THE STUDY OF POLLUTANT REMOVAL FROM URBAN STORMWATER USING A CONSTRUCTED WETLAND

HONOURS PROJECT

Department of Environmental Management

Victoria University of Technology

Name: Bram Mason

Supervisor: Dr Paul Lam

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1.0 ABSTRACT:

The purpose of this investigation was to examine the Shankland Valley Wetland for its ability to treat urban stormwater pollutants. Monitoring was conducted during two moderate storm events and two non-storm events. Pollutant concentration was measured at 24 hour intervals over periods of approximately one week.

Data indicated that the wetland was reducing some pollutants but seemed to increase the concentration of others. It was also found that Roxburgh Park seems to be the major contributor of pollutants to Shankland wetland. The receiving waterway, Yuroke Creek, had higher concentrations of phosphorus than the stormwater drains (SWD). Since phosphorus is a limiting nutrient for algal growth, it was found that it may be worth directing the flow of Yuroke creek through the wetland to reduce the concentration. Generally all other pollutants were lower in Yuroke Creek than the effluent from the wetland. Therefore, it is possible to say that during the period tested, the Shankland Wetland is situated in the correct position to treat pollutants so as they do not increase in Yuroke Creek and any downstream catchments. A brief macroinvertebrate study was also carried out for future reference.

2.0 INTRODUCTION

2.1 REASONS FOR STUDY

Stormwater run-off from roofs, parking lots, roadways, and landscapes impacts and degrades water quality and habitat values within existing water courses. The Shankland Wetland was primarily designed to reduce the bulk of the pollutants that enter the waterways during the first part of a storm. Shankland drain (from Meadow Heights) was considered to need the most amount of treatment, compared to the stormwater drain (SWD) from Roxburgh Park. This was because Roxburgh Park stormwater is ment to be treated to a reasonable extent by the wetlands north of Somerton road (appendix A).

A comparison has been made between American and Australian urban data to help identify monitoring needs in Australian urban catchments (Bufill M.C, 1993). From this particular article it was found that more monitoring and treatment was needed in the highly urbanised areas. Not many articles were found initially on the monitoring and treatment of urban runoff, then the chance arose to do a study on a newly constructed wetland servicing the Roxburgh Park and Meadow Heights housing estates with Melbourne Water. A more comprehensive literature search was carried out and the following was recognised. There is a lack of data on the treatment performance of constructed wetlands (Brix.H, 1993). A more thorough understanding of the transport and fate processes that are operative in constructed wetlands is needed (Tchobanoglous.G, 1993). There is one some questions concerning wetland treatment system longevity, the effects on wetland biota, and design innovations to enhance pollutant assimilation (Knight.RL, et al., 1993). Additional research is also needed to determine the adequate pollutant loading rates to assure the biological integrity of wetlands (Ethridge B.J, et al., 1993)

2.2 WATER QUALITY PROBLEMS

Urban stormwater runoff has been found to cause severe dissolved oxygen depletion, poor water clarity, and extensive algal growth, particularly during the summer recreational months in Washington (Bautista M.F.). Accumulative effects such as eutrophication and toxicity resulting from nutrient, heavy metal and organic micropollutant loadings are also associated with stormwater pollution (Ellis J.B., 1990; Jacobsen B.N, 1993; Segarra-Garcia R. and V.G. Loganathan, 1992).

The majority of stormwater pollutants mentioned above are associated with particulates as a result of adsorption to solids and other surface processes. Therefore effective particulate removal via sedimentation and filtration by vegetative cover should yield efficient pollutant reductions (Ellis, 1990).

Water quality data collected at Lake Lacamas Washington, suggested that phosphorus was the limiting nutrient in controlling the amount of biological activity in the Lake (Bautista M.F, 1993).

It has been found that when urban stormwater was treated using a gross pollutant trap followed by a wetland detention facility, nitrate levels were found to increase during the winter months (Bautista M.F, 1993). However, since the

Lake where the resulting treated water was being drained into was phosphorus limited, it is thought that the nitrate should not adversely affect the lake. The Shankland wetland which comes under study in this thesis is a fresh water system as is Lake Lacamas, so any high levels of nitrate resulting from treatment should not cause any adverse effects downstream in Yuroke Creek.

It is hard to distinguish between a "clean" and "dirty" water catchment. Ellis 1990, reported that variations between these dirty and clean catchments can be within an order of magnitude, whilst the variation in quality between different runoff events can be within a factor of three.

Leachate from disused landfill sites can cause major problems if allowed to enter the natural water course. It is important to minimise the polluting potential of the leachate before this occurs. Hadden and Murphy 1994, noted the potential of using a wetland to treat the leachate before entry into the natural water course. They also noted that if a wetland is used to collect any surface runoff before it has a chance to soak into the soil of disused landfill sites, leachate will be minimised.

The type and amount of pollutants that can be found in stormwater is highly variable with pollutant characteristics closely related to land use and rainfall characteristics (Livingston E.H, 1993). The catchment area serviced by the Shankland wetland ~~was~~ farmland, becoming residential. One area is already established, Meadow Heights, the other area is a new housing estate, Roxburgh Park.

Of primary importance to water quality is the first washing action that stormwater has on accumulated pollutants in the water-shed after a long period of time without rain. This washing action is termed the "FIRST FLUSH". During this first storm, impervious surfaces are washed creating a shock loading of pollutants into the water shed (Livingston E.H, 1993). Studies in Florida USA, have indicated that the first flush caries 90 % of the pollution load from a storm event (Livingston E.H, 1993). The importance of the first flush is also recognised by Bautista, 1993.

For treatment of the entire runoff body, a storage space large enough to hold the runoff is needed. This results in the total pollutant load being trapped and eventually treated; otherwise an overflow can occur leading to contamination of the receiving water body (Segarra-Garcia. R, 1992).

Pollutants can also affect the macroinvertebrate population. The semipermanent flooding which contains the pollutants has been reported to eliminate environmental cues necessary for oviposition, embryonic development and hatch among dominant taxa (Neckless, H.A, et al, 1990). This leads to the depletion of density of total invertebrates.

2.3 POLLUTANT TREATMENT MECHANISMS

Wetlands allow transformations of some elements, function as a sediment filter, or act as temporary sinks. One major factor that leads to pollutant reduction is dilution from the small amount of water from the storm water drains, entering the large body of water, the wetland. Pollutants can be lost to the atmosphere by volatilisation, incorporation into sediments or biota, or can be degraded. Generally initial removal mechanisms are physical and chemical followed by biological processes (Mitsch & Gosselink, 1986; and Kusler & Kentula, 1990). Other more specific factors are mentioned below.

Treatment of pollutants using a biofiltration system or something similar can be enhanced if the underlying soil has a relatively high organic content and cation exchange capacity (Ellis. J.B, 1990).

Sedimentation and filtration are important in the reduction of pollutants. For these processes to be successful, the designed flow rate must be at a minimum. Flow rates above 0.5 - 0.8 m/s are able to destroy vegetation and inhibit sedimentation (Ellis. J.B, 1990).

The slope where macrophytes grow can also affect the treatment efficiency. Generally the minimum slope for biofilters should be 2% and the maximum slope being 4%. Emergent species can be planted on a flatter slope. The main objective of the gradient is to maximise vegetation and soil contact of pollutants (Ellis. J.B, 1990).

Once the solids have been filtered through the biofilter and settle to the bottom of the pond/wetland, it is estimated that the solids will stay there for approximately one hundred years (East. C, 1994).

Given the influence on growth rate of algae from phosphorus and nitrogen, their importance in urban runoff is of considerable interest and concern.

2.3.1 PHOSPHORUS REMOVAL:

Phosphorus is required for algae to grow. Algae can grow at phosphate levels as low as 0.05 mg/L. For growth inhibition phosphate levels are required well below 0.5 mg/L (Manahan. S.E, 1991). In municipal wastes, phosphate can be found around the concentration of 25 mg/L (Manahan. S.E, 1991). This usually differs from stormwater concentrations by a factor of 10 (Livingston. E.H, 1993). The forms of phosphate typical are; o-phosphates, polyphosphates and insoluble phosphates (Manahan. S.E, 1991).

Phosphorus removal may occur due to primary settling of solids; due to aeration such as an activated sludge unit, or; after secondary waste treatment (Manahan. S.E, 1991). Constructed wetlands incorporate primary settling in a Gross pollutant trap, and secondary settling due to the slow movement of water through macrophyte beds in the wetland.

Where high levels of dissolved oxygen and pH are found, efficient phosphorus removal has been attained as high as 60-90% (Manahan. S.E, 1991). When gas is removed by the degradation of organic material, the levels of CO2 are relatively high, which results in a low pH due to the presence of carbonic acid. This results in the phosphorus being in the form of $H_2PO_4^-$ ION.

With aeration rates in relatively hard water, the CO2 is removed, and the pH rises and the following reaction occurs;

$$5\,Ca^{2+} + 3HPO_4^{2-} + H_2O \rightarrow Ca_5OH(PO_4)_3\,(s) + 4H^+$$

The precipitated phosphate in the form of hydroxyappatite or other form of calcium phosphate is incorporated into the suspended solids that later settle into the sludge (Manahan S.E, 1991). This reaction is hydrogen ion dependent and an increase in concentration drives the equilibrium back to the left. If anaerobic conditions prevail, the sludge becomes more acidic due to the abundance of CO2 and calcium returns to solution.

2.3.2 NITROGEN REMOVAL:

In freshwater systems nitrogen is the next important chemical to remove to reduce algal growth. Nitrogen is generally present as organic nitrogen or ammonia. The ammonia is oxidised to nitrate through the presence of nitrifying bacteria. Nitrogen can also be removed through NH3 gas, even more if the pH is substantially higher than the pKa of the $NH4^+$ ion (Manahan. S.E, 1991).

Nitrification coupled with denitrification is an adequate technique for the removal of nitrogen. First the ammonia and organic nitrogen are converted to nitrate under aerobic conditions;

$NH_4^+ + 2O_2$ (nitrifying bacteria) --> $NO_3^- + 2H^+ + H_2O$

This nitrate can then be converted to nitrogen gas by bacteria with a sufficient carbon source and reducing agent.

$$6NO_3^- + 5CH_3OH + 6H^+ \text{ (denitrifying bacteria) } \rightarrow 3N_2\,(g) + 5CO_2 + 13\,H_2O$$

Alternate wetting and drying which occurs in biofiltration allows both aerobic oxidation (nitrification), and anaerobic reduction (denitrification) to occur (Ellis .J.B, 1990).

Plant uptake is also a significant removal stage. As much as 400-500 kg/ha/yr of nitrogen and 30-50 kg/ha/yr of phosphorus can be achieved by macrophytic uptake with the plants apparently serving as ammonia strippers, taking up ammonium and then evolving ammonia gas (Ellis .J.B, 1990). The nutrients that are taken up by plants can be released back into effluent if the vegetation dies and decays. Harvesting of the plant material has been suggested by some authors ~~papers,(~~ Ellis. J.B, 1990, & Nuttal. P.M, 1985) to maintain a good quality outflow. However there is some discrepancy in the literature, other sources say that the major role of nutrient removal appears to be filtering and settling out of the organic material rather than plant uptake.

3.0 AIMS:

The main aims of this thesis are;

To determine whether the Shankland Valley Wetland is situated in the correct location to treat urban stormwater pollutants, and whether the wetland is efficient in reducing the pollutants present in urban stormwater runoff during periods of rain and no rain.

When considering this issue a number of other questions need to be answered to help explain any results. What mechanisms are responsible for pollutant reduction, if any? Where is the bulk of the pollutant load coming from? What are the pollutant effects on Yuroke Creek? Is the diversity of life in Yuroke Creek being greatly affected.

4.0 METHODS AND MATERIALS

4.1 STUDY AREA

The Shankland Drain Wetland is a stormwater treatment facility situated in the city of Broadmeadows. It is designed to treat approximately 336 ha of catchment, 160 ha of which is within the Urban Land Authority's development of Roxburgh Park. This area is used for residential purposes. This facility also treats 176 ha of Meadow Heights land. This zone is also residential with the Meadow Heights shopping centre and Somerton Reservoir. Two main drains feed the treatment facility, water samples were taken from both of these drains.

4.2 SAMPLING METHODS

Tests were carried out to test the treatment efficiency of the wetland during times of rain and no rain. The results were then compared to look for trends. The following parameters were analysed for; coliforms, total suspended solids, nitrate, nitrite, total oxidised nitrogen, phosphate and total phosphorus. Samples were stored in polyethylene bottles for periods of no more than forty eight hours at temperatures of 14°C(American Public Health Association, 1990).

4.3 TEST PROCEDURE

Argent 1991, conducted a comparative study on the enumeration of E.coli in water. In this study he compared a new defined substrate method with membrane technique. The membrane technique involved using one hundred millilitre aliquots of sample, filtering through a 0.45 micron cellulose nitrate membrane, and then incubating at 37 °C for 24-28 hours. The results were then expressed as most probable numbers per 100 mL. Each test was carried out four times. The American Public Health Association, 1990, also suggests the membrane filter technique. The filter paper was placed onto lauryl tryptose agar, inverted and then incubated. For counting, the Qubec type colony counter was used.

~~The~~ Homogenous samples of water were filtered through a weighed glass fibre filter and then the residue retained on the filter was dried to constant weight at 103-105°C. The increase in weight of the filter represented the total suspended solids (American Public Health Association, 1990).

For the determination of nutrients in the sample water, ASTM stated that the use of flow injection analysis (FIA) was appropriate and efficient. FIA is the automation or semi-automation of a conventional manual method, and often results in a decrease in the number and level of interferents. Therefore undesirable side reactions don't have the opportunity to develop to an extent in such a short residence time (60 sec) (Valcarrel. M, 1988). FIA involves kinetic, physical and chemical aspects which may lead some people into thinking that the method is not precise. However the reproducibility levels are high.

Nitrate, nitrite and o-phosphate can all be analysed by FIA without any previous preparation. Total oxidised nitrogen and total phosphorus both needed to be oxidised under pressure and temperature. To meet these requirements, the samples had potassium persulphate added to them and were autoclaved at 120°C for 30 minutes. Once cooled the samples were immediately injected into the FIA.

For analysing nitrogen samples using FIA, all nitrogen must be reduced to nitrite, this was accomplished by installing a cadmium reductor on the FIA. The nitrite is then reacted with an acid sulphanilamide solution to form a diazo compound. The diazo compound is coupled with N-(1-naphtyl)-Ethylene Diamine Dihydrochloride (NED) to form a purple azo dye. The azo dye is then measured at 540 nm.

Phosphorus samples had to be oxidised to ortho- phosphate if they were not already. The ortho-phosphate reacts with ammonium molybdate to form heteropoly molybdophosphoric acid. The acid is then reduced to phosphomolybdenum blue by stannous chloride in a sulfuric acid medium. The blue colour is then measured at 690 nm.

5.0 RESULTS:

Pollutants

5.1 MAJOR CONTRIBUTING STORMWATER DRAIN TO SHANKLAND WETLAND:

Pollutant concentration in stormwater runoff was measured during periods of rain and no rain.

VARIABLE	MEAN	RANGE
o-PHOSPHATE	150 ± 34.29 ug/L	(11.11 - 488.86)
TOTAL PHOSPHORUS	300 ± 197 ug/L	(26 - 1370)
NITRITE	20 ± 7.38 ug/L	(0 - 90.92)
NITRATE	1370 ± 185 ug/L	(893.62 - 3347.99)
TOTAL OXIDISED N	18 ± 0.23 mg/L	(16810 - 18520)
SUSPENDED SOLIDS	0.5 ± 0.14 mg/L	(0.045 - 1.65)
COLIFORMS	10200 ± 2164 /100mL	(5400 - 20200)

TABLE 1: ROXBURGH PARK STORM WATER DRAIN (SWD) MEAN AND RANGE CONCENTRATIONS FOR PERIODS OF NO RAIN.

VARIABLE	MEAN	RANGE
o-PHOSPHATE	120 ± 22.5 ug/L	(56 - 258.25)
TOTAL P	0.160 ± 0.065 mg/L	(41 - 525)
NITRITE	6.5 ± 2.9 ug/L	(0 - 31.77)
NITRATE	1530 ± 214 ug/L	(671.35 - 3535.05)
TOTAL OXIDISED N	17.5 ± 0.15 mg/L	(17070 - 18080)
SUSPENDED SOLIDS	0.45 ± 0.26 mg/L	(0.045 - 3.52)
COLIFORMS	15600 ± 1429 /100mL	(11400 - 21300)

TABLE 2: MEADOW HEIGHTS SWD MEAN AND RANGE CONCENTRATIONS DURING PERIODS OF NO RAIN.

VARIABLE	MEAN	RANGE
o-PHOSPHATE	170 ± 23.72 ug/L	(37.77 - 319.35)
TOTAL P	0.280 ± 0.101 mg/L	(64 - 843)
NITRITE	25 ± 7.01 ug/L	(1.09 - 122.81)
NITRATE	1010 ± 80.4 ug/L	(561 - 1418.11)
TOTAL OXIDISED N	19 ± 0.7 mg/L	(16500 - 20930)
SUSPENDED SOLIDS	0.6 ± 0.28 mg/L	(0.08 - 3.8)
COLIFORMS	16800 ± 3600 /100mL	(5300 - 30800)

TABLE 3: COMBINATION OF ROXBURGH PARK AND MEADOW HEIGHTS SWD(s) DURING PERIODS OF NO RAIN.

VARIABLE	MEAN	RANGE
o-PHOSPHATE	310 ± 120.7 ug/L	(48.55 - 1681.35)
TOTAL P	390 ± 117.2 ug/L	(151.55 - 757.2)
NITRITE	30 ± 8.5 ug/L	(1.25 - 100.21)
NITRATE	1060 ± 57.5 ug/L	(784.55 - 1396.08)
TOTAL OXIDISED N	1.0 ± 0.051 mg/L	(820 - 1110)
SUSPENDED SOLIDS	0.8 ± 1.14 mg/L	(0.255 - 3.6)
COLIFORMS	19200 ± 5500 /100mL	(3500 - 60000)

TABLE 4: ROXBURGH PARK SWD MEAN AND RANGE CONCENTRATIONS FOR PERIODS OF RAIN.

VARIABLE	MEAN	RANGE
o-PHOSPHATE	190 ± 45.77 ug/L	(0 - 565.4)
TOTAL P	380 ± 63.15 ug/L	(194.1 - 523.6)
NITRITE	15 ± 6.83 ug/L	(0 - 69.57)
NITRATE	1260.61 ± 92.7 ug/L	(388.33 - 1659.98)
TOTAL OXIDISED N	1.1 ± 0.087 mg/L	(0.86 - 1.33)
SUSPENDED SOLIDS	0.1 ± 0.05 mg/L	(0.03 - 0.24)
COLIFORMS	23000 ± 5500 /100mL	(7500 - 60000

TABLE 5: MEADOW HEIGHTS SWD MEAN AND RANGE CONCENTRATIONS FOR PERIODS WITH RAIN.

VARIABLE	MEAN	RANGE
o-PHOSPHATE	270 $\pm$ 88.2 ug/L	(41.45 - 1260)
TOTAL P	350 $\pm$ 47.75 ug/L	(255.9 - 471.4)
NITRITE	670 $\pm$ 153.8 ug/L	(5.75 - 70.5)
NITRATE	980 $\pm$ 53.64 ug/L	(686.1 - 1376.88)
TOTAL OXIDISED N	0.85 $\pm$ 0.043 mg/L	(0.755 - 0.97)
SUSPENDED SOLIDS	0.5 $\pm$ 0.17 mg/L	(0.16 - 1.64)
COLIFORMS	27200 $\pm$ 3700 /100mL	(8900 - 44600)

TABLE 6: COMBINATION OF ROXBURGH PARK AND MEADOW HEIGHTS SWD(s) DURING PERIODS OF RAIN.

The above tables (one through six) indicate mean and range concentrations for various parameters in two stormwater drains, from Roxburgh Park and Meadow Heights. The combination results in table three and six indicates concentrations after the stormwater from both drains has been mixed.

From these tables it can be seen that the Roxburgh Park SWD during periods of dry weather supplies the wetland with the highest concentrations of ortho-Phosphate, total phosphorus (TP), nitrite, total oxidised nitrogen (TON), and suspended solids. The Meadow Heights drain, during the same conditions supplied the highest concentrations of nitrate and coliforms.

Under wet conditions, the Roxburgh Park SWD seems to be responsible for the highest concentrations of ortho-Phosphate, total phosphorus, nitrite suspended solids. The Meadow Heights SWD also seems responsible for the highest concentrations of nitrate, total oxidised nitrogen, and coliforms.

Flow rate data was unattainable from the two stormwater drains, so the measurements given are in terms of grams per litre or coliforms per 100mL.

5.2 REMOVAL EFFICIENCY OF WETLAND:

POLLUTANT	8.6mL RAIN	3.2mL RAIN	NO RAIN	NO RAIN
NO_2	36	25	+ 33	+ 29
NO_3	33	62	96	56
TON	-----	47	-----	+ 19
PO_4	75	44	29	12
TP	-----	36	-----	29
TSS	58	-----	21	57

TABLE 7: PERCENTAGE REMOVAL OF POLLUTANTS FROM STORMWATER BY WETLAND PROCESSES.

Graphs of the above table can be seen on the corresponding pages.

Addition signs in the above table represent an increase in that parameter under conditions of rain or no rain. Strokes indicate that ~~that~~ particular parameter was not completed within the Australian Standard Test Methods time limit before the samples deteriorated in quality.

A T-test was carried out on parameters with complete data, to see if there was a significant difference between pollutant concentrations during periods of rain and periods of no rain. Nitrite showed a significant difference ($t=8.2$, $df=1/n=2$, $p< 0.05$). Nitrate showed no significant difference ($t=0.83$, $n=2$, $p> 0.05$). ortho-Phosphate also showed no significant difference between periods of rain and no rain ($t=5.57$, $n=2$, $p> 0.05$).

Examples of raw data for the above removal efficiencies can be found in appendices one through six, along with a sample calculation of the removal efficiency and mass flow rate in appendix 7.

Rainfall data on dates 16/6/94 - 23/6/1994 (days 2,3,4 & 5) and 3/8/94 - 7/8/1994 (days 1,2 & 3). Dates with no rain were 15/4/94 - 19/4/1994 and 23/5/94 - 28/5/1994.

5.3 EFFECTS ON YUROKE CREEK FROM EFFLUENT RELEASED FROM WETLAND:

Pollutant effects on Yuroke Creek were observed by plotting site 6 (upstream Yuroke Creek) concentrations and site 8 (downstream of wetland) concentrations on a graph of concentration versus time. A map of the Shankland Wetland can be found in appendix B. The difference in area between the two curves of site 6 and site 8, indicates the amount that the concentration of the pollutant has increased or decreased. Flow rate in Yuroke Creek was similar at sample points 6 (Upstream Yuroke creek) and 8 (downstream Yuroke creek), see appendix 8. Appendices 9 through 15 are graphical representations of the effects on Yuroke Creek.

The data regarding the effects on Yuroke creek can also be used to see if the wetland is situated in the correct spot to treat storm water.

Generally coliform concentration at site 6 and 8 was similar on each day, however, the concentration varies through the week. No major trend can be seen in dry or wet periods.

Suspended solid concentrations were higher at site 8 than site 6, upstream of the confluence of the Shankland drain. However during wet periods, site 6 concentrations are higher than site 8.

Nitrate concentrations at site 6 were consistently higher than those at site 8 during periods of no rain. However when it rains site 8 concentrations exceed site 6 concentrations.

Nitrite levels during periods of no rain fluctuate and are very erratic. During periods of rain data is more consistent indicating higher levels of nitrite at site 8 than site 6.

Total oxidised nitrogen (TON) concentrations during periods of no rain, are generally higher at site 8 than site 6. A similar trend is noted during rainy periods.

The ortho-phosphate concentration varied considerably between the four times monitoring was undertaken.

Total phosphorus concentrations in Yuroke creek during dry periods are erratic, with site 6 being higher than site 8 one day and visa versa the next. During the period of rain, concentrations at site 6 were generally higher than those at site 8.

5.4 MACROINVERTEBRATE SURVEY OF YUROKE CREEK AND SHANKLAND WETLAND:

LOCATION	MACROINVERTEBRATE PRESENT
WETLAND site 4 & 5.	Daphnia spp. cyclopoda, copepoda calanoida, copepoda
EFFLUENT site 7	calanoida, copepoda
UPSTREAM site 6	cyclopoda, copepoda tubifex spp.
DOWNSTREAM site 8	cyclopoda, copepoda calanoida, copepoda daphnia, carinata daphnia spp. midge larvae

TABLE 8: QUALITATIVE ANALYSIS OF MACROINVERTEBRATES IN AND AROUND SHANKLAND WETLAND.

Samples were taken by using plankton nets and then placed into plastic containers for transport to the laboratory. Identification was then accomplished with the aid of Herbert P.D.N, 1977. From the above table it can be seen that site 8 Yuroke creek had the greatest diversity. Abundance was not measured.

6.0 DISCUSSION:

6.1 MAJOR CONTRIBUTING STORMWATER DRAIN TO SHANKLAND WETLAND:

From the results section 5.1, it can be seen that during dry periods Roxburgh Park SWD has higher concentrations of ortho-phosphate, TP, nitrites and suspended solids, than Shankland drain (from Meadow Heights). Roxburgh Park is a new residential estate with building, landscaping etc still being undertaken.

Building and landscaping may increase the input of nutrients and suspended solids into the local hydrology (including the stormwater drains). This may result in the larger concentrations of pollutants in Roxburgh Park SWD compared to Shankland drain.

During these same dry periods Meadow Heights SWD supplied the highest concentrations of nitrate and coliforms. Meadow Heights is an older established residential area which is also sewered. As mentioned earlier in the methods and materials, Meadow Heights consists of 176 ha including a shopping centre. A greater amount of runoff would be expected from Meadow Heights since it is larger in area than Roxburgh Park (160 ha). However, it was noted that each time samples were taken from the two drains, more water was coming down from Roxburgh Park. Roxburgh Park also has the larger diameter drain.

The higher concentrations from Roxburgh Park could also be attributed to the larger flow rate from Roxburgh Park SWD, compared to Meadow Heights SWD concentrations.

During wet periods a similar trend was noted to that during dry periods. The SWD from Roxburgh Park carried highest concentrations of o-phosphate, total phosphorus, nitrite and suspended solids. The Meadow Heights SWD carried highest concentrations of nitrate, total nitrogen and coliforms.

Comparing results between the combination of both stormwater drains and upstream Yuroke Creek will enable us to see if the wetland was situated in the correct spot. These results can be found in the form of graphical representation in appendices 16-37.

From these graphs, the following can be assumed. During periods of rain, coliforms, suspended solids, nitrate, nitrite, total oxidised nitrogen and total phosphorus all had higher concentrations in the combination drain than at upstream Yuroke creek. Only ortho-phosphate during this period was higher in Yuroke creek than the combination drain.

During periods of no rain, generally coliforms, suspended solids, nitrate and total phosphorus were higher in the combination drain than upstream Yuroke creek. Total oxidised nitrogen and ortho-phosphate were generally higher in Yuroke creek compared to the combination drain. Nitrite during this period fluctuated between being higher in Yuroke Creek and the combination drain.

So therefore it can be assumed that in most cases except for ortho-phosphate, the concentration in the combined drain is higher than the unaffected

Yuroke Creek. Therefore the wetland is in an appropriate position to intercept pollutants from the stormwater drain so they do not adversly effect Yuroke creek.

In some cases there is little difference in the concentration of pollutants between Yuroke creek and the combined stormwater. Therefore it may be worth diverting Yuroke creek through the wetland.

6.2 REMOVAL EFFICIENCY OF WETLAND:

There is a constant cycling of nutrients through the wetland, and concentrations provide information on the amount of nutrient before and after the wetland. No information was gathered on the processes undertaken occurring. The only evidence provided is, the drop or increase in the amount of nutrient. We can only speculate as to what is happening by looking at previous examples of wetland treating liquid waste.

A T test was performed on complete data in table 7, and it was found that nitrate and ortho-phosphate were not significantly different between events of rain and no rain, however nitrite did show a significant difference between events of rain and no rain.

During dry periods, nitrite concentration increased in the effluent compared to the influent. At the sampling points where effluent was collected during the dry periods, ammonia/ammonium may have been undergoing nitrification, resulting in a large amount of nitrite at that time.

Nitrite is an unstable form of nitrogen and is easily oxidised to nitrate or some other oxide of nitrogen. The transformation of nitrogen through a biological system results in many forms of nitrogen and is cyclic. It operates on the principal of nitrogen reaching the most stable state. For this process to be cyclic however, the most stable species must be converted to a species of higher free energy of formation (less stable). This reaction requires a large amount of energy. The nitrogen cycle is carried out to a large extent by microorganisms. These microorganisms are able to couple other cyclic processes (such as the carbon cycle) to supply the energy required for the formation of less stable species (O'Neill P, 1985). An example of the nitrogen cycle and phosphorus cycle can be found in appendix 38.

A reduction in nitrites through the wetland during periods of rain, as seen in table seven, could be due to the following processes.

During wet periods a large amount of water is being supplied to the wetland. This should increase the mixing rate in the wetland. Therefore any nitrite that is coming into the wetland during this period should be diluted in the wetland rapidly. Also the increased mixing rate would lead to an increase in aeration. The higher concentration of oxygen in the wetland would lead to chemical conversion of the unstable nitrite to nitrate. The low concentration of nitrite could also be converted to nitrate by nitrification (Harper. D, 1992; O'Neill. P, 1985; and Brix. H, 1993). Nitrite may also be reduced to dinitrogen biologically (Harper. D, 1992).

Nitrite is potentially lethal since it can form nitrosamines by combining with amino acids. These nitrosamines are carcinogenic. Nitrite can also combine with haemoglobin in red blood cells leading to methaemoglobinaemia. This can effect humans and cattle (O'Neill P, 1985).

A t-test was preformed upon nitrate removal during wet and dry periods, section 5.2. The result of this test was that the difference between nitrate reductions during wet and dry periods was not significant. The amount of water coming down the drain would then seem not to effect the biological, physical and chemical processes in the wetland that reduce the amount of nitrate.

Nitrate undergoes denitrification and assimilation by plants (O'Neill. P, 1985). Denitrification is the regeneration of dinitrogen from nitrate, and occurs under both aerobic and anaerobic conditions in the soil and water. Under anaerobic conditions microorganisms can use nitrate to replace dioxygen as an electron acceptor and as their source of respiratory energy.

$$5CH_2O + 4NO^{3-} + 4H^+ \dashrightarrow 2N_2 + 5CO_2 + 7H_2O$$

The reduction of nitrate does not always form dinitrogen, gaseous dinitrogen oxide may also be produced (O'Neill. P, 1985).

Macrophytes can also remove pollutants, such as nitrate, by assimilating them into their tissue (Breen P.F.A, 1990; H. Brix, 1993; and Finlayson *et al,* 1982). This is one component of primary production where the assimilated nutrients are used to produce organic matter via photosynthesis (Hicks D.B and Q.J. Stober)

The Macrophytes in the water column, stems, leaves and detritus, also provide attachment sites for the growth of microbial colonies. The macrophytes diffuse oxygen through aerenchyma tissue to the root tips forming an oxidised zone in a usually anaerobic substrate. This oxidised zone allows aerobic microorganisms to conduct desirable modifications of nutrients and other compounds (Pullin B.P and D.A. Hammer,).

Total oxidised nitrogen (TON) removal is also reported in table 7, section 4.2. From this table and attached graph, it can be seen that TON removal occurs only during periods of rain. During period of no rain the amount of TON leaving the wetland exceeds the amount coming in. Total oxidised nitrogen represents the total amount of nitrogen present in a water sample expressed as nitrate.

The most probable explanation of the drop in TON would be a dilution effect caused by the extra amount of rain coming down the drain, and the addition of TON to a large body of water.

The processes mentioned below would also contribute to the drop in TON.

Generally nitrogen removal can be described as:

(1) Adsorption of ammonium ion by the soil surface.

(2) Nitrification of ammonium to nitrite and then to nitrate.

(3) Transport of nitrate to the anaerobic zone in the saturated soil pores.

(4) Denitrification of nitrate to gaseous forms in the anaerobic zone, and

(5) Plant assimilation.

Nitrate transport is reported to be the limiting step of nitrogen removal (Ellis, J.B, 1990).

TON increase during periods of no rain could mean that most of the ammonia present in the wetland is being oxidised to nitrate. Since a measure of ammonia was not carried out during the study, it is hard to precisely find where the ammonia is coming from. Ammonification is a possibility. This is where ammonia is formed from amino acids and proteins by the reactions of microorganisms. Another possibility, however less iikely is nitrogen fixation (O'Neill .P, 1985).

The Shankland Valley Wetland was not constructed a long time ago, therefore the emergent vegetation is still new and fairly unestablished. This would mean that the vegetation would not be able to extract nutrients from the water column and soil as effectively as older vegetation. The way the wetland has been designed would mean that water to be treated flows along the surface of the soil and over the emergent vegetation. However, pollutants would be better treated if they were in a more constant contact with the rhizosphere.

Soil particles are able to adsorb a certain amount of ammonium. But this is a finite way of treatment and the soil particles would eventually become saturated. If the equilibrium changes the ammonium would then be released back into the water column.

ortho-Phosphate percentage reduction was also recorded in table 7. The results given for periods with and without rain were tested to see if there was a significant difference between them. This was done by using the t-test. From this it was found there was not a significant difference between them. Generally o-phosphate is reduced through the wetland. To a greater extent during rainy periods than periods with no rain.

Total phosphorus (TP) also showed very little difference in percentage reduction between periods with rain and no rain, table 7.

Phosphorus enters aquatic systems from catchment runoff primarily as particulate forms, adsorbed onto inorganic silt and clay particles (Harper .D, 1992; Richardson C.J and C.B. Craft, 1993; and Brix .H, 1993). This is a strongly seasonal process, with 90% or more running off during winter or spring months (Harper .D, 1992).

Phosphorus adsorption and retention in freshwater wetland soil is controlled by interaction of redox potential, pH, Fe, Al, and Ca minerals, and the amount of phosphorus in native soils (Lindsay A.L, 1979, and, Faulkner S.P and C.J. Richardson, 1989). Redox potential and pH both control the mobility of phosphorus in the environment. In acidic soils, inorganic phosphorus is adsorbed to hydroxides of iron and aluminium, and may precipitate as insoluble iron-phosphates and aluminium-phosphates. In soils with a pH above 7.0, phosphorus is transformed to insoluble precipitates of calcium phosphate (Richardson C.J. and C.B. Craft, 1993).

Both phytoplankton and macrophytes are able to take up large amounts of phosphorus. Recent studies show that phytoplankton are more efficient at uptaking phosphorus than macrophytes (Howard-Williams C, 1985).

Emergent wetland vegetation also takes up phosphorus from the surrounding soil environment. After these plants die, a lot of the stored phosphorus is returned to the surface water. Therefore the short term effect of the rooted emergent vegetation is to release phosphorus from the sediment to the water column. Root and residual decomposition products result in long term phosphorus storage due to peat (Richardson C.J. and C.B. Craft, 1993).

In the majority of freshwater systems, phosphorus is the limiting nutrient for algal growth (Baker .L.A, 1993). If there is an excess of phosphorus, it can lead to algal blooms, especially during warm dry conditions. It has been reported that total phosphorus concentrations paralleled suspended solid concentrations. However, total phosphorus concentrations were probably associated with fluctuations in point sources. Where increases occurred in phosphorus, statistical associations between total phosphorus increases and measures of fertilised acreage and cattle population were found.

Suspended solids removal efficiency can be found in table 7, section 5.2. An incomplete data set for suspended solids meant that a t-test was unable to be preformed. A general look at the data available would seem to indicate that the effect of rain on suspended solid removal is minimal if any.

Suspended solids are generally removed from a water body by gravitational settling and filtration due to emergent vegetation. Suspended solid concentrations may be increased in a pond due to the action of turbulence caused by wind and wave action on the shore (Hellawell J.M, 1986). Suspended solid concentrations only pose a threat to freshwater communities when they are present either at abnormally high levels or for long periods, thereby changing the nature of the habitat.

Suspended solid concentrations may effect the aquatic environment in the following ways:

(1) Reducing light penetration effecting the photosynthetic rates of algae and submerged macrophytes.

(2) Exerting mechanical effects on organisms by increasing abrasion, clogging the respiratory surfaces or interfering with feeding through inadvertent collection of feeding appendages.

(3) Modifying the nature of the habitat by changing the character of the substratum when they collect by settlement as flows are reduced.

The ultimate effect on the biota of suspended solids is clearly dependent upon the nature of the material held in suspension, including size, density, nutritive value, toxicity, and its potential for bacterial decomposition (Hellawell J.M, 1986).

If available storage is provided to hold an entire runoff event, the total wash-off load (amount of pollutants in one runoff event) will be trapped and eventually treated or diluted to an acceptable concentration; otherwise an overflow of the pollutants occurs into the accepting water body. In this case Yuroke Creek (Segarra-Garcia .R and V.G. Loganathan, 1992). This could lead to an increase in the amount of nutrient leaving the wetland, thereby reducing the removal efficiency of the wetland.

6.3 EFFECTS ON YUROKE CREEK FROM EFFLUENT RELEASED FROM WETLAND:

Comparing the results for coliform concentration in upstream and downstream Yuroke creek, section 5.3,the one generalisation that can be made is that upstream concentrations of coliforms are higher than downstream concentrations, most of the time. Between these two sampling sites is the outlet for the wetland. It seems that the water from the wetland is diluting the creek water, reducing the concentration of coliforms in the creek. For the purpose of removal of coliforms from Yuroke creek, it seems a good idea to transfer the water from the creek through the wetland.

Land uses further upstream Yuroke creek (at Attwood Creek) will effect the pollutant load in the creek at the site near the wetland. The area at Attwood Creek is unsewered and relies on septic tanks to treat domestic sewage. The septic tanks could be failing resulting in the higher concentrations of coliforms before the wetland. However, since the difference is very small, this is unlikely. Paddocks adjoining the Shankland wetland where Yuroke Creek flows through, have horses and cattle that use the creek for drinking water. These animals defecate in and around the creek. Horses and cattle are warm blooded and therefore have coliforms in their guts. These coliforms are released in the faeces, and may end up in the creek. This seems to be the most probable answer to the high concentration of colifoms in upstream, site 6, Yuroke Creek.

Suspended solid concentrations during periods of no rain are higher downstream Yuroke creek than upstream. However, this value does fluctuate slightly. Therefore during dry periods the wetland increases the suspended solid loading of Yuroke creek. However, wind causing waves on the wetland water surface will increase suspended solids. Wind velocity was not measured during sampling. If the wind was strong, this could help explain the increase in concentration downstream.

During wet periods the wetland dilutes the loading of suspended solids in Yuroke Creek. See section 5.3. Rain could be beneficial for the treatment of suspended solids.

Nitrate concentration was higher upstream Yuroke creek then after the wetland during periods of no rain. This could mean that the nitrate in the wetland it being treated efficiently so that the effluent leaving the wetland is low in nitrate. The effluent would then dilute the concentration of nitrate in Yuroke creek. Therefore, it would be even more beneficial to divert Yuroke creek through the wetland.

Nitrate concentrations increase downstream Yuroke Creek during wet periods. This could mean that the rain has diluted the concentration of nitrate in upstream Yuroke creek. As well as the wetland reaches its treatment limit for nitrate and releases excess nitrate to Yuroke creek. Looking at the graphs for nitrate in section 5.3, the downstream concentration of nitrate during the dry period is around 200 *u*g/L. However, during the wet interval the concentration of nitrate downstream was around 350 *u*g/L.

This fairly consistent increase during the wet interval would seem to support the idea that the wetland has reached its treatment limit or holding capacity for nitrate. The extra water could also increase aeration of the water leading to physical oxidation of nitrogen compounds to nitrate.

Nitrite concentrations show no consistent data during periods with no rain. This is probably because of the transformations of the nitrogen cycle varying the amount of nitrite.

When it did rain it was found that nitrite was higher downstream of the wetland than upstream. The wetland may have reached its treatment limit or holding capacity thereby releasing nitrite into the creek.

During periods of rain and no rain the concentration of total oxidised nitrogen followed a similar trend. That is, the concentrations downstream were higher than upstream of the wetland. Therefore the wetland is increasing the concentration of total oxidised nitrogen in Yuroke creek.

From the graphs of o-phosphate in section 5.3 a generalisation can be made as to what is happening to o-phosphate. Upstream concentrations seem higher than downstream of the wetland concentrations. Therefore the wetland probably does not increase the concentration of o-phosphate in Yuroke creek during wet or dry periods. The wetland possibly dilutes the o-phosphate in the creek.

Generally upstream of the wetland has high concentrations of total phosphorus compared to downstream of the wetland. this is similar to o-phosphate. Once again the wetland is probably treating the total phosphorus efficiently and diluting the concentration of total phosphorus in Yuroke creek.

6.4 MACROINVERTEBRATE SURVEY OF YUROKE CREEK AND SHANKLAND WETLAND:

Examination of table 8 in section 5.4, one can note the prevalent trend in the increase in macroinvertebrates in the water column downstream of the wetland. Organisms found in upstream Yuroke creek and in the wetland combine with other organisms to increase the diversity of Yuroke creek after the wetland. The habitat after the wetland does not seem greatly altered from the habitat before the wetland.

Suspended solids depositing in downstream Yuroke Creek, the addition of excess nutrients and the possible increase in flow during storms from the wetland seem the only dangers to the macroinvertebrate population and diversity in Yuroke Creek. Any increase in deposition of solids and nutrients that may occur from the wetland will almost certainly be resuspended and washed away during winter spates, thereby cleaning the creek for the next deposition.

7.0 CONCLUSION:

Seasonal variations, the local hydrology, and the channelisation of Shankland wetland will all effect the concentration of nutrients and the abundance of biota in the wetland and Yuroke creek.

The major contributing storm water drain (SWD) for phosphorus compounds, nitrite and suspended solids during wet or dry conditions comes from Roxburgh Park. Meadow heights SWD was confirmed as carrying the highest concentrations of nitrate and coliforms.

Looking at results comparing concentrations in the SWD(s) and Yuroke creek, it is possible to say that during the period tested, the Shankland wetland is situated in the correct position to treat pollutants so ~~as~~ that they do not increase in Yuroke creek and any downstream catchments.

It was shown that rain may increase the removal of nitrite in the wetland before entering Yuroke creek. The wetland reduced nitrate efficiently to the same extent during wet and dry periods. During periods of rain, the removal of total oxidised nitrogen was sufficient, but during dry periods, TON concentrations increased through the wetland. ortho-Phosphate, total phosphorus and suspended solids were also reduced through the wetland to the same extent during wet and dry periods.

It was also found that the wetland did not increase the concentration of coliforms, o-phosphate, total phosphorus or total oxidised nitrogen during wet or dry periods in Yuroke Creek.

Suspended solid concentration only increased in Yuroke creek when it did not rain. When it did rain, nitrate and nitrite concentrations increased inYuroke Creek after the addition of effluent from the wetland.

The macroinvertebrate study was only carried out for future reference if Subsequent succession studies are carried out on Shankland wetland. As a result, the information provided was brief.

8.0 REFERENCES

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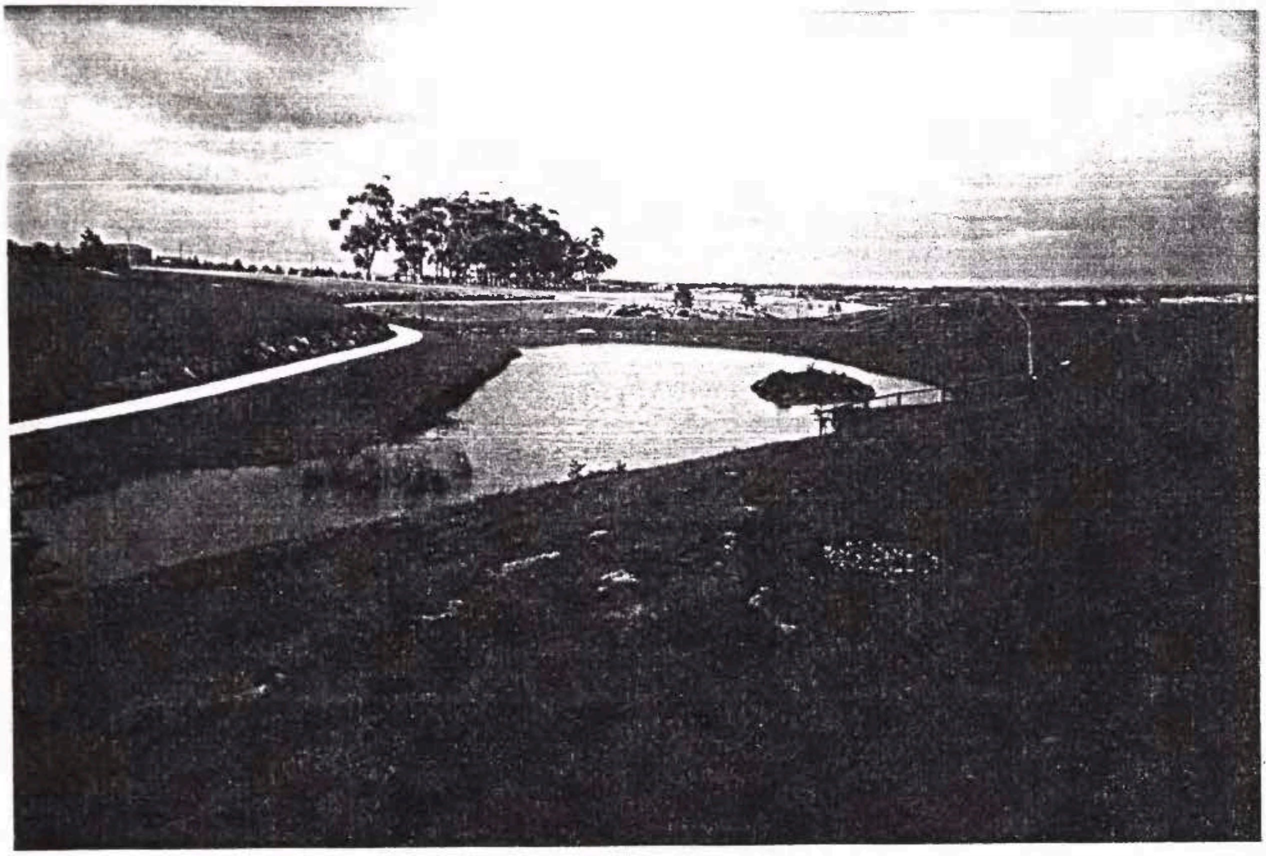
APPENDIX A

ROXBURGH PARK WETLANDS



APPENDIX B

MAP OF SHANKLAND WETLAND

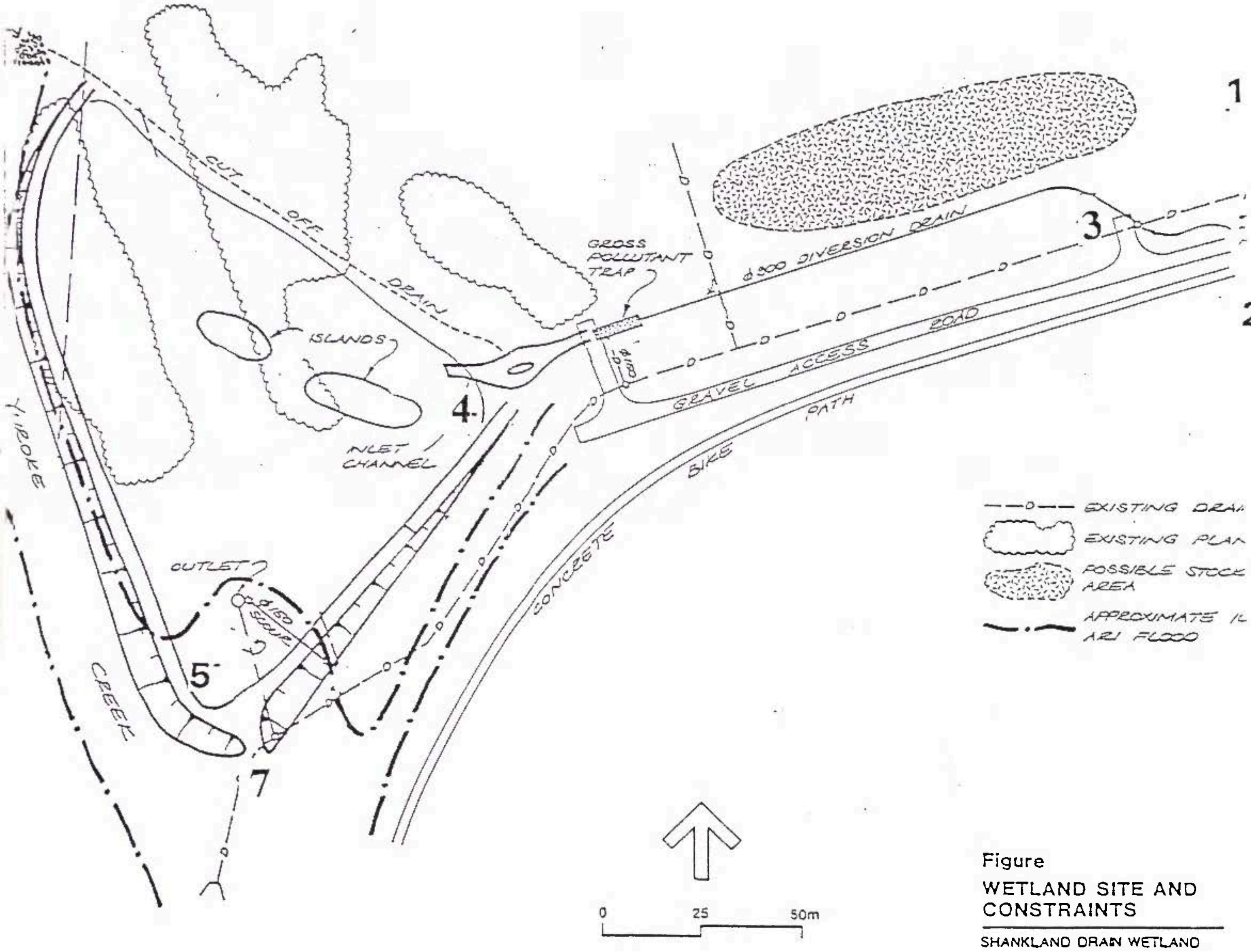
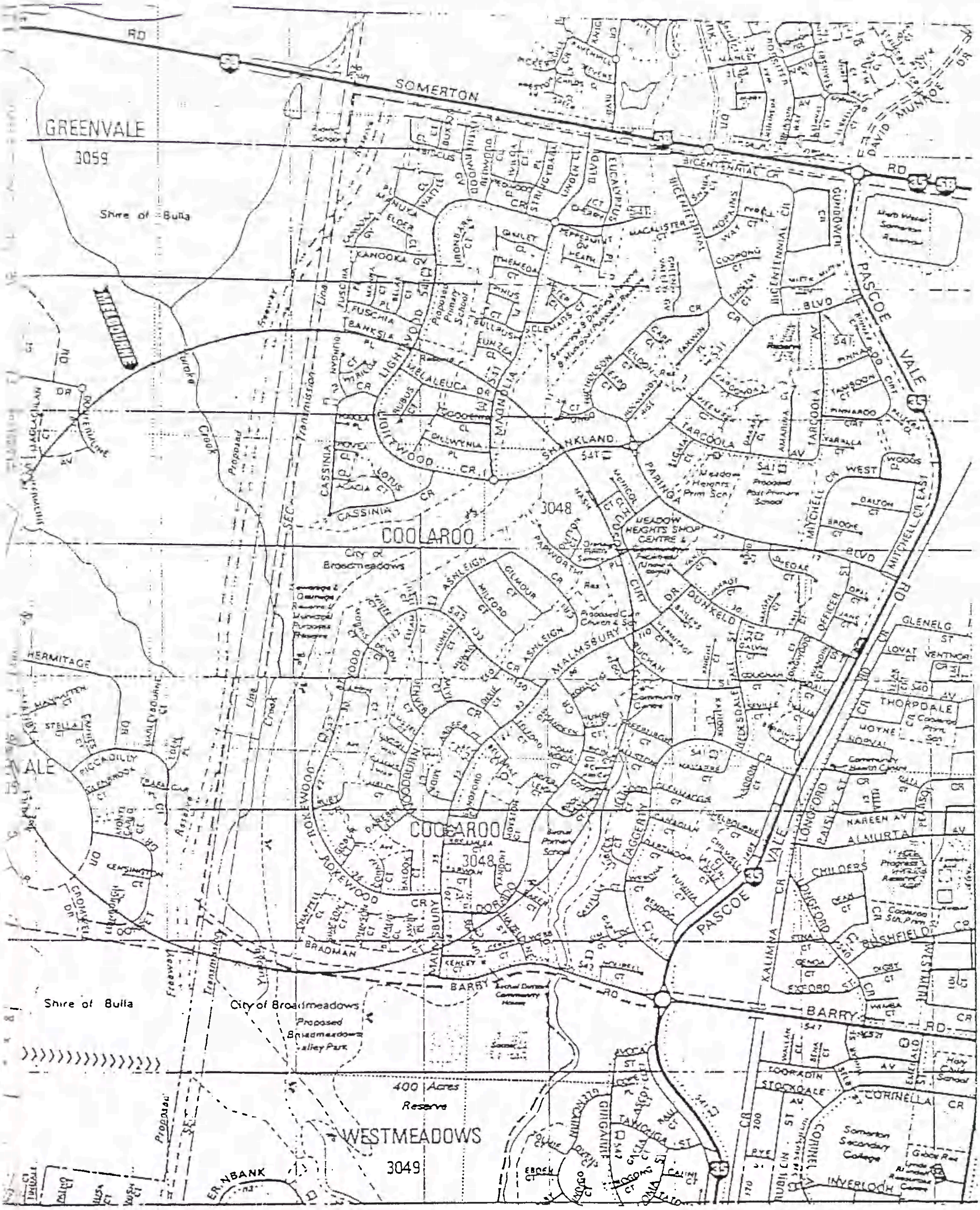


Figure
WETLAND SITE AND CONSTRAINTS
SHANKLAND DRAIN WETLAND

8

KEY FOR MAP OF SHANKLAND WETLAND

SITE	DESCRIPTION
1	SWD FROM ROXBURGH PARK
2	SWD FROM MEADOW HEIGHTS
3	COMBINATION OF BOTH SWD(s)
4	ENTRANCE OF WETLAND
5	END OF WETLAND
6	UPSTREAM YUROKE CREEK
7	EXIT OF WATER FROM WETLAND
8	DOWNSTREAM YUROKE CREEK



LOCALITY MAP

APPENDIX 1

SUSPENDED SOLIDS

mg/L

DATE : 15/4/94 – 21/4/94

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
15/4/94								
n 1	0.73	0.32	0.57	0.46	0.5	0.2	0.34	0.29
n 2	0.71	0.33	0.59	0.46	0.48	0.21	0.36	0.22
mean	0.72	0.325	0.58	0.46	0.49	0.205	0.35	0.23
SD	0.01	0.01	0.01	0	0.01	0.01	0.01	0.05
SE	0.007	0.007	0.007	0	0.007	0.007	0.007	0.04
16/4/94								
n 1	0.03	0.28	0.34	0.34	0.34	0.17	0.27	0.21
n 2	0.06	0.3	0.33	0.36	0.31	0.2	0.23	0.25
mean	0.05	0.29	0.335	0.35	0.33	0.135	0.25	0.23
SD	0.02	0.01	0.01	0.01	0.02	0.02	0.03	0.03
SE	0.01	0.007	0.007	0.007	0.01	0.01	0.02	0.02
17/4/94								
n 1	1.8	3.53	1.13	0.47	0.39	0.37	0.28	0.23
n 2	1.5	3.51	1.19	0.47	0.37	0.38	0.3	0.21
mean	1.65	3.52	1.16	0.47	0.38	0.375	0.29	0.22
SD	0.21	0.01	0.04	0	0.01	0.01	0.01	0.01
SE	0.15	0.007	0.03	0	0.007	0.007	0.007	0.007
18/4/94								
n 1	1.26	0.31	3.7	1.98	0.26	0.18	0.9	0.41
n 2	1.3	0.28	3.9	1.9	0.27	0.16	0.9	0.43
mean	1.28	0.295	3.8	1.94	0.265	0.17	0.9	0.42
SD	0.3	0.02	0.01	0.06	0.01	0.01	0	0.01
SE	0.02	0.01	0.007	0.04	0.007	0.007	0	0.007
19/4/94								
n 1	0.63	0.19	0.19	0.24	0.23	0.15	0.22	0.28
n 2	0.61	0.18	0.19	0.2	0.23	0.17	0.21	0.3
mean	0.62	0.185	0.19	0.22	0.23	0.16	0.215	0.29
SD	0.01	0.01	0	0.03	0	100	0.01	0.01
SE	0.007	0.007	0	0.02	0	0.007	0.007	0.007
20/4/94								
n 1	0.29	0.21	0.23	0.26	0.37	0.13	0.17	0.17
n 2	0.31	0.22	0.21	0.3	0.35	0.14	0.18	0.19
mean	0.3	0.215	0.22	0.28	0.36	0.135	0.175	0.18
SD	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01
SE	0.007	0.007	0.007	0.02	0.007	0.007	0.007	0.007
21/4/94								
n 1	0.7	0.18	0.13	0.2	0.16	0.16	0.14	0.14
n 2	0.8	0.2	0.15	0.18	0.16	0.14	0.12	0.19
mean	0.75	0.19	0.14	0.19	0.16	0.15	0.13	0.165
SD	0.07	0.01	0.01	0.01	0	0.01	0.01	0.04
SE	0.05	0.007	0.007	0.007	0	0.007	0.007	0.03

APPENDIX 2

		NITRATE						
		ug/L						
	DATE :	15/4/94 - 21/4/94						
15/4/94								
	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
n 1	1340.3	126300	784.15	378.15	393.91	146.23	394.38	156.02
n 2	1344.6	1272.1	791.62	383.24	401.11	152.78	395.21	155.99
mean	1342.5	1267.6	787.89	380.7	397.51	149.51	394.8	156.01
SD	3.01	6.44	5.29	3.6	5.09	4.63	0.59	0.02
SE	2.13	4.55	3.74	2.55	3.6	3.27	0.42	0.01
16/4/94								
n 1	976.91	1002.1	676.9	388.42	411.2	176.83	309.62	212.32
n 2	982.3	995.47	674.58	381.79	406.19	167.37	300.19	207.24
mean	979.61	998.78	675.74	385.11	408.7	172.1	304.91	209.78
SD	3.81	4.67	1.64	4.69	3.54	6.69	6.67	3.59
SE	2.69	3.3	1.16	3.32	2.5	4.73	4.72	2.54
17/4/94								
n 1	888.79	673.68	565.54	341.42	355.45	106.93	317.73	222.5
n 2	898.44	669.02	556.45	34000	356.72	109.07	313.16	226.46
mean	893.62	671.35	56100	340.71	356.09	10800	315.45	224.48
SD	6.82	3.3	6.43	100	0.9	15100	3.23	2.8
SE	4.82	2.33	4.55	0.71	0.64	1.07	2.28	1.98
18/4/94								
n 1	3345.4	1654	708.5	571.47	397.06	160.37	556.1	236.03
n 2	3350.6	1639.8	712.8	581.4	382.01	171.13	546.23	233.31
mean	3348	1646.9	710.65	576.44	389.54	165.75	551.17	234.67
SD	3.73	10.08	3.04	7.02	10.64	7.61	6.98	1.92
SE	2.64	7.13	2.15	4.96	7.52	5.38	4.94	1.36
19/4/94								
n 1	1376.7	1491	1416.1	382.34	405.54	352.6	385.76	355.43
n 2	1370.1	1500	1420.2	391.12	411.82	349.97	380.56	350.73
mean	1373.4	1495.6	1418.1	386.73	408.68	351.29	383.16	353.08
SD	4.64	6.44	2.91	6.21	4.44	1.86	3.68	3.32
SE	3.28	4.55	2.06	4.39	3.14	1.32	2.6	2.35
20/4/94								
n 1	984.5	2645	1400.2	316.46	385.99	184.69	324.17	294.54
n 2	990.46	2630.1	1403.2	320.21	390.62	184.02	326.53	294.54
mean	987.48	2637.6	1401.7	318.34	388.31	184.36	325.35	294.54
SD	4.21	10.52	2.14	2.65	3.27	0.47	1.67	0
SE	2.98	7.44	1.51	1.87	2.31	0.33	1.18	0
21/4/94								
n 1	1967.2	359	1396	353.21	389	141.74	287.79	182.17
n 2	1979.3	3521.1	1399	350.62	372.11	144.77	288.69	192.32
mean	1973.3	3535.1	1397.5	351.92	380.56	143.26	288.24	187.25
SD	8.54	19.73	2.17	1.83	11.94	2.14	0.64	7.18
SE	6.04	13.95	1.53	1.29	8.44	1.51	0.45	5.08

APPENDIX 3

			NITRITE					
			ug/L					
		DATE :	15/4/94 - 21/4/94					
15/4/94								
	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
n 1	49.7	6.8	37.6	64.05	63.29	12.52	52.02	82.08
n 2	52.16	7.3	39.11	60.66	63.31	15.05	56.87	82.16
mean	50.93	7.05	38.36	62.36	63.3	13.79	54.45	82.12
SD	1.74	0.35	1.07	2.4	0.01	1.79	3.43	0.06
SE	1.23	0.25	0.76	1.7	0.01	1.27	2.43	0.04
16/4/94								
n 1	0.189	27.35	22.27	58.11	56.71	9.83	50.76	26.86
n 2	0.21	25.62	20.31	61.52	52.88	10.62	55.32	20.91
mean	0.2	26.49	21.29	59.72	54.8	10.23	53.04	23.89
SD	0.01	1.22	1.39	2.27	2.71	0.56	3.22	4.21
SE	0.01	0.86	0.98	1.61	1.92	0.4	2.28	2.98
17/4/94								
n 1	44.1	33.42	53.16	39.48	44.75	24.87	31.67	19.5
n 2	48.6	30.12	58.21	32.62	40.82	20.9	35.62	25.62
mean	46.35	31.77	55.69	36.05	42.79	22.89	33.65	22.56
SD	3.18	2.33	3.57	4.85	2.78	2.8	2.79	4.33
SE	2.25	1.65	2.52	3.43	1.97	1.98	1.97	3.06
18/4/94								
n 1	89.65	0	125	77.73	28.94	7.53	30.7	19.97
n 2	92.19	0	120.62	79.37	23.06	10.11	38.1	25.62
mean	90.92	0	122.81	78.55	31	8.82	34.4	22.8
SD	1.8	0	3.1	1.6	2.9	1.82	5.23	4
SE	1.27	0	2.19	0.82	2.06	1.29	3.7	2.83
19/4/94								
n 1	8.32	0	7.25	26.76	27.96	9.4	23.54	13.67
n 2	10.62	0	8.32	30.99	25.21	13.6	20.45	16.72
mean	9.47	0	7.79	28.88	26.59	11.5	22	15.2
SD	1.63	0	0.76	2.99	1.94	2.97	2.18	2.16
SE	1.15	0	0.54	2.11	1.37	2.1	1.54	1.53
20/4/94								
n 1	15.7	0	19.25	55.74	62.41	10.31	47.93	22.46
n 2	19.08	0	25.61	50.13	59.21	13.1	50.71	25.52
mean	17.39	0	22.43	52.94	60.81	11.71	49.32	23.99
SD	2.39	0	4.5	3.97	2.26	1.97	1.97	2.16
SE	1.69	0	3.18	2.81	1.6	1.39	1.39	1.53
21/4/94								
n 1	12.76	0	10.25	43.59	53.3	8.96	36.61	17.43
n 2	12.01	0	8.62	50.43	50.81	8	41.21	18.21
mean	12.39	0	9.44	47.01	52.06	8.48	38.91	17.82
SD	0.53	0	1.15	4.84	1.76	0.68	3.25	0.55
SE	0.37	0	0.81	3.42	1.24	0.48	2.3	0.39
n 1								
n 2								
mean								
SD								
SE								

APPENDIX 4

TOTAL OXIDISED NITPOGEN

mg/L

DATE : 15/4/94 – 21/4/94

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
15/4/94								
n 1	18.08	17.15	18.64	18.89	19.39	18.19	20.05	19.27
n 2	18.73	16.98	18.71	18.76	19.23	17.99	19.92	19.31
mean	18.41	17.07	18.68	18.83	19.31	18.09	19.99	19.29
SD	0.46	0.12	0.05	0.09	0.11	0.14	0.09	0.03
SE	0.33	0.08	0.04	0.06	0.07	0.1	0.06	0.02
16/4/94								
n 1	18.26	17.42	20.07	18.98	19.63	24.57	19.39	19.88
n 2	18.34	17.61	20.11	18.88	19.58	24.61	19.42	19.83
mean	18.3	17.52	20.09	18.93	19.61	24.59	19.41	19.86
SD	0.06	0.13	0.03	0.07	0.04	0.03	0.02	0.04
SE	0.04	0.09	0.02	0.05	0.03	0.02	0.01	0.03
17/4/94								
n 1	17.56	17.83	17.29	19.49	20.27	18.38	19.6	22.06
n 2	17.53	17.91	17.32	19.47	20.14	18.43	19.55	22.01
mean	17.55	17.81	17.31	19.48	20.21	18.41	19.58	22.04
SD	0.02	0.06	0.02	0.01	0.09	0.04	0.04	0.04
SE	0.01	0.04	0.01	0.01	0.06	0.03	0.02	0.02
18/4/94								
n 1	17.95	18.05	20.99	19.72	20.33	16.97	17.25	17.54
n 2	18.02	18.11	20.82	19.81	20.36	17.07	17.32	17.49
mean	17.99	18.08	20.91	19.77	20.35	17.02	17.29	17.52
SD	0.05	0.04	0.12	0.06	0.02	0.07	0.05	0.04
SE	0.04	0.03	0.08	0.04	0.01	0.05	0.04	0.03
19/4/94								
n 1	18.54	17.79	16.41	19.71	16.4	19.72	19.11	20.82
n 2	18.49	17.71	16.58	19.68	16.38	19.68	19.19	20.73
mean	18.52	17.75	16.5	19.7	16.39	19.7	19.15	20.78
SD	0.04	0.06	0.12	0.02	0.01	0.03	0.06	0.06
SE	0.03	0.04	0.08	0.01	0.01	0.02	0.04	0.04
20/4/94								
n 1	16.85	17.15	17.31	19.56	19.21	17.01	19.46	16.95
n 2	16.77	17.02	17.39	19.5	19.37	17.12	19.52	17.07
mean	16.81	17.09	17.35	19.53	19.29	17.07	19.49	17.01
SD	0.06	0.09	0.06	0.04	0.11	0.08	0.04	0.08
SE	0.04	0.06	0.04	0.03	0.08	0.06	0.03	0.06
21/4/94								
n 1	18.28	17.26	20.99	19.12	16.12	16.32	15.97	17.39
n 2	18.33	17.24	20.87	19.13	16.17	16.28	16.05	17.43
mean	18.31	17.25	20.93	19.13	16.15	16.3	16.01	17.41
SD	0.04	0.01	0.08	0.01	0.04	0.03	0.06	0.03
SE	0.03	0.01	0.06	0.01	0.03	0.02	0.04	0.02

APPENDIX 5

			O-PHOSPHATE					
			ug/L					
			DATE :	15/4/94 - 31/4/94				
15/4/94								
	SITE 1	SITE 3	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
n 1	495.1	85.31	212	140.15	115.6	117.05	135.15	189.7
n 2	482.61	90.7	310.11	144.65	111.33	119.08	166.01	181.32
mean	498.96	87.96	311.06	142.4	113.47	118.07	150.58	185.51
SD	8.83	3.88	1.34	3.18	3.02	1.44	21.82	5.93
SE	6.24	2.74	0.95	2.25	2.14	1.02	15.43	4.19
16/4/94								
n 1	46.8	46.15	129.1	110.1	102	82.99	92.09	73.45
n 2	50.07	45.21	125.61	107.32	101.99	80	92.97	77.32
mean	48.44	45.68	127.36	108.71	102	81.5	92.53	75.39
SD	2.31	0.66	2.47	1.97	0.007	2.11	0.62	2.74
SE	1.63	0.47	1.75	1.39	0.005	1.49	0.44	1.94
17/4/94								
n 1	49.55	0	79.2	55.01	78.83	179.9	37.01	64.26
n 2	53.26	1.12	83.09	51.21	70.11	172.83	39.25	60.59
mean	51.41	0.56	81.15	53.11	74.47	176.37	38.13	62.43
SD	2.62	0.79	2.75	2.69	6.17	5	1.58	2.6
SE	1.85	0.56	1.94	1.9	4.36	3.54	1.12	1.98
18/4/94								
n 1	164.8	89.08	317.4	312.4	48.78	93.83	40.9	66.92
n 2	71.03	85.62	321.29	315.79	45.21	90.89	44.65	69.08
mean	167.92	87.35	319.35	314.1	47	92.36	42.78	68
SD	4.41	2.45	2.75	2.4	2.52	2.08	2.65	1.53
SE	3.12	1.73	1.94	1.7	17800	1.47	1.86	1.08
19/4/94								
n 1	10.41	73.43	92.3	37.42	81.17	148.8	129.5	127.3
n 2	11.8	77.32	90.12	38.56	86.23	144.76	132.1	130.6
mean	11.11	75.38	91.21	37.99	83.7	146.78	130.8	128.95
SD	0.98	2.75	1.54	0.81	3.58	2.86	1.84	2.33
SE	3.12	1.95	1.09	0.57	2.53	2.02	1.3	1.65
20/4/94								
n 1	92.19	46.28	51.56	12.95	127.5	210.5	66.46	184.9
n 2	96.21	40.31	53.61	10.92	130.12	215.72	66.11	190.81
mean	94.2	43.3	52.59	11.94	128.81	213.11	66.29	187.86
SD	2.84	4.22	1.45	1.44	1.85	3.69	0.25	4.18
SE	2.01	2.98	1.03	1.02	1.31	2.61	0.18	2.96
21/4/94								
n 1	21.18	75	37.31	90.72	73.19	129.9	64.68	99.78
n 2	22.13	75.62	38.23	96.29	70.23	133.97	60.45	103.62
mean	21.66	75.31	37.77	93.51	71.71	131.94	62.57	101.7
SD	0.67	0.44	0.65	3.94	2.09	2.88	2.99	2.72
SE	0.47	0.31	0.46	2.79	1.48	2.04	2.11	1.92

APPENDIX 6

	TOTAL PHOSPHORUS							
	mg/L							
	DATE :	15/4/94 - 21/4/94						
15/4/94								
	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
n 1	1.39	0.032	0.363	0.276	0.223	0.085	0.203	0.114
n 2	1.36	0.049	0.351	0.283	0.236	0.077	0.219	0.2
mean	1.38	0.041	0.357	0.279	0.23	0.081	0.211	0.157
SD	0.021	0.012	0.008	0.005	0.009	0.006	0.011	0.061
SE	0.014	0.008	0.006	0.004	0.006	0.004	0.008	0.043
16/4/94								
n 1	0.13	0.24	0.283	0.327	0.206	0.149	0.165	0.203
n 2	0.142	0.199	0.291	0.364	0.294	0.156	0.18	0.219
mean	0.136	0.22	0.287	0.346	0.25	0.153	0.173	0.211
SD	0.008	0.029	0.006	0.026	0.062	0.005	0.011	0.011
SE	0.006	0.021	0.004	0.018	0.044	0.004	0.008	0.008
17/4/94								
n 1	0.164	0.532	0.204	0.081	0.02	0.259	0.171	0.216
n 2	0.174	0.518	0.211	0.083	0.018	0.229	0.189	0.222
mean	0.169	0.525	0.208	0.082	0.019	0.244	0.18	0.219
SD	0.007	0.01	0.005	0.001	0.001	0.021	0.03	0.004
SE	0.005	0.007	0.004	0.001	0.001	0.015	0.009	0.003
18/4/94								
n 1	0.24	0.081	0.844	0.076	0.034	0.224	0.14	0.137
n 2	0.211	0.089	0.841	0.099	0.052	0.261	0.135	0.201
mean	0.226	0.085	0.843	0.088	0.043	0.243	0.138	0.169
SD	0.021	0.006	0.002	0.016	0.013	0.026	0.004	0.045
SE	0.015	0.004	0.001	0.011	0.009	0.018	0.003	0.032
19/4/94								
n 1	0.04	0.043	0.173	0.152	0.216	0.168	0.126	0.143
n 2	0.11	0.059	0.158	0.123	0.236	0.173	0.143	0.132
mean	0.075	0.051	0.166	0.138	0.226	0.171	0.135	0.138
SD	0.049	0.011	0.011	0.021	0.014	0.004	0.012	0.008
SE	0.035	0.008	0.008	0.015	0.01	0.003	0.008	0.006
20/4/94								
n 1	0.05	0.052	0.079	0.231	0.241	0.103	0.16	0.071
n 2	0.062	0.071	0.083	0.201	0.261	0.118	0.209	0.1
mean	0.056	0.062	0.081	0.216	0.251	0.111	0.185	0.086
SD	0.008	0.013	0.003	0.021	0.014	0.011	0.035	0.021
SE	0.006	0.009	0.002	0.015	0.01	0.008	0.025	0.015
21/4/94								
n 1	0.024	0.102	0.056	0.16	0.113	0.158	0.159	0.3
n 2	0.027	0.123	0.071	0.154	0.121	0.142	0.163	0.281
mean	0.026	0.113	0.064	0.157	0.117	0.15	0.161	0.291
SD	0.002	0.015	0.011	0.004	0.006	0.011	0.003	0.013
SE	0.001	0.011	0.008	0.003	0.004	0.008	0.002	0.009

APPENDIX 7

CALCULATION OF MASS FLOW RATE

AND

REMOVAL EFFICIENCIES

Concentration was converted to g/L.
Scince we know how many litres per day of water was flowing down the SWD or yuroke creek, from the flow rate data, appendix 8, we can calculate how many grams per day was coming down each SWD / Yuroke Creek.
Removal efficiencies were then calculated from influent and effluent flow rates.

APPENDIX 8

FLOW RATE DATA

FLOW RATE IN DRAIN WITH RAIN INFLUENCE = 8,640 L/DAY

FLOW IN DRAIN WITH NO RAIN INFLUENCE = 3,600 L/DAY

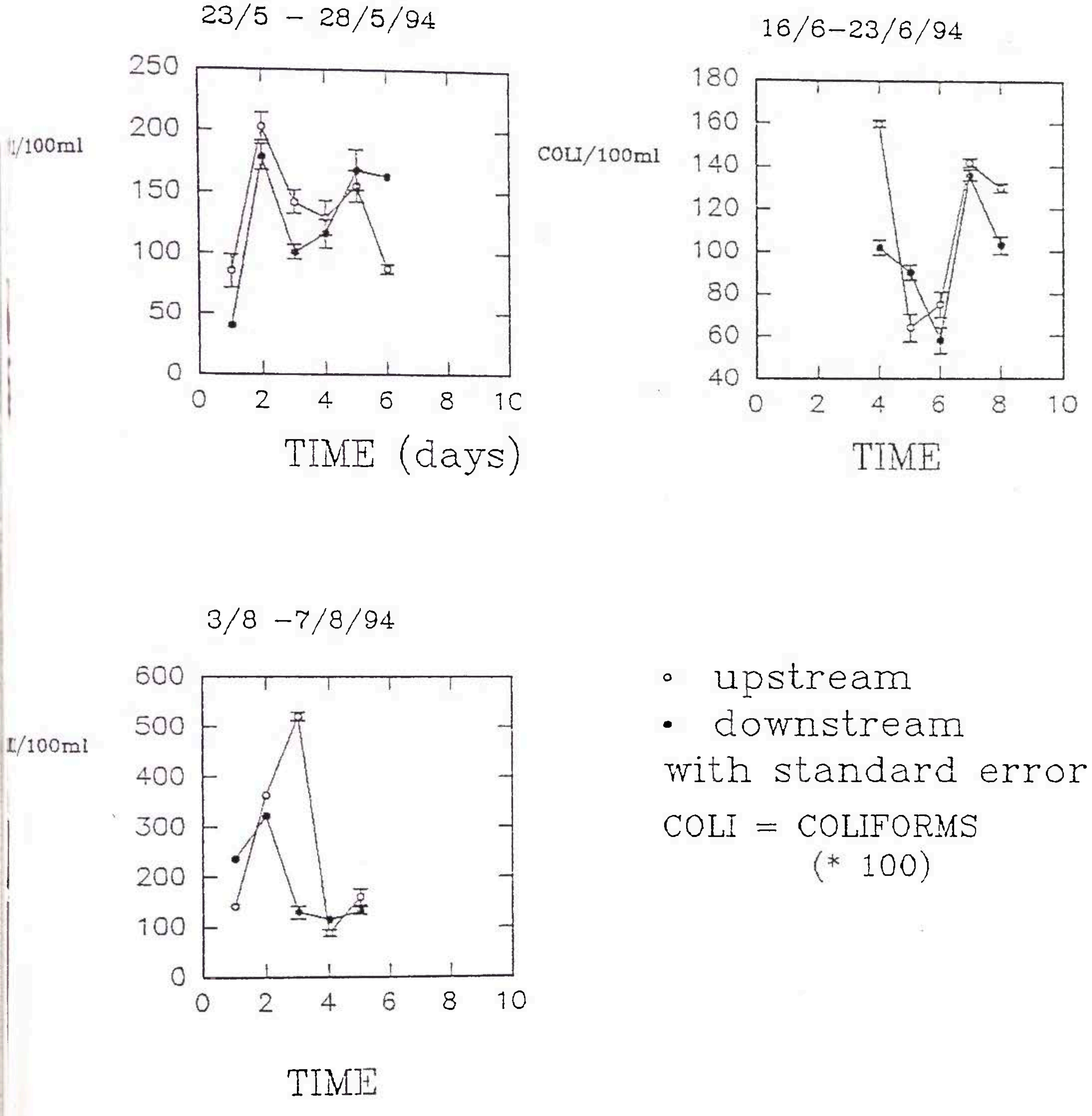
FLOW RATE AT SAMPLE POINT 6 = 4,320 L/DAY

FLOW RATE AT SAMPLE POINT 8 = 4,320 L/DAY

The above are crude measurements, flow rates will differ at each point depending upon environmental conditions

APPENDIX 9

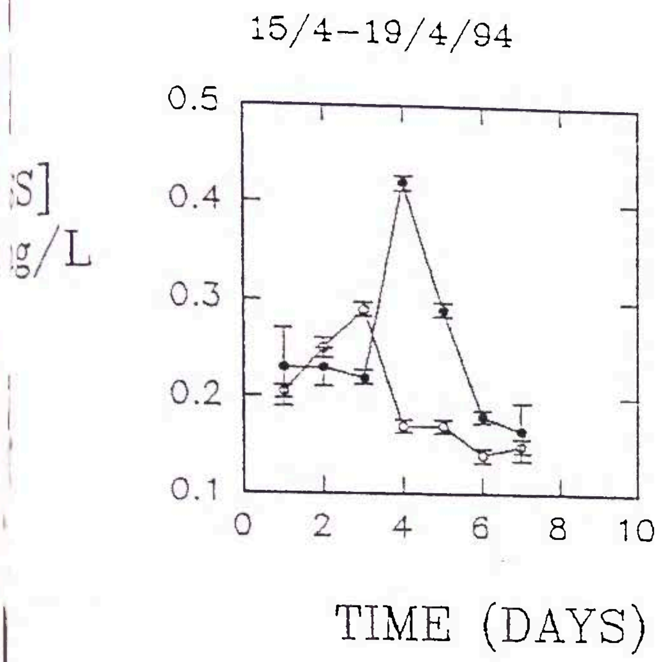
COLIFORM EFFECTS ON YUROKE CREEK

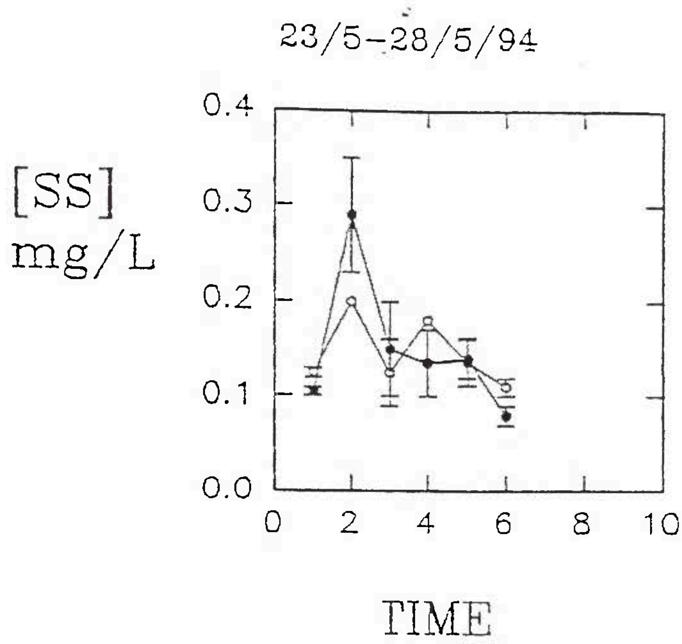


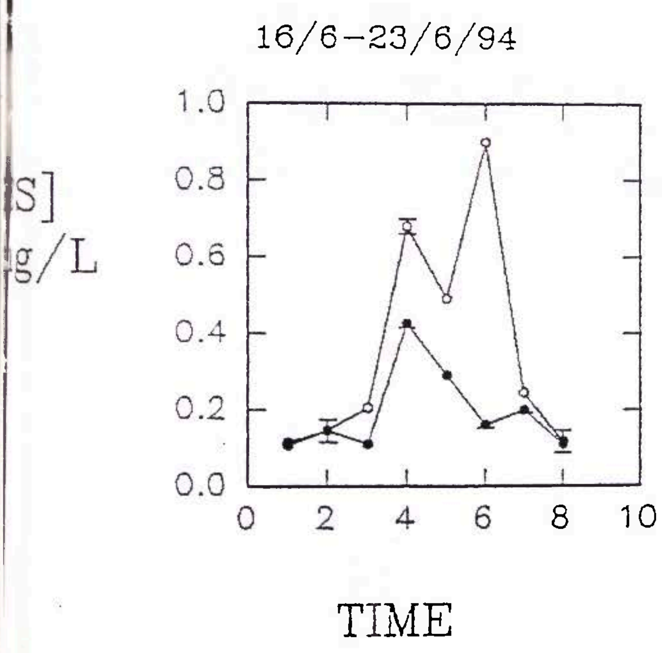
∘ upstream
• downstream
with standard error
COLI = COLIFORMS
(* 100)

APPENDIX 10

SUSPENDED SOLIDS EFFECT ON YUROKE CREEK







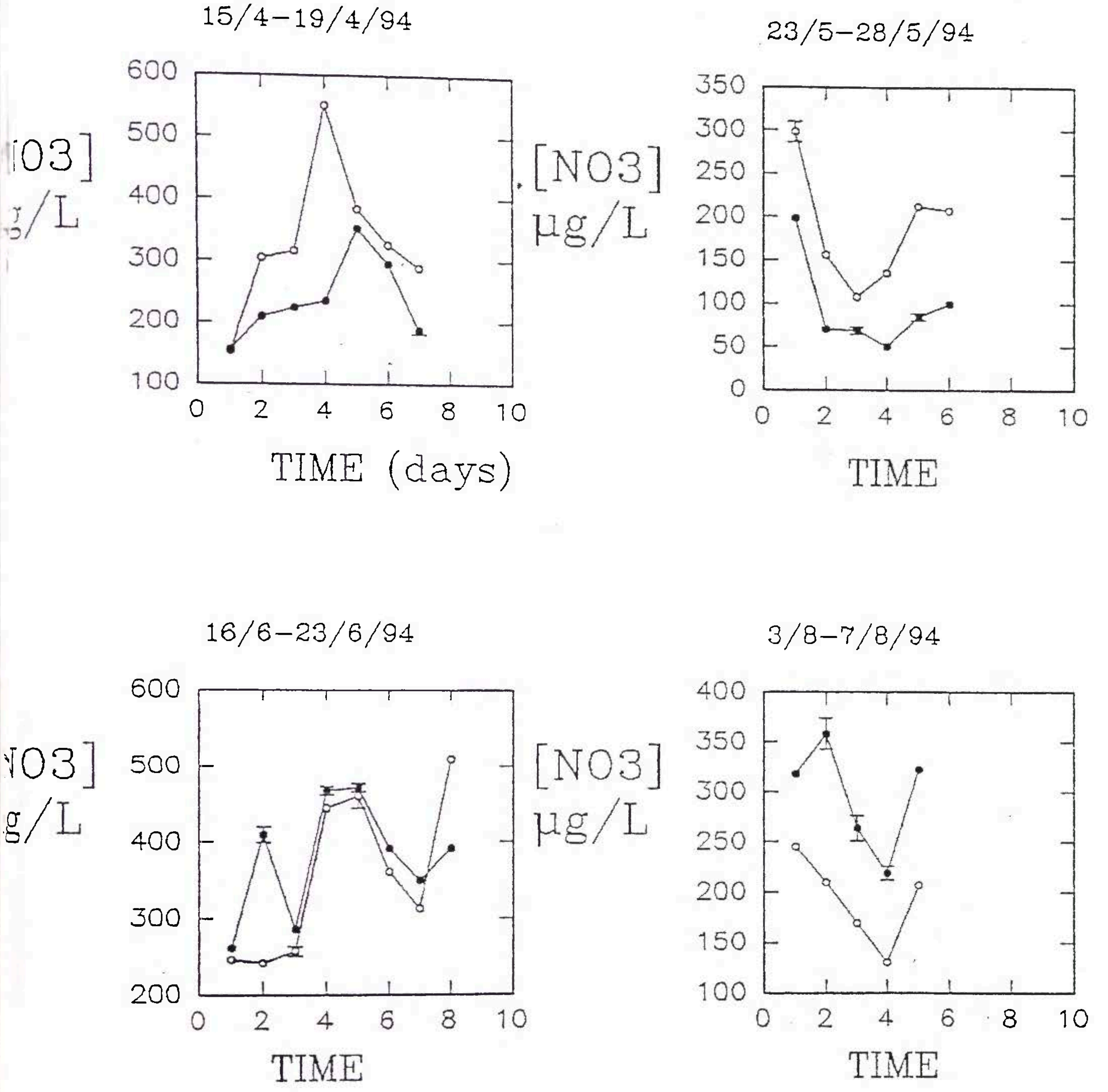
∘ upstream

• downstream

with standard error

APPENDIX 11

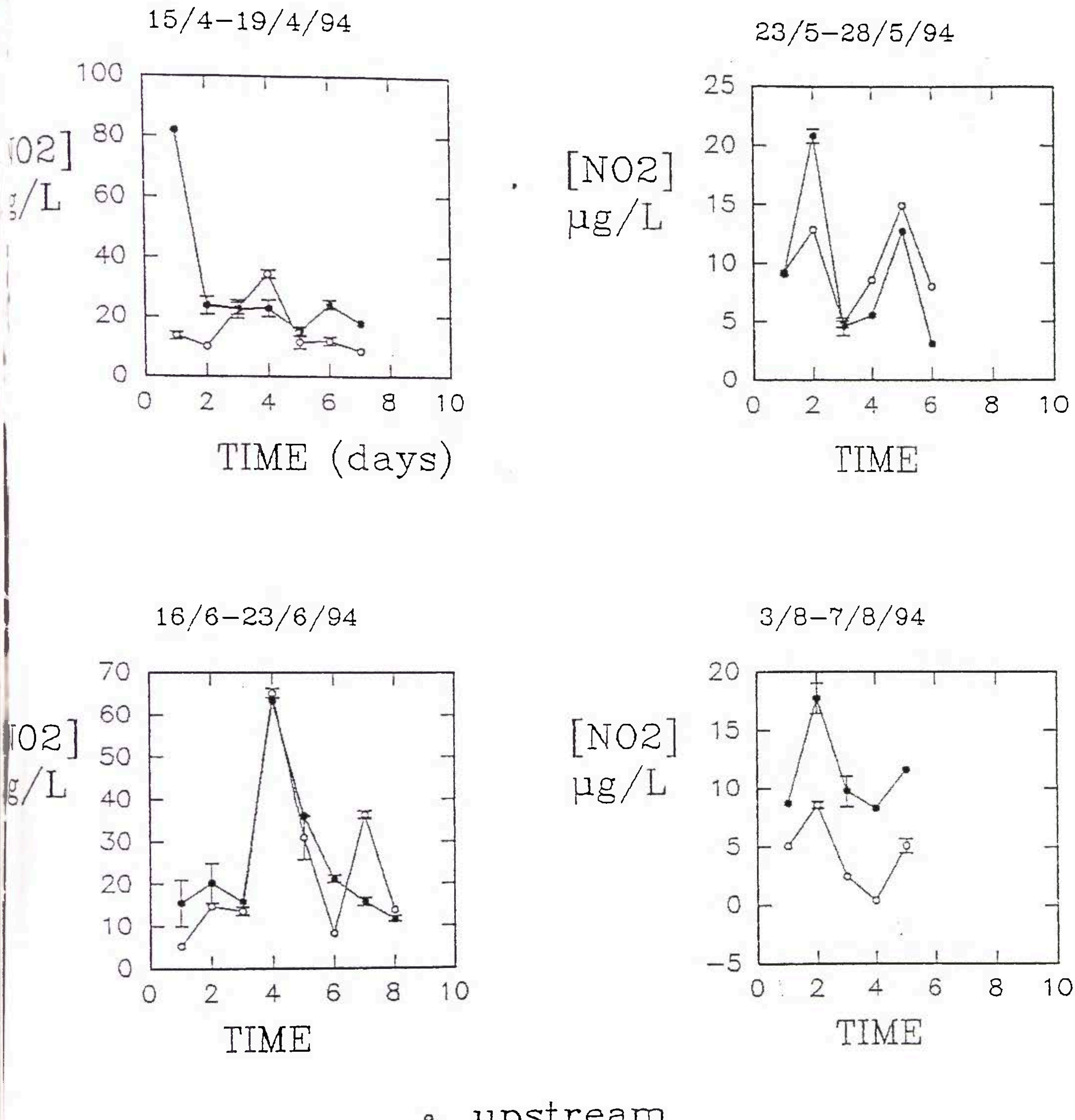
NITRATE EFFECTS ON YUROKE CREEK



∘ upstream
• downstream
with standard error

APPENDIX 12

NITRITE EFFECTS ON YUROKE CREEK

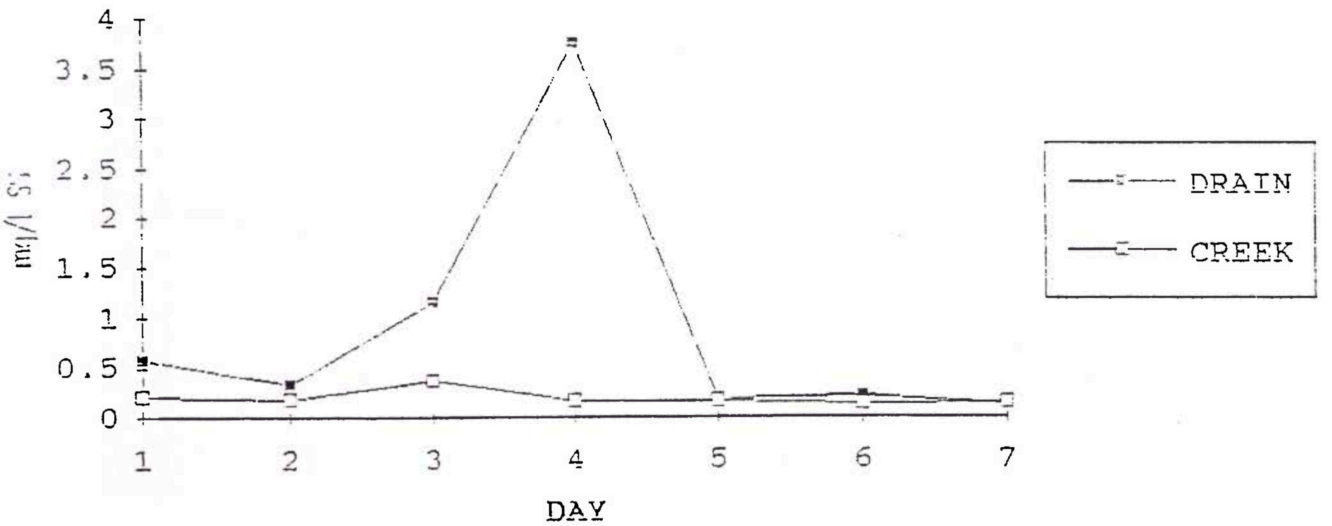


∘ upstream
• downstream
with standard error

APPENDIX 16

15/4/94 - 19/4/1994

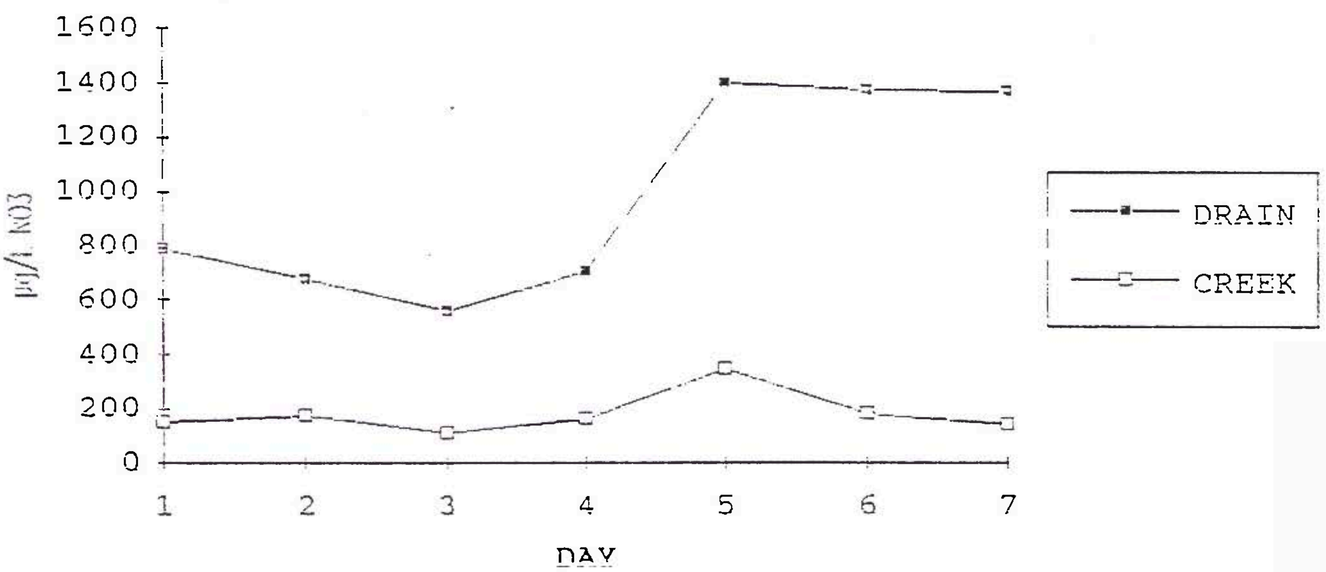
SUSPENDED SOLIDS DIFFERENCE IN SWD AND YUROKE CREEK



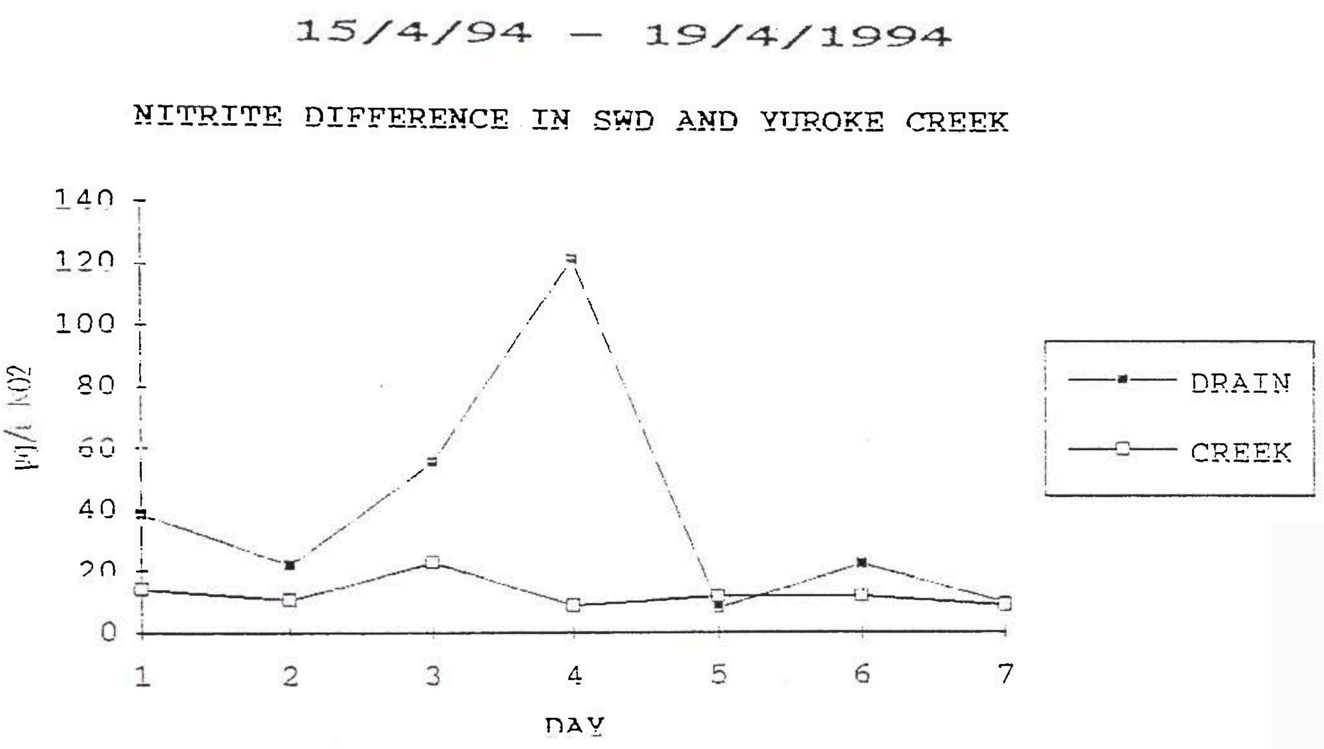
APPENDIX 17

15/4/94 – 19/4/1994

NITRATE DIFFERENCE IN SWD AND YUROKE CREEK

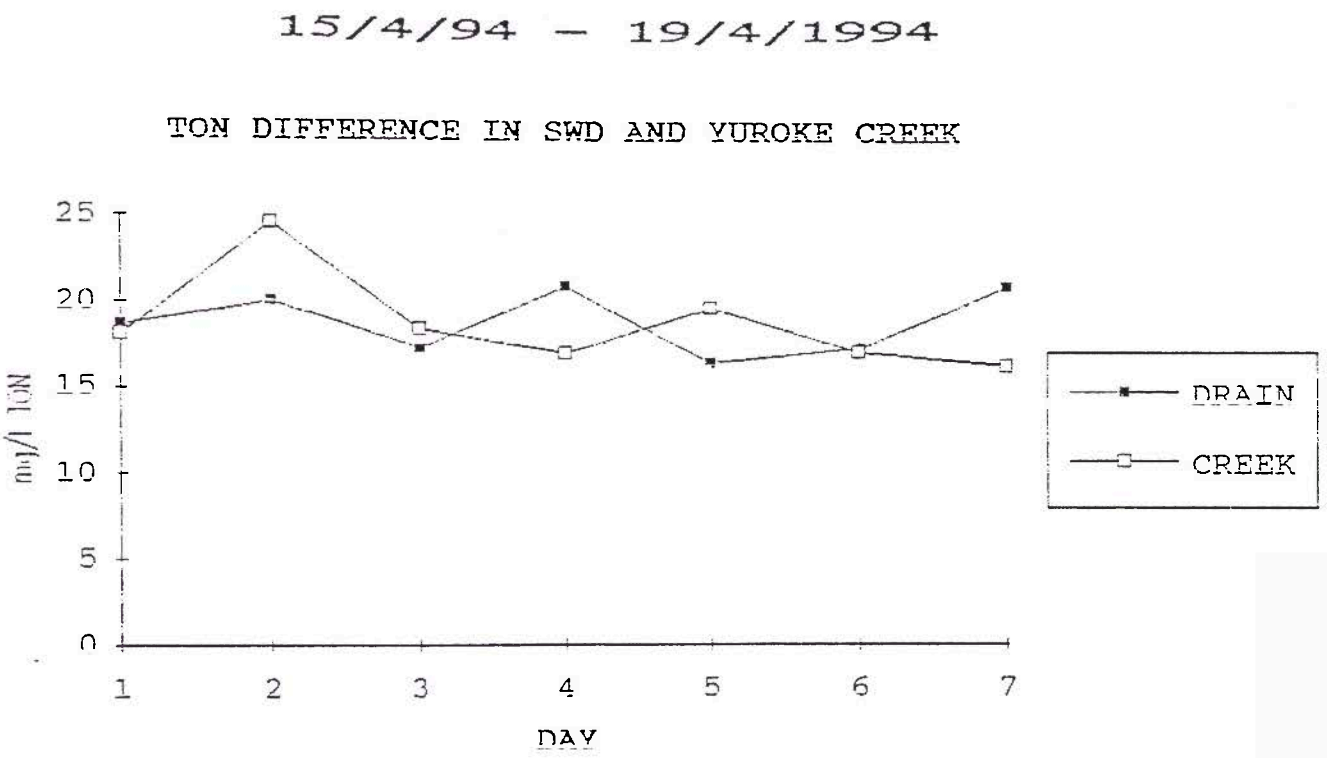


APPENDIX 18



15/4/94 — 19/4/1994
NITRITE DIFFERENCE IN SWD AND YUROKE CREEK
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
DAY
DRAIN
CREEK

APPENDIX 19

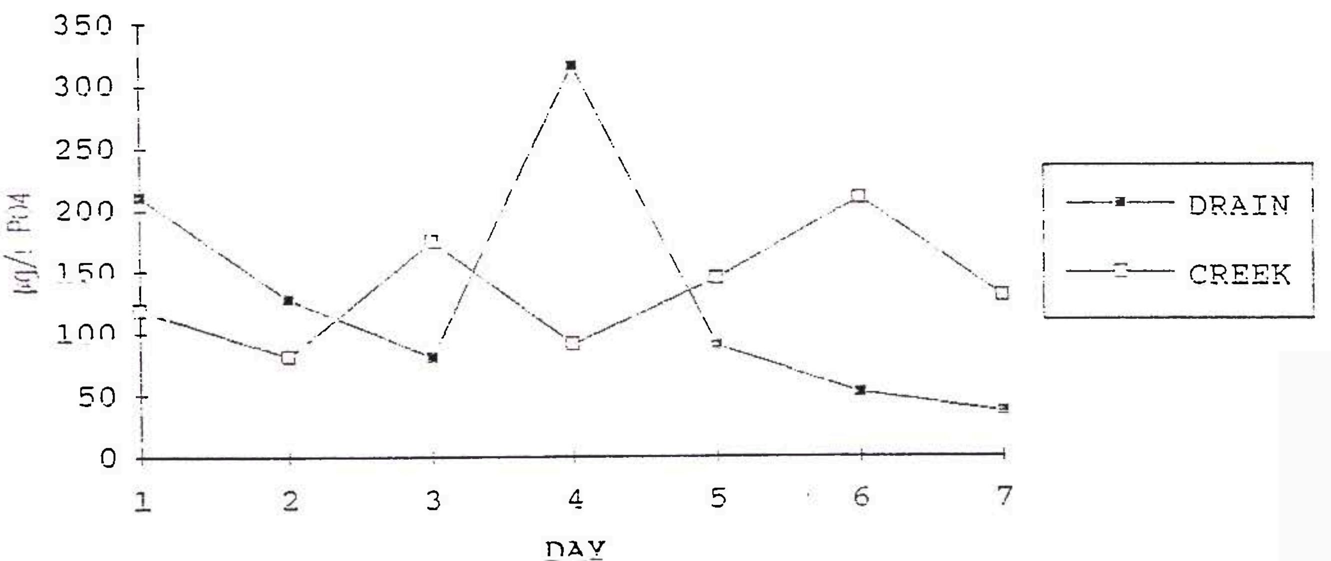


15/4/94 – 19/4/1994
TON DIFFERENCE IN SWD AND YUROKE CREEK
mg/l TON
DAY
DRAIN
CREEK
0
5
10
15
20
25
1
2
3
4
5
6
7

APPENDIX 20

15/4/94 – 19/4/1994

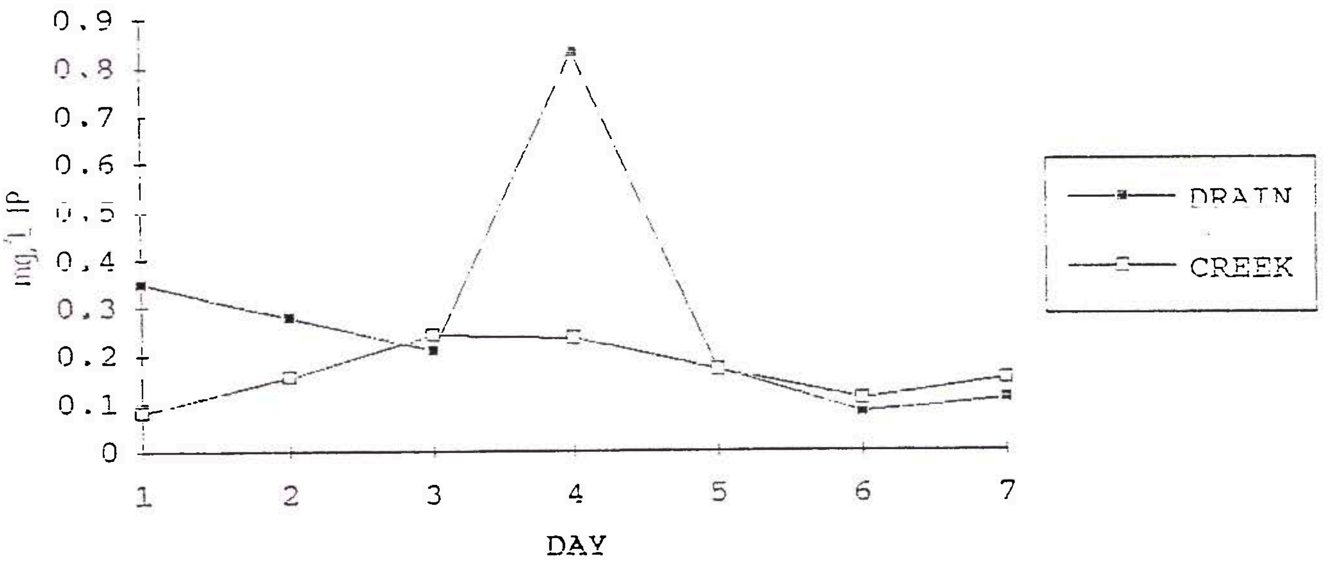
ortho-PHOSPHATE DIFFERENCE IN SWD AND YUROKE CREEK



APPENDIX 21

15/4/94 – 19/4/1994

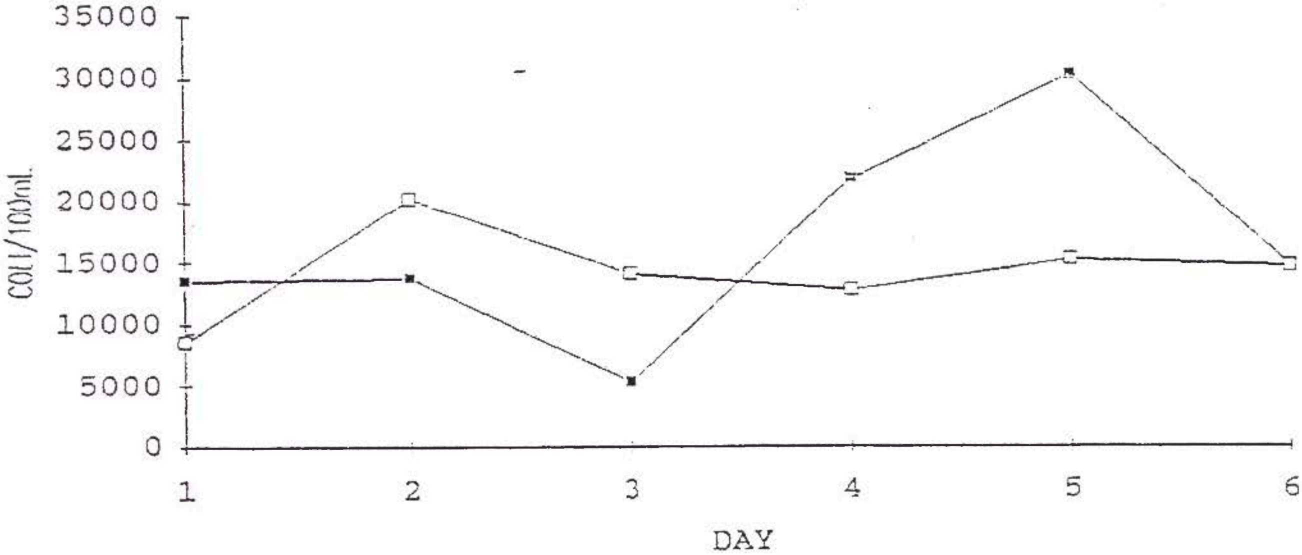
TP DIFFERENCE IN SWD AND YUROKE CREEK



APPENDIX 22

23/5/94 – 28/5/1994

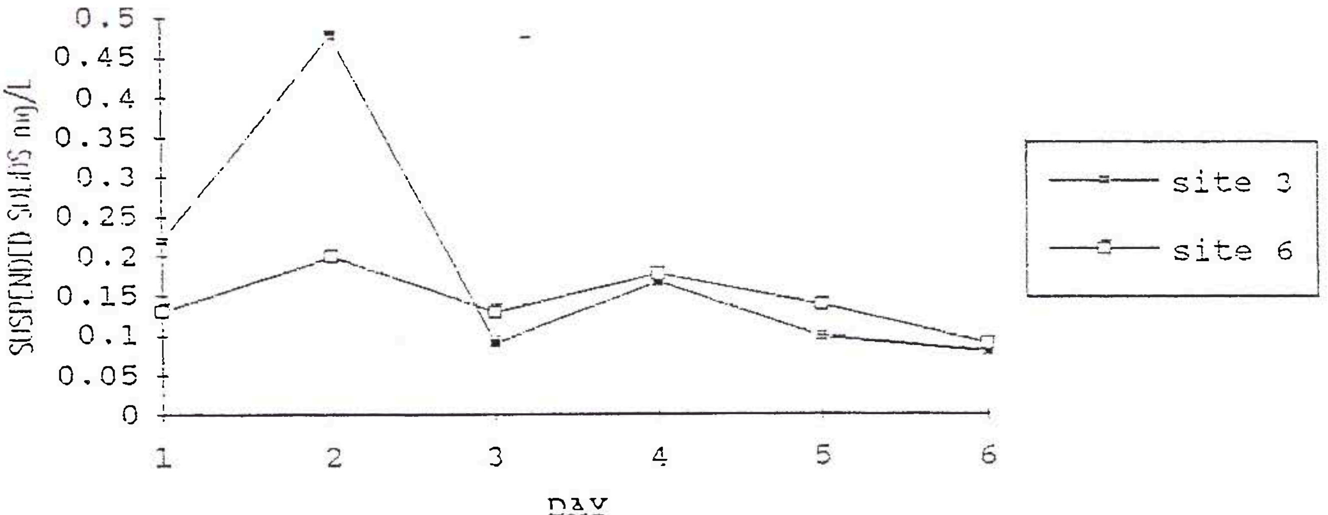
COLIFORM DIFFERENCE IN SWD AND YUROKE CREEK



APPENDIX 23

23/5/94 – 28/5/1994

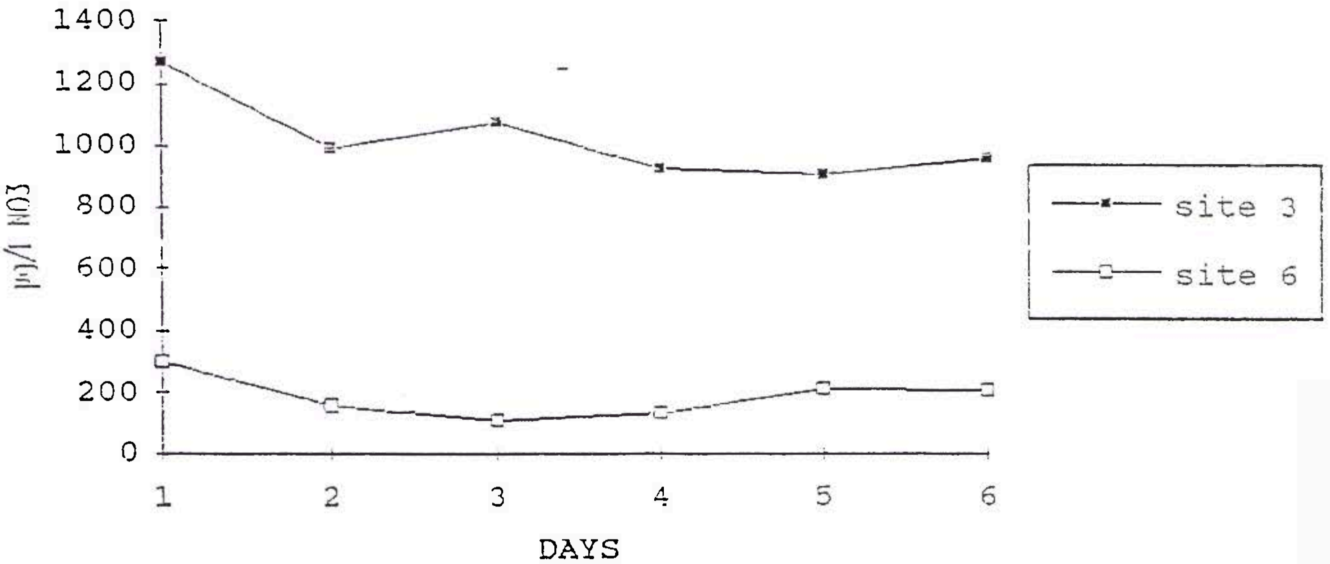
SUSPENDED SOLIDS DIFFERENCE IN SWD AND YUROKE CREEK



APPENDIX 24

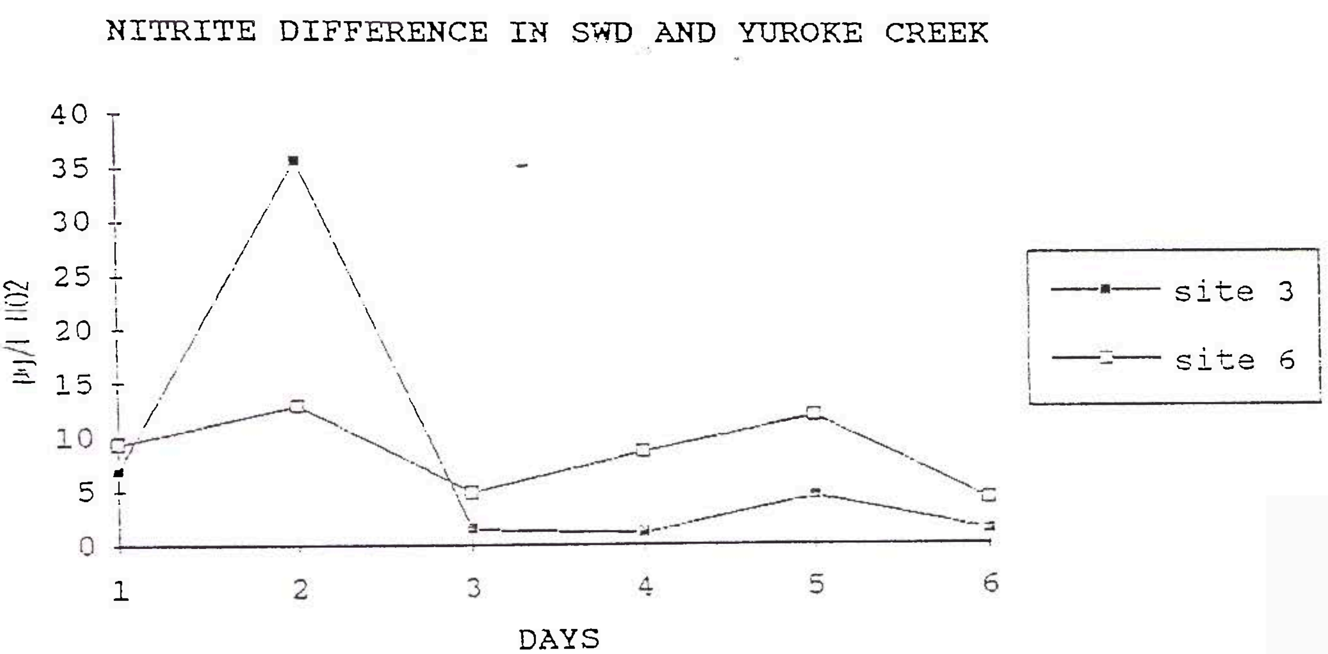
23/5/94 — 28/5/1994

NITRATE DIFFERENCE IN SWD AND YUROKE CREEK



APPENDIX 25

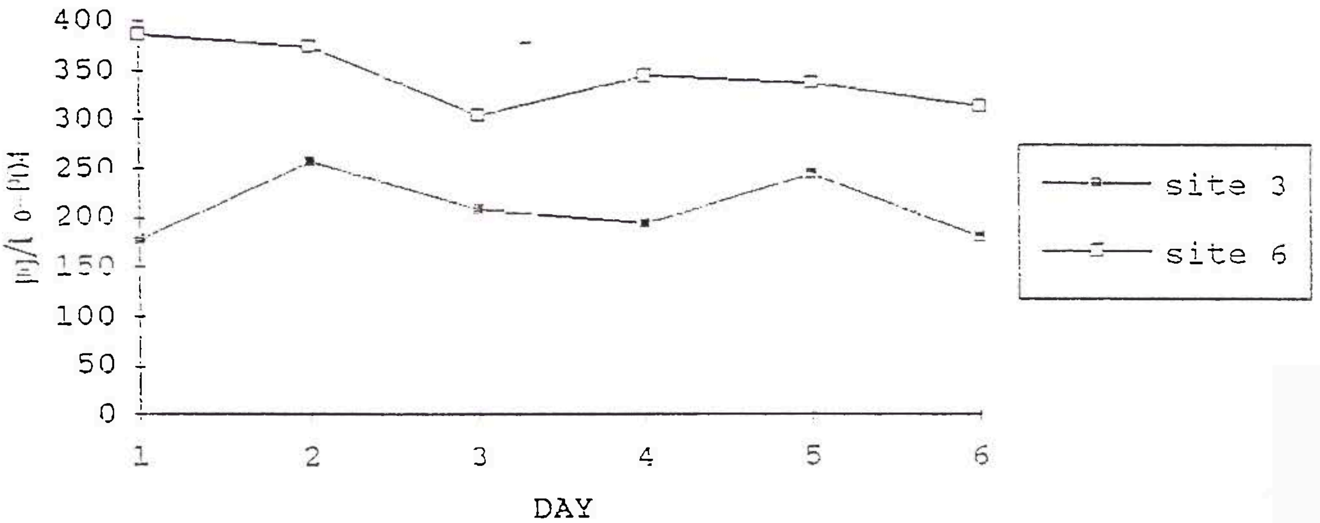
23/5/94 – 28/5/1994



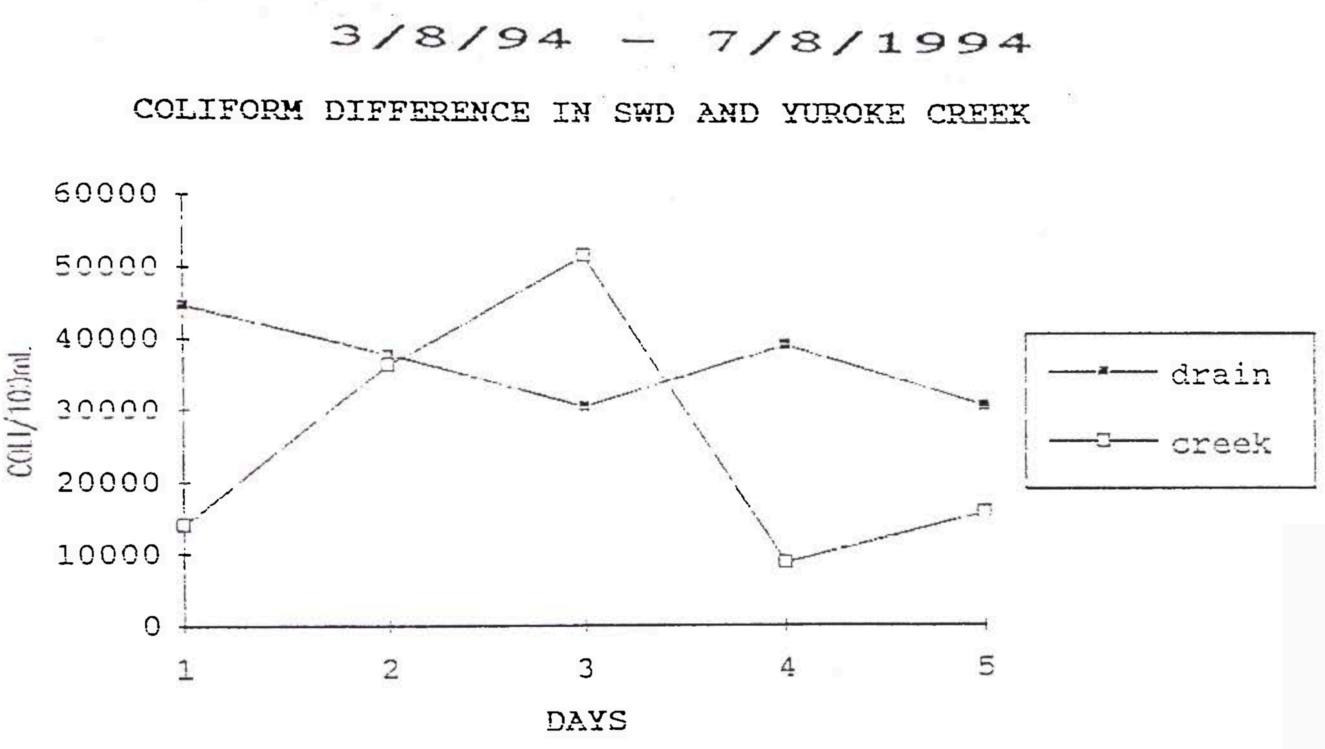
APPENDIX 26

23/5/94 - 28/5/1994

ortho-PHOSPHATE DIFFERENCE IN SWD AND YUROKE CREEK

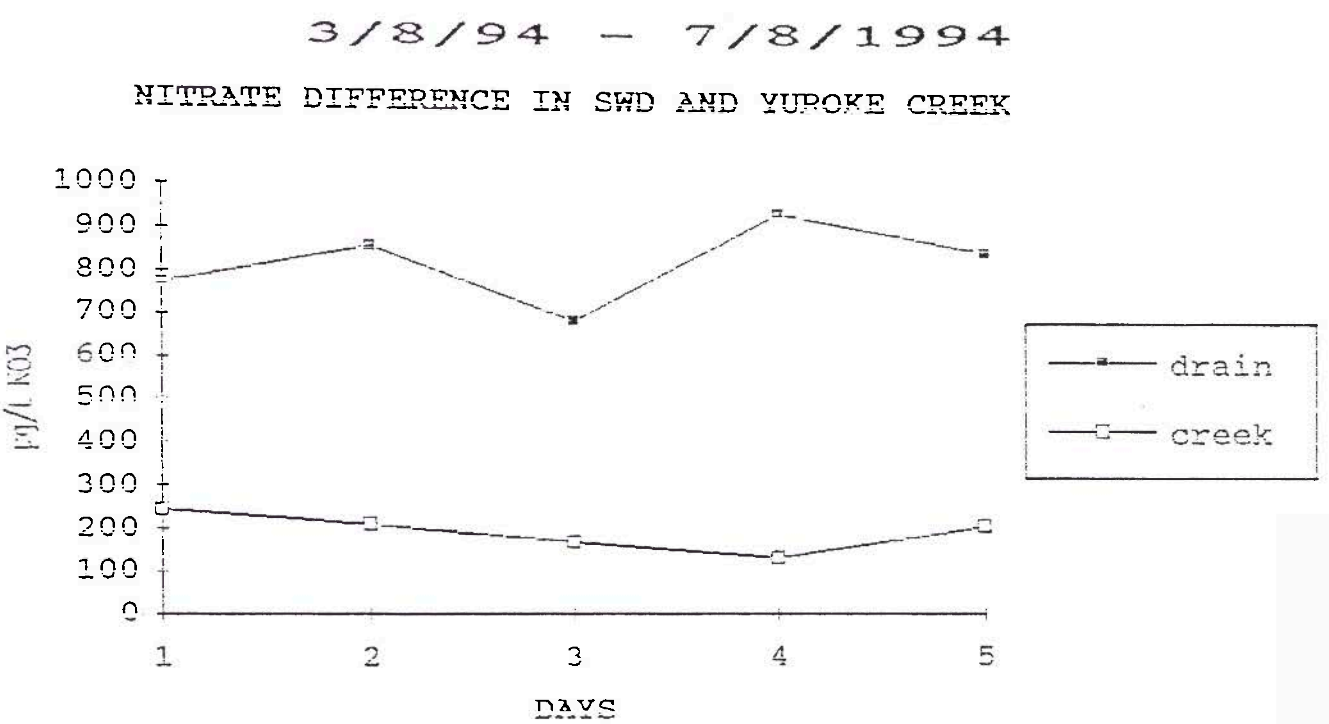


APPENDIX 27



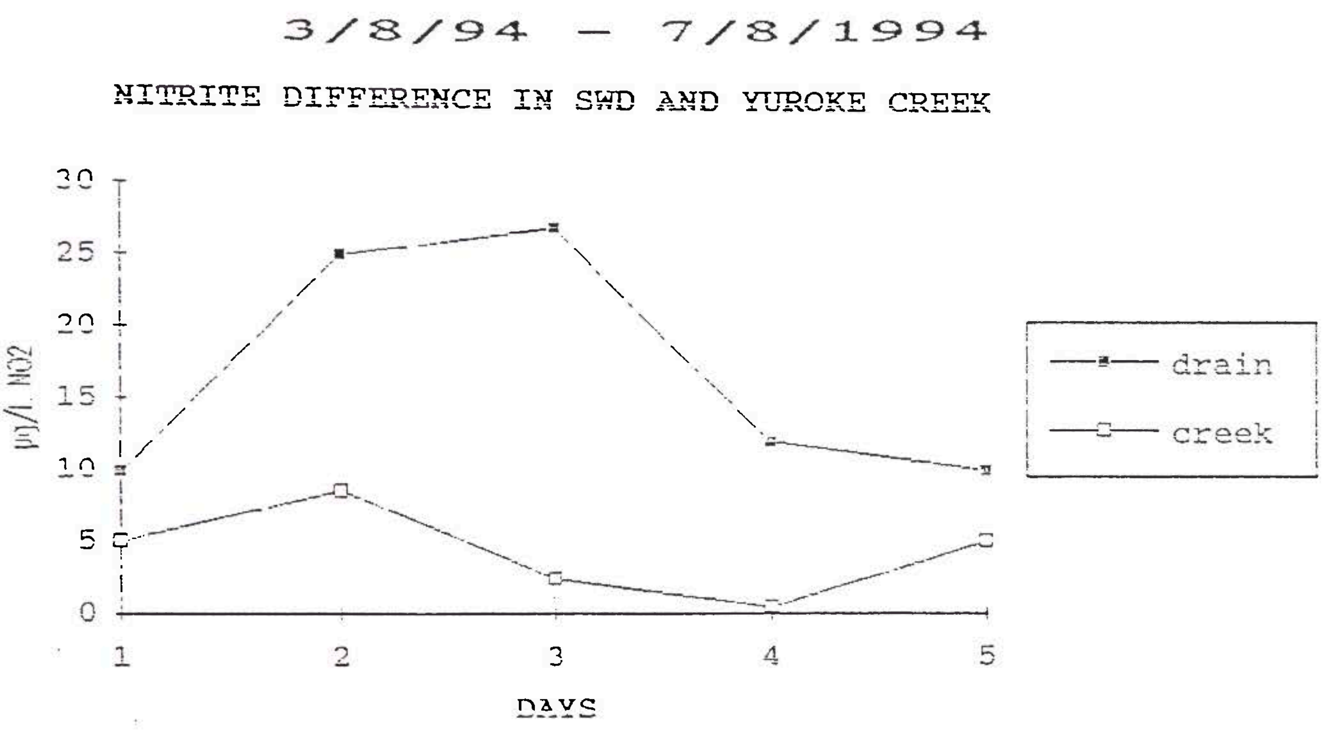
3/8/94 — 7/8/1994
COLIFORM DIFFERENCE IN SWD AND YUROKE CREEK
60000
50000
40000
30000
20000
10000
0
COLI/100ml
1
2
3
4
5
DAYS
drain
creek

APPENDIX 28



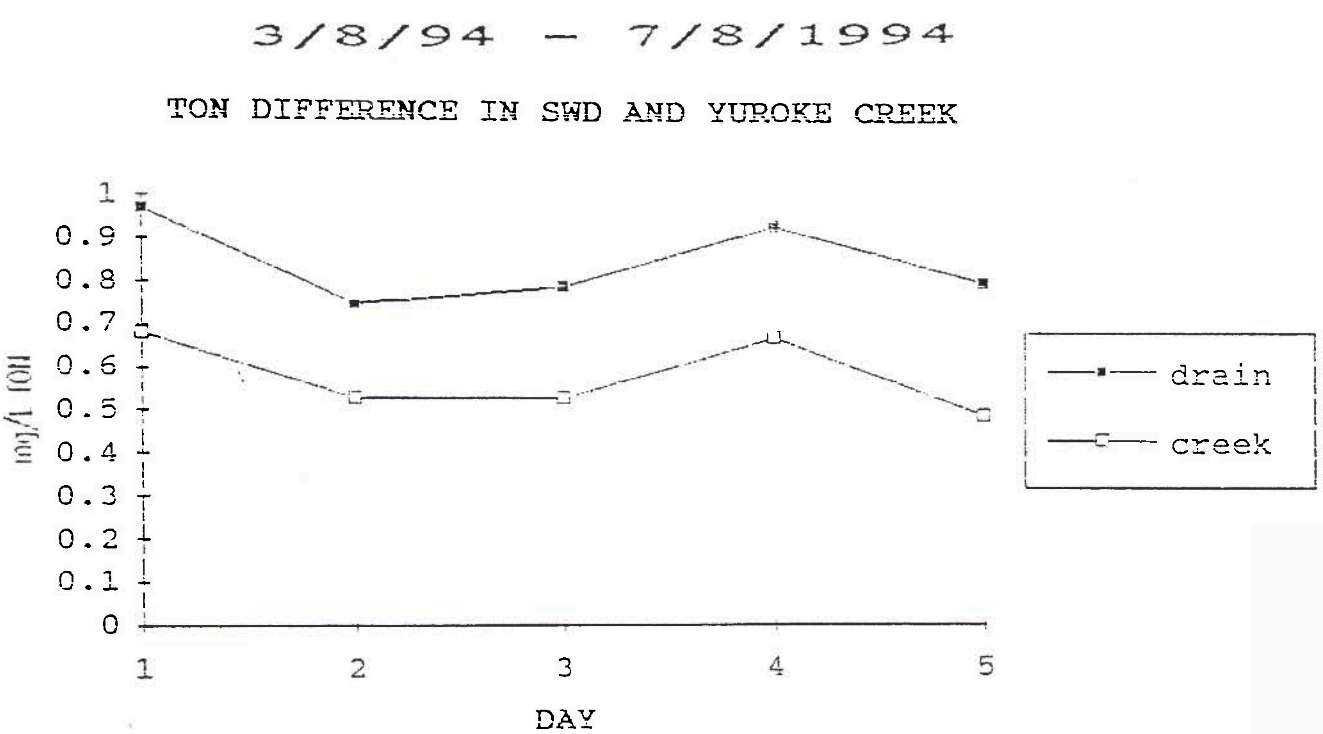
3/8/94 — 7/8/1994
NITRATE DIFFERENCE IN SWD AND YUROKE CREEK
1000
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
DAYS
drain
creek

APPENDIX 29



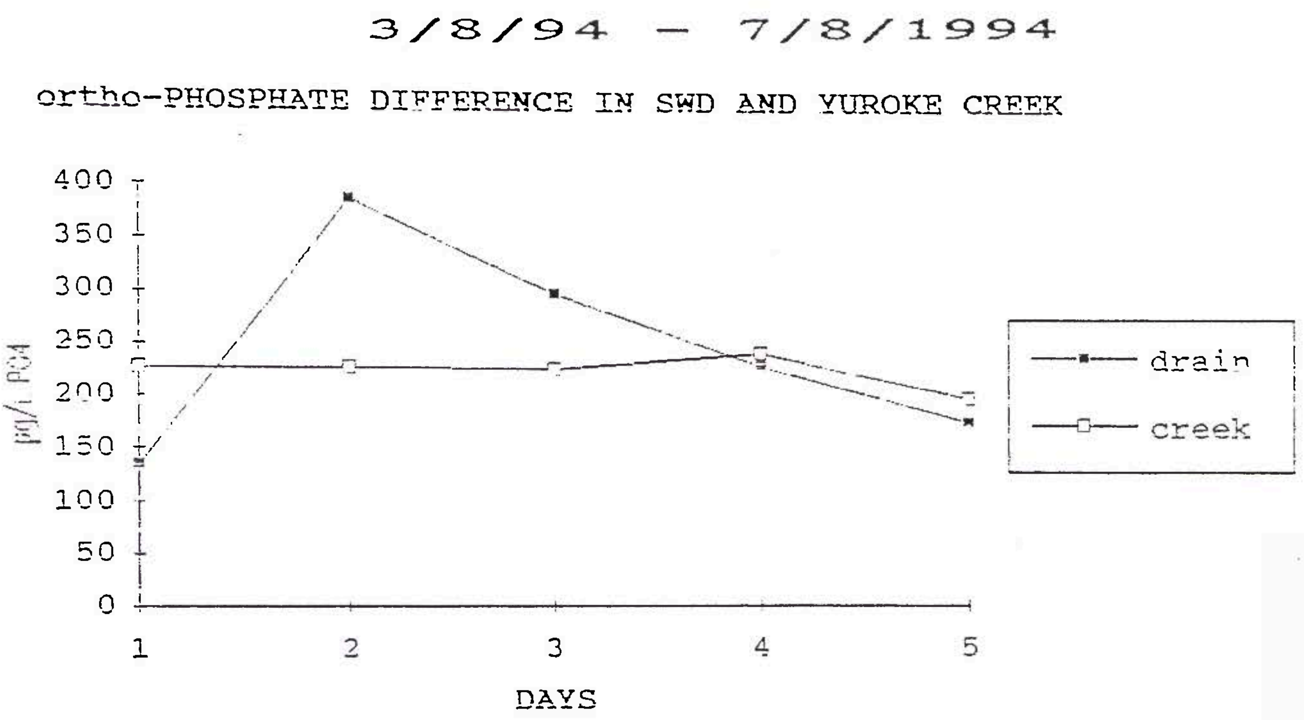
3/8/94 – 7/8/1994
NITRITE DIFFERENCE IN SWD AND YUROKE CREEK
30
25
20
15
10
5
0
µg/L NO2
1
2
3
4
5
DAYS
drain
creek

APPENDIX 30



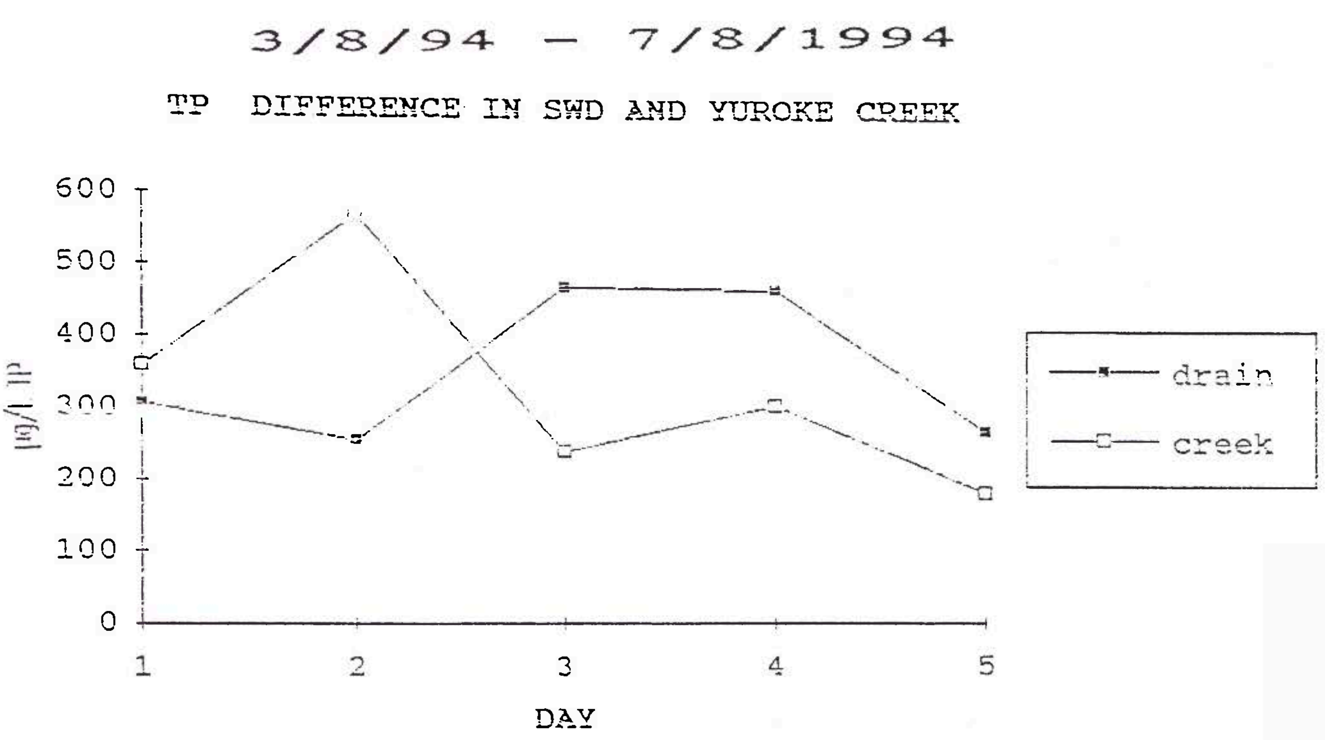
3/8/94 - 7/8/1994
TON DIFFERENCE IN SWD AND YUROKE CREEK
mg/l TON
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
DAY
drain
creek

APPENDIX 31

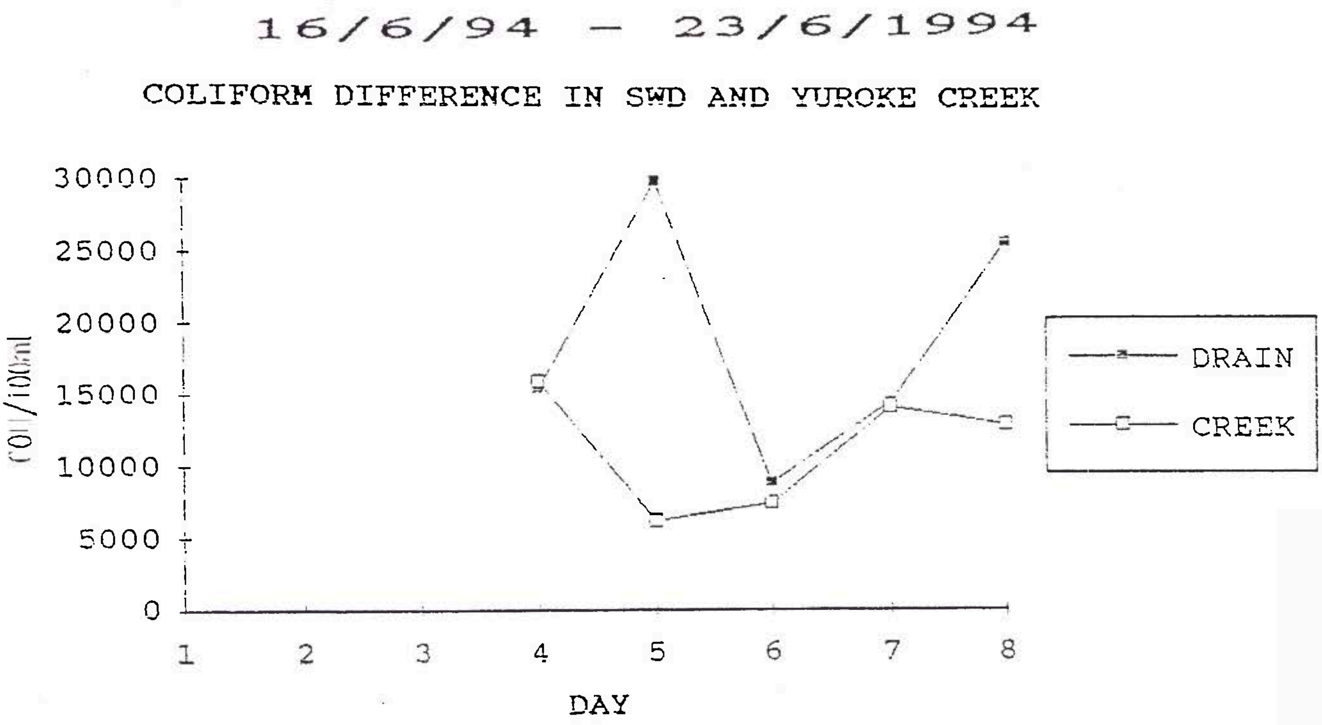


3/8/94 — 7/8/1994
ortho-PHOSPHATE DIFFERENCE IN SWD AND YUROKE CREEK
µg/l PO4
400
350
300
250
200
150
100
50
0
1
2
3
4
5
DAYS
drain
creek

APPENDIX 32


3/8/94 - 7/8/1994
TP DIFFERENCE IN SWD AND YUROKE CREEK
600
500
400
300
200
100
0
µg/l P
1
2
3
4
5
DAY
drain
creek

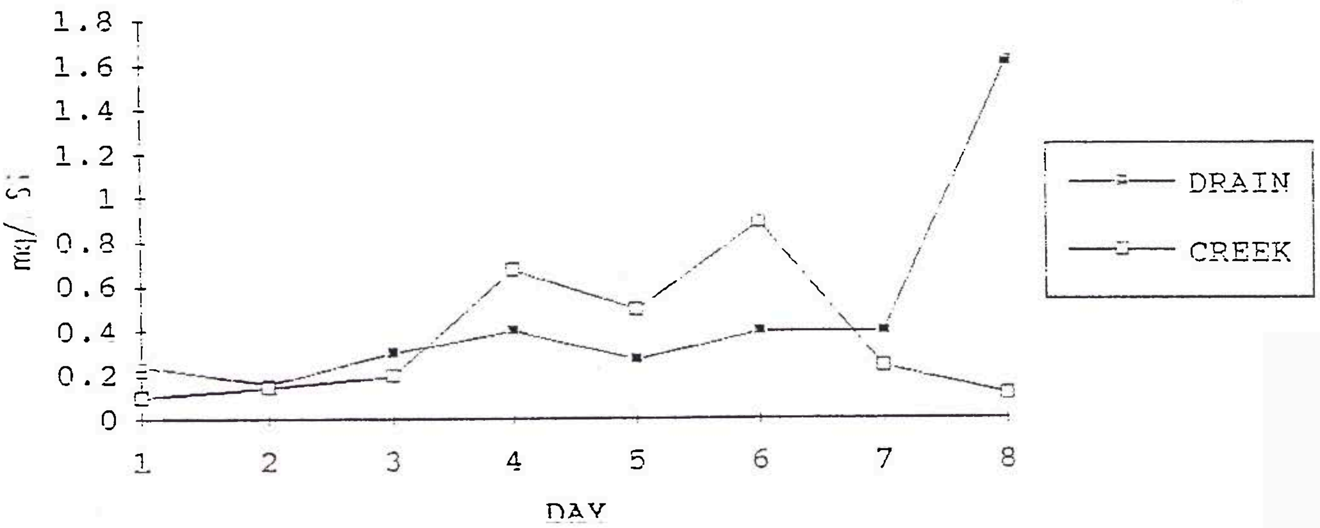
APPENDIX 33


16/6/94 – 23/6/1994
COLIFORM DIFFERENCE IN SWD AND YUROKE CREEK
30000
25000
20000
15000
10000
5000
0
COL/100ml
1
2
3
4
5
6
7
8
DAY
DRAIN
CREEK

APPENDIX 34

16/6/94 – 23/6/1994

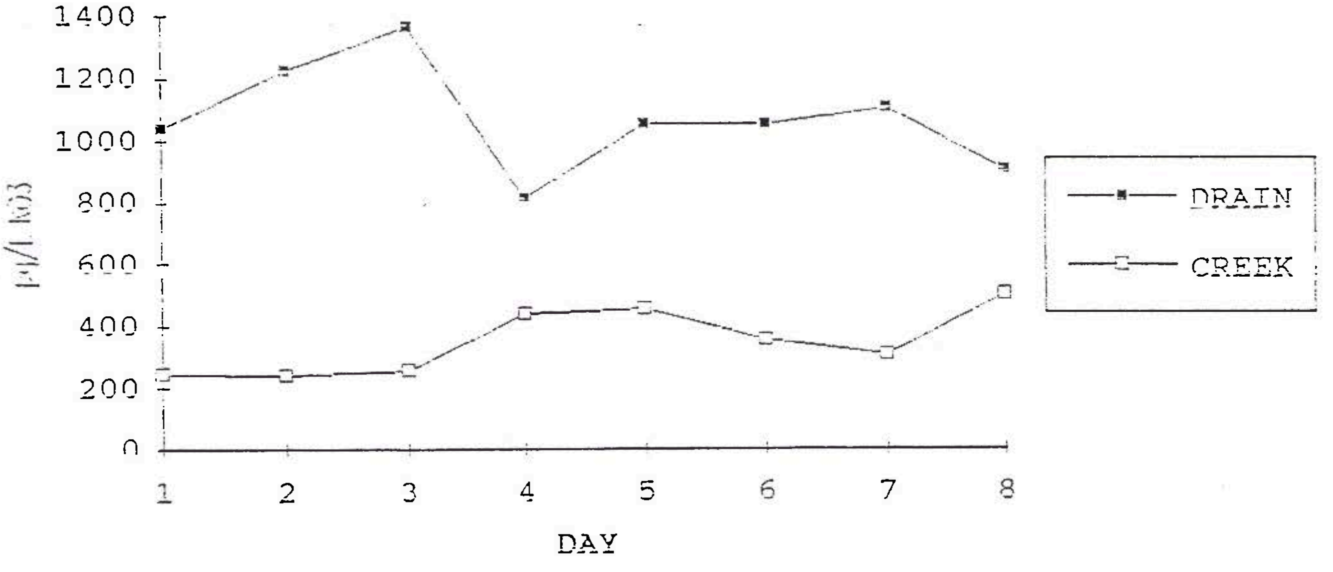
SUSPENDED SOLIDS DIFFERENCE IN SWD AND YUROKE CREEK



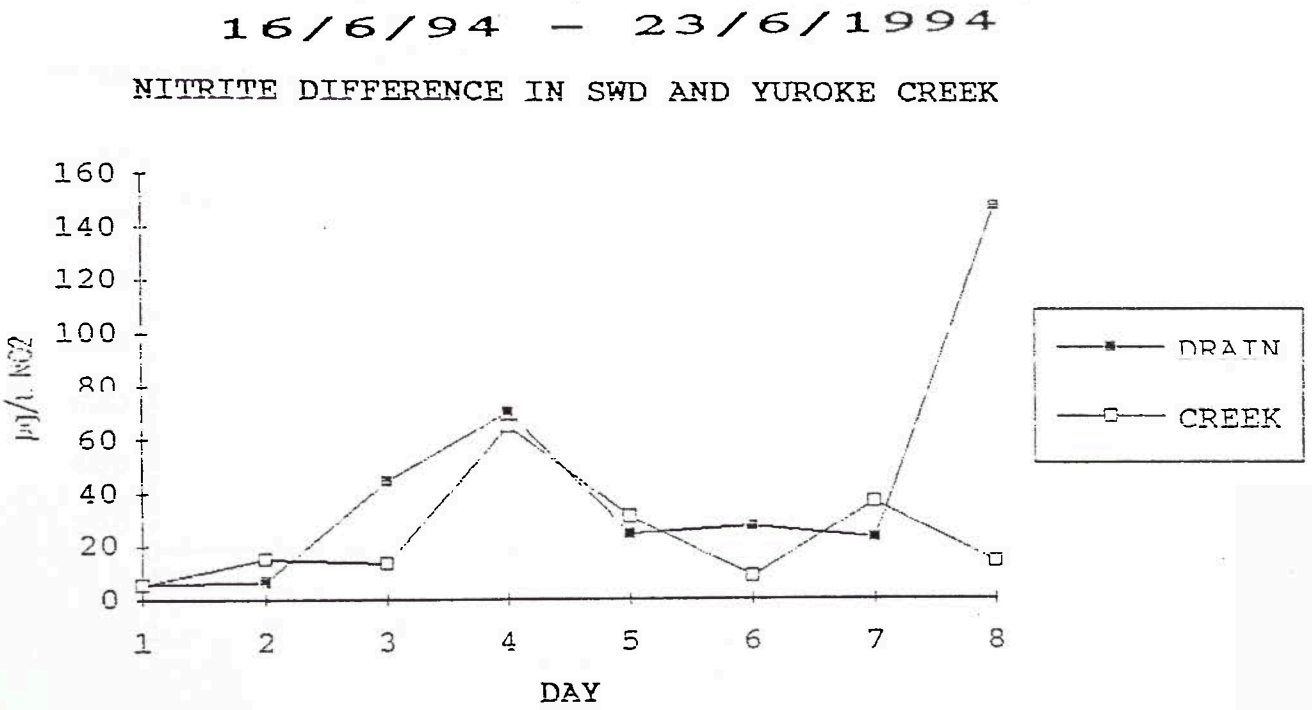
APPENDIX 35

16/6/94 – 23/6/1994

NITRATE DIFFERENCE IN SWD AND YUROKE CREEK

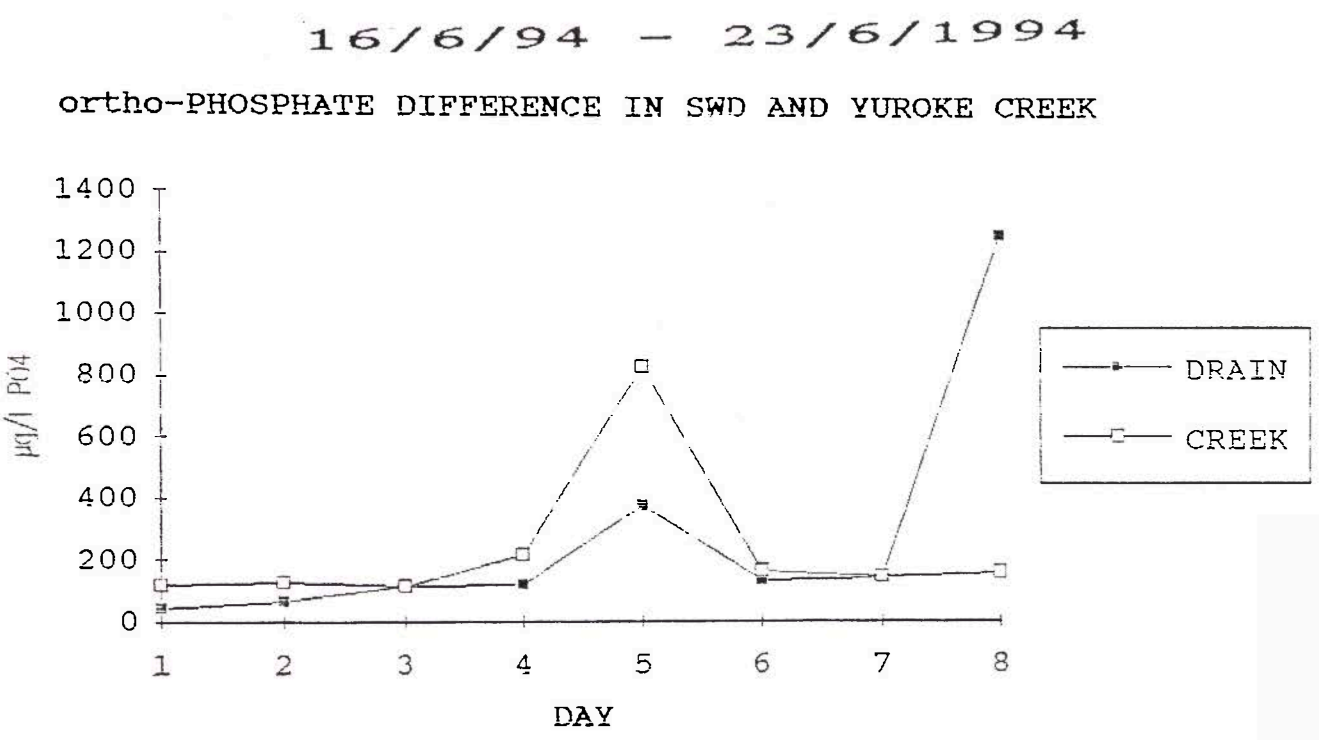


APPENDIX 36



16/6/94 – 23/6/1994
NITRITE DIFFERENCE IN SWD AND YUROKE CREEK
160
140
120
100
80
60
40
20
0
µg/L NO2
1
2
3
4
5
6
7
8
DAY
DRAIN
CREEK

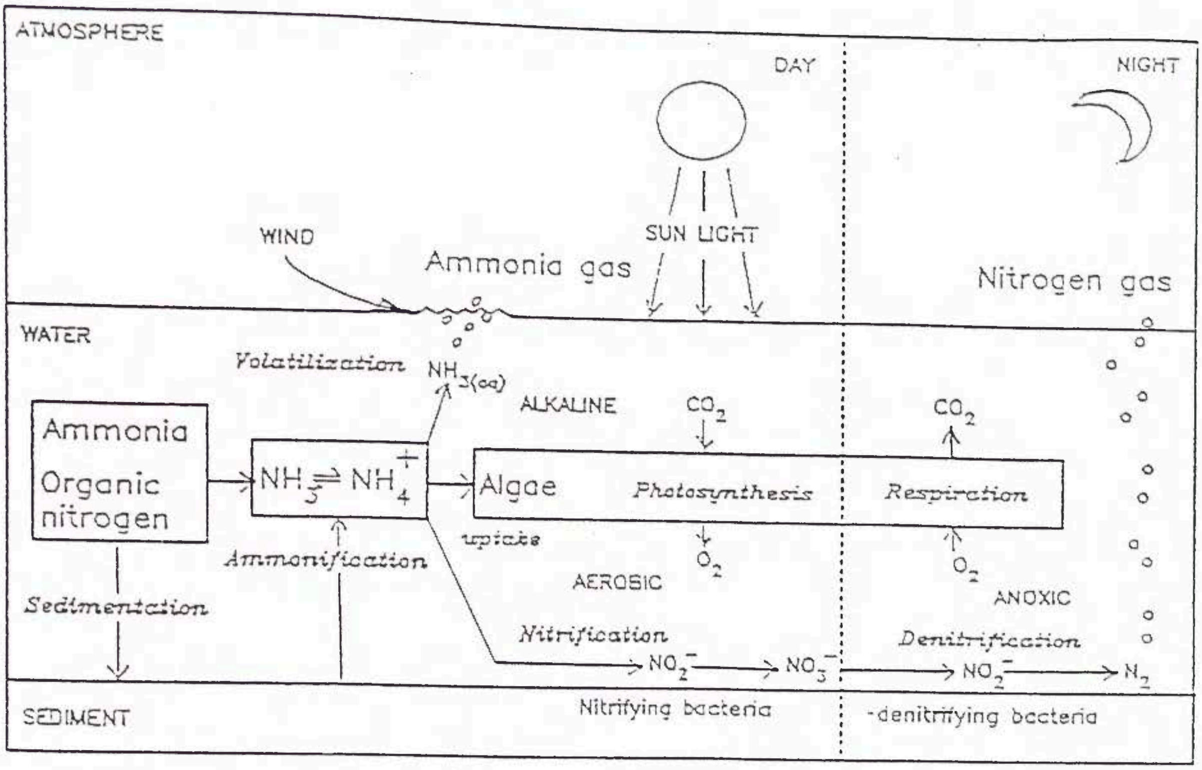
APPENDIX 37


16/6/94 - 23/6/1994
ortho-PHOSPHATE DIFFERENCE IN SWD AND YUROKE CREEK
1400
1200
1000
800
600
400
200
0
μg/l PO4
1
2
3
4
5
6
7
8
DAY
DRAIN
CREEK

APPENDIX 38

NITROGEN AND PHOSPHORUS CYCLES

NITROGEN



PHOSPHORUS