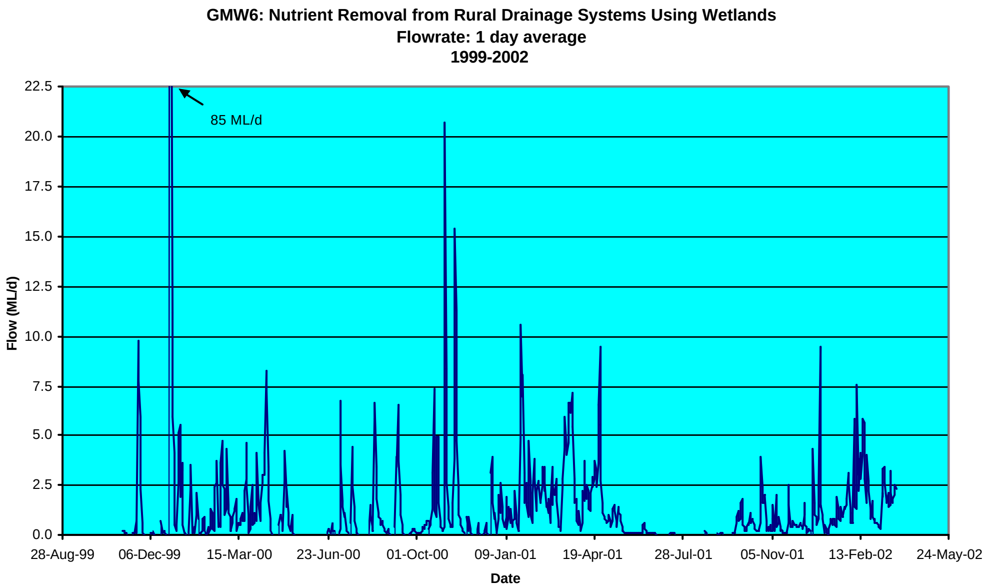
The EC in the drain is generally below 600 and in the range between 200 and 400 EC. A spike in the EC measurements occurred during July and August 2001. It is felt this spike is likely to be instrument error as the manual measurements were only approximately 300 EC and similar trends were not observed at Stations 759 and 760. The EC recorded in Shepparton Drain 8/1A/12 is not high and generally well below the 800 EC threshold which is considered suitable for irrigation.

Figure 4.3 Average Daily pH 1999 - 2002



The pH in the drain generally varied between 6.5 and 7.5. It is not known what caused the two spikes in the spring of 2001.

Figure 4.4 Average Daily Flowrate 1999-2002



The flow through the drain is discussed in more detail in **Section 4.4.3**.

4.3.3 Nutrient Removal

The reduction in nutrients in the trial section relative to the control section are included in **Table 4.5**. The results are based upon approximately 350 samples for the automatic sampling and 85 samples for the manual sampling. A description of each column is included below:

- Sample Average Change: the average change across the trial section less the average change across the control section. The more negative a result the greater the effectiveness of the aquatic plants.
- Percentage Change: the percentage change across the trial section minus the percentage change across the control section. The more negative the result the greater the effectiveness of the aquatic plants.
- Significant Reduction: The result of the t-test. "Yes" means the conclusion that the trial is reducing nutrients relative to the control section is statistically significant at a 95% confidence. "No" means that there may be a reduction in nutrients across the trial section but merely that the result is not significant.
- 95% Confidence limits: The range either side of the sample average which will contain the true average 95 times out of 100.

Table 4.5: Relative Nutrient Removal due to the Trial Section 1999/2002

Nutrient	Measure	Method of Collection	Control Section Change	Trial Section Change	Sample Average Change	% Change	Statistically Significant Reduction	95% Confidence limits
Total Phosphorus	Concentration (mg/L)	Manual	0.22	-0.18	-0.40	-23%	Yes	± 0.30
		Automatic	0.38	-0.21	-0.59	-32%	Yes	± 0.18
	Loads (kg/d)	Manual	0.13	0.25	0.12	4%	No	N/A
		Automatic	0.49	-0.20	-0.69	-26%	Yes	± 0.29
Total Nitrogen	Concentration (mg/L)	Manual	-0.08	-0.28	-0.20	-6%	No	N/A
		Automatic	0.20	0.01	-0.19	-7%	No	N/A
	Loads (kg/d)	Manual	-0.23	-0.38	-0.15	-3%	No	N/A
		Automatic	0.45	0.19	-0.26	-8%	No	N/A

Most measures of nitrogen and phosphorus shows that the in-line wetland resulted in a reduction of nutrients relative to the control section. However due to the large amount of scatter in the data only three of the results in **Table 4.5** can be considered statistically significant. The results are discussed further in **Section 5.3**.

Due to the evident influence of inflows from Teague's inlet on the nutrient balance in the control section (as discussed in **section 3.3.1** and **5.1.1**), it is of value to look at the trial section in isolation. These results are detailed in **Table 4.6**.

Table 4.6: Trial Section in Isolation: Nutrient Reduction 1999/2002

Nutrient	Measure	Method of Collection	Average value at Station 405760	Average Change	% Change	Significant Reduction	95% Confidence Limits
Total Phosphorus	Concentration (mg/L)	Manual	1.89	-0.18	-10%	Yes	± 0.17 mg/L
		Automatic	2.09	-0.21	-10%	Yes	± 0.11 mg/L
	Loads (kg/d)	Manual	3.08	0.25	8%	No	N/A
		Automatic	3.03	-0.20	-7%	Yes	± 0.16 kg/d
Total Nitrogen	Concentration (mg/L)	Manual	3.62	-0.28	-8%	Yes	± 0.24 mg/L
		Automatic	3.16	0.01	0%	No	N/A
	Loads (kg/d)	Manual	5.97	-0.34	-6%	No	N/A
		Automatic	3.95	0.19	5%	No	N/A

Though there is some indication of a reduction in nutrient levels across the trial, the results are inconsistent between concentration and loads, and manual and automatic data. An interpretation is included in **Section 5.3**.

4.3.4 Turbidity and Suspended Solids

The average measurements throughout the period of the trial have been included in **Table 4.7**.

Table 4.7: Average Turbidity 1999/2002

Sample Type	Average Turbidity (Ntu's)		
	405759	405760	405761
Manual	44	46	34
Automatic	39	59	39

A similar analysis to that employed for the nutrient analysis has been applied to the turbidity, the results of which are included in **Table 4.8**.

Table 4.8: Relative Turbidity Reduction due to the Trial Section

Method of Collection	Control Average Change (NTUs)	Control: % Change	Trial Average Change (NTUs)	Trial: % Change	Relative: % Change	Significant Reduction	95% Confidence Limits (NTUs)
Manual	2	5%	-12	-26%	-31%	Yes	± 10
Automatic	20	51%	-20	-34%	-85%	Yes	± 7

Again due to the influence of Teague's inlet, it is of value to look at the trial section in isolation (**Table 4.9**).

Table 4.9: Turbidity Reduction due to the Trial Section in Isolation

Method of Collection	Average value at Station 405760	Average Change (NTUs)	% Change	Significant Reduction	95% Confidence Limits
Manual	46 NTU's	-12	-26%	Yes	± 6
Automatic	59 NTU's	-20	-34%	Yes	± 4

The reduction in turbidity as water flowed through the trial section is clearly evident. Across the trial section alone, both the manual and the automatic data show the same trend with manual measured turbidity being reduced by between 6 and 18 NTU's (13% - 39%) and automatically measured turbidity being reduced by between 16 and 24 NTU's (27% - 41%)

The relative reduction in turbidity of 31% and 85% for manual and automatic samples respectively is even more impressive. However the automatic data at Station 405760 seems inconsistently high and should be used with caution. The reason for this is not known but possible explanations include Teague's Inlet, carp and ducks disturbing the pool of water.

Further information supporting the reduction in turbidity is the depositions of sediment throughout the aquatic plants. Survey of cross sections at 200m intervals along the trial section from 1998 to 2002 show up to 200mm of silt deposition in the upstream 400m of the trial.

Suspended solids have also been reduced by the trial section as shown in **Table 4.10** and **Table 4.11**. However due to the degree of scatter (Turbidity variance is approximately 1300 but the suspended solids variance is approximately 10,000), the results are not statistically significant. There is slight reduction in suspended solids through the control section. However this is likely due to deposition within the backwater pool created upstream of the trial section plantings.

Table 4.10: Average Suspended Solids 1999/2002

Sample Type	Average Suspended Solids		
	405759	405760	405761
Concentration (mg/L)	148	142	123
Load (kg/d)	178	176	155

Note: Suspended Solids data was only collected manually

Table 4.11: Relative Suspended Solids Reduction due to the Trial Section

Parameter	Method of Collection	Measure	Average Change	% Reduction	Significant Reduction	95% Confidence Limits
Concentration (mg/L)	Manual	Control	-6	-7%	No	N/A
		Trial	-18	-13%	No	N/A
		Relative	-12	-6%	No	N/A
Loads (kg/d)	Manual	Control	-2	-1%	No	N/A
		Trial	-21	-12%	No	N/A
		Relative	-19	-11%	No	N/A

4.4 Seasonal Trends

The water quality parameters documented in this report were collected over three irrigation seasons:

- November 1999 to May 2000;
- June 2000 to May 2001; and
- June 2001 to March 2002.

The analysis performed for each was the same as that used in **Section 4.3**. However due to the smaller datasets for each season there were less statistically significant results. The effectiveness of the aquatic plants in trial section was analysed relative to the control section and in isolation.

4.4.1 Nutrient reduction

1999/2000 Season

The 1999/2000 season was the first period of the trial. At the commencement of the trial, the plants were merely tubestocks and drain was relatively uncongested compared to subsequent seasons. The plants grew rapidly during this period and batter stabilisation techniques succeeded in vegetating most of the northern batter. The results for the 1999/2000 season are tabulated in **Table 4.12** and **Table 4.13**.

Table 4.12: Relative Nutrient Reduction due to the Trial Section 1999/2000

Nutrient	Measure	Method of Collection	Sample Average Change	% Change	Statistically Significant Reduction	95% Confidence limits
Total Phosphorus	Concentration (mg/L)	Manual	0.00	0%	No	N/A
		Automatic	-0.54	-28%	Yes	± 0.37
	Loads (kg/d)	Manual	0.00	0%	No	N/A
		Automatic	-0.83	-18%	Yes	± 0.72
Total Nitrogen	Concentration (mg/L)	Manual	-0.34	-10%	No	N/A
		Automatic	0.45	15%	No	N/A
	Loads (kg/d)	Manual	-0.48	-26%	No	N/A
		Automatic	-1.13	-20%	Yes	± 1.12

Table 4.13: Trial Section in Isolation: Nutrient Reduction 1999/2000

Nutrient	Measure	Method of Collection	Average value at Station 405760	Average Change	% Change	Significant Reduction	95% Confidence Limits
Total Phosphorus	Concentration (mg/L)	Manual	1.56	-0.07	-5%	No	N/A
		Automatic	2.30	-0.13	-6%	No	N/A
	Loads (kg/d)	Manual	0.77	-0.02	-2%	No	N/A
		Automatic	4.64	-0.15	-3.2%	No	N/A
Total Nitrogen	Concentration (mg/L)	Manual	4.03	-0.85	-21%	Yes	± 0.45
		Automatic	2.94	0.33	11%	No	N/A
	Loads (kg/d)	Manual	1.89	-0.49	-26%	Yes	± 0.40
		Automatic	5.14	-0.44	-9%	Yes	± 0.55

These results are consistent with those reported in the Water Quality Analysis report 16 November 1999 to 28 May 2000 (SKM December 2000) in which the regression analysis was used. This report stated that for nitrogen there was a relative nutrient reduction of between 16 and 30% for the manual data. **Table 4.12** and **Table 4.13** show a nitrogen reduction of between 10 and 26%. However the results indicate the reductions over such a short period of time are not statistically significant.

The results tabulated above for phosphorus are also consistent with the SKM 2000 report. The regression analysis in the report found there was no reduction using the manual samples; and though the automatic results were inconclusive, there were indications of a reduction. The above tables agree with this finding as the only statistically significant reduction was the automatic data for the trial section relative to control. A possible explanation for the relative reduction is the influence of the inlet supplying phosphorus to the control section.

<u>2000/2001 Season</u>

By the commencement of the 2000/2001 season the plants were mature. A dieback phase during the winter resulted in the presence of dead organic material in the trial section and tannin could be seen in the water at times (see **Figure 5.3**). This material was a possible nutrient source. The trial section was now congested and flow restricted resulting in a pool of water immediately upstream of the plants. The results for the 2000/2001 Season are tabulated in **Table 4.14** and **Table 4.15**.

Table 4.14: Relative Nutrient Removal due to the Trial Section 2000/2001

Nutrient	Measure	Method of Collection	Sample Average Change	% Change	Statistically Significant Reduction	95% Confidence limits
Total Phosphorus	Concentration (mg/L)	Manual	-0.69	-37%	Yes	± 0.45
		Automatic	-0.09	-7%	No	N/A
	Loads (kg/d)	Manual	-0.12	-5%	No	N/A
		Automatic	0.14	4%	No	N/A
Total Nitrogen	Concentration (mg/L)	Manual	-0.26	-8%	No	N/A
		Automatic	-0.02	-2%	No	N/A
	Loads (kg/d)	Manual	-0.37	-5%	No	N/A
		Automatic	0.31	6%	No	N/A

Table 4.15: Trial Section in Isolation: Nutrient Reduction 2000/2001

Nutrient	Measure	Method of Collection	Average value at Station 405760	Average Change	% Change	Significant Reduction	95% Confidence Limits
Total Phosphorus	Concentration (mg/L)	Manual	2.15	-0.26	-12%	Yes	± 0.24
		Automatic	1.73	0.06	3%	No	N/A
	Loads (kg/d)	Manual	3.76	0.28	7%	No	N/A
		Automatic	2.68	0.19	7%	No	N/A
Total Nitrogen	Concentration (mg/L)	Manual	3.47	-0.17	-5%	No	N/A
		Automatic	2.82	0.10	4%	No	N/A
	Loads (kg/d)	Manual	6.77	-0.56	-8%	No	N/A
		Automatic	3.62	0.59	16%	No	N/A

<u>2001/2002 Season</u>

No changes were made to the methodology for the trial this season. The only observed difference was a significant increase in the presence of weeds such as paspalum (water couch). Monitoring continued to investigate if the trial section of drain remained a nutrient source from the previous year or reverted back the nutrient sink indicated in the first year. As drought conditions persisted throughout the season, the flows were particularly low and the drain was often dry during the winter. No significant flow events were recorded.

Though flow measurement on Teague's inlet indicated that it had little influence, a site inspection revealed that there was leakage (a constant trickle flow) through the inlet which was not being recorded by the monitoring.

The dry conditions resulted in only 25 days of manual sampling. The automatic data has provided a much larger data set. The results for the 2001/2002 season are included in **Table 4.16** and **Table 4.17**.

Table 4.16: Relative Nutrient Removal due to the Trial Section 2001/2002

Nutrient	Measure	Method of Collection	Sample Average Change	% Change	Statistically Significant Reduction	95% Confidence limits
Total Phosphorus	Concentration (mg/L)	Manual	-0.21	-12%	No	
		Automatic	-1.35	-68%	Yes	± 0.40
	Loads (kg/d)	Manual	0.16	7%	No	N/A
		Automatic	-1.59	-68%	Yes	± 0.59
Total Nitrogen	Concentration (mg/L)	Manual	-0.19	-5%	No	N/A
		Automatic	-1.07	-31%	Yes	± 0.49
	Loads (kg/d)	Manual	0.12	2%	No	N/A
		Automatic	-1.28	-34%	Yes	± 0.64

Table 4.17: Trial Section in Isolation Nutrient Reduction 2001/2002

Nutrient	Measure	Method of Collection	Average value at Station 405760	Average Change	% Change	Significant Reduction	95% Confidence Limits
Total Phosphorus	Concentration (mg/L)	Manual	1.64 mg/L	-0.20	-12%	No	
		Automatic	2.37 mg/L	-0.67	-28%	Yes	± 0.26
	Loads (kg/d)	Manual	2.54 kg/d	0.04	2%	No	
		Automatic	2.80 kg/d	-0.64	-23%	Yes	± 0.31
Total Nitrogen	Concentration (mg/L)	Manual	3.88 mg/L	-0.18	-5%	No	
		Automatic	3.80 mg/L	-0.47	-12%	Yes	± 0.26
	Loads (kg/d)	Manual	5.84 kg/d	-0.20	-3%	No	
		Automatic	4.13 kg/d	-0.80	-19%	Yes	± 0.36

The results for this season clearly show the influence of the inlet on the trial. The automatic sampling of nutrients provided statistically significant reduction of both phosphorus and nitrogen for both concentrations and loads. These results are entirely due to high nutrient recordings at Station 405760. These results again confirm the effect of Teague's inlet on data from the middle station. Due to this influence the relative nutrient removal is not valid for the automatic data, however the reduction of nutrients across the trial section in isolation stills shows significant for both phosphorus and nitrogen.

The manual samples, which were not taken if the inlet was flowing, however only showed small reductions in concentrations of nutrients and a small increase in nutrient loads. None of the manual results are statistically significant.

4.4.2 Turbidity and Suspended Solids Reduction

The turbidity results for each season are detailed below in **Table 4.18**

Table 4.18 Seasonal Changes in Turbidity

Year	Method of Sampling	Control Average Change (NTUs)	Control: % Change	Trial Average Change (NTUs)	Trial: % Change	Relative: % Change	Significant Reduction	95% Confidence Limits (NTUs)
1999/2000	Manual	27	36%	-66	-93%	-129%	Yes	± 64
	Automatic	9	38%	-16	-46%	-84%	Yes	± 10
2000/2001	Manual	2	4%	-3	-5%	-9%	No	N/A
	Automatic	6	11%	0	0%	-11%	Yes	± 7
2000/2002	Manual	-1	-3%	-6	-26%	-23%	No	N/A
	Automatic	37	134%	-40	-62%	-196%	Yes	± 14

The turbidity results show a reduction in turbidity in trial section relative to the control section for all years for both sampling methods. The results show that in the first and third years turbidity was drastically reduced whereas much smaller changes occurred in the 2000/2001 season.

The collection of suspended solids data did not effectively commence until the 2000/2001 season (only seven samples in the 1999/2000 season) thus **Table 4.19** only lists the results for suspended solids for two seasons.

Table 4.19 Seasonal Changes in Suspended Solids

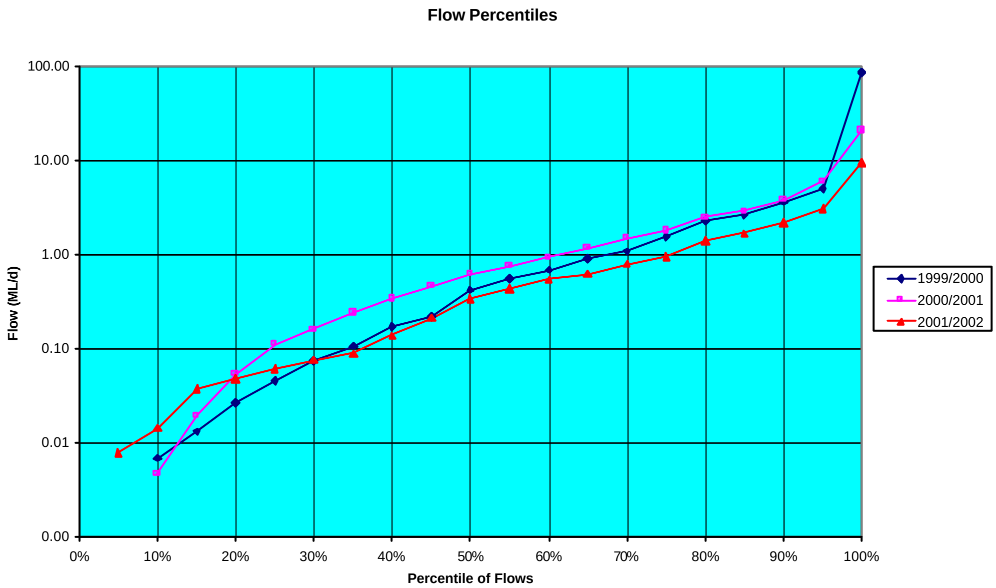
Year	Measure	Sample Average Change		% Change			Statistically Significant Reduction	95% Confidence limits
		Control	Trial	Control	Trial	Relative		
2000/1	Concentrations (mg/L)	-6.7	-11.9	-6%	-10%	-4%	No	N/A
	Loads (kg/d)	-5.5	-23.4	-3%	-11%	-8%	No	N/A
2001/2	Concentrations (mg/L)	-27.5	-14.1	-36%	-18%	18%	No	N/A
	Loads (kg/d)	-18.6	-11.4	-16%	-12%	4%	No	N/A

Table 4.19 shows in 2001/2 that though there has been a reduction of suspended solids through the trial section, a greater quantity of suspended solids was reduced by the control section. This result is discussed further in **Section 5.3.1**.

4.4.3 Nutrient Removal and Drain Flow

During the period of monitoring from 16 November 1999 to 25 May 2002, the flows were typically within the baseflow region of 0 to 3 ML/d. **Figure 4.5** shows the percentile of the flows and the variation of flows from season to season. The chart uses a logarithmic scale for the y-axis and illustrates that for all three seasons 95% of the flow was less than 10ML/d. The chart also shows season 2001/2002 was the driest.

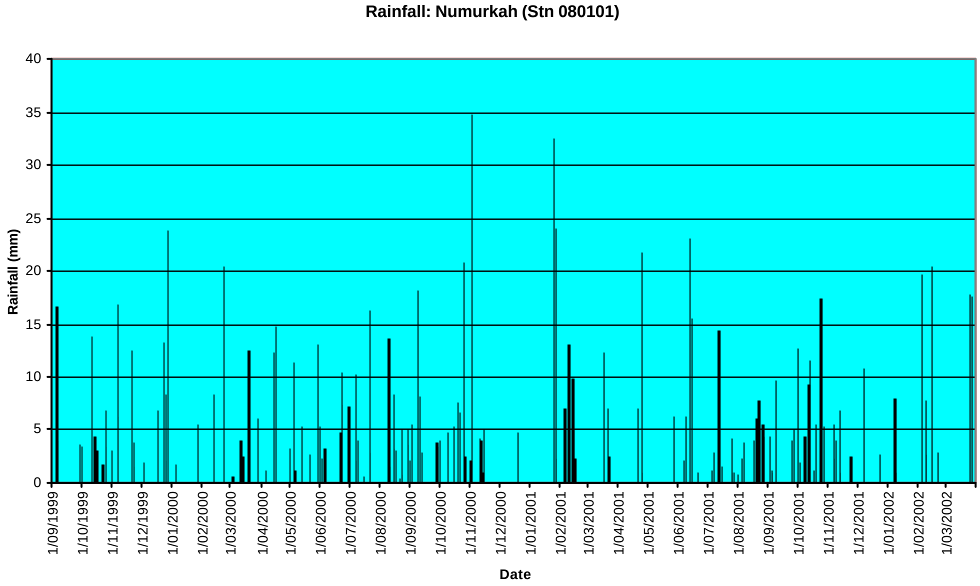
Figure 4.5 Percentile of Flows



4.5 Impacts on Drain Operation

The major feature of drain operation expected to be effected by the in-line wetlands is the serviceability to irrigators. The drain cross section was widened to allow for a reduction in drainage capacity due to the wetland. As the plants were expected to flatten in high flows, the change to the capacity should not be significant. Unfortunately there was only one high flow (greater than 20 ML/d) that has been investigated. This is due to the dry conditions which persisted throughout the project (See **Section 5.1.4**). The rainfall over the duration of the trial is shown below in **Figure 4.6.**

Figure 4.6 Rainfall during the Trial



The one event was a 35mm rainfall on the 1 November 2000 and produced flows rated by Theiss at 32ML/d (Note modelling indicated the flow could have been as high as 60ML/d). Little flow was observed through the vegetation and the majority of water flowed along the berms (See **Figure 4.7** & **Figure 4.8**).

This event has raised concerns about the detrimental effect of the wetland on drainage capacity but unfortunately no events large enough have occurred to investigate the serviceability issues further.

Figure 4.7 Trial Site Looking Upstream 2/11/00

Figure 4.8 Trial Site Looking Downstream 2/11/00

5. Discussion of Results

The interpretation of the results documented in **Section 4** requires some discussion on the relative methods of the monitoring techniques and the integrity of the data due to external influences. Discussion is also required about the various processes which are occurring in the drain to influence the results.

5.1 General Discussion

There were a number of factors that had an influence on the results that require discussion before any interpretation of the results. These factors include:

- The influence of Teague's inlet;
- The two types of sampling: manual and automatic;
- The persistence of drought conditions and the subsequent lack of medium to high flows during the trial period;
- The relative importance of loads and concentrations.

5.1.1 Teague's Inlet

Following the concerns about Teague's inlet during the first year of the trial the measures discussed in **Section 3.3.1** were undertaken. This successfully eliminated the influence of the inlet in the 2000/2001 season when flows through the drain were relatively constant. However in 2001/2002, the drain stopped flowing for substantial periods of time. Often, during these periods, water would trickle through the inlet mixing with the pool of water upstream of the aquatic plants. The average nutrient concentrations in the water from Teague's inlet were 3.22 mg/L (Standard Deviation 2.05 mg/L) for Total Phosphorus and 7.41 mg/L (Standard Deviation 4.3 mg/L) for Total Nitrogen. These are at least 50% higher than the average flows through the drain and over time would, increase drainage nutrient concentrations during periods of no flow. This is apparent in the results for season 2001/2002. The manual data which was not collected if the inlet was trickling indicated there was no change in nutrients across the control section. The automatic data however had an increase of 19% for total nitrogen and 40% for total phosphorus. The flow monitor did not register the trickle flows through the inlet and the extent of the impact on the automatic data collected from the control section could not be quantified. This uncertainty means that the relative changes in nutrient concentrations and loads can not be determined with confidence.

It is for these reasons that to gauge the relative value of the trial section, the results from the manual data are preferred to those from the automatic sampling. The automatic data is still considered to be valuable when considering the performance of the trial section in isolation.

5.1.2 Lack of Correlation between Manual and Automatic Data

As stated in **Section 3.1,** two sampling methods were undertaken: manual sampling and automatic sampling. A direct comparison of the results between the two methods shows poor correlation. There is bound to be some natural variability given the automatic and manual samples are not taken at the same time and the drain flow environment is not necessarily consistent (ie nutrient levels could change over short periods of time) however general trends should be similar to enable confident conclusions about the behaviour of the drain. Teague's inlet discussed above is one reason for the variability but this should not effect measurements across the trial section in isolation. The lack of correlation is the result of a combination of errors in experimental design, sampling (eg different sampling times) and laboratory analysis.

5.1.3 Loads or Concentration

The ability of the aquatic plants to remove nutrients has been analysed with regards to concentrations and loads. However the two measures tend to produce inconsistent results. For example **Table 4.6** shows that whilst the manual samples indicate a phosphorus concentration reduction of 11%, phosphorus loads are increasing by 6%. Although the relative importance of each measure depends on the time of year and flows in the receiving waterway, it was concluded after discussions with the project working group that loads are the more important of the two measures. The trial drain has concentrations around 2 mg/L of total phosphorus and as algal blooms are triggered by concentrations significantly lower than this (pers com P Breen 13/6/01), concentration reductions may not provide worthwhile water quality benefits.

5.1.4 Lack of High Flow Data

There were very few flows greater than 10 ML/d. This constrains the application of the trial results to a small range of flow conditions. However sufficient data was collected to:

- verify the starting hypothesis that in-line wetland systems would have limited ability to achieve significant nutrient reduction unless protected from higher flow events;
- provide an indication of the limiting hydraulic/hydrologic loading that could be applied to a wetland system for nutrient removal in irrigation drains similar to the trial site (hence allowing wetland areas and inflow limits on other similar drains to be scaled from the trial);
- indicate the potential reduction in nutrient loads that could be achieved by application of suitably scaled wetland systems in appropriate locations.

A statistical problem produced by few large flows is the presence of outliers. To assess nutrient load reductions through the trial involves multiplying the concentration by the flow. Thus the few large flows tend to create outliers which skew the load results, particularly the averages. More high flow data points would reduce the effect of a single event and provide more reliability for the data measured at the high flow ranges. The analysis performed for this study has removed these outliers, hence does not include any data from events greater than 26 ML/d.

5.1.5 Statistician's Reports

At the working group meeting on the 13th of June 2001 it was suggested to employ a Biometrician to review the data analysis by Sinclair Knight Merz. The subsequent report is included in **Appendix C**. The biometrician used time series analysis of the difference between stations. (ie Station 405760 – Station 405759 and Station 405761 – Station 405760) rather than the regression analysis used by Sinclair Knight Merz at the time. Though the biometrician made no attempt to quantify the changes in the trial, his analysis confirmed Sinclair Knight Merz's general findings for that season. These findings were that phosphorus was being exported in the trial section and that the amount exported was related to the flowrate.

The data analysis methodology which has been included in this report was the result of discussions with Dr Rory Nathan, a hydrologic statistician from Sinclair Knight Merz.

5.1.6 Flow Data Reliability/Influences

Thiess have acknowledged that the rating at the trial site has changed considerably with time as the plants in the trial section have matured and grown, trapping sediments and resulting in backing up in the control. This may introduce some uncertainties in the measurement of nutrient loads, however Thiess have regularly modified the rating to account for the changes.

5.2 Investigation of Wetland Performance at Low Flows

Throughout the trial it was evident that the wetland was more effective at removing nutrients at low flows. For example the overall results indicate that total phosphorus concentrations were being reduced yet total phosphorus loads were being exported. To enable such a result nutrient concentrations must be increasing through the trial section at higher flows and decreasing at the lower flows.

Figure 5.1 is a plot of the change in total phosphorus versus flow. Though there is a lot of scatter, the plot indicates that nutrients were generally removed at 2.5 ML/d or lower and exported at flows higher than 2.5 ML/d.

Figure 5.1 Change in Total Phosphorus Concentrations versus Flow

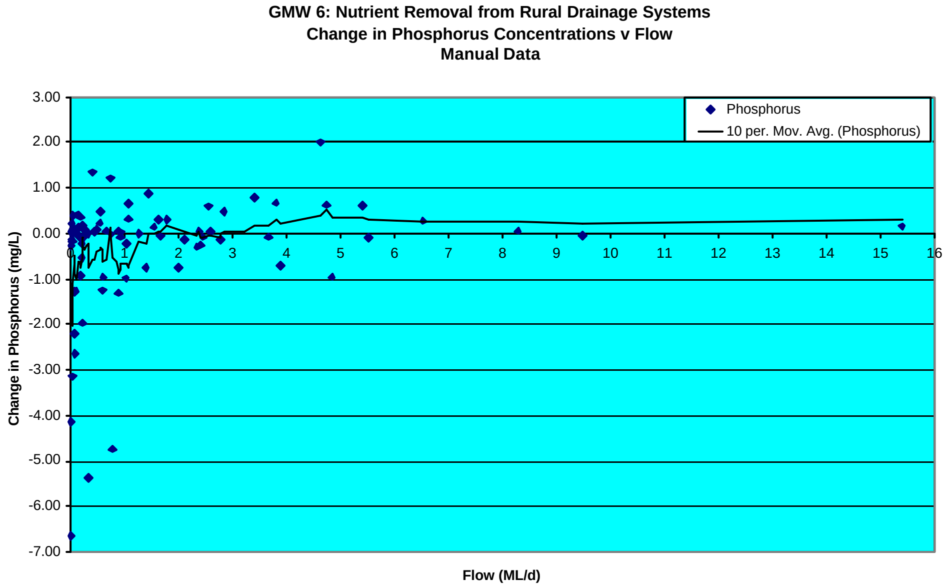


Figure 5.2 Change in Total Nitrogen Concentrations versus Flow

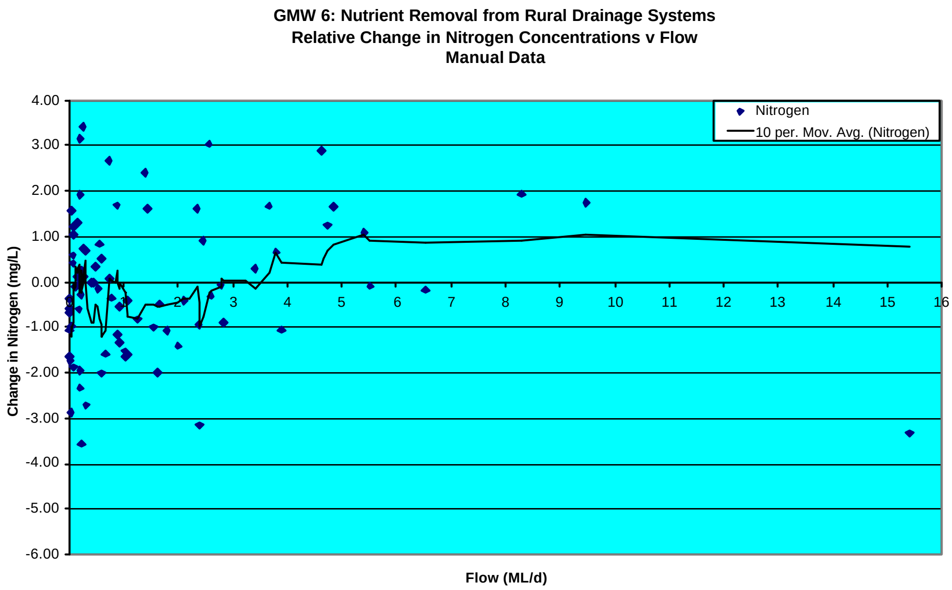


Figure 5.2 illustratres total nitrogen change as flow increases. As both the nitrogen loads and concentrations are being reduced, the relationship between flow and nutrient removal is not as clear.

Based on these results nutrient removal was investigated when the flow was 2.5 ML/d or less and presented in **Table 5.1** and **Table 5.2.**

Table 5.1 Relative Nutrient Removal, Flows <2.5 ML/d, 1999-2002

Nutrient	Measure	Method of Collection	Control Section Change	Trial Section Change	Average Change	% Change	Statistically Significant Reduction	95% Confidence limits
Total Phosphorus	Concentration (mg/L)	Manual	0.22	-0.29	-0.51	-29%	Yes	± 0.37 mg/L
		Automatic	0.40	-0.23	-0.63	-34%	Yes	± 0.19 mg/L
	Loads (kg/d)	Manual	0.05	-0.09	-0.14	-11%	No	N/A
		Automatic	0.31	-0.17	-0.48	-31%	Yes	± 0.18 kg/d
Total Nitrogen	Concentration (mg/L)	Manual	-0.01	-0.37	-0.36	-10%	No	N/A
		Automatic	0.17	0.01	-0.16	-6%	No	N/A
	Loads (kg/d)	Manual	-0.04	-0.26	-0.22	-10%	No	N/A
		Automatic	0.31	-0.12	-0.43	-17%	Yes	± 0.33 kg/d

Table 5.2 Trial Section in Isolation; Nutrient Removal, Flows <2.5 ML/d, 1999-2002

Nutrient	Measure	Method of Collection	Average value at Station 405760	Average Change	% Change	Significant Reduction	95% Confidence Limits
Total Phosphorus	Concentration (mg/L)	Manual	1.84	-0.29	-16%	Yes	± 0.18 mg/L
		Automatic	2.06	-0.22	-11%	Yes	± 0.22 mg/L
	Loads (kg/d)	Manual	1.18	-0.09	-7%	Yes	± 0.10 kg/d
		Automatic	1.58	-0.17	-11%	Yes	± 0.10 kg/d
Total Nitrogen	Concentration (mg/L)	Manual	3.62	-0.37	-10%	Yes	± 0.27 mg/L
		Automatic	3.18	-0.02	0%	No	N/A
	Loads (kg/d)	Manual	2.27	-0.26	-12%	Yes	± 0.20 kg/d
		Automatic	2.17	-0.12	-5%	No	N/A

A comparison of these results with those from **Table 4.5** and **Table 4.6** shows:

- There has been only minor alterations to the change in nutrients through the control section for flows less than 2.5 Ml/d compared to the entire data set;
- There has been an increase in the reduction of nutrients through the trial section for most of the measures particularly for manual phosphorus loads. Nitrogen did not show such a significant change. The change in the automatic nitrogen load figures is due to one event on the 30/12/1999.
- The results are more likely to be statistically significant because the variation of the data in the lower flow ranges is not so great particularly for the loads.
- All the results for the manual data for the trial section in isolation show the nutrient loads and concentrations are significantly lower downstream of the trial.
- Whilst the manual data for nitrogen indicates the concentrations and loads are significantly lower, the automatic data indicates little change.

Whilst the results for nitrogen are inconsistent and inconclusive there is an indication that nitrogen is being removed. This fact and the fact that phosphorus is consistently and significantly lower downstream of the trial shows that there may be value in offline wetlands which are not exposed to the higher flows. This would involve the construction of a separate parallel channel and controls to direct low flows to the wetland and whilst retaining high flows in the drain or alternatively constructing a high flow bypass around the section of drain converted to a wetland.

Before extrapolating this data to other wetlands it should be noted that it is the velocity not the discharge which is the controlling parameter. At the Invergordon site a discharge of 2.5 ML/d corresponds to a velocity of 0.035 m/s. Based upon extensive experience with other wetland treatment systems, it is highly probable that improved performance (ie. Higher inflows for the same treatment efficiency or improved efficiency for the same inflow limit) could be achieved by modifying the length/width ratio with the same wetland area. Increasing the width of the flow reduces the velocities and assists with the filtration and deposition process.

Issues involved with the construction of an offline wetland include:

- extra cost (See section **5.2**) of earthworks and control structures;

- strategic site selection to minimise the cost of excavation and structures. ;
- land acquisition costs;
- grasping opportunities for multi-purpose design and use of sediment traps, wetlands and control works for farm re-use, enhanced environmental values and increased biodiversity.

An aspect for further research may be to sample the silt trapped in the trial section of the drain and determine the particle size and composition. This would assist with the design of sediment traps and wetlands needed to remove sediments and nutrients in areas with different soil types and flows.

5.3 Water Quality Parameters

An assessment of the water quality parameters and the processes behind the results that are detailed in **Section 4** are provided below. Both the seasonal changes and the results for the entire three year period have been discussed.

5.3.1 Turbidity and Suspended Solids

The reduction in turbidity and suspended solids is evident. The analysis of the manual samples in **Table 4.8** shows an average reduction of 26% across the trial section. The water entering the trial section was on average 46 NTU's whilst the average turbidity of water leaving the trial was 34 NTU's. In addition, the water downstream of the trial appears visibly cleaner. This is particularly obvious during periods of reasonable flow when the turbid water from a tributary drain mixes with the relatively clear water from the trial section (See **Figure 5.3**).

Figure 5.3: Junction of Dr 8/1A/12 and 1/8/1A/12

The turbidity results show greater reductions in 1999/2000 and 2001/2002 seasons than in the 2000/2001 season. The turbidity reduction in the first year is worth highlighting. It is immediately after construction before vegetation is established that a drain is particularly susceptible to erosion. Yet the batter stabilisation and bed vegetation not only prevented the modified drain section from adding the sediment load but actually reduced the load from the catchment.

Statistical analysis of the results has been unable to show any relationship between suspended solids or turbidity with flow. Such a result may be expected in catchments where soils and surfaces are disturbed and exposed. Soils in this condition will deliver turbid runoff regardless of the magnitude of the flow event.

Suspended solids shows reductions across the trial section for both seasons data was collected. In season 2001/2002, the control section reduced more suspended solids than the trial. This is likely to be the result of a combination of low flows and sedimentation within the pool upstream of the trial section. Due to the sequential nature of the control and trial sections, suspended solids entering the trial section during low flows would consist of fine particles that did not settle upstream in the control section. As a result the percentage reduction based upon mass could be expected to be less than the control. (i.e. the heavy particles have already settled out in the control section pool.)

5.3.2 Phosphorus

The comparison of the trial section to the control section for total phosphorus indicates a reduction of both concentrations and loads over the three years in the trial section. Concentrations were significantly reduced. The sample average reduction shows a reduction by an average of 23% and the application of confidence limits shows that with 95% confidence, the true (or population) average is at least a reduction of 0.10 mg/L (5%). There was, however, a slight increase in total phosphorus loads as water passes through the trial section.

The analysis of the trial section in isolation provides similar results. Though the average concentration reduction for both the manual and automatic samples is only 10%, the hypothesis that phosphorus is being reduced is still statistically significant. The analysis of the loads across the trial section in isolation indicates an increase in total phosphorus of 0.25 kg/d (8%) for manual samples and a decrease of 0.20 kg/d (7%) for automatic samples. This can be explained by particulate phosphorus from the whole catchment being trapped in the trial section during low flows. The phosphorus is accumulated in small, low density particles. During occasional medium to high flow periods any unconsolidated particles are remobilised and exported from the trial section. This is the same process that occurs in lotic systems.

The hypothesis, made at the beginning of the trial, that phosphorus would be reduced by filtration and deposition is supported by several findings:

- the data (see **Table 5.3**) shows 67% of the total phosphorous concentration reduction and 83% of total phosphorus loads (see **Table 5.4**) was due to insoluble P or sediment P. Note phosphates were only measured for the manual samples;
- the reduction of total phosphorus occurred in the second and third years of trial once the plants had reached maturity;
- the reduction of total phosphorus tended to occur during periods of low flows when sediments are more prone to removal by filtration and deposition;

- though the results showed a significant reduction for the concentration of phosphorus, the results for the loads are inconsistent. The manual data shows an increase but the automatic data shows a significant decrease. This could be due to the fact that the manual sampling was less likely to investigate as many low flows as the automatic sampling and therefore less times when insoluble phosphorus will be filtered or deposited.

Table 5.3 Breakdown of Phosphorus Concentrations: Manual Samples

	405760	405761			
	(mg/L)	(mg/L)	Δ	%Δ	%of ΔP
Total Phosphorus (TP)	1.89	1.70	-0.184	-10%	
Phosphates (FRP)	1.05	0.99	-0.062	-6%	33%
Sediment P (TP - FRP)	0.84	0.72	-0.123	-15%	67%

Table 5.4 Breakdown of Phosphorus Loads: Manual Samples

	405760	405761			
	(kg/d)	(kg/d)	Δ	%Δ	%of ΔP
Total Phosphorus (TP)	3.08	3.33	0.25	8%	
Phosphates (FRP)	1.87	1.91	0.04	2%	17%
Sediment P (TP - FRP)	1.21	1.42	0.21	17%	83%

5.3.3 Nitrogen

Table 4.5 shows there is a reduction in total nitrogen for all the measures and sampling methods when comparing the trial section to the control of 3% - 8% but that none shows a statistically significant reduction at a 95% confidence limit. When considering the trial section in isolation (refer **Table 4.6)**, the manually sampled concentrations and loads are significantly lower downstream of the trial. Concentrations have been reduced by 8% and loads by 6%. The automatic data doesn't show reductions of either nitrogen concentrations or loads.

Similar to the change in phosphorus, the nitrogen reduction is greater during periods of low flow. The reduction of manually sampled nitrogen loads is not statistically significant when analysing all flows but is significant for flows less than 2.5 ML/d (See **Table 5.2**). The automatic data results whilst remaining not significant show a greater reduction for low flows. There seems to be two processes involved in the reduction, filtration/sedimentation and some nitrification. Both processes are more effective during low flows.

The breakdown of the nitrogen concentration reduction is included in **Table 5.5**. Total nitrogen (TN) consists of Total Kjeldahl Nitrogen (TKN), Nitrates (NO_3) and Nitrites (NO_2). NO_x is nitrites plus nitrates. Ammonia (NH_4) plus Organic N are combined in the Total Kjeldahl Nitrogen measurement. The breakdown of the reduction shows the reduction in nitrogen is almost entirely due to TKN. Of the TKN reduction, ammonia (NH_4) accounts for 60% and organic N 40%. The nitrification process converts ammonia to nitrates and the reduction of ammonia with a corresponding increase in nitrates indicates this process may be occurring. **Figure 5.4** supports this theory as the chart shows the decreases in ammonia corresponding with increases in nitrates particularly at times of low flow.

Figure 5.4 Ammonia and Nitrates over time

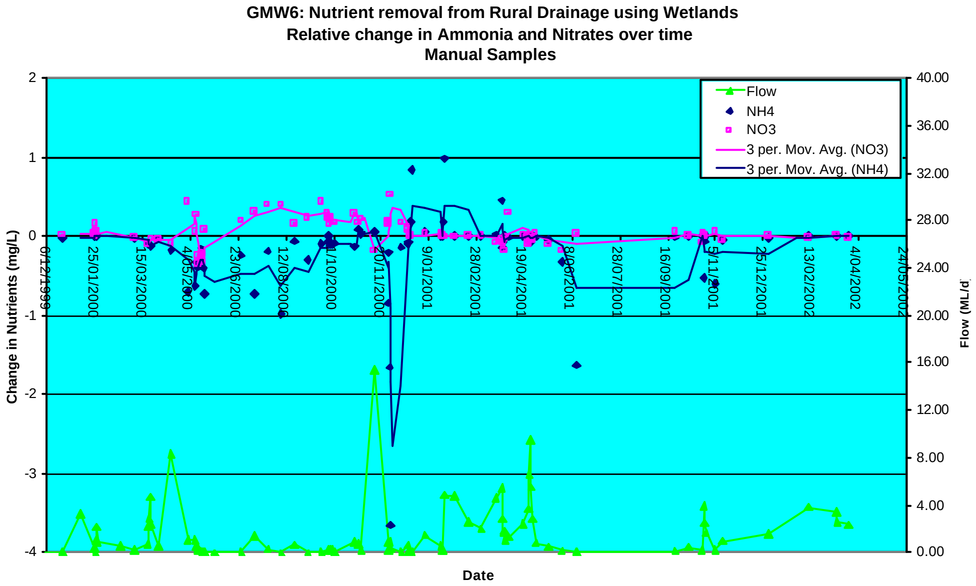


Table 5.5 Breakdown of Nitrogen Concentrations; Manual Samples

	Station		Δ	%Δ	% of Δ TN	% of TK-N
	405760	405761				
	(mg/L)	(mg/L)				
TN	3.616	3.339	-0.277	-8%		
TK-N	3.315	3.015	-0.300	-9%	-108%	
NO_2	0.037	0.021	-0.016	-43%	-6%	
NO_3	0.258	0.303	0.045	17%	16%	
NOx	0.295	0.324	0.029	10%	10%	
NH_4	0.468	0.287	-0.181	-39%	-65%	60%
Organic N	2.847	2.727	-0.119	-4%	-43%	40%

Table 5.6 shows that nitrogen loads are not showing the same reduction in Ammonia nor an increase in Nitrates. This is possibly due to the fact that nitrification is a slow process and at times when there are greater flows and thus greater changes in loads, there is not enough time for nitrification to occur.

Table 5.2 shows that nitrogen reductions tend to increase for flows which are less than 2.5 ML/d. For concentrations of total nitrogen, the increased reduction divided among the components of total nitrogen.

Table 5.6 Breakdown of Nitrogen Loads

	Station		Δ	%Δ	% of Δ TN	% of TK-N
	405760	405761				
	(kg/d)	(kg/d)				
TN	5.861	5.477	-0.384	-7%		
TK-N	5.589	5.310	-0.278	-5%	73%	
NO_2	0.051	0.034	-0.017	-34%	4%	
NO_3	0.319	0.282	-0.037	-12%	10%	
NOx	0.371	0.316	-0.055	-15%	14%	
NH_4	0.730	0.681	-0.049	-7%	13%	18%
Organic N	4.859	4.630	-0.229	-5%	60%	82%

That 82% of the nutrient load removal is organic N indicates a large proportion of the nutrient load removal is filtration and sedimentation.

For flows less than 2.5 ML/d, the decrease in nitrogen across the trial is 12%, 5% higher than that shown in **Table 5.6**. A large proportion of the change is due to ammonia which decreased 39% across the trial for flows below 2.5 ML/d compared to the 7% shown above.

5.4 Trial Section in Catchment Context

To put the extent of the trial section in perspective, it is worth comparing it to the catchment that it serves. **Table 5.7** shows the length and the total catchment area for this drain upstream of the trial section.

Table 5.7 Comparison of Trial Size with Catchment

	Upstream Catchment	Trial Section	% (Trial to Catchment)
Drain Length	7550 m	800 m	10.6
Approximate Area	8,600,000 m^2	1,600 m^2	0.02

This data reveals the area of the vegetated drain bed relates to only 0.02% of the total catchment area. The length of the trial section is about one tenth of the upstream length of the main and spur drains feeding into it.

Further studies would be required to determine the extent to which water quality changes observed in this trial could be extrapolated to determine whole of catchment impacts in other areas.

6. Costs

The construction of the Invergordon in-line wetland was $38,500 for 800 m of drain. The breakdown of this amount is included in **Table 6.1.**

Table 6.1: Breakdown of Construction Costs

Item	Cost ($)	Cost ($/m)
G-MW Construction Unit	14,826.75	$18.53
Survey	12,350.23	$15.44
Signs	840.00	
Hydromulching	3,128.00	$3.91
Vegetation	6,660.00	$8.33
Trial Vegetation	635.00	
Total	**38,439.98**	

In other in-line wetland sites trial vegetation costs would not be included thus the actual cost to establish 800m of wetland would be $36,965. As stated earlier the trial was established in October 1999 and therefore these costs would need to be adjusted to represent current prices. The survey cost would also be significantly lower for future wetlands as it would be part of the overall drain survey. The survey costs detailed above included the establishment of 10 temporary benchmarks for future reference.

The hydromulching cost was $0.68/m^2$ for 4600m. The cost of the aquatic vegetation was approximately $1.00 for each seedling and 6300 were required for the trial section.

An offline wetland or high flow bypass have been discussed as options (See **section 5.2**). The preferred approach would be to construct the wetland offline so as to take advantage of higher treatment efficiencies offered through best practice design.

Assuming the cost to construct a channel for the wetland is the same cost as a traditional drain, the extra capital cost to reduce nutrients includes the control structures and the new channel and are detailed below:

Item	Quantity	Unit	Rate $	Amount $
Extra drain length	1	km	40,000	40,000
Low Level Weir	1	item	10,000	10,000
Piped Culvert	1	item	20,000	20,000
Hydromulching	800	m	3.91	3,128
Vegetation	800	m	8.33	6,660
Total (approx)				**80,000**

Note: Costs are to provide an indication only. The capacity and cross sectional area for the drain would be required for a more accurate estimate.

The extra maintenance costs would be approximately $700/year based upon the standard drainage maintenance cost for primary drains in the Shepparton Irrigation Region

Based on the above costs and using the nutrient reductions from **Table 5.1** (the relative data from using manual samples is most accurate), the Net Present Value per kilogram of nutrient removed can be calculated for comparison to other treatments. The calculations are included in **Appendix G**. Based over 100 years at a discount rate of 6% **Table 6.2** shows the cost in terms of nutrient removal in terms of $/kg/yr.

Assumptions made in the analysis are:

- That wetlands will need to be desilted and revegetated every 30 years;
- That the structures will need to be replaced every 60 years;
- That structure maintenance is 0.75% of capital cost;

Table 6.2 Nutrient Removal Cost ($/kg/year)

Nutrient	Average $/kg/yr	95% Range	
		Minimum	Maximum
Total Phosphorus	$1,994	$963	#N/A
Total Nitrogen	$1,269	$465	#N/A

Note: #N/A means nutrients increased

These figures have been calculated for comparison against other techniques of nutrient removal (for example those given in the GBWQWG Irrigation Issues paper) but should be used with caution. Whilst the figures have been based upon the average nutrient removal, there is substantial variation in the data and it is possible further research may reveal the cost per kilogram of nutrient removed by off-line wetlands is quite different.

7. Recommendation for Future Trials

Additional research is needed to fully assess the benefits and costs of wetlands in irrigation drainage systems. Future areas of research include:

- Assessment of the cost effectiveness of different techniques to improve water quality. Wetlands in rural drainage systems are but one component of a nutrient management strategy and one which treats the symptoms rather than the causes. Other techniques include:

  i) reducing drainage of sediment and nutrients off farms (including modification of fertiliser and cropping practices as well as reducing water input volumes and improving on-farm design);

  ii) diverting drainage water back onto the farm;

  iii) batter stabilisation.

  Future trials would perhaps examine all the methods together and create comparisons in-terms of $/kg/year of nutrient removed with that achieved at Invergordon. From this investigation optimal solutions for an integrated system of nutrient removal using a variety of all three techniques could be developed. However there can be no doubt that reducing the nutrient inputs to the drainage system will prove far more cost effective than treatment thereafter.

- Assessment of the implications of the trial site on the hydraulic capacity of the drain and drain maintenance costs. A result couldn't be determined during this trial because of the small range of flow events. If the wetland is to be built off-line, drainage capacity will be maintained however the continuation of water level and flow monitoring would provide valuable information if agreement from affected parties could be obtained.

- Assessment of the potential for use of excavated silt traps in conjunction with the aquatic plants to further enhance the sediment and nutrient removal. This could be commenced through an investigation into the type and size of material being trapped at Invergordon.

- Assessment of where the nutrient removal is occurring. Are nutrients removed at a constant rate throughout the length of the trial thus a rate of nutrient removal in kilograms per metre is applicable? The survey results show most of the sedimentation occurred in the first 400 m of the trial but the results could not prove a direct relationship between sedimentation and nutrient removal.

- Development of design criteria for treatment facilities if significant nutrient reduction is demonstrated to be cost-effective. This includes issues such as the required width and length of the treatment facility to suit different flow conditions, soil types and nutrient levels. The long thin wetland is the least efficient form. A wider system of equal area would be far more efficient. As this project only investigated nutrient removal over one length ie. 800 m it was not possible to interpolate nutrient removal per unit length of wetland.

- Any benefits that may be derived from harvesting the wetland plants.

There have been many lessons learnt from this trial which would be of value for future projects:

- Keep the trial section and the control section sufficiently apart so that the trial does not have an effect on the control section. Where budgets allow, typical experimental design would have a series of test and control sites in various drainage systems;
- Completely remove the other potential point nutrient sources such as local irrigation drainage inlets or suitably monitor these inflows;
- For nutrient removal efficiency, wetland treatment systems should be built offline with inflow limits appropriately set to protect against scouring of retained pollutants;
- Where wetland plants are used on-line within drainage systems the plants selected should not reach a height that could significantly affect the capacity and level of service of the drain. Though the effect of the tall clubrush on capacity has not been tested as yet at Invergordon, a smaller plant may be more appropriate. Examples of suitable plants may be Marsh Club Sedge (*Bolboschoenus Medianus*) for the wetter or in-line drainage applications and Common Spike Rush (*Eleocharis Acuta*) for applications where the wetland may be dry for short periods of time (pers com Paul O'Connor 5/12/02);
- The importance of knowing the time that the automatic-samples are taken.
- Plants grown in tubestock are more successful than viro-cells (seedlings) as the latter can be affected by high drain flows.

8. Conclusions and Recommendations

"The Nutrient Removal from Rural Drainage Systems using Wetlands" has reached completion following the collection of two and half years of data. The data collection and analysis has been quite intensive throughout this period and has resulted in a valuable and extensive data set.

The three project objectives listed in **Section 2.2** of the report can be summarised by two headings:

- Determining the effectiveness of wetland technology within drainage systems with respect to nutrient removal;
- Further design and implementation of nutrient mitigation measures within the Shepparton Irrigation Region with the potential to retrofit existing drains and modify design of new drains.

1. Determining the effectiveness of wetland technology within drainage with respect to nutrient removal

There were two aspects of nutrient removal to be explored:

- The stabilisation of the drainage system to prevent drainage infrastructure from contributing to drainage sediment and nutrient loads;
- The use of in-line aquatic plants to remove nutrients from the drainage water.

i) The stabilisation of the drainage system to prevent drainage infrastructure from contributing to drainage sediment and nutrient loads

The trial section of Shepparton Drain 8/1A/12 has been successfully stabilised. Through a combination of the batter stabilisation techniques and the in-line wetland, erosion of the batters and the bed during the trial period was prevented. This was proven through two investigations:

- The cross sectional survey data which showed a build up of silt in the first 400m of the trial and little change to the cross section for the remaining 400m
- The turbidity reduction through the trial section of approximately 30% and suspended solid load reductions of 20%.

Though there were few high flow events, the few that did occur had the potential to cause erosion particularly an event early in the trial when the drain was most susceptible. However the batter stabilisation and in-line wetland prevented the drain from adding to sediment loads and there was only minor visible erosion.

The potential has clearly been demonstrated for the use of in-line aquatic plants to reduce suspended sediment and turbidity even at high flows.

ii) The use of in-line aquatic plants to remove nutrients from the drainage water

The manual sampling results detailed **section 4.3.3** provide a summary of the performance of the in-line wetland over the duration of the trial. These figures indicate:

- an average reduction in TP concentrations of 23%;
- an increase in TP loads across the trial section of 4%;
- an average reduction in TN concentrations by 6%;
- an average reduction in TN loads of 3%;
- an average reduction in turbidity of 31%;
- an average reduction of suspended solids concentrations of 6% and loads by 11%.

Though most of these results show reductions in nutrients and sediments, the further application of in-line wetland treatment similar to the trial in Shepparton Drain 8/1A/12 has not been proven in this study to be viable for nutrient reduction for the following reasons:

(i).The reduction of nutrient is not statistically significant

The reduction in nutrients, with the exception of phosphorus concentrations, is not large and neither is the nutrient concentration significantly lower (95% confidence) downstream of the trial.

(ii).Limited range of flows during the trial

The small variation in flows through the drain during the trial period, limit the conclusions that can be drawn about the effectiveness of the trial. It shows benefit for wetland technology for nutrient removal where inflow could be limited to less than 2.5ML/d. Sediment loads and turbidity were both reduced.

Whilst the performance of an in-line wetland during higher flows could not be determined, the results and the sedimentation/filtration processes involved in the nutrient removal suggest that higher flows would result in the export of nutrients. This indicates quite clearly that wetland systems for nutrient reduction should be built off-line and protected from higher flow events or a high flow diversion channel constructed around the wetland.

(iii). Unproven impact on drain serviceability

The limited range of flows during the trial has made it difficult to confidently draw conclusions about the impact of the in-line wetland on drain operation. Serviceability during high flow events was intended to be maintained through the water pressure flattening the aquatic plants. The behaviour of the trial after the November 1 rainfall event of 35mm was recorded in detail. The plants did not flatten and the water flowed along the berms either side of the plants. This event indicated that the plants in this drain at least may not fully flatten in higher flow events. Therefore the plants have the potential to reduce serviceability. Unfortunately there were no other higher flow events to assist with confirmation of this hypothesis.

(iv). Unknown Impact on Drainage Maintenance Costs.

Drainage maintenance would be increased by the construction of in-line wetland plantings. A variety of weeds grew in the trial section including paspalum, cumbungi and typha. Spot spraying of weeds such as these would be a necessary part of the in-line wetland maintenance.

Whilst costs of such activities and monitoring has been estimated, there is currently insufficient data to confirm the need for, and cost of, other possible maintenance requirements such as plant harvesting, and sediment removal/reprofiling. It needs to be kept in mind that any method of treatment of water already within drains will require extra maintenance.

2. Further design and implementation of nutrient mitigation measures within the Shepparton Irrigation Region with the potential to retrofit existing drains and modify design of new drains.

Analysis of results of nutrient removal for low flows (less than 2.5 ML/d) provided positive results. Nutrient removal by the control section relative to the trial section was greater for all measurements and investigations of the trial section in isolation showed that nutrients were significantly lower downstream of the aquatic plants for manual concentrations and loads. These results support the proposal that for nutrient removal efficiency, wetland treatment systems should be constructed off-line with controls over the inflows and a high flow diversion.

When considering the value of an offline wetland the average nutrient reduction was between 10% and 29% relative to the control section. The estimated cost of removal of TP and TN from drainage using wetland treatment of the form and scale trailed at Invergordon is between $1,994/kg/year and $1,269/kg/year respectively (based upon 100 year life, @ 6% discount rate).

Improvements in treatment efficiency/ha of wetlands could be anticipated through the use of modified wetland length/width ratios compared with the trial section at Invergordon. Experiences with urban treatment wetland systems would provide valuable guidance in this regard.

Manual methods or software packages such as the MUSIC model (CRC for Catchment Hydrology, version 1, 2002) could be used to size and determine the treatment performance of stormwater treatment wetlands. However these methods are intended for urban drainage systems and modifications are required to adapt the runoff and nutrient generation parameters to rural conditions. These parameters could be estimated through the use of software such as RAFTS and empirical nutrient data collected from drains.

The location of offline wetlands within a catchment is dependent on catchment characteristics and land availability. For small catchments a single wetland at the end of the catchment may be appropriate. For larger catchments a distributed wetland treatment system may be more appropriate with wetlands located in the lower sections of sub-catchments.

Where wetland plants are used on-line within drainage systems, the plants selected should not reach a height that could significantly affect the capacity and level of service of the drain. Though the effect of the tall clubrush on drain hydraulic capacity has not been fully tested as yet at Invergordon, it is considered likely that a smaller plant such as Marsh Club Sedge (*Bolboschoenus Medianus*) may be more appropriate.

Wetlands in rural drainage systems are but one (important) component of a nutrient management strategy, but one which treats the symptoms rather than the cause of the problems. Reducing off-farm drainage of sediment and nutrients (including modification of fertiliser and cropping practices as well as reducing water input volumes and improving on farm drainage design) diverting drainage water back onto the farm, and batter stabilisation are all important features of a nutrient removal strategy. There can be no doubt that reducing nutrient inputs to the drainage system will prove far more cost effective than treatment thereafter.

Though in-line wetlands may not be significantly effective in nutrient removal, potential was shown for the use of in-line aquatic plants to retain sediment and reduce turbidity even at high flows. The most appropriate location for inline wetlands is in the upper reaches of catchments where the hydraulic loadings will be lowest and risk of scour reduced.

Thus the total drainage strategy could include in-line wetland plantings to reduce sediments and offline wetlands to reduce nutrients.

9. References

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Appendix A Locality Plan

Appendix B Water Quality Sampling Data

Appendix C Biometrician's Report

Appendix D SKM Statistician Report

Appendix E Photographic Record

Appendix F Project Survey

Appendix G Net Present Value Calculations

NPV of Wetland Costs

Filename: I:\WTAT\WT00157\004_Report\rep99_03.09\[D01JG_NPV.xls]NPV
Date: 25-Nov-02
Job No. WT00157.004
Compiled JG
Checked

Summary DISCOUNT RATE **4%** **NPV**
6% **NPV**
8% **NPV**

YEAR	E'WORKS REPLACE	E'WORKS MAINT	STRUCTURE REPLACE	STRUCTURE MAINT	VEGETATION CAPITAL	NPV
PV @ 4%	46,750	17,140	32,966	5,509	14,500	116,865
PV @ 6%	43,334	11,630	30,964	3,738	12,223	101,890
PV @ 8%	41,786	8,746	30,320	2,811	11,191	94,853

YEAR	E'WORKS REPLACE	E'WORKS MAINT	STRUCTURE REPLACE	STRUCTURE MAINT	VEGETATION CAPITAL	ANNUAL EXPEND
1	40,000	-	30,000	-	10,000	80,000
2	-	700	-	225	-	925
3	-	700	-	225	-	925
4	-	700	-	225	-	925
5	-	700	-	225	-	925
6	-	700	-	225	-	925
7	-	700	-	225	-	925
8	-	700	-	225	-	925
9	-	700	-	225	-	925
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89	-	700	-	225	-	925
90	15,000	700	-	225	10,000	25,925
91	-	700	-	225	-	925
92	-	700	-	225	-	925
93	-	700	-	225	-	925
94	-	700	-	225	-	925
95	-	700	-	225	-	925
96	-	700	-	225	-	925
97	-	700	-	225	-	925
98	-	700	-	225	-	925
99	-	700	-	225	-	925
100	-	700	-	225	-	925

From Table 5.1 R013JG_D118.DOC

Nutrient	Manual Change (kg/d)			Automatic Removal	
		Average	(kg/year)	(kg/d)	(kg/year)
Phosphorus	Minimum	0.01	3.65	-0.30	-109.5
	Average	-0.14	-51.1	-0.48	-175.2
	Maximum	-0.29	-105.85	-0.66	-240.9
Nitrogen	Minimum	0.16	58.4	-0.10	-36.5
	Average	-0.22	-80.3	-0.43	-156.95
	Maximum	-0.60	-219	-0.76	-277.4

Over a 100 year period $/kg/year using a 6% discount rate
NPV = $ 101,889.62

Nutrient	Average $/kg/yr	95% Range	
		Minimum	Maximum
Phosphorus	$1,994	$963	#N/A
Nitrogen	$1,269	$465	#N/A