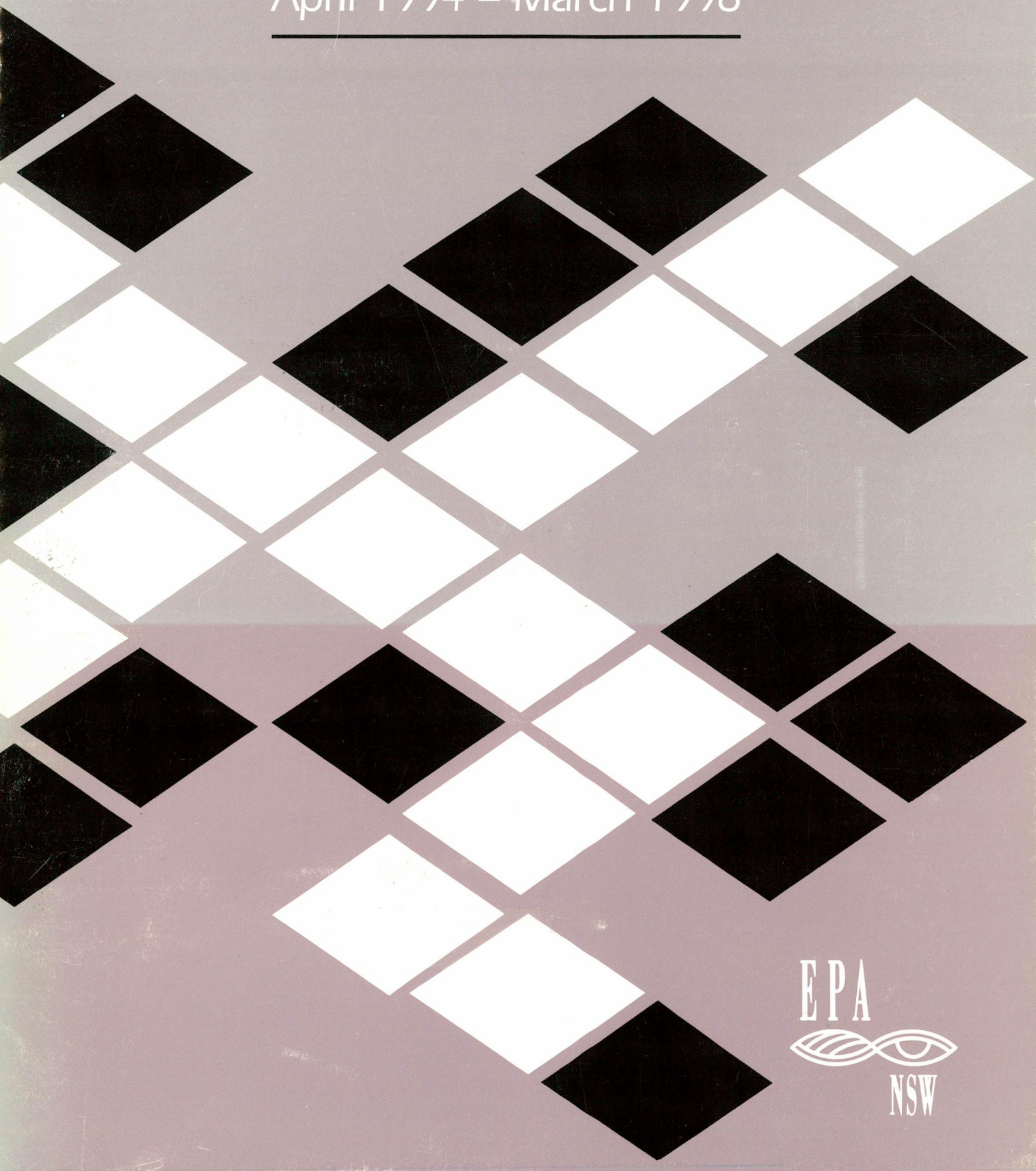
Recreational Water Quality

Hawkesbury–Nepean River System

April 1994 – March 1996



EPA NSW

RECREATIONAL WATER QUALITY HAWKESBURY-NEPEAN RIVER APRIL 1994 – MARCH 1996

SER/NSWEPA 98/12 980408(2)

17.Oct.1998 Ian Shannon

Recreational Water Quality

Hawkesbury–Nepean River System

April 1994 – March 1996

EPA
NSW

ACKNOWLEDGEMENTS

This report was prepared by Marie Egerrup and Lara Gallagher, Environmental Science Branch, NSW Environment Protection Authority.

Assistance in preparing and reviewing this report was provided by David Leece, Klaus Koop, Tony Church, Bill Hall and Mark Roberts from the EPA Environmental Science Branch.

Staff from the EPA Water Studies Section assisted in field sampling, especially Graham Sherwin, Sean Hardiman, Danny Roberts, Sharon Cummins, Murray Root, Nadia Meucci, Victoria Adair, Helen Martin, Troy Collie and Yoshi Kobayashi.

We thank Peter Yates and the staff of the EPA Sydney Region for their assistance during the program.

For technical information about this report, contact:
Environmental Science Branch
Environment Protection Authority
Civic Tower
Cnr Rickard Road & Jacobs Street
Locked Bag 1502
Bankstown 2200
Phone: (02) 9795 5000
Fax: (02) 9795 5002

Published by:
Environment Protection Authority
799 Pacific Highway
PO Box 1135
Chatswood 2057
Phone: (02) 9795 5000 (main switchboard)
http://www.epa.nsw.gov.au

For publications and information requests:
Phone: 131 555
Fax: (02) 9325 5572
Email: info@epa.nsw.gov.au

ISBN 07313 0151 X
February 1998
EPA 98/12
Printed on recycled paper

Recreational Water Quality
Hawkesbury-Nepean River System
April 1994 to March 1996

SUMMARY

Between April 1994 and March 1996, the NSW Environment Protection Authority (EPA) monitored recreational water quality at 12 recreation sites in the Hawkesbury-Nepean River between Menangle and Berowra. In February 1995, sampling commenced at an additional site in the mainstream Hawkesbury River at Sackville ferry, making a total of 13 sites. This report summarises the findings.

The monitoring program was designed specifically to evaluate water quality at locations where the community chooses to use the river for recreation. The program used national guidelines for sampling and data interpretation that are designed to provide information on the potential effect on human health and safety of contact with the waters.

At each site on each sampling occasion, three water samples were collected for bacteriological analysis. At the same time, EPA staff measured pH, temperature, electrical conductivity, turbidity and clarity *in situ* and recorded the presence of any algae or surface films.

Data were assessed not only on a monthly basis, but also on the basis of an overall assessment using all relevant indicators. This overall assessment permitted a detailed insight into the variability within the long-term trends in recreational water quality.

Assessed against the criterion of faecal bacterial contamination, all sites except Macquarie Park (Windsor) and South Creek (Windsor) were suitable for secondary contact recreation during the entire study period. High faecal bacterial densities made these sites unsuitable for secondary contact recreation for periods of two months each. Additional sites (Cattai, Sackville, Lower Portland and Wisemans Ferry) had high levels of blue-green algae at times, thereby making these sites unsuitable for diect contact activities during those periods. Some sites were suitable for primary contact recreation for the entire period, while other sites were affected by one or more of the following factors: high faecal bacterial densities, poor water clarity, blue-green algal blooms or surface films; and by low water temperatures in winter.

Regression analyses of turbidity and faecal bacterial densities showed that faecal bacterial levels increased with increasing turbidity at five

sites. There were no strong relationships between faecal bacterial densities and rainfall, or turbidity and rainfall at any of the sites over the two year period. These findings, along with those from other studies, would discourage the use of these environmental parameters as indicators of faecal contamination.

The high variability found in faecal bacterial densities demonstrates the need for the collection of replicate samples in recreational water quality assessments.

Investigative studies to determine sources of faecal bacterial contamination at three sites [Tench Reserve ramp, Macquarie Park (Windsor) and South Creek (Windsor)] are continuing and will be reported at the completion of those studies.

A list of abbreviations used in this report

ANZECC	Australian and New Zealand Environment and Conservation Council
BGATF	Blue-Green Algae Task Force
EPA	Environment Protection Authority, New South Wales
NHMRC	National Health and Medical Research Council.

TABLE OF CONTENTS

continued next page

LIST OF TABLES

LIST OF FIGURES

Recreational Water Quality
Hawkesbury-Nepean River System
April 1994 to March 1996

1. THE AIM OF THIS REPORT

This report summarises the findings of the EPA's monitoring of recreational water quality at 13 sites in the Hawkesbury-Nepean River and its tributaries between April 1994 and March 1996, and provides insight into the trends in recreational water quality at those sites over this two-year period.

A preliminary study to validate the methodology was conducted between October 1993 and March 1994 (EPA 1994). As a result of the study's findings the method was altered before the main study commenced and so the results of the preliminary study have not been included in the present assessment.

Earlier reports (EPA 1995a; EPA 1995b; EPA 1996a; EPA 1997) provided a seasonal analysis. This report assesses the entire two-year data set and reports on the overall suitability of sites for recreational use.

2. INTRODUCTION

The EPA began monitoring recreational water quality in the Hawkesbury-Nepean River in October 1993. The monitoring program was the first to specifically evaluate water quality at the locations where the community chooses to use the river for recreation. It used guidelines for sampling and data interpretation that are designed to provide information relevant to public health and aesthetic assessments. Reports on this program were produced every six months — for the summer (October to March) and winter (April to September) seasons (EPA 1995a; EPA 1995b; EPA 1996a; EPA 1997).

During the summer 1993-94 season, eight recreational sites between Camden and Sackville were sampled. In April 1994, the number of sites was increased to 12, between Menangle and Berowra Creek. Sampling at Sackville ferry was discontinued in April 1994, but was recommenced in February 1995 in response to community interest, making a total of 13 sites. This report summarises the monitoring data from these recreational sites between Menangle and Berowra Creek from April 1994 to March 1996.

2.1 Assessment criteria

There are two authoritative Australian guidelines for assessing recreational water quality: the National Health and Medical Research Council's *Australian Guidelines for Recreational Use of Water* (NHMRC 1990), and the chapter, 'Recreational Water Quality and Aesthetics', in the Australian and New Zealand Environment and Conservation Council's *Australian Water Quality Guidelines for Fresh and Marine Waters* (ANZECC 1992). The two guidelines are very similar; both set out a range of parameters relevant to determining recreational water quality:

- an assessment of bacterial water quality using the indicator organisms, faecal coliforms and enterococci
- an assessment of the presence of nuisance organisms, such as algae
- an assessment of visual clarity and colour
- a measurement of pH
- a visual assessment of surface films
- a measurement of temperature.

Faecal bacteria such as the faecal coliform group are used as indicators of faecal pollution. Faecal coliforms are abundant in the lower gut of warm blooded animals and are present in their faeces. They are generally not in themselves a health risk but are indicative of faecal contamination and hence the possible presence of disease-causing microorganisms such as certain bacteria, viruses or protozoa. National guidelines (ANZECC 1992 and NHMRC 1990) recognise the health risks for humans associated with contact with faecally contaminated water.

On the advice of the NSW Department of Health, the EPA has adopted the NHMRC (1990) guidelines as the guide for the collection and interpretation of data relevant to bacterial water quality. The EPA uses the ANZECC (1992) guidelines to assess algal and physico-chemical indicators of water quality.

The NHMRC (1990) and ANZECC (1992) guidelines both make the following distinction between primary and secondary contact recreation:

- *primary contact* recreation is characterised by bodily immersion or submersion where there is direct contact with the water, and includes activities such as swimming, diving, water skiing and surfing
- *secondary contact* recreation includes activities such as the paddling activities of children, wading, boating and fishing in which there is some direct contact with the water but where the probability of swallowing water is unlikely.

The assessment criteria used in this program are summarised in Table 1. For a detailed discussion of the various water quality parameters refer to NHMRC (1990), ANZECC (1992) and EPA seasonal reports (EPA 1994, EPA 1995a, EPA 1995b, EPA 1996a, EPA 1997).

3. METHODS

3.1 Site description

Twelve sites were sampled for the first 10 months of this study. An extra site was added at Sackville ferry in February 1995, making a total of 13 sites (Figure 1). Sites were selected on the basis of recreational use and to provide spatial coverage of the river between Menangle and Berowra Creek. Locations, site codes, number of months sampled, map identification, latitude and longitude details for each of the thirteen sites are given in Appendix A. Detailed site descriptions are given in Section 4.3.

3.2 Sampling procedure and *in situ* measurements

Water samples were collected in accordance with NHMRC (1990) and ANZECC (1992) guidelines every six days from 3 April 1994 to 29 March 1996. The NHMRC (1990) guidelines recommend that sampling should be conducted where and when swimmers are present. In this study, sampling occurred between 6:30 am and 1 pm.

One team sampled eight sites from the shore while another team sampled five water-skiing sites from a boat (see section 4.3). Because of the spatial extent of recreational use, the water-skiing sites, sampled from a boat, were divided into sections. At each water-skiing site the river was divided lengthwise into four sections, each 150 m in length, with the total length for that site being 600 m. Prior to sampling, a

Table 1
Summary of NHMRC (1990) and ANZECC (1992) criteria used to assess waters for suitability for primary and secondary contact recreation, where 'cfu' = colony forming units and 'N/A' = not applicable

Indicator	Primary contact	Secondary contact	Source
Faecal coliforms[1]	median value not exceeding 150 cfu/100 mL[2] with 4 out of 5 samples less than 600 cfu/100 mL	median value not exceeding 1000 cfu/100 mL with 4 out of 5 samples less than 4000 cfu/100 mL	NHMRC (1990)
Enterococci[1,3]	geometric mean < 33 cfu/100 mL	N/A	NHMRC (1990)
Algae[4]	15,000–20,000 blue-green algae cells/mL	15,000–20,000 blue-green algae cells/mL	ANZECC (1992)
Clarity	Horizontal sighting of a 200 mm black (Secchi) disc > 1.6 m	N/A	ANZECC (1992)
pH	5.0–9.0	N/A	ANZECC (1992)
Temperature	15–35 °C	N/A	ANZECC (1992)
Surface films	Absent	Absent	ANZECC (1992)

Note:

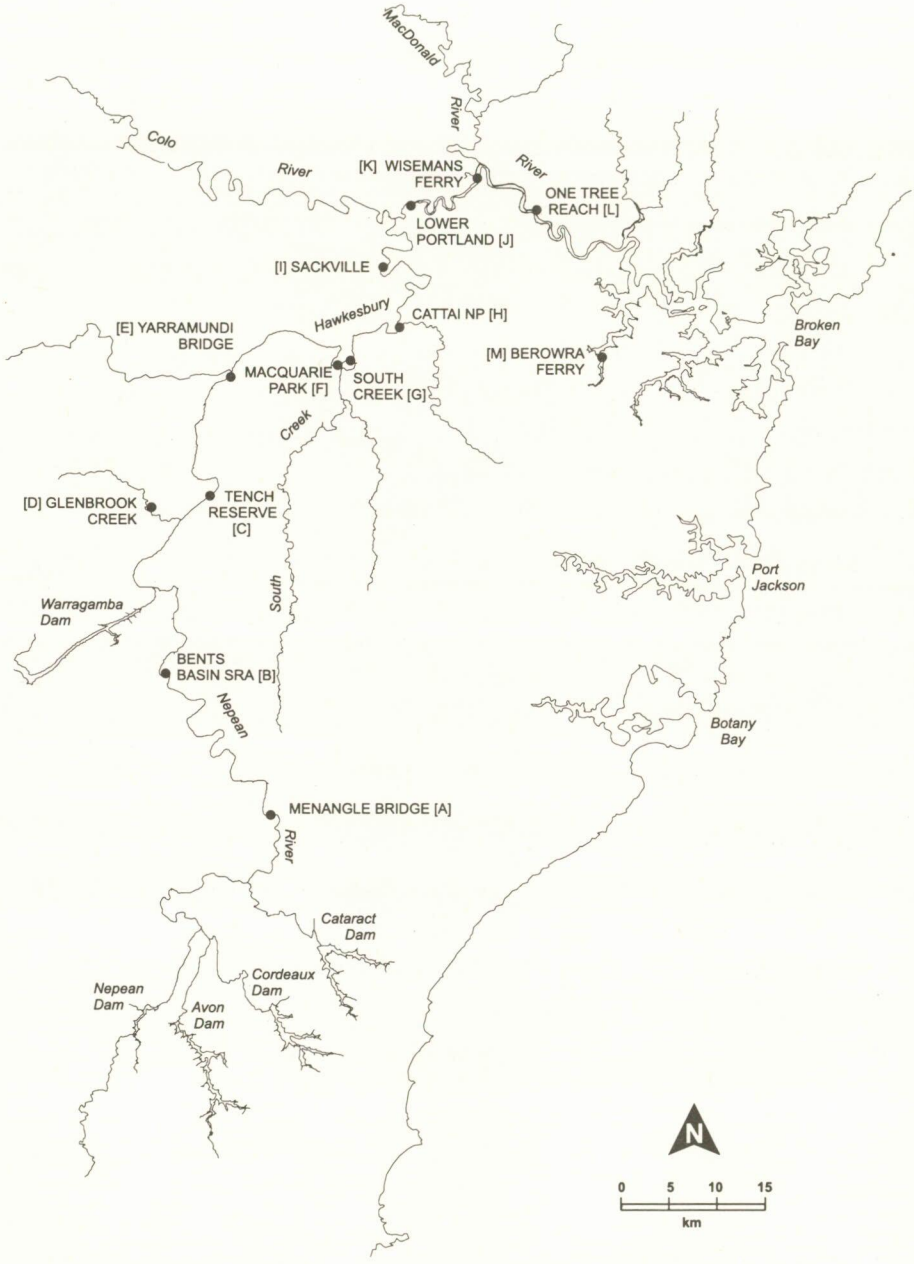
1 Minimum of five samples taken at regular intervals not exceeding one month.

2 The NHMRC (1990) guidelines state that this equates to a geometric mean level of 200 cfu/100 mL. This criterion is used in the long-term assessment of individual sites (see section 3.5).

3 The NHMRC (1990) guidelines state that enterococcus has been used in marine waters and may be useful where pollution is suspected, but only low numbers of faecal coliforms can be detected.

4 The NSW Government has adopted recommendations of the Blue-Green Algae Task Force (1992) regarding alert levels for recreational use of waters which contain blue-green algae. Recommendation 10 of the Blue-Green Algae Task Force Final Report (1992) states that public health warnings for domestic use, recreation and stock watering should be issued when potentially toxic blue-green algae exceed 15,000 cells/mL. It is this criterion which has been used in this report.

Figure 1
Sampling sites on the Hawkesbury–Nepean River



single 150 m section was chosen randomly from within the site and was sampled on that day. Through time, each of the sections was equally represented. Samples collected within each 150 m section were collected randomly across the breadth of the river to accommodate any within-site cross-sectional spatial heterogeneity. The sites which were

sampled from the shore were about 100 m in length and samples from these sites were collected randomly from the river bank. A 1.5 m extension pole was used to collect the sample away from the bank in an upstream movement.

In accordance with experience gained during summer 1993–94 season (EPA 1994), three replicate water samples were collected for bacteriological analysis at each site from a depth of 50 cm (or as close as possible to that depth). Samples were collected in sterile 500 mL plastic containers using aseptic techniques. The samples were stored on ice and transported in a portable ice chest ('esky') to the laboratory.

In addition, two algal samples were collected at each site. One sample was collected using a 20 µm mesh plankton net to provide a concentrated sample for species identification. The other, either a surface grab sample (at sites upstream of Windsor from May 1995) or a sample collected using an integrated vertical sampler (Venrick 1978) (at Windsor and downstream of Windsor), was collected in a 100 mL plastic bottle for species enumeration. Algal samples were stored and transported in the same manner as the bacteriological samples.

A single measurement of pH, temperature, electrical conductivity and turbidity was recorded *in situ* at each site at about 50 cm depth on each sampling occasion, using a Grant YSI 3800 water quality logger or a Hydrolab H2O which had been calibrated the previous day as per the manufacturer's instructions (Grant 1992, Hydrolab Corp. 1993). In addition, horizontal Secchi distance was measured from June 1994 at the sites sampled from the bank. Vertical Secchi depth was measured from October 1994 at the sites which were sampled from the boat, as it was not possible to measure horizontal Secchi distance at those sites.

A field sheet was completed at each site and included the following information: weather, presence of nuisance organisms, oily films on surface or shoreline, floating debris or grease, odour, frothing, colour/ appearance of water, and flow conditions.

3.3 Bacteriological analysis

All bacteriological samples were analysed for faecal coliforms and enterococci. From 3 April 1994 to 27 February 1995 samples were analysed by Microtech Laboratories (NSW) Pty Ltd, using methods described in *Standard Methods for the Examination of Water and*

Wastewater (18th ed. 1992) sections 9222D (faecal coliforms) and 9230Ca (enterococci). Samples were analysed using the membrane filtration (MF) technique. Microtech Laboratories modified the faecal coliform methods by overlaying the M-FC medium agar with resuscitation agar to improve recoveries. Enterococci analysis involved two modifications in the confirmation step: the use of tryptone soya agar (TSA) instead of brain heart infusion agar (BHI) and a higher incubation temperature of 37°C instead of 35°C.

From 5 March 1995 to 29 March 1996, bacteriological samples were analysed by EML Consulting Services Pty Ltd, using methods described in *Standard Methods for the Examination of Water and Wastewater* (18th ed. 1992), sections 9222D and 9230Ca. This laboratory did modify standard procedures.

The bacteriological analysis always started within eight hours of sample collection and the confirmed results were received from the laboratory within five working days of sample delivery.

The detection limit for bacteriological analysis was one colony-forming unit per 100 mL of sample (1 cfu/100 mL). Results reported as <1 cfu/100 mL were entered as half the detection limit (0.5 cfu/100 mL) for statistical analysis.

3.4 Algal counts

The concentrated samples collected by plankton net during this study were inspected for the presence of blue-green algae (*Microcystis* spp. and *Anabaena* spp.) cells. Where these species were detected, a full identification and count using the Lund cell technique (Lund *et al.* 1958) was carried out on the integrated vertical sample for that site.

3.5 Long-term assessment

Bacteriological data

On the advice of the Department of Health, the bacteriological data were assessed on a monthly basis in accordance with the NHMRC (1990) guidelines. As these guidelines require five faecal coliform values per month, the geometric mean of the three replicate faecal coliform results for each site was calculated and used for further analysis. This geometric mean will be referred to as the *faecal coliform value*.

To assess the suitability of water for primary and secondary contact recreation on a monthly basis, the data were divided into 24 one-month periods (or 14 one-month periods for the Sackville ferry site). The median and the fourth-highest *faecal coliform values* were calculated for each monthly period. These values were compared to the NHMRC (1990) faecal coliform guidelines. Each site was then ranked into one of four divisions, according to the percentage of months that each site complied with the NHMRC (1990) faecal coliform guidelines for primary and secondary contact recreation (Table 2).

Overall assessment

Earlier reports (EPA 1995a; EPA 1995b; EPA 1996a; EPA 1997) assessed only the data collected during a single season. Although identical methods of data assessment are used in this report, analysis of the full dataset enables an assessment of whether recreational water quality has been consistent at each site throughout the study or whether it has varied from season to season.

To gain an overview of recreational water quality using all relevant indicators, each site was assessed initially on a daily basis, then the daily assessments were used in an assessment of the whole 24-month study period.

The use of a daily assessment has the advantage of giving a more detailed insight into variability within the long-term trends in recreational water quality than would be given by the more conventional monthly assessments.

The parameters chosen for this analysis were:

- for *secondary contact* recreation: faecal coliforms[1], algae and oily films
- for *primary contact* recreation: faecal coliforms[2], pH, temperature, clarity, algae and oily films.

The percentage of sampling days that each parameter complied with the relevant criteria was calculated.

---

1 For this purpose a daily faecal coliform value (geometric mean, n=3) of 1000 cfu/100 mL was used as the criterion.

2 For this purpose a daily faecal coliform value (geometric mean, n=3) of 200 cfu/100 mL was used as the criterion. The NHMRC (1990) guidelines state that a monthly median value of 150 cfu/100 mL equates to a geometric mean level of 200 cfu/100 mL.

Table 2
Percent compliance and the corresponding rankings and icons

Percent compliance	Ranking	Icon
75 - 100	Good	Green
50 - 74	Fair	Yellow
25 - 49	Poor	Orange
0 - 24	Very Poor	Red

Occasional technical difficulties during sampling and/or analysis had led to some gaps in the data set. Missing observations were not included in the calculations of percentage compliance.

A *composite index* was calculated for each site. This index represents the percentage of sampling occasions on which all parameters measured complied with the relevant criteria, thereby providing a single value as an overall assessment of the suitability of each site for either primary or secondary contact recreation.

Each site was then ranked into one of four divisions, according to the percentage compliance with the individual relevant criteria and the composite index value for primary and secondary contact recreation for that site (Table 2).

3.6 Rainfall data

Daily rainfall data recorded at 0900 hours were obtained for each of the 13 sites from gauging stations near sampling sites. Where possible, the total rainfall for the six days preceding each sampling day was calculated for each site.

The rainfall gauge station number and location used for each sampling site are listed in Appendix B.

3.7 Regression analyses

To examine potential relationships between faecal bacterial densities and other parameters, a simple linear regression analysis was performed for each site using:

- rainfall as the independent (X) variable and bacterial density as the dependent (Y) variable
- turbidity as the independent (X) variable and bacterial density as the dependent (Y) variable
- rainfall as the independent (X) variable and turbidity as the dependent (Y) variable.

The coefficient of determination (r^2) was calculated for each regression analysis.

To examine the relationship between turbidity and Secchi distance/ depth, a simple linear regression analysis was performed using:

- turbidity as the independent (X) variable and the reciprocal of horizontal Secchi distance as the dependent (Y) variable
- turbidity as the independent (X) variable and the reciprocal of vertical Secchi depth as the dependent (Y) variable.

To examine the relationship between turbidity and the variability in faecal bacterial densities of the QA/QC duplicate samples, a simple linear regression analysis was performed using:

- turbidity as the independent (X) variable and the relative difference between the faecal coliform densities for each pair of samples as the dependent (Y) variable
- turbidity as the independent (X) variable and the relative difference between the enterococcus densities for each pair of samples as the dependent (Y) variable.

The proportion (or percentage) of the total variation in Y that is explained or accounted for by the fitted regression is termed the *coefficient of determination,* r^2 (Zar 1974). For example, if there is a strong relationship between rainfall and faecal bacterial densities at a particular site, r^2 will approach or equal 1 (or 100 %); if the relationship is weak r^2 will approach or equal 0 (0 %).

3.8 Quality assurance /quality control (QA/QC)

QA/QC procedures and results have been reported previously in seasonal reports (EPA 1994; EPA 1995a; EPA 1995b; EPA 1996a; EPA 1997).

Details of the program's QA/QC component are given in Appendix C.

4. RESULTS AND DISCUSSION

4.1 Bacteriological data

Compliance at each of the 13 sites with the NHMRC (1990) bacterial guidelines for primary and secondary contact recreation on a monthly basis is shown in Table 3. Information relating to each site's compliance with these faecal coliform guidelines was used to allocate a rank from 'good' to 'very poor', for each site for primary and secondary contact recreation, as represented by the coloured icons in Figure 2.

Based on the NHMRC (1990) faecal coliform criteria, 11 of the 13 sites were suitable for secondary contact recreation throughout their entire sampling period. The two Windsor sites: Macquarie Park [F] and South Creek [G], each failed to comply for two months. All sites were suitable for secondary contact recreation for more than 75% of months sampled and so were ranked as 'good' (Figure 2).

Table 3
Number of months between April 1994 and March 1996 that each site complied with the NHMRC (1990) bacterial guidelines for primary and secondary contact recreation, where 'FC' = faecal coliform and 'Ent' = enterococcus

Site	Primary Contact		Secondary Contact	Months sampled
	FC	Ent	FC	
Menangle Br [A]	22	19	24	24
Bents Basin [B]	24	24	24	24
Tench Reserve [C]	22	13	24	24
Glenbrook Ck [D]	23	22	24	24
Yarramundi Br [E]	22	18	24	24
Macquarie Pk [F]	10	2	22	24
South Creek [G]	13	4	22	24
Cattai NP [H]	23	15	24	24
Sackville ferry [I]	14	13	14	14
Lower Portland [J]	24	24	24	24
Wisemans Ferry [K]	24	24	24	24
One Tree Reach [L]	24	24	24	24
Berowra Creek [M]	24	23	24	24

Figure 2: Individual site compliance with the NHMRC (1990) faecal coliform guidelines (April 1994 - March 1996).

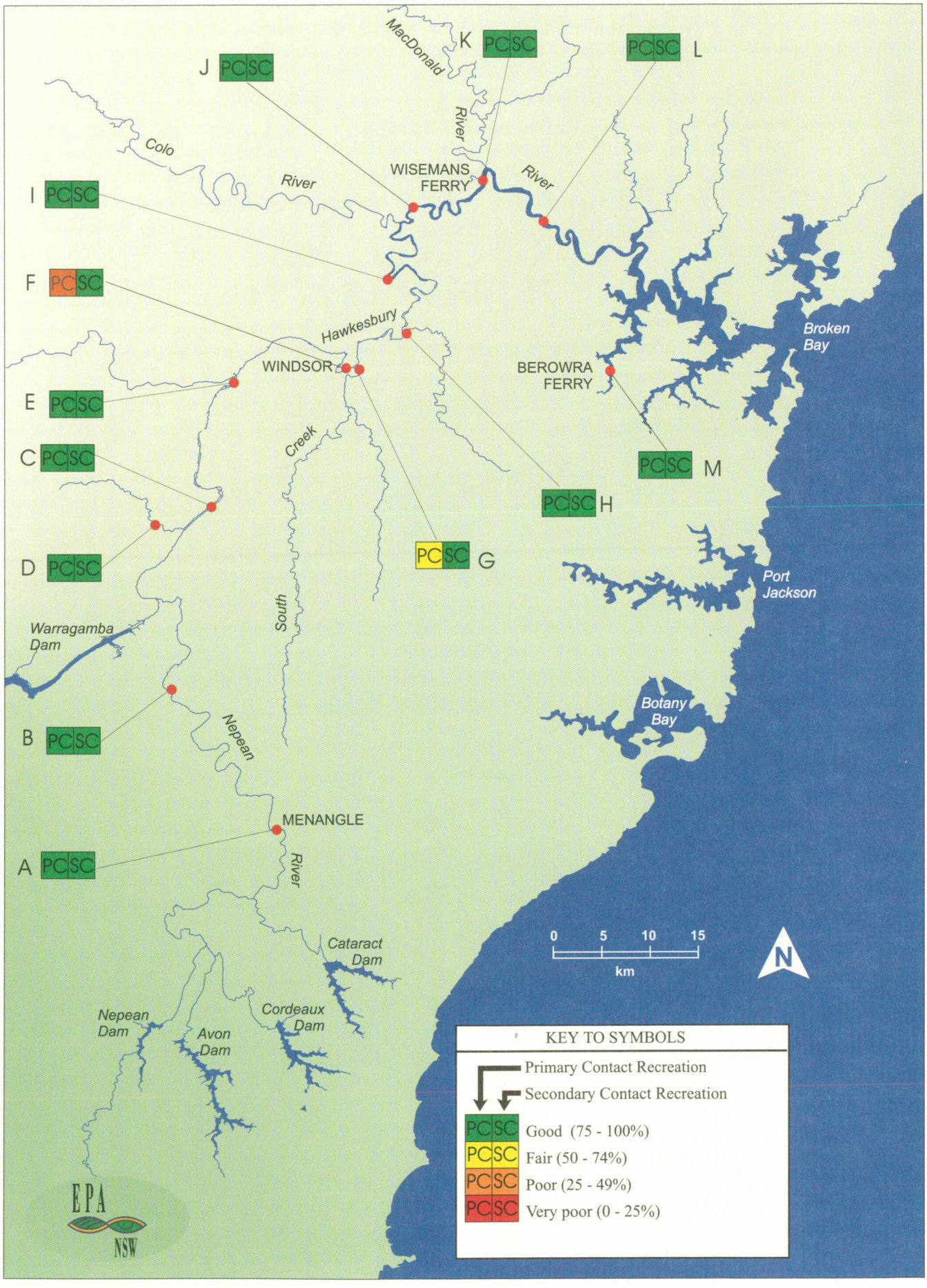


Figure 3: Individual site compliance with relevant water quality criteria for primary contact recreation including composite index values during 1994-95 and 1995-96 summer seasons (October 1994 to March 1995 and October 1995 to March 1996).

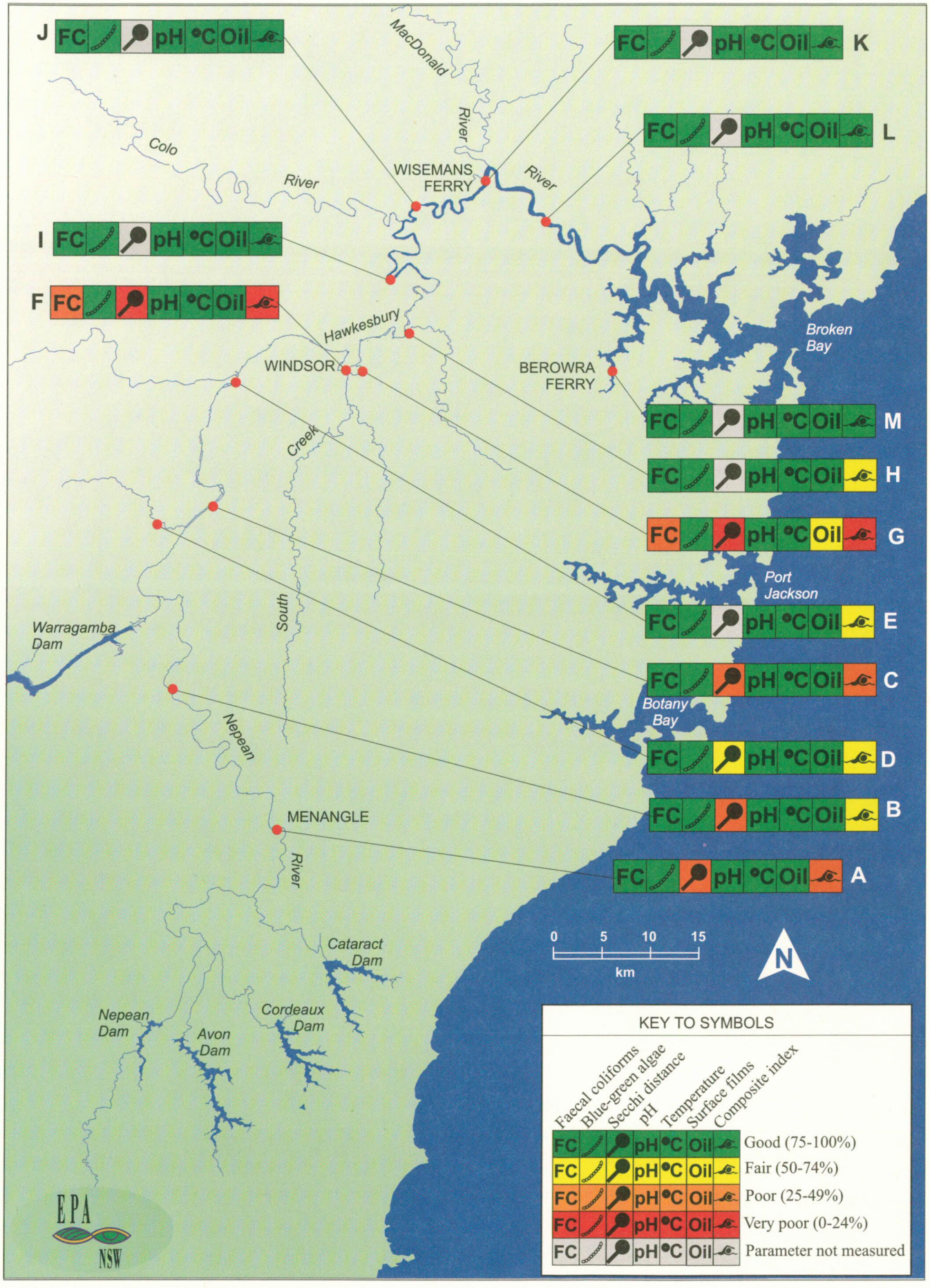


Figure 4: Individual site compliance with relevant water quality criteria for primary contact recreation including composite index values during 1994 and 1995 winter seasons (April to September 1994 and April to September 1995).

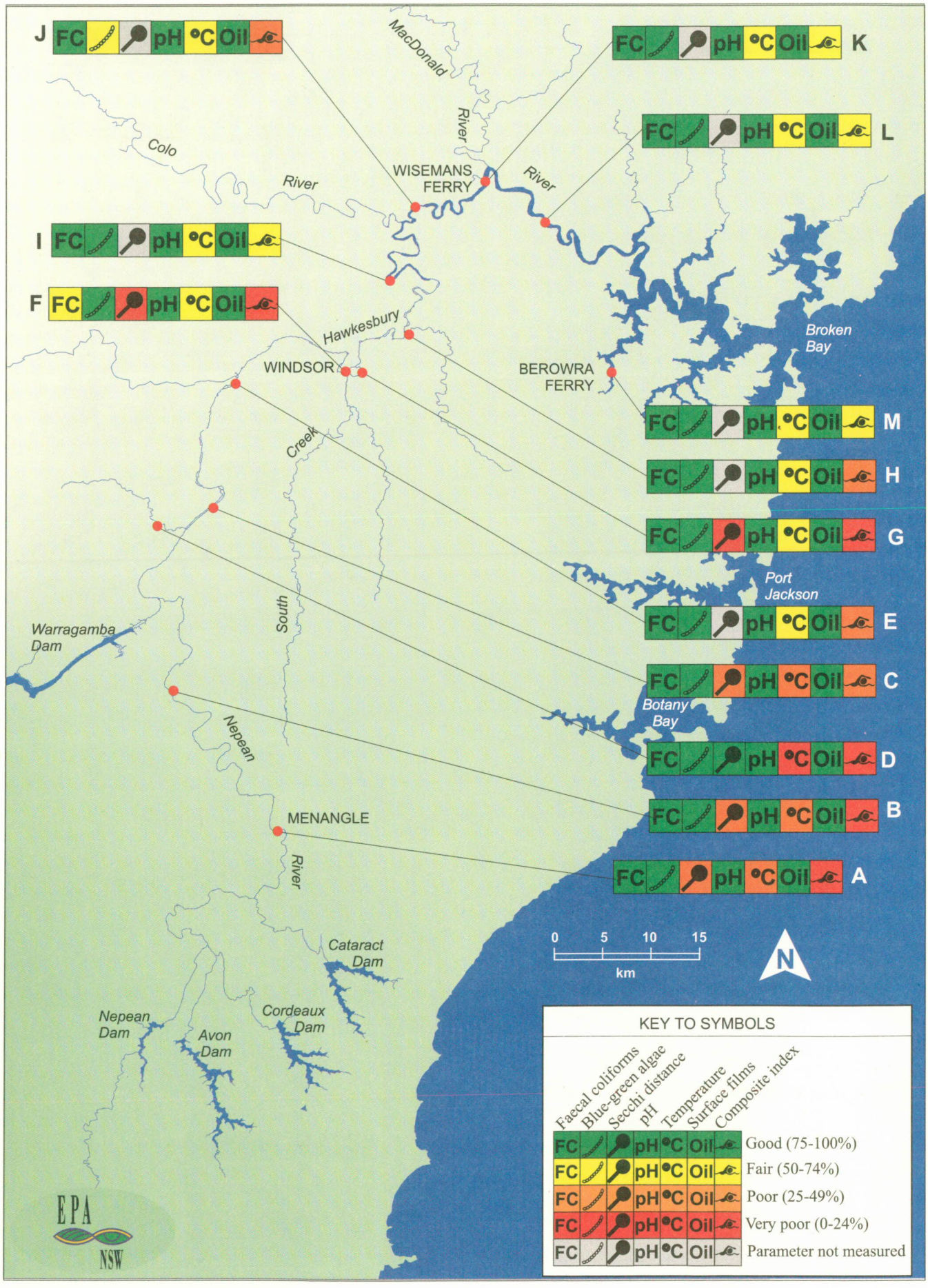
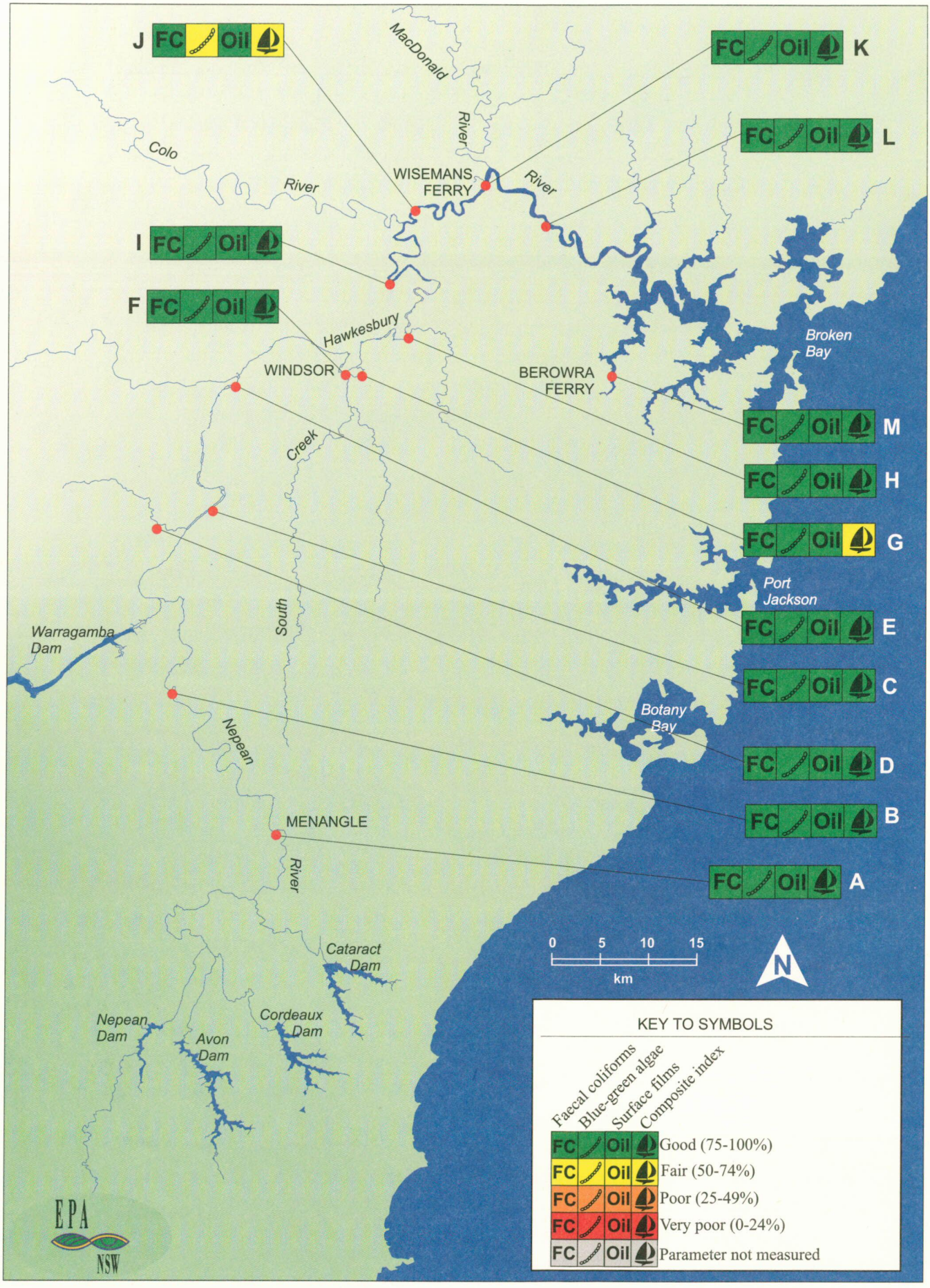


Figure 5: Individual site compliance with relevant water quality criteria for secondary contact recreation, including composite index values (April 1994 to March 1996).



Eleven of the 13 sites complied with the NHMRC (1990) faecal coliform criteria for primary contact recreation for more than 75 % of months sampled and so were ranked as 'good' (Figure 2). Macquarie Park [F] and South Creek [G] complied for only 42 % and 54 % of the time and so were ranked as 'poor' and 'fair' respectively (Figure 2).

Of the 13 sites, nine exceeded the enterococcus reference value for primary contact recreation for periods of one to 22 months (Table 3). The reference value was developed for marine and estuarine waters and is not used by health authorities as a primary indicator to define suitability for primary contact recreation and so this information was not included in Figure 2. Enterococci tend to survive longer in water than faecal coliforms, so their presence at elevated levels in water that contains few faecal coliforms may indicate some residual faecal contamination.

4.2 Overall assessment

Percentage compliance against the relevant water quality parameters and the resulting composite index values for each site for primary and secondary contact recreation for April 1994 to March 1996 are shown in Appendix D. These values were used to allocate rankings, from 'good' to 'very poor', for each site for primary and secondary contact recreation and are represented by icons in Figures 3, 4 and 5. These assessments were based, among other parameters, on *daily faecal coliform values*, rather than monthly assessments as per the NHMRC (1990) guidelines. This method of assessment gives an indication of the *percentage of sampling days* that each parameter complied with the relevant criteria. As such, individual sites' rankings for compliance with faecal coliform criteria in Figures 3, 4 and 5 may differ from those shown in Figure 2. Figure 2 shows compliance with NHMRC (1990) on a *monthly* basis. Summary physico-chemical and field data for each of the 13 sites are presented in Appendix E.

Figures 3 and 4 show the individual site compliance with the relevant water quality criteria for the summer (October 1994 to March 1995 and October 1995 to March 1996) and winter (April to September 1994 and April to September 1995) seasons respectively. This division of the dataset permits a comparison of each site's compliance with the relevant guidelines for primary contact recreation during the summer and winter seasons.

In general, the rankings for the composite index values for the 13 sites were lower during the winter seasons than for the summer seasons. Comparison of Figures 4 and 5 shows that the lower winter temperatures had a marked effect on recreational water quality at all 13 sites. All sites were ranked as 'good' for temperature during the summer seasons (Figure 3) but were ranked as 'fair', 'poor' or 'very poor' during the winter seasons (Figure 4).

Rankings for all other parameters showed little or no seasonal differences, with the exception of faecal coliforms (Macquarie Park and South Creek) and algae (Lower Portland). Faecal coliforms at Macquarie Park and South Creek were ranked as 'poor' during the summer seasons but were ranked as 'fair' and 'good', respectively, during the winter seasons. This is thought to be due to the longer survival rates of faecal bacteria in the warm summer seasons.

Algae at Lower Portland was ranked as 'good' during the summer seasons and 'poor' during the winter seasons. This was due to an unseasonal cyanobacterial bloom at this site from April to August 1994.

4.3 Individual site assessments

Faecal bacterial densities and compliance with the NHMRC (1990) and ANZECC (1992) guidelines at each site for the 1994 winter, 1994-95 summer, 1995 winter and 1995-96 summer seasons are detailed in EPA (1995a), EPA (1995b), EPA (1996a) and EPA (1997) respectively.

Figures 6 to 18 give a brief description of each site, type of recreational use, compliance at each site with the relevant guidelines, the recreational water quality at that site and a graphical representation of faecal bacterial densities over the April 1994 to March 1996 study period (Figures 6 to 18). Data points shown in the graphs in Figures 6 to 18 represent the geometric mean of three samples collected on each sampling occasion. The horizontal lines at 150 cfu/100 mL and 33 cfu/100 mL indicate the NHMRC (1990) faecal coliform and enterococcus guideline values for primary contact recreation. Results reported as below the detection limit (i.e. < 1 cfu/100 mL) were entered as half the detection limit (0.5 cfu/100 mL).

4.4 Regression analyses

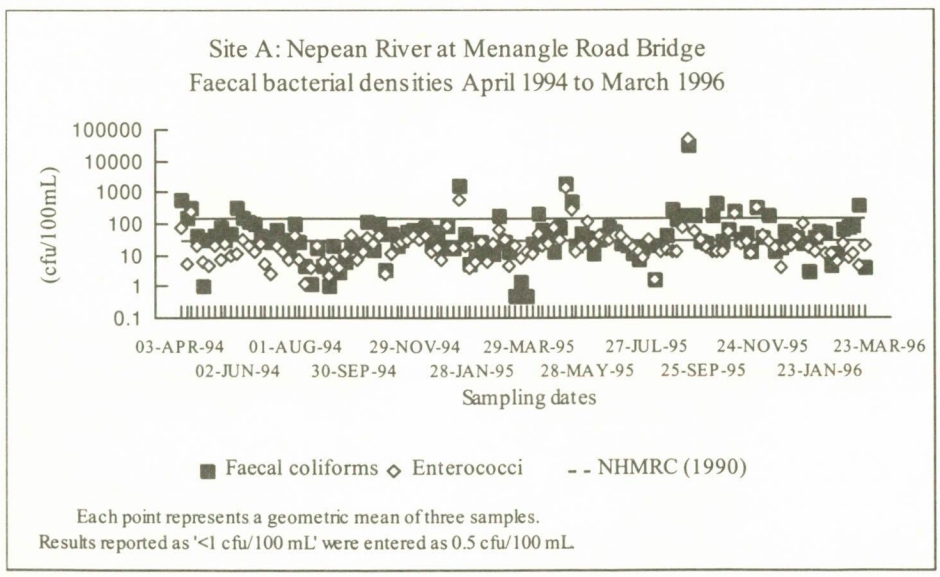
Results from seasonal regression analyses have been reported previously (EPA 1994; EPA 1995a; EPA 1995b; EPA 1996a; EPA 1997) for

Figure 6
Site A: Nepean River at Menangle Road Bridge

Site description
The samples were collected from the shore, about 50 m upstream of the bridge, on the eastern bank of the river. At this point the river is about 20 m wide and several metres deep.

Recreational use
This site is a popular swimming location, with a picnic area nearby.

Compliance with guidelines
This site complied with the NHMRC (1990) bacteriological guidelines for secondary contact recreation during the entire sampling period. The site complied with the guidelines for primary contact recreation, using faecal coliforms as the indicator organism, during all months sampled except April 1994 and September 1995. This site, however, exceeded the enterococcus guideline value for primary contact recreation during January 1995, May 1995, June 1995, September 1995 and November 1995. Surface films and algal blooms were not observed at this site. Horizontal Secchi distance was below the minimum 1.6 m recommended by ANZECC (1992) on most (74 of the 104) occasions. pH levels complied with the ANZECC (1992) criterion for primary contact recreation for the whole study period. Temperatures were generally unsuitable for prolonged exposure during the winter seasons.



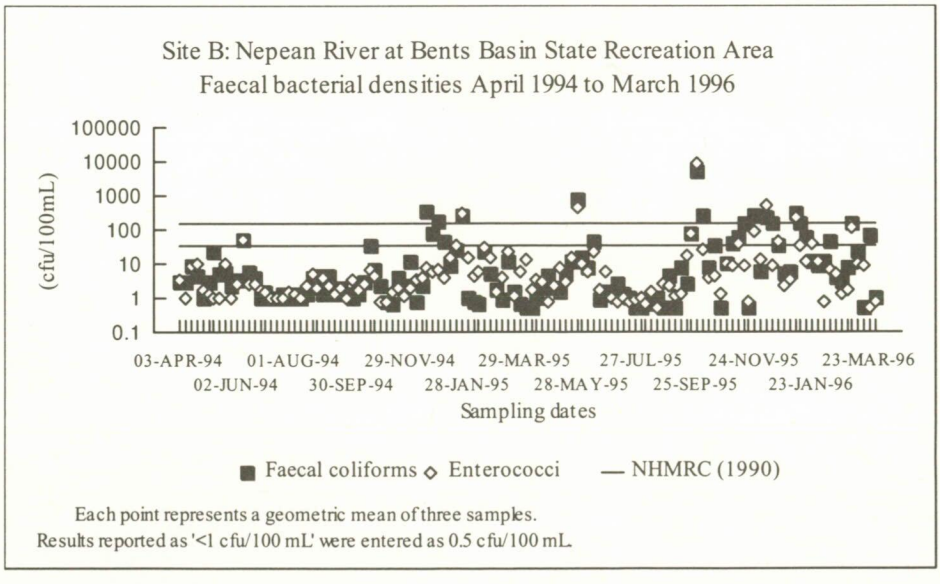
Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100 mL' were entered as 0.5 cfu/100 mL.

Figure 7
Site B: Nepean River at Bents Basin State Recreation Area

Site description
This section of the river forms a wide and deep basin about 250 m x 150 m, and 24 m deep. The samples were collected from the shore, within 50 m of either side of the bridge, at the point where the river leaves the basin.

Recreational use
This is a popular camping, picnicking and swimming location.

Compliance with guidelines
This site complied with the NHMRC (1990) bacteriological guidelines for primary and secondary contact recreation over the entire sampling period. Horizontal Secchi distance was below the minimum 1.6 m recommended by ANZECC (1992) on more than half (65 of the 105) of the sampling occasions. Blue-green algal blooms were not observed at this site during the study period. Oily films were observed on three occasions. pH levels complied with the ANZECC (1992) criterion for primary contact recreation for the whole study period. Temperatures were unsuitable for prolonged exposure for most of the time during the winter seasons.



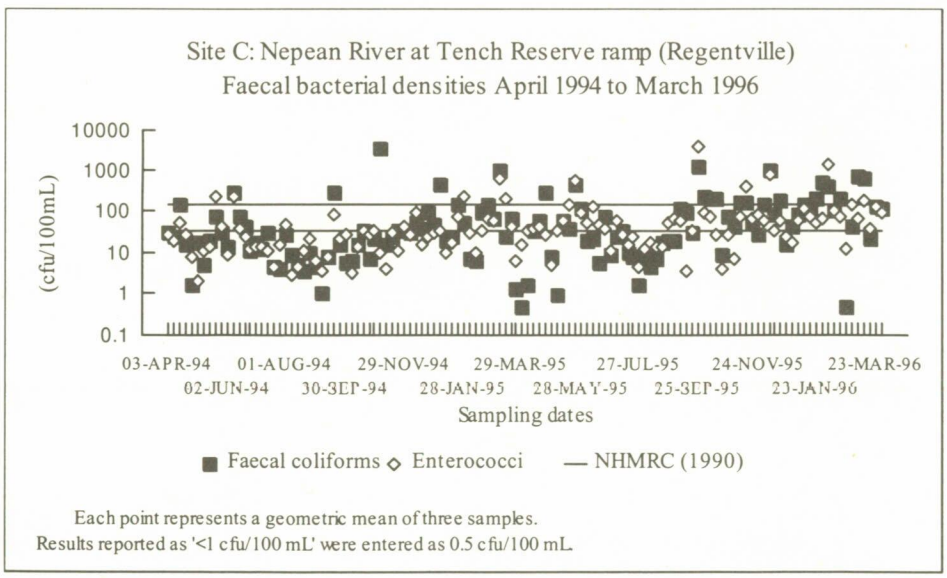
Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100 mL' were entered as 0.5 cfu/100 mL.

Figure 8
Site C: Nepean River at Tench Reserve Ramp (Regentville)

Site description
The samples were collected from the boat ramp at Tench Reserve, Regentville (downstream of the Western Motorway bridge). The river is about 150 m wide and about 3 m deep at this point.

Recreational use
This stretch of river is used for swimming, picnicking, canoeing, rowing, boat launching, fishing and jet-skiing.

Compliance with guidelines
This site complied with the NHMRC (1990) bacteriological guidelines for secondary contact recreation for the entire study period. The site complied with the guidelines for primary contact recreation, using faecal coliforms as the indicator organism, during all months except November 1995 and March 1996. This site, however, exceeded the enterococcus guideline value for primary contact recreation for a total of 9 months. Surface films were observed on 17 sampling occasions. No algal blooms were observed at this site. Horizontal Secchi distance was below the minimum 1.6 m recommended by ANZECC (1992) for primary contact recreation on the majority of (66 of the 101) occasions. pH was elevated (pH > 9.0) on one occasion in October 1995. Temperatures were unsuitable for prolonged exposure for most of the time during the winter seasons.



Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100 mL' were entered as 0.5 cfu/100 mL.

Figure 9
Site D: Glenbrook Creek at Jellybean Pool

Site description
The samples were collected from the shore at Jellybean Pool. The creek is several metres wide at this point and 1–3 m deep. There was a constant flow during the sampling period, with flow increasing after periods of rain.

Recreational use
This is a popular swimming, walking and picnicking location.

Compliance with guidelines
This site complied with the NHMRC (1990) bacteriological guidelines for secondary contact recreation for the whole sampling period. The site complied with the guidelines for primary contact recreation, using faecal coliforms as the indicator, during all months except January 1996. The enterococcus guideline value was exceeded during October 1995 and December 1995. The creek usually looked turbid after rain but was very clear at other times. No algal blooms were observed. Surface films were noted on one occasion. Horizontal Secchi distance was less than the minimum 1.6 m recommended by ANZECC (1992) for primary contact recreation on 28 sampling occasions. pH levels complied with the ANZECC (1992) criterion for primary contact recreation during the entire study period. Temperatures were unsuitable for prolonged exposure for most of the winter seasons.

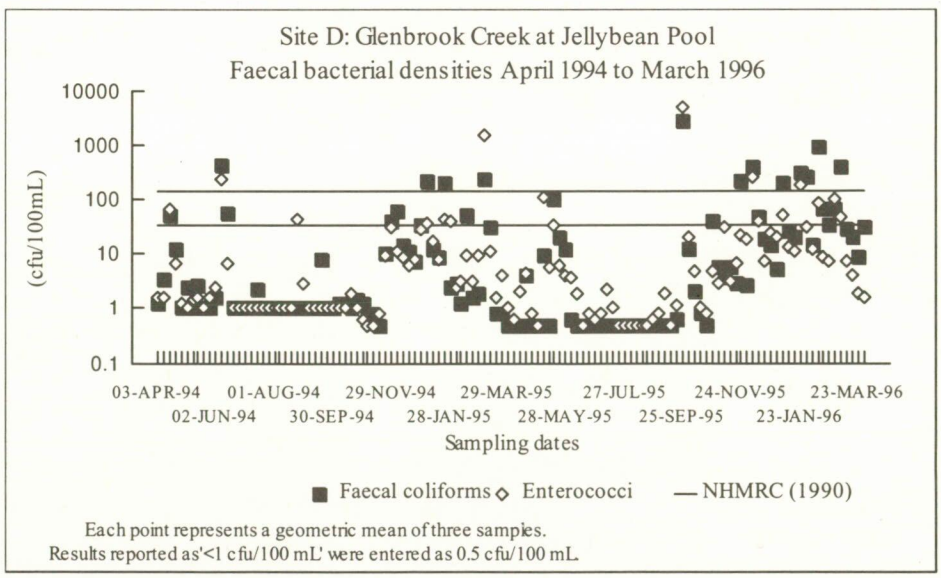


Figure 10
Site E: Nepean River at Yarramundi Bridge

Site description

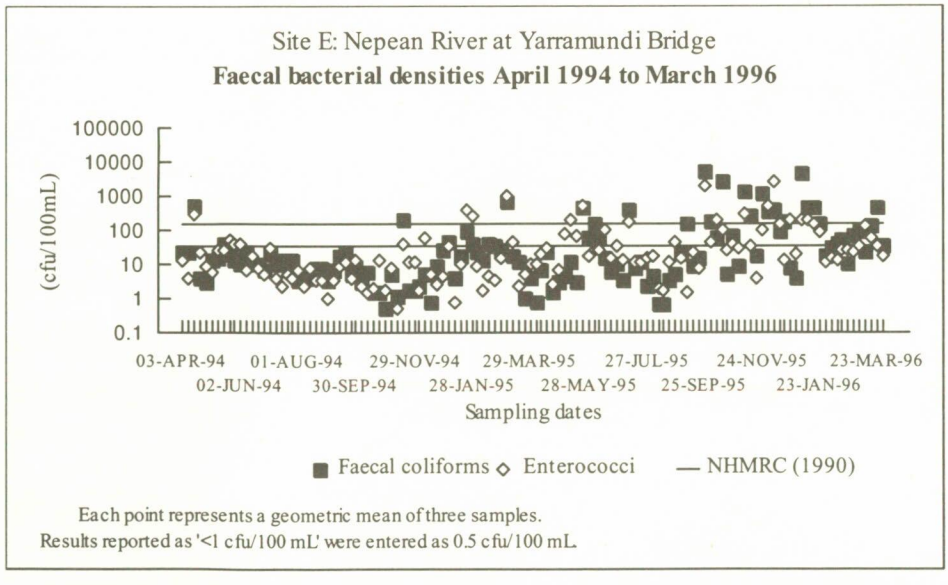
The samples were collected from the shore, 40 m upstream of the Springwood Road bridge, on the western side of the river. At this point the river is about 30 m wide. The level was higher than normal on a couple of sampling occasions due to heavy rainfall. On one occasion during May 1995, the nearby lagoon was connected to the mainstream river and flow was greatly increased.

Recreational use

This is a popular fishing, picnicking and wading location.

Compliance with guidelines

This site complied with the NHMRC (1990) guidelines, using faecal coliforms as the indicator organism, for primary contact recreation during all months sampled except November 1995 and January 1996. This site, however, exceeded the enterococcus guideline value for primary contact recreation during a total of six months. This site was suitable for secondary contact recreation during the entire sampling period. Surface films were present on 10 occasions. Blue-green algal blooms were not observed, but submerged macrophytes and algal mats were present at times. Horizontal Secchi distance could not be measured at this site for logistical reasons. pH levels at this site did not comply with ANZECC (1992) criterion for primary contact recreation on 12 occasions. Temperatures were unsuitable for primary contact recreation for much of the time during the winter seasons.



Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100 mL' were entered as 0.5 cfu/100 mL.

Figure 11
Site F: Hawkesbury River at Macquarie Park (Windsor)

Site description

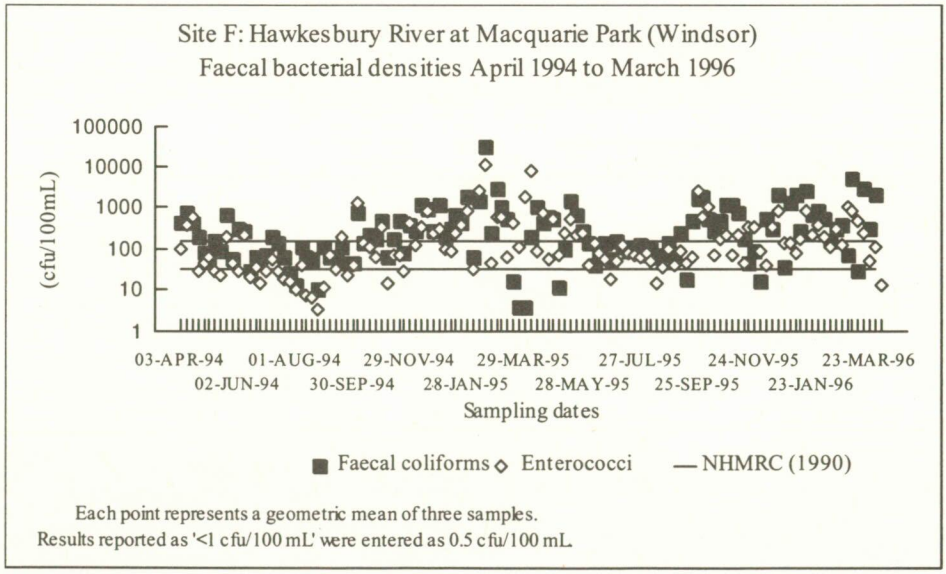
The samples were collected from the shore about 100 m upstream of the Windsor Bridge. The Hawkesbury River is tidal at this point and is about 100 m wide. Depth at this site varies. This site has a sandy beach about 30 m long.

Recreational use

This site is a popular picnicking, fishing and wading location. Downstream of this site is popular for boating and water-skiing.

Compliance with Guidelines

This site complied with the NHMRC (1990) primary contact recreation guidelines, using faecal coliforms as the indicator, during a total of ten months. However, the site exceeded the enterococcus guideline value for a total of 22 months. This site failed to comply with the NHMRC (1990) bacteriological guidelines for secondary contact recreation in February 1995 and March 1996. Oily films were observed on seven occasions. A blue-green algal bloom was observed in the vicinity on one occasion during the 1994 winter season. The water looked brown and turbid on most occasions. Horizontal Secchi distance was consistently below the minimum 1.6 m recommended by ANZECC (1992) for primary contact recreation (failed 105 of 105 occasions). pH levels complied with ANZECC (1992) for the entire period. Temperatures were often too low for prolonged exposure during the winter seasons.



Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100 mL' were entered as 0.5 cfu/100 mL.

Figure 12
Site G: South Creek at Governor Phillip Park ramp (Windsor)

Site description

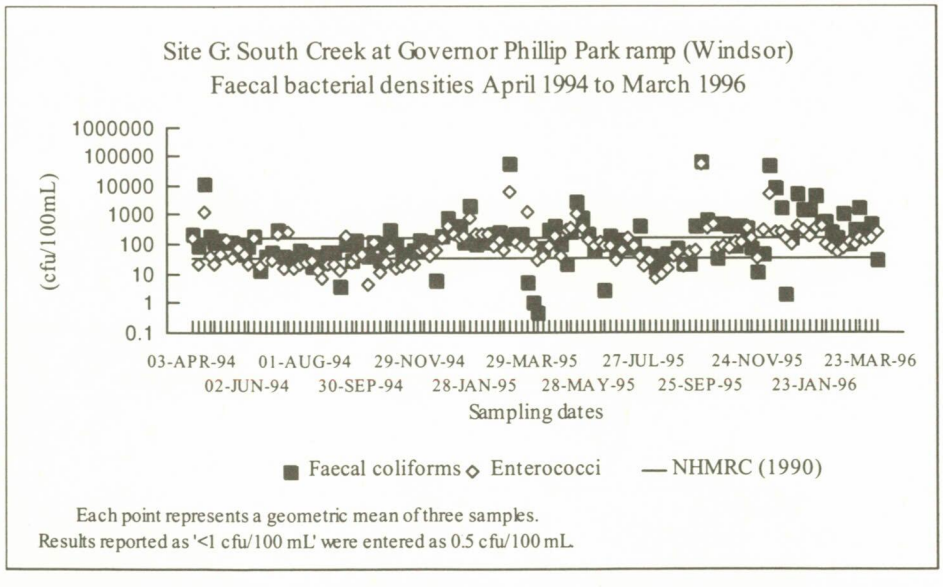
The samples were collected from the boat ramp at Governor Phillip Park. South Creek is tidal at this point and is about 20 m wide and several metres deep.

Recreational use

This is a very popular site for boat launching. Downstream of this site is popular for boating, fishing and water-skiing.

Compliance with guidelines

This site complied with the NHMRC (1990) guidelines, using faecal coliforms as the indicator organism, for primary contact recreation for 13 of the 24 months sampled. This site, however, exceeded the enterococcus guideline value for primary contact recreation during a total of 20 months. This site failed to comply with the NHMRC (1990) bacteriological guidelines for secondary contact recreation during December 1995 and January 1996. The water looked green or brown on all sampling occasions and was usually turbid (ranging from 0 to 508 NTU). Oily films were present on 23 sampling occasions. Horizontal Secchi distance was always less than the 1.6 m required by ANZECC (1992) for primary contact recreation. A blue-green algal bloom was observed in the vicinity on one occasion during the 1994 winter season. pH levels complied with ANZECC (1992) for the entire study period. Temperatures were often too low for prolonged exposure during the winter seasons.



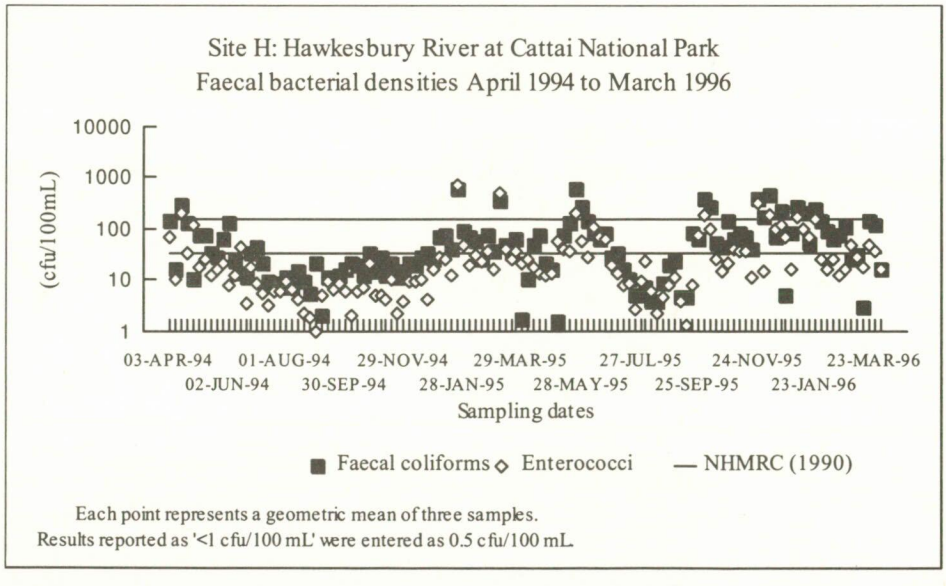
Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100 mL' were entered as 0.5 cfu/100 mL.

Figure 13
Site H: Hawkesbury River at Cattai National Park

Site description
The samples were collected by boat near the Cattai National Park (near the the Cattai Creek confluence). This site is tidal, with depth ranging from 3–12 m across the main channel. The river is about 100 m wide at this point.

Recreational use
The site is a popular boating and water-skiing location.

Compliance with guidelines
This site complied with the NHMRC (1990) bacteriological guidelines for secondary contact recreation for the entire period. This site complied with the NHMRC (1990) guidelines for primary contact recreation, using faecal coliforms as the indicator, during all months except in January 1996. However, the site exceeded the enterococcus guideline value during a total of nine months. Blue-green algal blooms were observed in the vicinity on six occasions. Surface films were observed once during the study period. The water was often turbid and appeared brown/green in colour. pH levels at this site exceeded the ANZECC (1992) criterion for primary contact recreation on seven occasions. Temperatures were unsuitable for prolonged exposure during most of the winter seasons.



Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100 mL' were entered as 0.5 cfu/100 mL.

Figure 14
Site I: Hawkesbury River at Sackville ferry

Site description
Samples were collected near the Sackville ferry. The site is tidal, with a depth of at least 3 m at low tide. The river is approximately 150 m wide.

Recreational use
The site is a popular boating and water-skiing location.

Compliance with guidelines
The site complied with the NHMRC (1990) bacteriological guidelines, using faecal coliforms as the primary indicator, for primary and secondary contact during the entire sampling period (14 months). The site, however, failed to comply with the enterococcus guideline value for primary contact recreation during June 1995. Blue-green algal blooms were observed at this site on four occasions. Surface films were not observed at any time. pH exceeded the ANZECC (1992) criterion on two occasions. Temperatures were not suitable for prolonged exposure for most of the 1995 winter season.

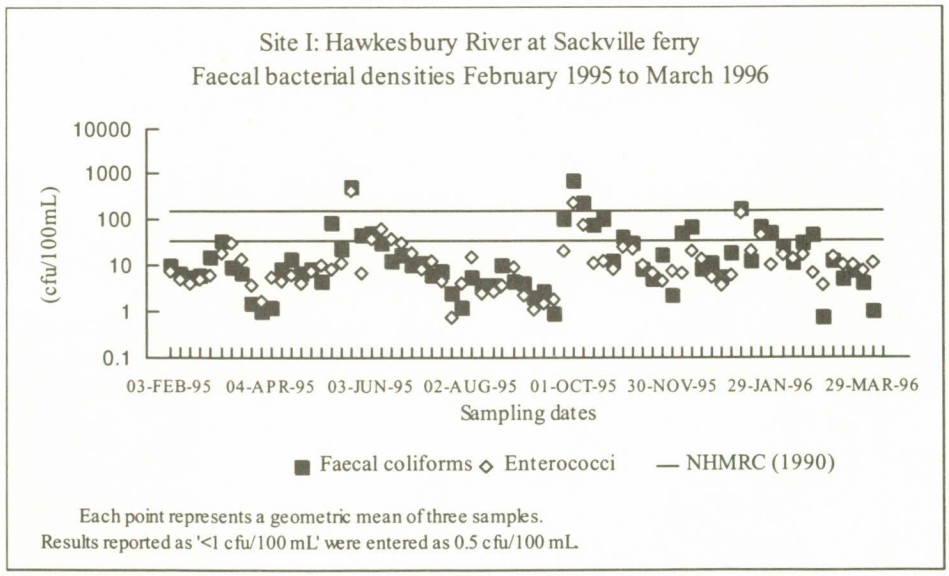
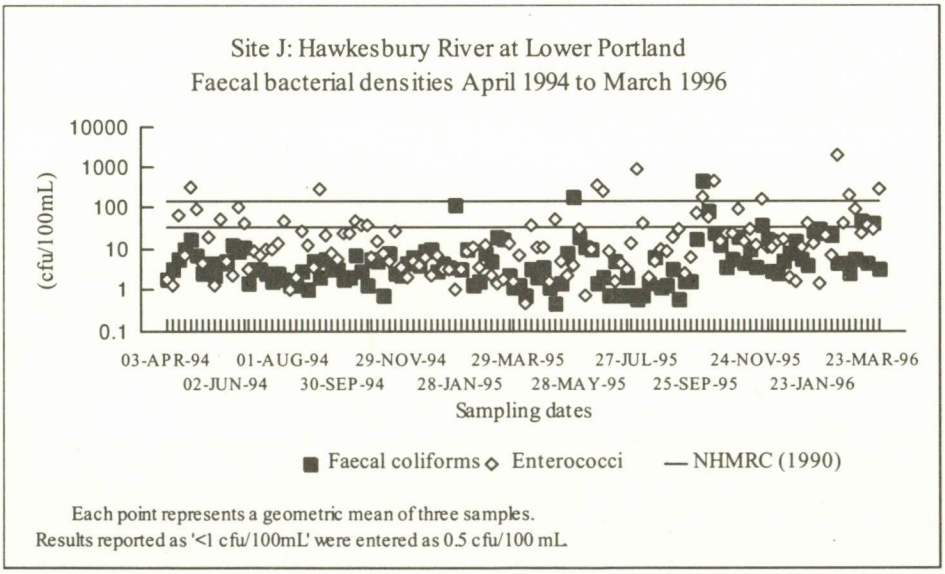


Figure 15
Site J: Hawkesbury River at Lower Portland

Site description
Samples were collected by boat downstream of the Colo River, near the South Sydney Junior Rugby League Club's recreational facilities. The river is tidal at this point and is approximately 200 m wide and several metres deep.

Recreational use
The site is a popular boating, camping, fishing and water-skiing location.

Compliance with guidelines
Bacteriological densities complied with the NHMRC (1990) guidelines for primary and secondary contact recreation during the entire sampling period. Oily films were not observed. Blue-green algal blooms were observed in the vicinity on 30 occasions. pH levels exceeded the ANZECC (1992) criterion for primary contact recreation on one occasion. Temperatures were unsuitable for prolonged exposure during much of the winter seasons.



Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100mL' were entered as 0.5 cfu/100 mL.

Figure 16
Site K: Hawkesbury River at Wisemans Ferry

Site description

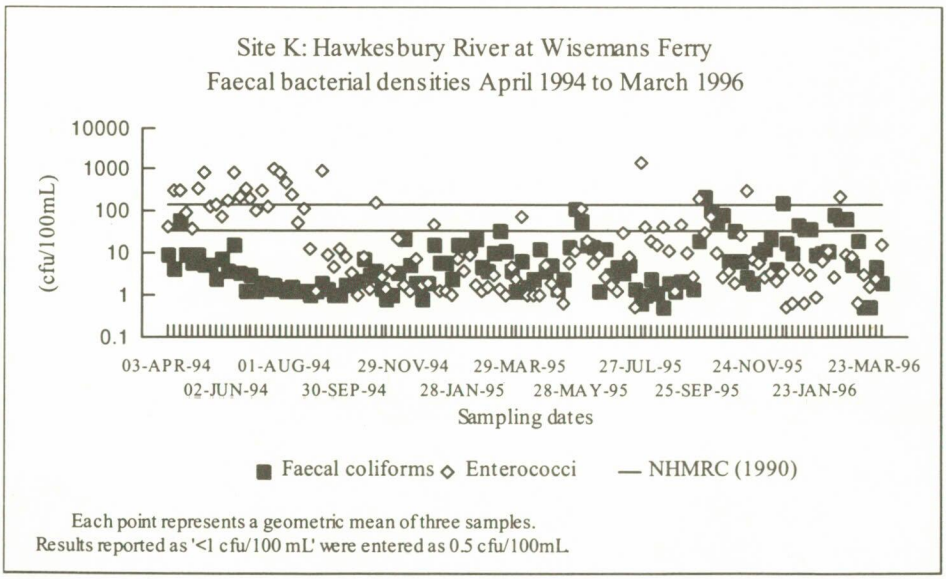
Samples were collected by boat upstream of the MacDonald River, near the Webbs Creek ferry. The river is tidal at this point and is about 300 m wide and at least 3 m deep (at low tide).

Recreational use

This is a popular boating, camping, swimming and water-skiing location.

Compliance with guidelines

This site complied with the NHMRC (1990) bacteriological guidelines for primary and secondary contact recreation for the entire sampling period. Surface films were not observed. Concentrations of blue-green algae in the vicinity of this site exceeded 15,000 cells/mL on four occasions. pH levels at this site complied with ANZECC (1992) criterion for primary contact recreation during the entire period. Temperatures were often too low for prolonged exposure during the winter seasons.



Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100 mL' were entered as 0.5 cfu/100mL.

Figure 17
Site L: Hawkesbury River at One Tree Reach

Site description
Samples were collected by boat from One Tree Reach (Gunderman) downstream of Laughtondale. The river is tidal, about 300 m wide and several metres deep at this point.

Recreational use
This site is a popular boating and water-skiing location.

Compliance with guidelines
This site complied with the NHMRC (1990) bacteriological guidelines for primary and secondary contact recreation for the entire sampling period. Blue-green algal blooms were not observed in the vicinity of this site during the study. Surface films were observed on two occasions. pH levels at this site complied with ANZECC (1992) during the entire period. Temperatures were often too low for prolonged exposure during the winter seasons.

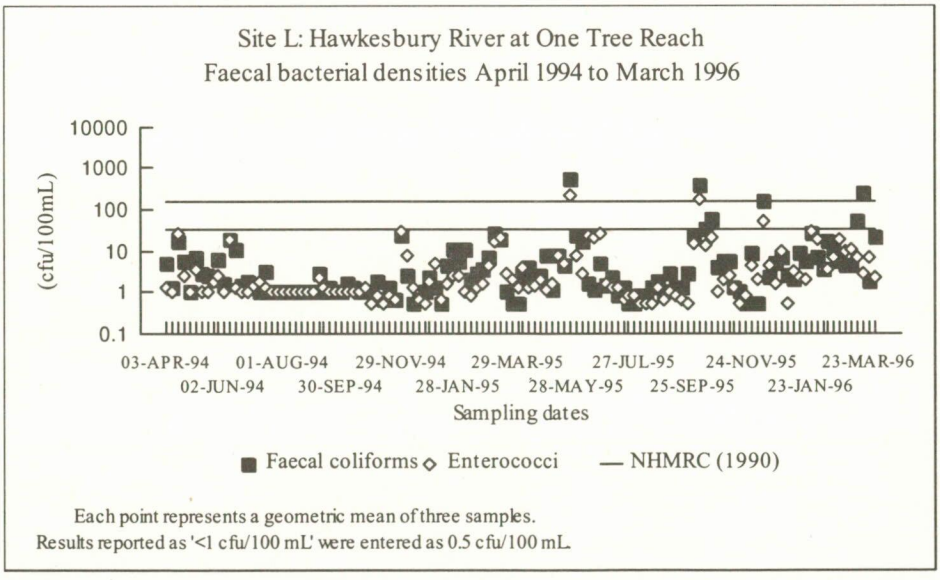
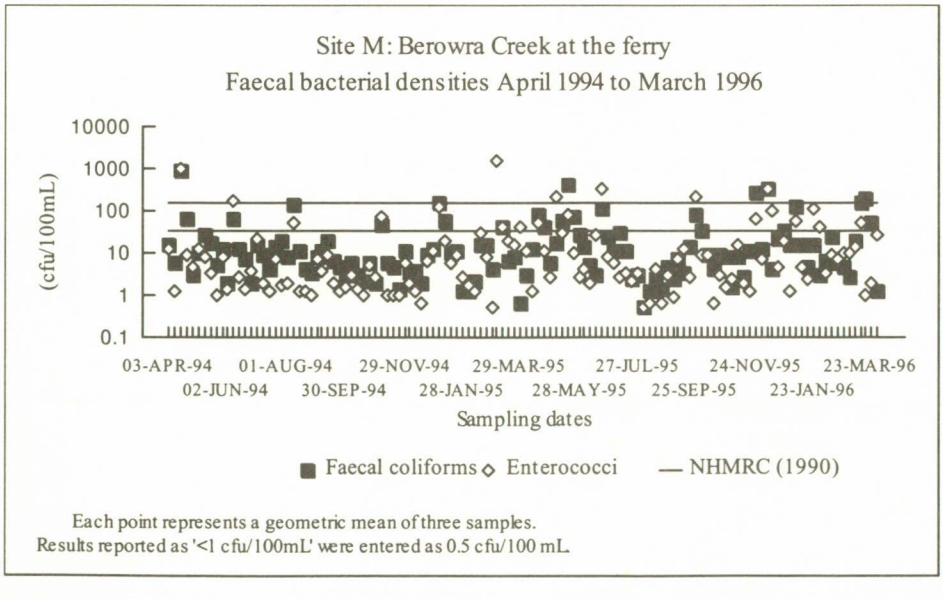


Figure 18
Site M: Berowra Creek at the ferry

Site description
Samples were collected from the shore near the Berowra ferry. The creek is 250 m wide and several metres deep at this point. The creek is estuarine and tidal.

Recreational use
This site is a popular boating, fishing, swimming and picnicking location.

Compliance with guidelines
This site complied with the NHMRC (1990) bacteriological guidelines, using faecal coliforms as the primary indicator, for primary and secondary contact recreation during the entire study period. This site, however, failed to comply with the enterococcus guideline value during March 1995. Surface films were observed on 15 sampling occasions. Blue-green algal blooms were not observed. pH levels at this site complied with the ANZECC (1992) criterion for primary contact recreation during the entire period. Temperatures were often too low for prolonged exposure during the winter seasons.



Each point represents a geometric mean of three samples.
Results reported as '<1 cfu/100mL' were entered as 0.5 cfu/100 mL.

each six-month period. The results from the analyses of the data collected over the full two-year period are presented in this report to identify any longer term trends.

Regression analyses of the two-year dataset revealed the following:

- Faecal bacterial levels increased with increasing turbidity at Menangle Bridge (r^2 for faecal coliforms = 0.979, enterococci = 0.980), Bents Basin (0.828, 0.803), Glenbrook Creek (0.742, 0.789), South Creek (0.621, 0.593) and Berowra Creek (0.587, 0.544). The remaining sites did not show strong relationships.
- There were no strong relationships between: faecal bacterial densities and rainfall; or turbidity and rainfall; at any of the sites.
- There were no strong relationships between turbidity and the variability in faecal bacterial densities of the QA/QC duplicate samples at any of the sites (Appendix F).

Some of these findings are in contrast to those from other studies (Van Roo et al. 1995; EPA 1996b). For example, Van Roo et al. (1995) found only weak positive correlations existed between log faecal coliform density and log turbidity in the Parramatta and Lane Cove rivers, but correlations were not significant in Port Jackson.

Beachwatch (EPA 1996b) also found that there was no strong relationship between faecal coliform density and water turbidity at five of their Sydney Harbour beach sites.

Van Roo et al. (1995) showed that an increase in the average faecal coliform density in Sydney Harbour is associated with the amount of rainfall. The amount of rain did not account for all of the variation in faecal bacterial densities, but showed a linear relationship between log faecal coliform density and the amount of rainfall.

Beachwatch (EPA 1996b), when discussing the use of rainfall and turbidity as predictors, stated that 'as a predictor of faecal coliform density under the conditions of this study, rainfall produced slightly better results than did turbidity'.

Neither of these studies reported on the relationship between rainfall and turbidity.

While the results from this two-year study revealed a strong relationship between faecal bacterial levels and turbidity at several sites, this strong correlation was not evident at all sites. As discussed, other studies have also shown poor relationships between faecal bacterial densities and turbidities, and faecal bacterial densities and rainfall. These findings would discourage the use of these environmental parameters as indicators of faecal contamination.

5. CONCLUSIONS

A major disadvantage in the use of bacterial indicators is that accurate results cannot be reported immediately. Confirmed results are not available until five working days after the samples are collected. Thus, results can only be used in retrospect, i.e. a site cannot be assessed on the day on which the samples are collected. The best retrospective use of bacterial data is in long-term trend analysis. Assessment of these long-term trends gives a good indication of overall recreational water quality at any site.

Assessed against the criterion of faecal bacterial contamination, all sites except Macquarie Park (Windsor) and South Creek (Windsor) were suitable for secondary contact recreation during the entire study period. High faecal bacterial densities made these sites unsuitable for periods of two months each. Additional sites (Cattai, Sackville, Lower Portland and Wisemans Ferry) had high levels of blue-green algae at times, thereby making these sites unsuitable for direct contact activities during those periods. Some sites were suitable for primary contact recreation for the entire period, whilst other sites were affected by one or more of the following factors: high faecal bacterial densities, poor water clarity, and blue-green algal blooms or surface films; and by low water temperatures in winter.

The major findings of this two-year study are summarised below. This information can be used by the community to help decide where to use the river for recreation.

1. **Recreational water quality at the 13 sites in the Hawkesbury-Nepean River was affected by several factors:** faecal bacterial densities, water clarity, pH, temperature, and the presence of blue-green algal blooms and surface films.

2. **Assessment of long-term trends in faecal bacterial densities showed that all sites except Macquarie Park**

(Windsor) and South Creek (Windsor) were suitable for primary and secondary contact recreation for most of the study period. A number of the sites, however, were unsuitable for primary contact recreation occasionally. These occasions were not predictable.

3. **Suitability for primary contact recreation at all sites was affected by low water temperature during the winter seasons (April to September).**

4. **Blooms of cyanobacteria (blue-green algae) between Cattai and Wisemans Ferry made some sites unsuitable for any direct contact recreation at times during the study period.** Suitability for primary contact recreation was, at times, also affected by elevated pH levels associated with these blooms at some sites.

5. **The presence of oily films was mostly associated with power boat activities.**

6. **The poor relationships between faecal bacterial densities and turbidity; and faecal bacterial densities and rainfall; at most sites would discourage the use of these environmental parameters as indicators of faecal contamination.**

7. **The high variability found in faecal bacterial densities demonstrates the need for the collection of replicate samples in recreational water quality assessments.**

BIBLIOGRAPHY

ANZECC (1992). *Australian Water Quality Guidelines for Fresh and Marine Waters.* Australian & New Zealand Environment & Conservation Council.

APHA (1992). *Standard Methods for the Examination of Water and Wastewater 18th ed.* American Public Health Association, Washington.

Blue-Green Algae Task Force (1992). *Blue-Green Algae - Final Report.* NSW Blue-Green Algae Task Force.

EPA (1994). *Recreational Water Quality, Hawkesbury-Nepean River System October 1993 to March 1994.* NSW Environment Protection Authority. EPA 94/104. ISBN 0 7310 3705 7.

EPA (1995a). *Recreational Water Quality, Hawkesbury-Nepean River System April to September 1994.* NSW Environment Protection Authority. EPA 95/25. ISBN 0 7310 3736 7.

EPA (1995b). *Recreational Water Quality, Hawkesbury-Nepean River System October 1994 to March 1995.* NSW Environment Protection Authority. EPA 95/52. ISBN 0 7310 3752 9.

EPA (1996a). *Recreational Water Quality, Hawkesbury-Nepean River System April to September 1995.* NSW Environment Protection Authority. EPA 96/68. ISBN 0 7310 3805 3.

EPA (1996b). *Harbourwatch 1995 Season Report.* Beachwatch, NSW Environment Protection Authority. EPA 96/19. ISBN 0 7310 3782 0.

EPA (1997). *Recreational Water Quality, Hawkesbury-Nepean River System October 1995 to March 1996.* NSW Environment Protection Authority. EPA 97/16. ISBN 0 7310 3835 5.

Grant (1992). *Grant YSI 3800 Water Quality Logger Instruction Manual.* Grant Instruments Cambridge, UK.

Hydrolab Corp. (1993). *H2O Operating Manual.* Hydrolab Corp. Aqualab Scientific Pty Ltd Sydney.

Lund, J. W., Kipling C. and Le Cren, E.D. (1958). 'An inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting'. *Hydrobiologia* 11:143-70.

McBride, G. B., Cooper, A. B. and Till, D. G. (1991). *Microbial Water Quality Guidelines for Recreation and Shell-Fish Gathering Waters in New Zealand.* Department of Health, Wellington.

NHMRC (1990). *Australian Guidelines for Recreational Use of Water.* National Health and Medical Research Council.

Van Roo, S., Garforth, S., Kirby, A and Collie, T. (1995). *Port Jackson Faecal Coliform Monitoring Program December 1992–March 1994.* Interpretive Report No. 94/103. Prepared for the Clean Waterways Unit, Sydney Water Corporation by AWT Ensight, Sydney.

Venrick, E.L (1978). 'Sampling Techniques'. In *Phytoplankton Manual* 35. edited by A. Sournia. United Nations Educational, Scientific and Cultural Organisation.

Zar, J. H. (1974). *Biostatistical Analysis.* Prentice-Hall Inc., USA

GLOSSARY

algal bloom — discolouration of the water due to high concentrations of algae.

blue-green algae — also referred to as cyanobacteria. Oxygen-producing photosynthetic bacteria which behave similar to algae. The blue-green is due to the presence of phycocyanin pigments. Includes *Anabaena* and *Microcystis* spp. High concentrations affect suitability of water for recreation and potable supplies.

catchment — an area of land which drains to a watercourse.

cfu — colony forming unit.

clarity — the maximum distance at which objects can be viewed through the water. This distance is measured as the maximum depth or horizontal distance in metres at which it is possible to distinguish a Secchi disk.

electrical conductivity — the water's ability to conduct an electrical current. It is related to the ionic content of the water, which is, in turn, a function of the dissolved (ionisable) solids concentration.

enterococci — bacteria which are a sub-group of the faecal streptococci. The enterococci are differentiated from other streptococci by their ability to grow in 6.5 % sodium chloride, at pH 9.6, and at 10 deg.C and 45 deg.C.

faecal bacteria — faecal coliforms and enterococci in the context of this report. These bacteria are used as indicators of sewage pollution as they are present in the faeces of virtually all warm blooded animals. Their presence in water is indicative that faecal contamination has occurred and that pathogens may be present.

faecal coliforms — bacteria which grow aerobically on agar-bile salt medium to ferment lactose, producing acid and gas, within 48 hours at 44 deg.C.

nuisance organisms — organisms which influence the recreational value of surface waters. Includes macrophytes, algal scums, filamentous algal mats, blue-green algae, sewage fungus, leeches, midges and aquatic worms.

NTU — nephelometric turbidity unit.

pathogen — a disease-causing organism; may be bacterial, viral or protozoan.

pH — the negative logarithm of the hydrogen ion concentration of a solution and is thus a measure of acidity. A pH of 7 is neutral; lower values are acidic, higher values alkaline.

turbidity — the extent of light scattering caused by a water sample. This light scattering is due to the presence of suspended particles such as clay, silt, phytoplankton, zooplankton and complex organic molecules.

APPENDIX A
INFORMATION RELATING TO SAMPLING SITES

Table A.1
Sampling site codes, site locations, number of months sampled, map ID, latitude and longitude

Site Code	Site Location	No. months sampled	Map ID 1:25 000	Latitude	Longitude
A	Nepean River at Menangle Road Bridge	24	9029-2-S	34°07'09"S	150°44'18"E
B	Nepean River at Bents Basin State Recreation Area	24	9030-3-S	33°55'59"S	150°37'53"E
C	Nepean River at Tench Reserve ramp (Regentville)	24	9030-3-N	33°46'0'S	150°39'39"E
D	Glenbrook Creek at Jellybean Pool	24	9030-3-N	33°47'00"S	150°37'15"E
E	Nepean River at Yarramundi Bridge	24	9030-IV-N	33°37'30"S	150°40'50"E
F	Hawkesbury River at Macquarie Park (Windsor)	24	9030-1-N	33°36'20"S	150°49'15"E
G	South Creek at Governor Phillip Park ramp (Windsor)	24	9030-1-N	33°36'00"S	150°49'57"E
H	Hawkesbury River at Cattai National Park	24	9030-1-N	33°33'42"S	150°53'19"E
I	Hawkesbury River at Sackville ferry	14	9030-1-N	33°30'8"S	150°52'22"E
J	Hawkesbury River at L Lower Portland	24	9031-2-S	33°25'40"S	150°53'43"E
K	Hawkesbury River at Wisemans Ferry	24	9031-2-S	33°23'19"S	150°58'45"E
L	Hawkesbury River at One Tree Reach	24	9131-III-S	33°25'28"S	151°01'46"E
M	Berowra Creek at the ferry	24	9130-4-N	33°35'54"S	151°07'25"E

APPENDIX B
RAINFALL GAUGE INFORMATION

Table B.1
Rainfall gauge location and station numbers for each sampling site

Site location	Rainfall gauge location	Rainfall gauge station no.
Nepean River at Menangle Road Bridge	Menangle Meteorological Station	568168
Nepean River at Bents Basin State Recreation Area	Warragamba Meteorological Station	568045
Nepean River at Tench Reserve boat ramp	Regentville (Factory Road)	567163
Glenbrook Creek at Jellybean Pool	Glenbrook Sewage Treatment Plant	563064
Nepean River at Yarramundi Bridge	Grose Wold	563080
Hawkesbury River at Macquarie Park	Riverstone Sewage Treatment Plant	567100
South Creek at Governor Phillip Park	Riverstone Sewage Treatment Plant	567100
Hawkesbury River at Cattai National Park	Wilberforce	563081
Hawkesbury River at Sackville ferry	Wilberforce	563081
Hawkesbury River at Lower Portland	Wilberforce	563081
Hawkesbury River at Wisemans Ferry	Wisemans Ferry Bowling Club	567108
Hawkesbury River at One Tree Reach	Wisemans Ferry Bowling Club	567108
Berowra Creek at the ferry	Hornsby Heights Sewage Treatment Plant	566053

APPENDIX C
QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

All procedures were fully documented, including preparation for sampling, locations of sampling sites, sampling procedures, sample storage and transport. All samples were submitted 'blind' to the laboratory, i.e. the laboratory was not advised of the locations from which the samples were taken. Sample codes were chosen randomly to prevent the laboratory from becoming confident of expected levels.

Confirmed results were received in printed form from the analytical laboratories within five working days of sample submission. All bacteriological and field data were transferred by field staff to a computer database. All data entries were checked and corrected against the original field and laboratory results sheets before archiving.

Transportation and field blanks

Four samples were submitted to the laboratory for bacteriological analysis (faecal coliforms and enterococci) after each sampling occasion as part of the program's QA/QC component. These four samples consisted of two samples which were submitted with the field samples from the shore sites and two which were submitted with the samples from the water-skiing sites. These four samples consisted of:

- two *transportation blanks* — i.e. QA/QC samples used to determine whether there had been any contamination during storage and transport. The transportation blanks were 500 mL samples of heat-sterilised river water which were poured aseptically into sterile sample bottles on the day of sampling before leaving the base. The samples were taken into the field from the base and were stored and transported with the field samples.
- two *field blanks* — i.e. QA/QC samples used to determine whether there had been any contamination during sample collection, storage and transport. The field blanks were 500 mL samples of heat-sterilised river water which were poured aseptically into sterile sample bottles at the first sampling site. The samples were then stored and transported with the field samples.

River water for the *transportation blanks* and *field blanks* was heat-sterilised (autoclaved) by the Division of Analytical Laboratories (Department of Health) prior to each sampling occasion.

Duplicate samples

To assess laboratory precision, each team collected two *duplicate* samples during each sampling day. For the duplicate samples, a one litre sample was collected using a prerinsed 1.5 litre container that was then shaken vigorously for one minute to homogenise the sample. This one litre sample was then decanted into two sterile 500 mL sample containers.

In-house laboratory procedures

In-house laboratory quality assurance/quality control procedures were performed by Microtech Laboratories (NSW) Pty. Ltd. during April 1994 to February 1995. All media used were subjected to sterility, appearance, pH and growth checks prior to use. Testing was conducted by qualified, trained staff. Training involved setting up and reading duplicate and dummy samples, followed by assistance with the setting up and reading of plates from field samples with a trained staff member. Trainees' techniques were assessed during these procedures to ensure satisfactory completion of all tasks. As a National Association of Testing Authorities, Australia (NATA) registered laboratory, Microtech Laboratories (NSW) Pty Ltd, participated in regular external NATA proficiency trials.

EML Consulting Services Pty Ltd also performed quality control procedures as part of their routine analyses. Each medium was tested to ensure good recovery for its intended purpose. All operators underwent regular internal proficiency trials to ensure good reproducibility for each sample. This laboratory also participated in regular external NATA proficiency trials. Results from these trials were generally within one standard deviation of the consensus mean.

Results from the QA/QC component of this study are reported in earlier seasonal reports (EPA 1994; EPA 1995a; EPA 1995b; EPA 1996a; EPA 1997).

APPENDIX D
PERCENTAGE COMPLIANCE AGAINST THE RELEVANT PARAMETERS AND COMPOSITE INDEX VALUES FOR EACH SITE

Table D.1
Percentage compliance against each index, including the composite index, at each site for **secondary contact recreation**, April 1994 to March 1996 (the number of observations is in brackets)

Site	Percentage compliance			Composite index*
	Faecal coliforms	Algae	Oily films	
Menangle Bridge [A]	98 (122)	100 (113)	100 (122)	98
Bents Basin [B]	99 (122)	100 (113)	98 (122)	98
Tench Reserve [C]	99 (122)	100 (113)	87 (122)	85
Jellybean Pool [D]	99 (122)	100 (113)	99 (122)	99
Yarramundi Bridge [E]	96 (122)	100 (113)	92 (122)	89
Macquarie Park [F]	84 (122)	99 (104)	94 (122)	80
South Creek [G]	91 (122)	99 (104)	81 (122)	69
Cattai National Park [H]	100 (122)	94 (103)	99 (122)	93
Sackville ferry [I]	100 (71)	93 (61)	100 (71)	95
Lower Portland [J]	100 (122)	71 (104)	100 (122)	71
Wisemans Ferry [K]	100 (122)	96 (104)	100 (122)	97
One Tree Reach [L]	100 (122)	100 (104)	98 (122)	99
Berowra Creek [M]	99 (122)	100 (104)	88 (122)	88

* Composite index:

A composite index, which provides a single value as an overall assessment of the suitability of each site for either primary or secondary contact recreation, is provided in Appendix Tables D.1 to D.4. This index is intended to facilitate interpretation and understanding of an otherwise complex set of data. The index records the percentage of time that *all* measured parameters at the site complied with the relevant guidelines. For example, where the index for a site is 100, this means that *every* parameter complied with the guidelines on *every* sampling occasion, i.e. there was full compliance throughout the relevant period. Where, however, the index is 60, this means that on 40% of occasions at least one parameter did not comply with the relevant guidelines, i.e. there was full compliance only 60% of the time.

Table D.2
Percentage compliance against each index, including the composite index, at each site for **primary contact recreation**, April 1994 to March 1996 (the number of observations is in brackets)

Site	Percentage compliance						Composite index*
	Faecal coliforms	Algae	Clarity	pH	Temp.	Oily films	
A	90 (122)	100 (113)	29 (104)	100 (121)	70 (121)	100 (122)	26
B	94 (122)	100 (113)	38 (105)	100 (120)	66 (121)	98 (122)	37
C	87 (122)	100 (113)	35 (101)	99 (120)	73 (121)	87 (122)	32
D	91 (122)	100 (113)	73 (105)	100 (119)	61 (121)	99 (122)	41
E	88 (122)	100 (113)	NM	90 (119)	78 (121)	92 (122)	52
F	51 (122)	99 (104)	0 (105)	100 (117)	79 (121)	94 (122)	6
G	65 (122)	99 (104)	0 (105)	100 (118)	79 (121)	81 (122)	8
H	90 (122)	94 (103)	NM	94 (119)	76 (120)	99 (122)	54
I	96 (71)	93 (61)	NM	97 (69)	83 (70)	100 (71)	73
J	99 (122)	71 (104)	NM	99 (120)	77 (121)	100 (122)	55
K	99 (122)	96 (104)	NM	100 (120)	79 (120)	100 (122)	75
L	98 (122)	100 (104)	NM	100 (118)	79 (121)	98 (122)	76
M	96 (122)	100 (104)	NM	100 (119)	78 (122)	88 (122)	67

*See Table D.1 for information regarding the interpretation of the composite index values.

NM not measured

A Nepean River at Menangle Road Bridge
B Nepean River at Bents Basin State Recreation Area
C Nepean River at Tench Reserve ramp (Regentville)
D Glenbrook Creek at Jellybean Pool
E Nepean River at Yarramundi Bridge
F Hawkesbury River at Macquarie Park (Windsor)
G South Creek at Governor Phillip Park ramp (Windsor)
H Hawkesbury River at Cattai National Park
I Hawkesbury River at Sackville ferry
J Hawkesbury River at Lower Portland
K Hawkesbury River at Wisemans Ferry
L Hawkesbury River at One Tree Reach
M Berowra Creek at the ferry

Table D.3
Summer seasons 1994–95 and 1995–96
Percentage compliance against each index, including the composite index, at each site for **primary contact recreation** October 1994 to March 1995 and October 1995 to March 1996 (the number of observations is in brackets)

Site	Percentage compliance						Composite index*
	Faecal coliforms	Algae	Clarity	pH	Temp.	Oily films	
A	92 (61)	100 (61)	28 (60)	100 (61)	98 (61)	100 (61)	31
B	90 (61)	100 (61)	48 (58)	100 (61)	100 (61)	95 (61)	52
C	82 (61)	100 (61)	35 (55)	98 (61)	100 (61)	89 (61)	39
D	84 (61)	100 (61)	64 (59)	100 (60)	100 (61)	98 (61)	62
E	82 (61)	100 (61)	NM	83 (60)	100 (61)	97 (61)	67
F	30 (61)	100 (52)	0 (59)	100 (58)	100 (61)	89 (61)	0
G	49 (61)	100 (52)	0 (60)	100 (60)	100 (61)	74 (61)	2
H	84 (61)	92 (52)	NM	90 (59)	100 (60)	98 (61)	64
I	95 (41)	89 (35)	NM	97 (39)	100 (40)	100 (41)	85
J	98 (61)	85 (52)	NM	98 (60)	100 (60)	100 (61)	82
K	98 (61)	94 (52)	NM	100 (59)	100 (59)	100 (61)	93
L	97 (61)	100 (52)	NM	100 (58)	100 (60)	98 (61)	95
M	95 (61)	100 (52)	NM	100 (59)	100 (61)	87 (61)	82

*See Table D.1 for information regarding the interpretation of the composite index values.

NM not measured

A Nepean River at Menangle Road Bridge
B Nepean River at Bents Basin State Recreation Area
C Nepean River at Tench Reserve ramp (Regentville)
D Glenbrook Creek at Jellybean Pool
E Nepean River at Yarramundi Bridge
F Hawkesbury River at Macquarie Park (Windsor)
G South Creek at Governor Phillip Park ramp (Windsor)
H Hawkesbury River at Cattai National Park
I Hawkesbury River at Sackville ferry
J Hawkesbury River at Lower Portland
K Hawkesbury River at Wisemans Ferry
L Hawkesbury River at One Tree Reach
M Berowra Creek at the ferry

Table D.4
Winter seasons 1994 and 1995
Percentage compliance against each index, including the composite index, at each site for **primary contact recreation** April to September 1994 and April to September 1995 (the number of observations is in brackets)

Site	Percentage compliance						Composite index*
	Faecal coliforms	Algae	Clarity	pH	Temp.	Oily films	
A	87 (61)	100 (52)	30 (44)	100 (60)	42 (60)	100 (61)	20
B	97 (61)	100 (52)	26 (47)	100 (59)	32 (60)	100 (61)	21
C	92 (61)	100 (52)	35 (46)	100 (59)	45 (60)	84 (61)	25
D	97 (61)	100 (52)	85 (46)	100 (59)	22 (60)	100 (61)	20
E	93 (61)	100 (52)	NM	97 (59)	55 (60)	87 (61)	36
F	72 (61)	98 (52)	0 (42)	100 (59)	58 (60)	98 (61)	11
G	80 (61)	98 (52)	0 (45)	100 (58)	57 (60)	87 (61)	15
H	95 (61)	96 (51)	NM	97 (60)	52 (60)	100 (61)	44
I	97 (30)	100 (26)	NM	97 (30)	60 (30)	100 (30)	57
J	100 (61)	56 (52)	NM	100 (60)	54 (61)	100 (61)	28
K	100 (61)	98 (52)	NM	100 (61)	59 (61)	100 (61)	57
L	98 (61)	100 (52)	NM	100 (60)	59 (61)	98 (61)	56
M	97 (61)	100 (52)	NM	100 (60)	57 (61)	89 (61)	51

*See Table D.1 for information regarding the interpretation of the composite index values.

NM not measured

A Nepean River at Menangle Road Bridge
B Nepean River at Bents Basin State Recreation Area
C Nepean River at Tench Reserve ramp (Regentville)
D Glenbrook Creek at Jellybean Pool
E Nepean River at Yarramundi Bridge
F Hawkesbury River at Macquarie Park (Windsor)
G South Creek at Governor Phillip Park ramp (Windsor)
H Hawkesbury River at Cattai National Park
I Hawkesbury River at Sackville ferry
J Hawkesbury River at Lower Portland
K Hawkesbury River at Wisemans Ferry
L Hawkesbury River at One Tree Reach
M Berowra Creek at the ferry

APPENDIX E
SUMMARY PHYSICO-CHEMICAL AND FIELD DATA FROM EACH OF THE 13 SITES

Table E.1

Summary data: Nepean River at Menangle Road Bridge [A]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	120	131	446	716
Total Dissolved Solids (mg/L)	120	84	285	458
Temperature (°C)	121	9.1	19.0	26.8
pH	120	6.1	7.4	8.8
Turbidity (NTU)	116	0	2	280
Salinity (‰)	120	0.1	0.2	0.4
Horizontal Secchi Distance (m)	104	0.1	1.4	2.8

Table E.2

Summary data: Nepean River at Bents Basin State Recreation Area [B]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	119	139	574	830
Total Dissolved Solids (mg/L)	119	89	367	531
Temperature (°C)	121	9.0	18.7	27.1
pH	120	6.3	7.6	8.3
Turbidity (NTU)	114	0	3	125
Salinity (‰)	120	0.1	0.3	0.4
Horizontal Secchi Distance (m)	105	0.1	1.3	2.8

Table E.3

Summary data: Nepean River at Tench Reserve ramp (Regentville) [C]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	120	126	265	401
Total Dissolved Solids (mg/L)	120	81	170	257
Temperature (°C)	121	10.1	19.8	27.7
pH	120	6.4	7.6	9.3
Turbidity (NTU)	115	0	2	108
Salinity (‰)	120	0.1	0.1	0.2
Horizontal Secchi distance (m)	101	0.1	1.4	2.5

Table E.4

Summary data: Glenbrook Creek at Jellybean Pool [D]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	120	86	155	256
Total Dissolved Solids (mg/L)	120	55	99	164
Temperature (°C)	121	6.8	17.1	26.6
pH	119	5.0	5.6	7.5
Turbidity (NTU)	116	0	1	47
Salinity (‰)	120	0.0	0.1	0.1
Horizontal Secchi Distance (m)	105	0.2	2.0	4.3

Table E.5

Summary data: Nepean River at Yarramundi Bridge [E]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	120	68	323	454
Total Dissolved Solids (mg/L)	120	44	207	291
Temperature (°C)	121	10.5	21.4	28.2
pH	118	6.3	7.6	10.2
Turbidity (NTU)	113	0	3	79
Salinity (‰)	120	0.0	0.2	0.5

Table E.6

Summary data: Hawkesbury River at Macquarie Park (Windsor) [F]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	120	98	293	1146
Total Dissolved Solids (mg/L)	120	63	188	733
Temperature (°C)	121	11.7	21.0	28.5
pH	117	6.2	7.6	9.0
Turbidity (NTU)	110	3	15	147
Salinity (‰)	120	0.1	0.1	0.6
Horizontal Secchi Distance (m)	101	0.1	0.4	0.9

Table E.7

Summary data: South Creek at Governor Phillip Park ramp (Windsor) [G]
4 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	120	190	439	1146
Total Dissolved Solids (mg/L)	120	122	281	733
Temperature (°C)	121	10.2	20.6	28.0
pH	118	6.5	7.3	8.6
Turbidity (NTU)	109	0	22	508
Salinity (‰)	120	0.1	0.2	0.6
Horizontal Secchi Distance (m)	105	0.1	0.3	0.8

Table E.8

Summary data: Hawkesbury River at Cattai National Park [H]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	119	21	430	686
Total Dissolved Solids (mg/L)	119	13	275	439
Temperature (°C)	118	10.9	19.9	27.9
pH	119	6.6	7.7	9.4
Turbidity (NTU)	113	0	27.4	240
Salinity (‰)	119	0.0	0.2	0.4
Vertical Secchi depth (m)	88	0.1	0.5	1.2

Table E.9

Summary data: Hawkesbury River at Sackville ferry [I]
3 February 1995 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	69	10	349	556
Total Dissolved Solids (mg/L)	69	6	223	356
Temperature (°C)	69	11.1	21.0	26.5
pH	68	6.4	7.6	9.5
Turbidity (NTU)	64	0	28	207
Salinity (‰)	69	0.0	0.2	0.3
Vertical Secchi depth (m)	67	0.2	0.6	1.2

Table E.10

Summary data: Hawkesbury River at Lower Portland [J]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	120	13	422	10260
Total Dissolved Solids (mg/L)	120	8	270	6566
Temperature (°C)	119	11.2	20.0	27.4
pH	119	6.3	7.6	9.5
Turbidity (NTU)	109	0	15	86
Salinity (‰)	120	0.0	0.2	5.8
Vertical Secchi depth (m)	86	0.3	1.0	2.4

Table E.11

Summary data: Hawkesbury River at Wisemans Ferry [K]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	120	16	10040	28100
Total Dissolved Solids (mg/L)	120	10	6426	17984
Temperature (°C)	120	11.2	20.0	27.1
pH	120	6.3	7.4	8.5
Turbidity (NTU)	114	0	14	143
Salinity (‰)	120	0.0	5.7	17.3
Vertical Secchi depth (m)	86	0.2	1.0	4.0

Table E.12

Summary data: Hawkesbury River at One Tree Reach [L]
3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	119	34	20745	38100
Total Dissolved Solids (mg/L)	119	22	13277	24384
Temperature (°C)	121	11.5	19.9	27.0
pH	117	6.5	7.4	8.0
Turbidity (NTU)	113	0	11	248
Salinity (‰)	119	0.0	12.4	24.2
Vertical Secchi depth (m)	86	0.2	1.2	5.6

Table E.13

Summary data: Berowra Creek at the ferry [M]

3 April 1994 to 29 March 1996

(where total dissolved solids (mg/L) = electrical conductivity (µS/cm) x 0.64)

Parameter	Number of results	Minimum	Median	Maximum
Electrical Conductivity (µS/cm)	117	30	40209	50182
Total Dissolved Solids (mg/L)	117	19	25734	32116
Temperature (°C)	120	9.5	19.4	27.0
pH	117	6.7	7.6	8.2
Turbidity (NTU)	116	0	1	105
Salinity (‰)	118	0.5	25.7	33.0
Vertical Secchi depth (m)	55	0.2	2.0	3.9

APPENDIX F
REGRESSION ANALYSES RESULTS

Establishing the existence of relationships between the parameters measured during this study is important because, if strong relationships exist, it may be possible to use the independent variable to predict the dependent variable. For example, if there is a strong relationship between bacterial densities or turbidity and rainfall, it may be possible to predict bacterial density or turbidity based on the amount of rainfall.

Regression analyses of faecal bacterial levels against rainfall resulted in varying coefficients of determination. No strong relationships were seen to exist for rainfall and faecal coliforms at any site, with r^2 values ranging from 0.003 at One Tree Reach [L] to 0.546 at South Creek [G] (Table F.1). Coefficients of determination for rainfall and enterococcus densities were also relatively low, ranging from 0.003 (Menangle Bridge) to 0.539 (Berowra Creek).

There was a positive relationship between bacterial densities and turbidity at Menangle Bridge [A], Bents Basin [B], Glenbrook Creek [D], South Creek [G] and Berowra Creek [M]. No strong relationships were found at the remaining sites, with r^2 values ranging from 0.000 to 0.472 (Table F.2). This suggests that factors other than turbidity had the primary influence on faecal bacterial densities at these sites. High turbidity levels downstream of Windsor were often caused by the presence of algae in the water column and therefore were not correlated with runoff. Faecal bacterial levels were generally low at these sites which also makes strong relationships unlikely.

Regression analyses of turbidity on rainfall resulted in relatively low coefficients of determination, ranging from 0.002 at Sackville ferry [I] to 0.460 at South Creek [G] (Table F.3).

A positive relationship was found between the reciprocal of horizontal Secchi distance and turbidity at most sites, with r^2 values ranging from 0.504 (Macquarie Park) to 0.915 (Glenbrook Creek). No strong relationship was seen to exist at South Creek [G] (Table F.4).

Cattai NP [H], Sackville ferry [I], Lower Portland [J] and Wisemans Ferry [K] showed positive relationships between the reciprocal of

vertical Secchi depth and turbidity (Table F.5). One Tree Reach [L] and Berowra Creek [M], however, failed to show a strong relationship, with r^2 values of 0.420 and 0.338 respectively.

There were no strong relationships between turbidity and the variability in faecal bacterial densities of the QA/QC duplicate samples at any of the sites (Table F.6).

In general, regression analyses showed that:

- faecal bacterial levels increased with increasing turbidity at Menangle Bridge, Bents Basin, Glenbrook Creek, South Creek and Berowra Creek;
- there were no strong relationships between faecal bacterial densities and rainfall, or turbidity and rainfall, at any of the sites;
- there were no strong relationships between turbidity and the variability in faecal bacterial densities of the QA/QC duplicate samples at any of the sites.

Table F.1
Coefficients of determination (r^2) for linear regression of faecal bacterial densities on rainfall, where 'n' is the number of measurements

Site	r^2 for faecal coliforms (n)	r^2 for enterococci (n)
Nepean River at Menangle Road Bridge	0.008 (120)	0.003 (120)
Nepean River at Bents Basin State Recreation Area	0.246 (108)	0.195 (108)
Nepean River at Tench Reserve ramp	0.069 (118)	0.278 (118)
Glenbrook Creek at Jellybean Pool	0.278 (122)	0.247 (122)
Nepean River at Yarramundi Bridge	0.254 (122)	0.309 (122)
Hawkesbury River at Macquarie Park (Windsor)	0.014 (122)	0.013 (122)
South Creek at Governor Phillip Park (Windsor)	0.546 (122)	0.245 (122)
Hawkesbury River at Cattai National Park	0.257 (122)	0.264 (122)
Hawkesbury River at Sackville ferry	0.005 (71)	0.004 (71)
Hawkesbury River at Lower Portland	0.004 (122)	0.022 (122)
Hawkesbury River at Wisemans Ferry	0.004 (112)	0.028 (112)
Hawkesbury River at One Tree Reach	0.003 (112)	0.006 (112)
Berowra Creek at the ferry	0.485 (122)	0.539 (122

Table F.2
Coefficients of determination (r^2) for linear regression of faecal bacterial densities on turbidity, where 'n' is the number of measurements

Site	r^2 for faecal coliforms (n)	r^2 for enterococci (n)
Nepean River at Menangle Road Bridge	0.979 (116)	0.980 (116)
Nepean River at Bents Basin State Recreation Area	0.828 (114)	0.803 (114)
Nepean River at Tench Reserve ramp	0.017 (115)	0.083 (115)
Glenbrook Creek at Jellybean Pool	0.742 (116)	0.789 (116)
Nepean River at Yarramundi Bridge	0.026 (113)	0.028 (113)
Hawkesbury River at Macquarie Park (Windsor)	0.001 (110)	0.000 (110)
South Creek at Governor Phillip Park (Windsor)	0.621 (109)	0.593 (109)
Hawkesbury River at Cattai National Park	0.332 (113)	0.236 (113)
Hawkesbury River at Sackville ferry	0.433 (64)	0.472 (64)
Hawkesbury River at Lower Portland	0.244 (109)	0.191 (109)
Hawkesbury River at Wisemans Ferry	0.345 (114)	0.071 (114)
Hawkesbury River at One Tree Reach	0.045 (113)	0.076 (113)
Berowra Creek at the ferry	0.587 (116)	0.544 (116)

Table F.3
Coefficients of determination (r^2) for linear regression of turbidity on rainfall
(where n is the number of measurements)

Site	r^2 (n)
Nepean River at Menangle Road Bridge	0.006 (114)
Nepean River at Bents Basin State Recreation Area	0.206 (102)
Nepean River at Tench Reserve ramp	0.036 (111)
Glenbrook Creek at Jellybean Pool	0.315 (116)
Nepean River at Yarramundi Bridge	0.036 (113)
Hawkesbury River at Macquarie Park (Windsor)	0.047 (110)
South Creek at Governor Phillip Park (Windsor)	0.460 (109)
Hawkesbury River at Cattai NP	0.037 (113)
Hawkesbury River at Sackville ferry	0.002 (64)
Hawkesbury River at Lower Portland	0.004 (109)
Hawkesbury River at Wisemans Ferry	0.006 (104)
Hawkesbury River at One Tree Reach	0.007 (103)
Berowra Creek at the ferry	0.288 (116)

Table F.4
Coefficients of determination (r^2) for linear regression of (horizontal Secchi distance)$^{-1}$ on turbidity (where 'n' is the number of measurements)

Site	r^2 (n)
Nepean River at Menangle Road Bridge	0.884 (99)
Nepean River at Bents Basin State Recreation Area	0.700 (98)
Nepean River at Tench Reserve ramp	0.570 (96)
Glenbrook Creek at Jellybean Pool	0.915 (100)
Hawkesbury River at Macquarie Park (Windsor)	0.504 (93)
South Creek at Governor Phillip Park (Windsor)	0.315 (94)

Table F.5
Coefficients of determination (r^2) for linear regression of (vertical Secchi depth)$^{-1}$ on turbidity, (where 'n' is the number of measurements

Site	r^2(n)
Hawkesbury River at Cattai National Park	0.722 (80)
Hawkesbury River at Sackville ferry	0.663 (61)
Hawkesbury River at Lower Portland	0.618 (76)
Hawkesbury River at Wisemans Ferry	0.746 (78)
Hawkesbury River at One Tree Reach	0.420 (79)
Berowra Creek at the ferry	0.338 (52)

Table F.6
Coefficients of determination (r^2) for linear regression of relative difference between faecal bacterial densities for each pair of QA/QC duplicates on turbidity, where 'n' is the number of measurements

Site	r^2 for faecal coliforms (n)	r^2 for enterococci (n)
Nepean River at Menangle Road Bridge	0.048 (14)	0.063 (14)
Nepean River at Bents Basin State Recreation Area	0.008 (16)	0.004 (16)
Nepean River at Tench Reserve ramp	0.098 (16)	0.003 (16)
Glenbrook Creek at Jellybean Pool	0.001 (16)	0.000 (16)
Nepean River at Yarramundi Bridge	0.007 (15)	0.039 (15)
Hawkesbury River at Macquarie Park	0.005 (10)	0.484 (10)
South Creek at Governor Phillip Park	0.248 (16)	0.013 (16)
Hawkesbury River at Cattai National Park	0.009 (18)	0.006 (18)
Hawkesbury River at Sackville ferry	0.027 (9)	0.138 (9)
Hawkesbury River at Lower Portland	0.000 (21)	0.031 (21)
Hawkesbury River at Wisemans Ferry	0.160 (17)	0.004 (17)
Hawkesbury River at One Tree Reach	0.001 (20)	0.002 (20)
Berowra Creek at the ferry	0.082 (16)	0.091 (16)
All data combined	0.002 (206)	0.002 (206)