A CATCHMENT APPROACH TO UNDERSTANDING THE SOURCES AND FATE OF INDICATOR BACTERIA IN AN INTENSIVE AGRICULTURAL AREA

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ABSTRACT

There is intense interest in the sources of faecal bacteria entering the Hawkesbury-Nepean River system, which at its lower reaches includes the city of Sydney. Agricultural stormwater runoff is a likely contributor. The research reported here is the first to quantify the loads of indicator bacteria arising from different rural land uses and link this to measurements of bacteria in the Hawkesbury-Nepean. The study was located in the Currency Ck sub-catchment. Pollution in this rural sub catchment was at times extreme, with 0.9×10^5 cfu/100mL faecal coliform (FC) at the outlet in large runoff events. Intensive agriculture was the major source of pollution, with up to 1.2×10^6 cfu/100mL from dairy pasture and 1.35×10^6 cfu/100mL from vegetable farms following fertilisation with poultry manure. However, even 'hobby farms' generated significant pollution. Farm dams significantly reduced exports, even when water was not detained. The cumulative impacts of frequent, smaller runoff events, though having lower bacterial concentrations and discharge, appear to contribute most to the long periods in which the local water body is unfit even for recreational use. This insight is discussed in relation to evaluating risks and abatement actions within a catchment context.

Keywords: catchment management, indicator bacteria, dairy, market garden

INTRODUCTION

The Hawkesbury-Nepean River system rises in the Great Dividing Range and in its lower reaches (the Sydney Basin) passes through the northern, western and southern outer suburbs of Sydney. The catchment is 25,000 km^2 of which only 5% is urbanised, the remainder being forested (63%) or rural (29%). 'Rural' includes land for agricultural production worth A$1 billion annually, and for rural residential purposes ('hobby farms'). More than 20 sewage treatment plants discharge to the river system. Pollution is a serious problem in the lower reaches, including faecal contamination indicated by counts of faecal coliform (FC) bacteria in the river that occasionally reach 5×10^5 cfu/100mL (Kerr 1993). Faecal contamination periodically renders recreational sites along the river unsuitable for primary and even secondary contact (Gallagher and Egerrup 1995).

Whilst the contribution of sewage treatment plants to pollution is easily measured, that of non point sources including agriculture is uncertain and difficult to quantify (Kerr 1993). However, with intensive agricultural production and 'hobby' farms dominating the non-urban areas of the Sydney Basin, these rural land uses may be significant contributors to diffuse pollution of the river system. Intensive dairies and vegetable farms in which poultry manure is used are common and 'hobby' farms frequently carry horses and cattle. Intensive dairies are well recognised as potential sources of faecal contamination (Steele 1995) although the relationships between agricultural land uses and stream bacterial counts in complex catchments, like the Hawkesbury-Nepean, are poorly understood (Pasquarell and Boyer 1995, Edwards *et al*. 1997). It is difficult to isolate the contribution by individual landuses and hence target remediation. The numbers of bacteria in surface water depend on the size of the source, which is determined by faecal deposition and bacterial die-off rates, mobilisation of the bacteria in runoff, and delivery to and die-off in the receiving water.

This paper summarises part of a study that aimed to quantify all of these processes in Currency Ck., a representative subcatchment of rural areas in the Sydney Basin, within the Hawkesbury-Nepean. Exports of indicator bacteria in stormwater runoff water were quantified over a 1-year period in a 'nested' monitoring program that enabled the total pollutant load to be separated into the contributions made by individual landuses (exports per unit land area) and die-off in the receiving water to be characterised. The aim was to evaluate both the relative risks posed by these land uses, and their contribution to pollution in this particular sub catchment, which is a function not only of pollutant export/area but the area of the landuse and in-stream processes.

METHODS

Monitoring sites were established in a representative 225 ha area of the Currency Creek sub catchment. Land uses included:

- a vegetable farm (16 ha), with irrigation and high fertiliser inputs including poultry manure,
- part of an intensive dairy (44 ha) with irrigated pasture (at times with effluent), carrying 4 cows/ha,
- an intensive poultry farm (caged birds, but inactive for much of the study period), and
- several 'hobby farms' (134 ha) with livestock generally equivalent to < 1 cow/ha (mostly horses cattle).

An unnamed watercourse drained the subcatchment. Two farm irrigation dams (~10 ML capacity) were located in this watercourse that discharged to Currency Ck near its confluence with the Hawkesbury River. Farm management was documented during the study period. Landform of the subcatchment comprises undulating low hills. Elevation is up to 100 m and local relief is 20-50 m. Soils in the study area are predominantly deep, imperfectly drained Kurosols and some Sodosols (Yellow Podzolic Soils/Soloths, Dy3.41, Dy2.41, Northcote 1979). Climate of the area is temperate, with monthly mean temperatures ranging from 10.4^0C in July to 23.5^0C in January. Annual rainfall averages 810 mm, falling in all months but with a slight dominance in summer. Rainfall during the study period of 12 months was 889 mm.

Five automatic monitoring stations were sited within the study area such that stormwater runoff from individual land uses could be measured, as well as the changes in numbers along the watercourse beyond farms but before discharging to Currency Creek. Monitoring stations each comprised a programmable logger to record data, calculate discharge in real time and control operations; a rain gauge; a depth gauge to measure runoff depth in the control structure; and an automatic water sampler that was controlled by the programmable logger. A typical field installation is fully described by Cornish *et al*. (2002). The autosampler took samples using a variable discharge-increment approach, based on changes in the calculated discharge through the control structure. Hydrologic data were recorded at three hourly intervals during dry periods and every 2 minutes during flow. Total discharge for events was calculated from the hydrograph. Automatic sampling was supplemented with manual sampling when runoff occurred but was insufficient to trigger automatic sampling.

A total of 10 runoff events occurred during the study period. Five events were sampled, 2 'large' and 3 'small', covering all seasons of the year. Calculation of recurrence intervals showed that the larger events would be expected to recur once or twice per year, the smaller events might recur 8-10 times per year. None of these events would be regarded as large events in hydrological terms.

Manual sampling was also undertaken at 4 locations along the watercourse on 6 occasions over a 21-day period following cessation of runoff from an event in October 1997. This was to determine die-off rates in the local receiving water after stormflow. Mean temperature in the period was 16^0C.

As soon as practicable after sampling by either method, samples were returned to the laboratory for enumeration of 'indicator' bacteria in the runoff water rather than pathogens themselves (Baxter-Potter and Gilliland 1988). Enumeration was undertaken using the membrane filtration technique (APHA 1998). Total coliform bacteria were enumerated after culturing on Mendo Les gel, faecal coliform on mFC agar, and Streptococci (not reported) on KFS agar (Difco Corp).

Concentrations of bacteria in runoff water were calculated and expressed in various ways: pollutographs showing the change in concentration during a runoff event; event-mean concentrations; total export loads per unit area for each land use for each event; and the proportion of the total load exiting the sub catchment, contributed by each land use. Comparisons between sites of sampling were made using the Mann-Whitney U-test.

From the data obtained following the event in October 1997, mortality rates were calculated by fitting die-off models to the concentration data for bacteria, over a measurement period:

$$\mathrm{Log}_{10}\,(N_t/N_0) = -KT \qquad (1)$$

where N_t and N_0 are bacterial concentrations at times time 't' and zero, respectively, K is the mortality rate (cfu/day) and T is time in days. Mortality rates were calculated for each of the four sections of stream using the statistical procedure of Zar (1984).

The 'trapping efficiency' of a dam in the flowline, located near the outlet of the catchment, was evaluated by comparing concentrations at the inlet and outlet of the dam on five occasions. Trapping efficiency was calculated as ((upstream load – downstream load)/upstream load) x100. Mean trapping efficiency for total and faecal coliform bacteria was compared using a paired t-test.

RESULTS AND DISCUSSION

The concentrations of total and faecal coliform bacteria in stormwater runoff from two relatively large events are shown in Figure 1. The main interest is in faecal coliforms, as these indicate any faecal contamination and possible health risks. The concentrations of faecal coliform (FC) bacteria at the catchment outlet averaged 0.9×10^5 cfu/100mL, far in excess of guidelines set by the Australian and New Zealand Environment and Conservation Council (ANZECC) for any purpose. The guide for secondary contact (recreational use) for example is <1,000 cfu/100mL.

The concentrations of FC bacteria over both events ranked in the order dairy = vegetable farming > 'hobby farm' pasture, with the difference between hobby farm pasture and the other land uses being significant ($P<0.01$). FC concentrations in runoff from the market garden varied greatly between events, apparently because poultry manure had been applied to the farm shortly before the rain.

The concentrations of TC were greatest in May (autumn), possibly because the runoff event in May was preceded by cooler and wetter weather than in October, favouring the survival or growth of soil micro-organisms. Although the concentrations in runoff from 'hobby farm' pasture were much lower than dairy or market gardens, the concentrations were still high (mean 1.5×10^4 cfu/100mL).

Pollutant loads are the product of the area of land use, pollutant concentration and discharge. When the concentration data (Figure 1) were combined with area of each land use and hydrologic data (not presented), then the two agricultural land uses contributed over 80% of the FC bacteria mobilised in these two runoff events, despite occupying only 26% of the sub catchment.

Whilst remedial action to reduce bacterial export would sensibly concentrate on dairy and vegetable production (in which manure is used), it is inevitable that FC concentrations in runoff will remain high without action on the extensive area of catchment occupied by hobby farms which have domestic animals that graze pasture.

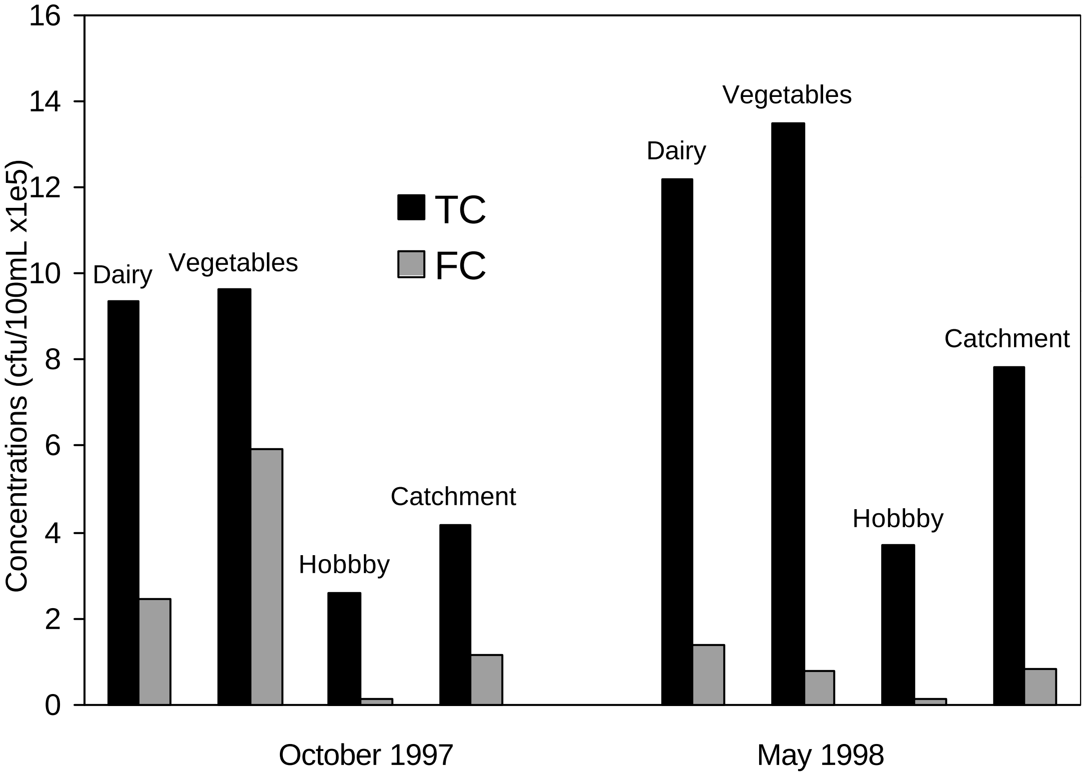

***Figure 1**. Event-mean concentrations (x10^5) of total (TC) and faecal (FC) coliform bacteria in runoff from various land uses in Currency Creek and at the catchment outlet.*

Runoff was also sampled from three smaller events (Figure 2). Concentrations varied at the catchment outlet measuring1,500, 5,000 and 50,000 cfu/100mL in the three events. This range is about an order of magnitude lower than in the larger events (mean 0.9x10^5 cfu/100mL). However, even these lower concentrations exceed water quality guidelines for any purpose.

In only two of the three smaller events did the 'hobby farm' pasture generate runoff, presumably because this land use is not irrigated, and is therefore likely to accept greater infiltration. Nevertheless, on the two occasions that water did run off, 1,200 and 4,300 cfu/100 mL were recorded. Thus, even in small events when concentrations tend to be lower, the hobby farms have the potential to contribute significantly to water pollution, bearing in mind they occupy more than 60% of this subcatchment and a similar proportion of the non-urban areas of the Sydney Basin.

Die-off rates in surface water after storms

Concentrations of TC and FC bacteria were studied following the October 1997 'large' runoff event. Sampling location had no significant effect on die-off rates, despite marked differences in chemical composition of water between the four locations along the watercourse (data not presented). The data were combined to calculate one die-off rate for each of FC and TC. The mean die-off rates are given in Table 1, together with the time for concentrations to decline to the ANZECC guideline for secondary contact (1,000 cfu/100mL), estimated from equation 1. The initial concentration was that mid way down the watercourse, just before runoff flow ceased.

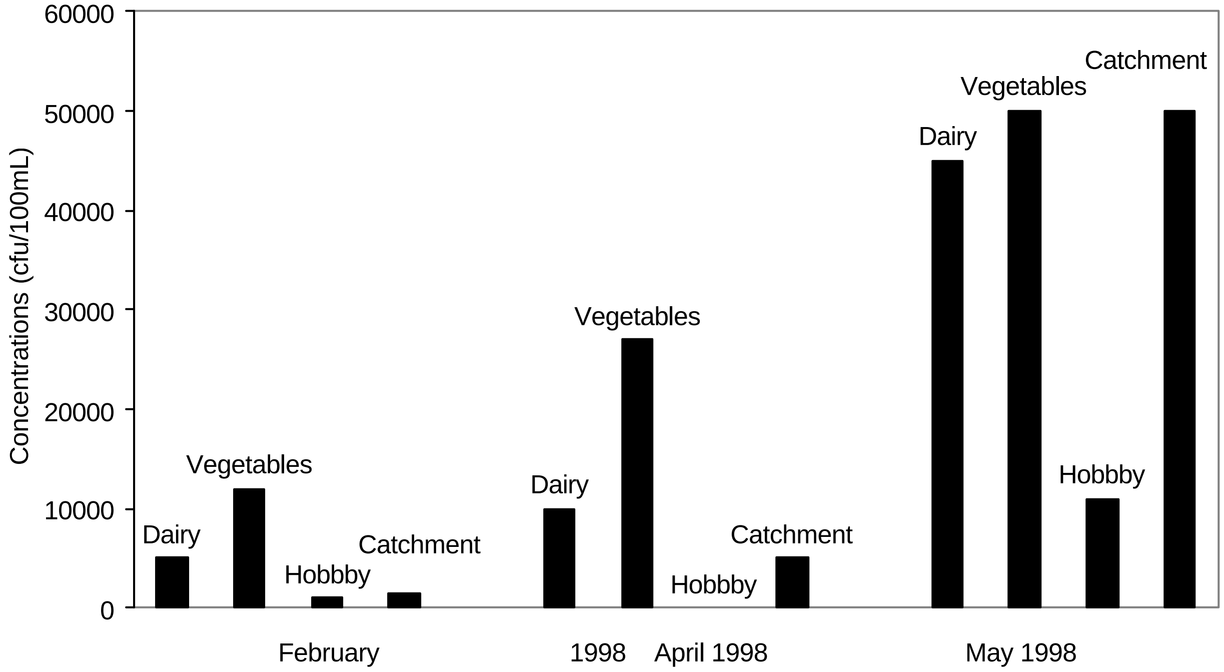

Figure 2. *Event-mean concentrations of faecal coliform in runoff from various land uses and the catchment outlet during three small runoff events.*

Table 1. Mortality rates for coliform bacteria after runoff in October 1997 and estimated time for concentrations to decline to ANZECC guidelines for secondary contact.

	Mortality rate ($\log_{10}$/day)	R^2	Initial concentration (cfu/100 mL)	Time to fall to 1,000cfu/100mL (days)
Total coliforms	0.116	0.86	1.1×10^6	21
Faecal coliforms	0.178	0.89	3.5×10^5	14

The die-off rate for FC was significantly greater than for TC. The rates are comparable to others reported in the literature at similar temperatures (16°C) (Crane *et a*l. 1983). The higher rate of FC, and their initially lower populations, meant that the estimated time for FC concentrations to decline to the ANZECC guideline of 1,000 cfu/100 mL was less, at 14 days, than for TC, at 21 days.

The die-off rates for FC in Table 1 were also used to calculate exclusion times from the stream following 'smaller events'. The concentrations of FC bacteria used in these calculations are those given in Figure 2. The times required for the 3 events were averaged for this estimation (Table 2). The times given in Table 2 represent water associated with each of the landuses, as well as a composite water sample passing the sub catchment outlet. The 'sub catchment' value applies to water discharging to Currency Ck.

Table 2. The estimated time required for stream water to return to 1,000 cfu/100 mL after 'small' events.

Land use	Time required (days)
Dairy	7
Vegetable	8
Hobby farm	3
Sub catchment	5

The overall impact of agricultural runoff on biological water quality over time in Currency Ck can now be assessed. It is assumed that two large runoff events and 8 small runoff events occur on average each year. This analysis ignores the much larger but infrequent events that cause flooding, and also ignores the effect of temperature on die-off rates (Harchegani unpublished).

Two larger events would result in a total of 28 days exclusion from recreational use of Currency Ck (from Table 1), whereas 8 smaller events result in 24-64 days exclusion (from Table 2), depending upon location within the sub catchment. From this simple assessment, it would appear that small but frequent events might have greater cumulative impact on year-round water quality than do the larger runoff events. This is an important observation, as pollution is normally associated with the larger, more erosive events that deliver the bulk of sediments and nutrients to streams. This suggests a paradigm shift in the way we think about biological pollution in this environment, from the more conventional focus on large runoff events that deliver most diffuse source pollution, to the smaller events. The difference arises from the non-persistent nature of the pollutant, and that the population decay is logarithmic with concentration increases on two orders of magnitude ($1x10^4$ to $1x10^6$) requiring only a doubling of time to decay to 'safe' concentrations. If our assessment is borne out by further study, then the implications for managing water quality in the local stream are significant, as attention should be focused on smaller events if local water quality is the prime concern. At this scale, pollution should be relatively easier to manage because of the smaller volumes of water to be treated.

Farm dam trapping efficiencies

The farm dam in the flow line had average trapping efficiencies of 53% (+/- 23) and 59% (+/- 22) for TC and FC over five runoff events. The TC and FC were not significantly different ($t<0.05$). The dam in this study was only intermittently used for irrigation, and remained full for most of the study period. Therefore the dam operated by extending the retention period in the flow line, allowing for sedimentation to occur. Other data, not presented, suggest that bacteria are generally associated with suspended sediment and can be reduced by the use of sediment detention basins or farm dams. This result is broadly consistent with other published results (Hann *et al*. 1994). The 'suspended sediment' associated with pasture runoff can be high in organic material (Cornish *et al*. 2002).

Management

Management of biological pollution will need to target both the source and the transport pathway. Management at source includes both the loading of pollutant onto the land, its subsequent die-off, and then mobilisation. In relation to transport, the observation that the cumulative impact of small events may exceed that of less frequent large events, provides an important clue to the direction that management might take. Also, Cornish *et al*. (2002) have shown in a nearby sub-catchment that near-stream areas contribute relatively more to runoff and nutrient pollution in small runoff events, compared with more distant areas in a catchment, which contribute relatively more to runoff in larger events. Therefore management should aim to minimise bacterial loadings in those parts of the landscape that shed the most water in smaller runoff events. Further, small runoff events might be detained in either detention basins or farm dams. Such dams also reduce bacterial concentrations in larger events, when dams spill.

The landuses contributing most to pollution, in terms of both concentration and total loads, are dairy farming (pasture) and vegetable farming. However, even pasture on 'hobby' farms yield runoff with faecal bacteria above guidelines.

The pollution associated with vegetable farming was closely associated with recent additions of poultry manure, and it is clear that elimination of animal manures or disinfection through composting would assist in managing pollution. Increased cultivation to bury manure soon after application would also assist, but may not be desirable on soil conservation grounds. This is an area requiring further research. Turf production is an important industry in the Sydney Basin, and although not included in the present study it does have the potential for high levels of pollution because poultry manure is regularly used.

Dairy pasture is highly polluting. Dairy farms in the Sydney Basin have been the subject of much work to reduce pollution, but the work has focused on nutrients, and in particular management of effluent from the milking parlour rather than the pastures on which the cows graze. Attention now must turn to the pastures, as these are a major source of both biological pollution and nutrients (see Cornish, these Proceedings). The high levels of bacteria appear to be associated with high animal numbers, as the hobby farms, with on average one-fifth of the animal stocking rates, yielded much less polluted water. If dairy farming is to be retained as an industry in this area, and economic forces preclude reduced cow numbers, then new approaches to managing biological pollution from dairy pasture will be needed. The observation that near-stream areas contribute the greatest proportion of runoff in small runoff events suggests that effluent should be disposed of in more elevated parts of the landscape, well removed from any watercourse. Similarly, grazing near the watercourse should be minimised to prevent defaecation where it can readily move to streams. The latter also applies to the much more widely distributed 'hobby farms'.

As smaller runoff events seem to contribute very significantly to pollution, these relatively simple measures should contribute significantly to environmental improvement. As dairy pasture is irrigated in this area, and effluent is applied in irrigation, maintaining a soil water deficit when irrigating will reduce the risk of runoff from subsequent rainfall as well as irrigation itself. During the course of this study it was not uncommon to see effluent runoff from irrigation, and small falls of rain often shed runoff from the dairy when hobby farm pasture did not yield runoff. Effluent irrigation should not be carried out when rainfall is imminent or soils are wet, meaning that effluent holding ponds need to be of an appropriate size.

The effective reduction in bacterial concentrations when water passed through a farm dam points to the value of transport pathway controls. Dams may be designed and managed differently to enhance pollutant capture, for example by maintaining a capacity to accept runoff without spilling.

CONCLUSIONS AND RECOMMENDATIONS

This study in a representative subcatchment of the lower Hawkesbury-Nepean has shown that intensive agriculture is a significant source of biological pollution in surface water. The problem is associated primarily with intensive dairy pasture and market gardens that use poultry manure. However, large residential blocks of land with carrying cattle or horses at times contributed runoff with high concentrations of bacteria, so even in the absence of agriculture, polluted runoff will enter the river system.

Whilst dairy is an important industry in the Sydney Basin, it is represented by a few large farms. On these farms, there is little scope to reduce bacterial loading to pasture except through further treatment of effluent before application to pasture, but even then the loading from direct defaecation to pasture will be high. So management should target mobilisation and transport of pollutant. Effluent application in higher positions in the landscape is recommended, along with irrigation practices that minimise runoff from both irrigation and subsequent rainfall. Grazing from the riparian zone including ephemeral drainage lines should be restricted. Farm dams along with runoff detention basins should form part of an integrated strategy to reduce pollutant loads.

Elsewhere in the Sydney Basin, intensive horticulture is the dominant agricultural land use. For these, elimination of uncomposted poultry manure is recommended. Other industries that use poultry manure, and poultry farms themselves, also have the potential to pollute.

The synthesis of results suggests the need for a paradigm shift in the approach to management of biological pollution, away from the focus on large runoff events, necessary to manage erosion, sediment and nutrient pollution, to the cumulative impact of smaller events.

REFERENCES

APHA (1998). Standard Methods for the Examination of Water and Wastewater. 20th Ed. American Public Health Association. Washington, DC.

Baxter-Potter, WR and Gilliland, MW (1988). Bacterial pollution in runoff from agricultural lands. *J. Env. Qual.* **17**, 27-34.

Cornish, PS; Hallisey, R and Hollinger, E (2002). Is a rainfall simulator useful for estimating phosphorus runoff from pastures–a question of scale dependency? *Aust. J. Exp. Agric.* **42**, 953-59.

Crane, SR; Moore, JA; Grismer, ME and Miner, JR (1983). Bacterial pollution from agricultural sources: A review. *Water, Air and Sol Pollution.* **27**, 411-439.

Edwards, DR; Coyne, MS; Daniel, PF; Vendrell, PF; Murdoch, JF and Moore, PA (1997). Indicator bacteria concentrations of two north west Arkansas streams in relation to flow and season. *Trans ASAE* **40**, 103-109.

Gallagher, L and Egerrup M (1995) Recreational water quality, Hawkesbury-Nepean River System. NSW Environment Protection Authority, Chatswood NSW, Aust.

Hann, CT; Barfield, BJ and Hayes, JC (1994). Design hydrology and sedimentology for small catchments. Acad. Press. San Diego, Calif. USA 588 pp.

Kerr, RJ (1993). Water Quality, Hawkesbury-Nepean River System, June 190 to June 1993. NSW Environment Protection Authority. Chatswood, NSW Aust.

Northcote, K. H. (1979). 'A Factual Key for the Recognition of Australian Soils.' 4th Edn. (Rellim Publications: Glenside, S. Aust.)

Pasquarell, GC and Boyer, DG (1995). Agricultural impacts on bacterial water qulityin Karst groundwater. *J Env. Qual.* **24**, 959-969.

Zar, HJ (1984). Biostatistical analysis. 2nd ed. Prentice-Hall Inc, NJ. USA.