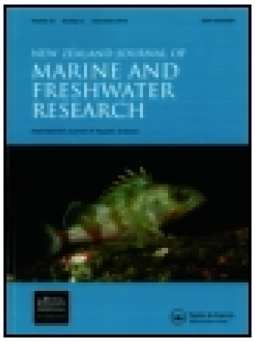

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Enterococcal numbers measured in waters of marine, lake, and river swimming sites of the Bay of Plenty, New Zealand

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Abstract In the Bay of Plenty, New Zealand, 32 coastal beach sites, 23 lake beach sites, and 31 river swimming hole sites were sampled for enterococci as indicators of bathing suitability over 3 summers (from 1991 to 1995). The median enterococcal numbers of 5 samples collected from each site over each season were compared to the guideline medians: 35 and 33 enterococci per 100 ml for marine and fresh waters, respectively. The "5-sample median" values generally agreed with longer-term medians (n = 24, 28) from river and estuary sites sampled between 1990 and 1994. During the summers of 1991 and 1993, high enterococcal numbers at marine and lake swimming sites were assumed to be derived primarily from sewage effluent and farm run-off, either directly or from freshwater inflows. Enterococcal numbers dropped significantly in these waters when effluents were either treated or removed from the waters. In 1995, all marine bathing waters complied with the guideline value of 35 enterococci per 100 ml. Evidence from long-term monitoring of estuary sites indicated that most marine bathing sites have high-quality bathing water with short-term variability caused by winds, tides, and outfall discharges. In 1995, all but one lake site complied with the freshwater median guideline of 33 enterococci per 100 ml. Most upstream river sites also complied with the freshwater guideline. However, river sites in the mid reaches and down stream recorded high enterococcal numbers which increased slightly at some sites from 1992 to 1995. The most significant increase in bacterial numbers was recorded in the small river and stream swimming holes which carry low volumes of water (< 1000 l s^{-1}), particularly in the western area of Lake Rotorua. The main source of enterococci in river waters was most likely run-off from dairy farms on the flood plains of the various rivers of the Bay of Plenty.

Keywords enterococci; bacteria; lake; river; marine; water; bathing suitability; Bay of Plenty; faecal streptococci; dairy farming

INTRODUCTION

Faecal material carries micro-organisms into the external environment. Most of these microbes are non-pathogenic but from time to time some are pathogenic. Most pathogens are difficult to detect because they are either absent from waters or present in low concentrations (Bonde 1977). Therefore, it is non-pathogenic micro-organisms that are generally measured:

1. as "indicators" of pathogens in faeces,
2. because of their relative ease of assay, and
3. because they parallel the survival of at least some pathogens (Burman et al. 1978; Cabelli 1978).

American epidemiological studies in the 1970s and 1980s showed that enterococcal numbers in bathing waters, contaminated by chlorinated effluents, often mimicked the survival of human-specific viruses (Cabelli et al. 1982, 1983). The USEPA (1986) marine recreational guidelines were derived from Cabelli et al. (1982) and have recently been criticised for pooling results from different environments (Fleisher 1991). Consequently many US states have not adopted the USEPA guidelines. However, more recent research has indicated that the faecal streptococci group (which contains

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enterococci) outlive faecal coliforms (Sinton et al. 1993). In a recent epidemiological survey of seven New Zealand marine swimming beaches, enterococcal numbers were also found more strongly associated with illness risk than faecal coliform numbers (Bandaranayake et al. 1995). In New Zealand, there are concerns about the applicability of United States-derived numerical criteria based on enterococci. In comparison to the United States, New Zealand has relatively few chlorinated effluents and a higher ratio of farm animals to humans. Consequently a high proportion of animal-derived faecal matter enters New Zealand rivers and lakes which may pose a different risk of disease to humans than human-derived faecal material (Calderon et al. 1991; McBride et al. 1992; Sinton & Donnison 1994).

In the Bay of Plenty, dairy shed effluents contain enterococcal numbers of the order of 10^5 per 100 ml (A. C. Bruere & J. Deely Environment BOP unpubl. report 96/9) and therefore the discharge of these effluents into rivers and streams indicate a threat to the bathing suitability and overall water quality. It is still uncertain whether or not enterococci or any other indicator bacteria derived from animal faecal material indicate potential health risk to humans. An epidemiological study on swimmers in a Connecticut pond receiving rural run-off found swimmer illness unrelated to high densities of common faecal indicator bacteria and high rainfall (Calderon et al. 1991). Swimmer illness was thought to be associated with high swimmer numbers per day and high densities of staphylococci. It was thought that illness was transmitted via swimmer-to-swimmer contact in the water.

McBride (1993) criticised the statistics used in the Connecticut study, stating that if a higher critical value had been used, then a relationship would have been found between animal-derived indicator bacteria and illness in the population. In support of McBride (1993), Bandaranayake et al. (1995) found no evidence of different illness risks between New Zealand marine beaches impacted by either rural or urban effluents.

The Resource Management Act (1991) has directed New Zealand's regional councils to monitor the state of the environment in their regions, as is necessary to carry out effectively their functions under the act. Environment BOP (Bay of Plenty Regional Council) initiated a Natural Environment Regional Monitoring Network (NERMN) in July 1990. The Water Quality Monitoring module of this network determines long-term trends in water quality by regular sampling at fixed sites. Triennial monitoring of bathing water suitability (using enterococci as the indicator bacteria) is a component of Water Quality Monitoring.

The present paper summarises the results of the first three monitoring occasions at a range of sites in 1992–95 (Fig. 1) and discusses regional concerns. The fuller data sets are available from Environment BOP in unpublished reports: F. Power 91/3; J. McIntosh 93/1, 93/33; K. Ruff & J. Deely 95/8.

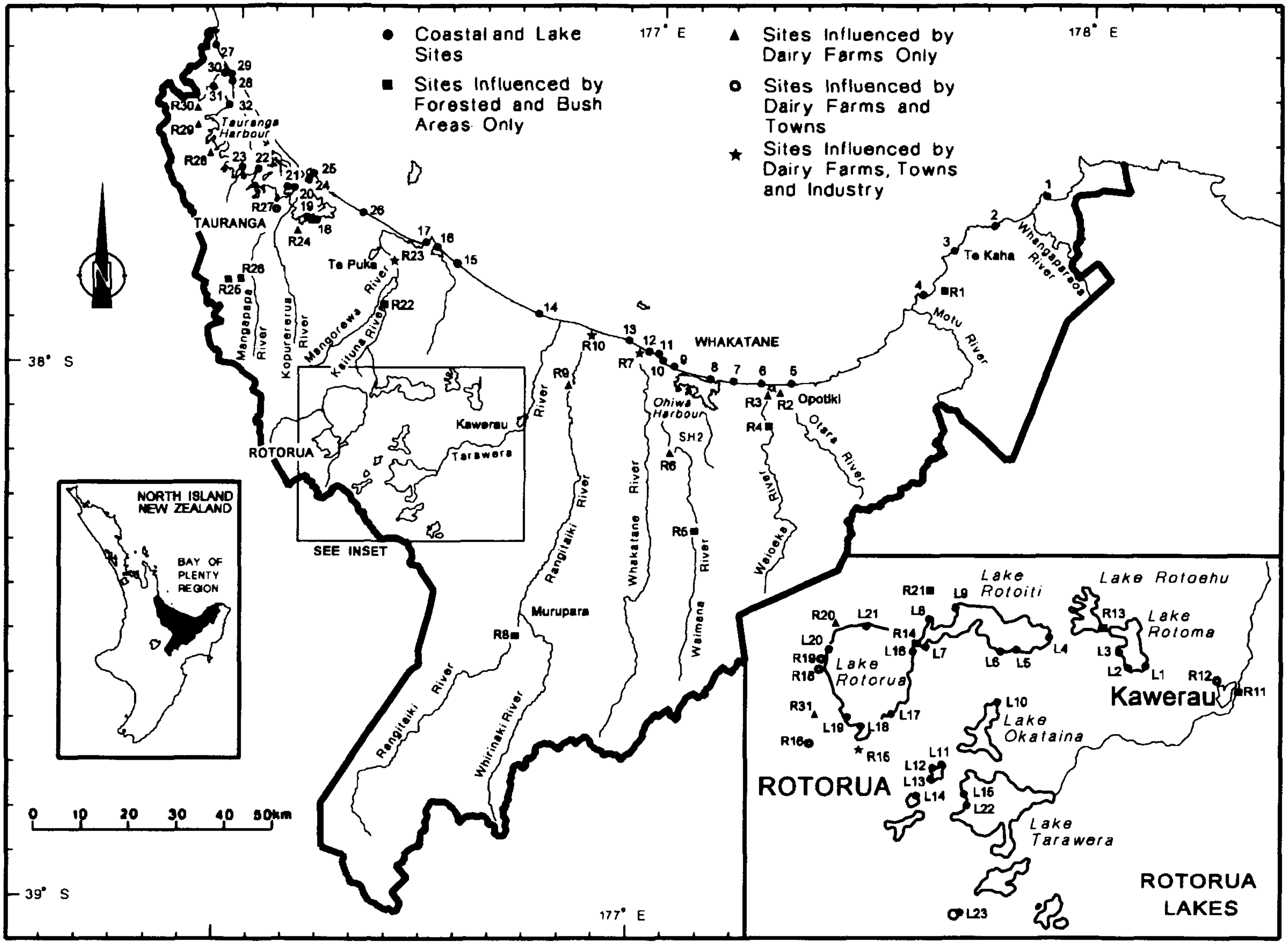
Bathing water suitability guidelines for enterococcal numbers

Before 1986, geometric mean counts of the faecal coliform group of bacteria were extensively used as indicators of faecal contamination of waters (Burman et al. 1978). From 1986, the United States Environmental Protection Agency (USEPA) has recommended using either enterococci for marine and fresh waters, or *Escherichia coli* for fresh waters only (USEPA 1986). In addition to the USEPA guidelines, faecal streptococci (which include enterococci) are included in the European Community Directive concerning bathing water quality (Anon 1976, 1994a, 1994b; Kay et al. 1994).

In 1992, the New Zealand Department of Health (DOH) set bathing suitability guidelines based on the USEPA criteria (McBride et al. 1992). However, the DOH guidelines use the median as a statistical measure of central tendency rather than the geometric mean. The compliance protocol states that the median of a minimum of five samples collected over the New Zealand "bathing season" (1 December to 1 March) should not equal or exceed 35 enterococci per 100 ml for marine waters or 33 enterococci per 100 ml for fresh waters. These guidelines were adopted in the present study.

The purpose of using a median value over the bathing season is to identify compliance in the long term. An appropriate upper limit for any one sample from a water body can be set using the relevant guideline. "Single-sample" limits provide an indication of the seriousness of any occasional elevations in enterococcal densities. Water quality criteria are breached if either the median or single-

Fig. 1 Map of the Bay of Plenty, New Zealand, showing sampling sites: for legends see Table 2 (marine sites), Table 3 (lake sites), and Table 4 (river sites).


● Coastal and Lake Sites
■ Sites Influenced by Forested and Bush Areas Only
▲ Sites Influenced by Dairy Farms Only
○ Sites Influenced by Dairy Farms and Towns
★ Sites Influenced by Dairy Farms, Towns and Industry
177° E
178° E
38° S
39° S
N
0 10 20 30 40 50km
NORTH ISLAND NEW ZEALAND
BAY OF PLENTY REGION
TAURANGA
Tauranga Harbour
Te Puke
ROTORUA
Kawerau
Tarawera
Murupara
WHAKATANE
Ohiwa Harbour
Opotiki
Te Kaha
SH2
SEE INSET
Mangapapa River
Kopurererua River
Mangorewa River
Kaituna River
Rangitaiki River
Whirinaki River
Whakatane River
Waimana River
Waioeka River
Otara River
Motu River
Whangaparaoa River
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R22 R23 R24 R25 R26 R27 R28 R29 R30
Lake Rotoiti
Lake Rotoehu
Lake Rotoma
Lake Rotorua
Lake Okataina
Lake Tarawera
ROTORUA
Kawerau
ROTORUA LAKES
L1 L2 L3 L4 L5 L6 L7 L8 L9 L10 L11 L12 L13 L14 L15 L16 L17 L18 L19 L20 L21 L22 L23
R11 R12 R13 R14 R15 R16 R18 R19 R20 R21 R31

sample limits are met or exceeded. Single-sample limits are set higher than medians in order to avoid unnecessary beach closures based on single instances of high bacterial numbers.

METHODS

Sample collection

In the Bay of Plenty, 32 coastal beach sites, 23 lake beach sites, and 31 river swimming hole sites (Fig. 1) were sampled on five occasions (during each of the first 3 months of 1992, 1993, and 1995) for enterococcal numbers as indicators of bathing suitability. The river sites are found in four catchment types. The southernmost sites were in the forested and bush catchment areas. Sites in the central plains area and zone west of Lake Rotorua are influenced by dairy farming. The lower catchments and areas adjacent to lakes and estuaries are influenced by run-off from dairy farms and towns. River sites near Whakatane, Rotorua, and Te Puke are influenced by a combination of dairy farms, towns, and industry. Sampling periods are listed in Table 1; the sampling regime complied with USEPA (1986) and DOH (McBride et al. 1992) protocols.

On each sampling occasion, either all coastal sites or all lake sites were visited in conjunction with some river swimming hole sites. All coastal sites were sampled within 1.5 h of high tide by wading out to either chest or waist depth (depending on the wave conditions). The river swimming hole samples were taken by wading out into the main flow of the river. As far as was possible, samples were taken during dry weather conditions when counts were not influenced by stormwater run-off. Therefore all counts should be indicative of the baseflow conditions in Bay of Plenty swimming waters.

Water samples were collected in 500 ml polyethylene bottles which had been sterilised by steaming in an autoclave at 121°C for 15 min. Care was taken to avoid touching the inside of each bottle or its cap.

Sample analysis

Samples were analysed in Environment BOP's laboratory using membrane filtration (APHA 1992). Depending on the dilution required, this involved filtering a 10, 30, 50, or 100 ml aliquot of each sample through a sterilised membrane filter. The filter was transferred using sterilised forceps to a previously prepared Petri dish containing solid agar (mE). After incubation at 41 ± 0.5°C for 48 ± 4 h, the filters were transferred to enterococcus agar EIA and incubated at 41 ± 0.5°C for 20 min. Subsequently, the colonies utilising esculin and forming a characteristic brown precipitate were counted (APHA 1992).

Statistical calculations on the data were undertaken using the SYSTAT computer program (Wilkinson et al. 1992). The computations included medians, box plots, Lillifors test for normality, and analyses of variance such as ANOVA and Kruskal-Wallis tests.

RESULTS

Marine beaches

The median enterococcal concentrations at the marine beach sites for each season are presented in Table 2. In 1991, bacterial numbers were below 35 enterococci per 100 ml for 28 of the 32 sites; in 1993, 26 of the 32 sites complied with the guideline; and in 1995, all sites recorded enterococcal numbers below the guideline value. In addition, on no occasion in 1995 did enterococcal numbers at any beach site exceed the single sample limit of 96 per 100 ml (K. Ruff & J. Deely, Environment BOP unpubl. report 95/8).

Lake beaches

Generally, lake sites showed excellent compliance with only two sites above or one site at the

Table 1 Periods over which sets of five enterococcal samples were collected from marine, lake and river swimming sites.

Year	Marine	Lake	River
1991	8–22 Jan	11 Jan–7 Feb	
1992			7 Jan–4 Feb
1993	12 Jan–12 Mar	18 Jan–19 Feb	12 Jan–12 Mar
1995	8 Feb–9 Mar	25 Jan–21 Mar	31 Jan–21 Mar

freshwater median guideline value of 33 enterococci per 100 ml (Table 3).

River and stream sites

The percentage of the 32 river sites that complied with the guideline each year dropped from 55% (18 sites) in 1992, to 39% (12 sites) in 1993, and 36% (11 sites) in 1995 (Table 4). Figure 2 shows the data in four groups relating to major influences on enterococcal numbers (refer to Fig. 1 for site locations). Eleven sites (Fig. 2A) are in the upper bush and forested catchment and other remote parts of the region. These sites contribute approximately one-third of the river swimming sites and had the lowest enterococcal numbers. Eight of these sites complied with the guideline of 33 enterococci per 100 ml in all three surveys.

Another third of the river swimming sites are in the mid reaches and influenced by run-off from dairy farming (Fig. 2B); 90% (9) of these exceeded the guideline. The number of enterococci counted at most sites increased from 1992 to 1995. The four sites with the highest enterococcal numbers in 1995 are all in the lower reaches of streams and rivers that drain agricultural areas.

All swimming sites in Fig. 2C exceeded the median guideline value in 1993 and 1995. These sites are located in streams either just upstream of or running alongside, small towns. As in Fig. 2B, the numbers of enterococci increased slightly from 1992 to 1995 at most sites, with the most significant increase recorded for the Ngongotaha Stream (R18). Enterococcal densities were in the same range as at sites influenced by dairy run-off.

Table 2 Median enterococcal numbers from marine beach sites (see Fig. 1).

			Enterococci per 100 ml		
Site	Beach	Description	1991	1993	1995
Median Bathing Suitability Guideline (marine waters) = 35					
1	Waihau Bay		22	**57**	3
2	Whanarua Bay		2	9	1
3	Maraetai Bay	Te Kaha Beach	18	7	5
4	Omaio Bay	Domain	2	3	2
5	Hikuwai Beach	End of Snell Road	5	6	<1
6	Waiotahi Beach	Surf Club	5	1	1
7	Waiotahi Beach	Estuary	23	8	3
8	Ohiwa Harbour	Boat Ramp at reserve	3	2	2
9	Ohope Beach	Motor Camp	21	26	3
10	Ohope Beach	Surf Club	**45**	**145**	11
11	Otarawairere Bay		**52**	**60**	1
12	Whakatane Heads	Oceanside of Boat Ramp	26	**64**	4
13	Piripai Beach	Ocean Beach	13	3	1
14	Kohioawa Beach	Murphy's Motor Camp	2	6	11
15	Pukehina Beach	Surf Club	4	3	<1
16	Little Waihi	Domain Boat Ramp	2	10	5
17	Maketu	Surf Club	4	5	<1
18	Maungatapu Reserve		7	4	<1
19	Waimapu Estuary	Motel-Motor Camp	17	16	7
20	Tilby Point	Reserve	**72**	24	<1
21	Otumoetai Beach	Reserve end of Beach	**39**	**48**	2
22	Omokoroa Beach		4	29	2
23	Pahoia	End of Beach	4	14	<1
24	Pilot Bay	Mid Beach	<1	4	<1
25	Mount Maunganui	Ocean Beach	4	1	1
26	Papamoa Beach	Surf Club	4	1	1
27	Waihi Beach	Surf Club	5	6	3
28	Anzac Bay	Bowentown Domain	13	4	1
29	Pio Ocean Beach	Pio Shores	10	2	<1
30	Athenree	Opposite Motor Camp	2	10	1
31	Tanners Point	Beach	2	25	3
32	Ongare Point	End of Ongare Point Road	2	**100**	3

Most sites in Fig. 2D are located near river outlets to lakes or the sea and are adjacent to small or larger towns. They could be affected by stormwater run-off containing enterococci derived from agricultural, industrial, and urban activities. For most sites, enterococcal numbers increased from 1992 through to 1995 as for sites in the mid reaches. Two sites showed a reduction in enterococcal numbers over the three surveys.

Reliability of the "5-sample median"

The median values calculated in this study were based on results obtained from analysing five samples from each site. The results were then used to derive an overview of the water quality at marine, lake, and river beach sites in the Bay of Plenty.

Long-term median values for enterococcal numbers in Bay of Plenty estuaries (from J. Deely & J. McIntosh, Environment BOP unpubl. report 94/23) are plotted in Fig. 3 as a check on the "5 sample medians" obtained from the marine bathing sites of this study. The box plots indicate that coastal estuary sites were "clean" from 1990 to July 1994, in agreement with data from the 1995 beach bathing survey. However, the outliers in Fig. 3 show that on rare occasions excessively high enterococcal numbers have been recorded. These results are similar to those found in the present study: see discussion below.

At marine swimming sites the reliability of the "5 sample median" may have been reduced by winds and tides during the three surveys.

The reliability of the medians calculated for nine river swimming sites were compared to medians calculated from longer-term water quality (NERMN) data collected from near the same sites during the period 1990 to 1994 (Fig. 4, from J. Deely & R. Donald, Environment BOP unpubl. report 95/7). The NERMN samples were collected every 2–3 months totalling 4–6 samples per year over the 5-year period ($n = 28$). Median values were not significantly different between the two data sets

Table 3 Median enterococcal numbers from lake beach sites (see Fig. 1).

Site	Lake	Description	Enterococci per 100 ml 1991	1993	1995
Median Bathing Suitability Guideline (freshwaters) = 33					
L1	Rotoma	Matahi Lagoon Road, Beach	2	1	<1
L2	Rotoma	Anaputa Point, Beach	7	<1	<1
L3	Rotoma	Whangaroa	4	1	3
L4	Rotoiti	Hinehopu, Jetty	5	4	<1
L5	Rotoiti	Gisborne Point	2	7	11
L6	Rotoiti	Ruato	4	2	2
L7	Rotoiti	Okawa Bay	4	3	2
L8	Rotoiti	Te Akau Point	2	1	1
L9	Rotoiti	Otaramarae	6	27	**33**
L10	Okataina	Beach	4	7	<1
L11	Okareka	SkiAqua-Millar Rd Reserve	<1	1	1
L12	Okareka	East end of dwellings	6	3	10
L13	Okareka	Jetty	4	15	13
L14	Tikitapu	Beach	2	2	<1
L15	Tarawera	Tarapatiki Point	4	28	6
L16	Rotorua	Mourea	1	2	8
L17	Rotorua	Holdens Bay	5	<1	23
L18	Rotorua	Motutara Point (Sulphur Point)	**230**	7	3
L19	Rotorua	Ohinemutu	21	7	17
L20	Rotorua	Ngongotaha	**38**	**54**	8
L21	Rotorua	Hamurana	9	**45**	16
L22	Tarawera	Rangiuru Bay			5
L23	Okaro	Ski Area			6

for the majority of sites. A similar result was obtained when comparing the means at each site using the Student's *t*-test. The comparison suggests that in river and lake bathing waters the "5 sample median" used in this study is usually representative of the long-term water quality of fresh water systems.

DISCUSSION

Marine beaches

The compliance of marine beaches with enterococcal guidelines improved from 81% in 1993 to 100% in 1995.

Some of the improvement in water quality was caused by more effective effluent treatment. For example, in 1991, Otumoetai foreshore (Site 21, Fig. 1) and Tilby Point (Site 20) bacterial numbers were predictably high (39 and 72 enterococci per 100 ml, respectively) owing to their proximity to the discharge point of Tauranga City's treated sewage effluent. The treated sewage effluent contained a median of 50 000 enterococci per 100 ml in August 1990 (F. Power, Environment BOP unpubl. report 90/2). Enterococcal numbers in the effluent dropped after May 1993, when ultra-violet radiation disinfection treatment began (S. Hodges & S. Park, Environment BOP unpubl. report 94/18). In February, March, April, and May 1995, Tauranga's disinfected wastewater contained median values of 15, 40, 30, and 10 enterococci per 100 ml respectively (unpubl. data, Environment BOP). Enterococcal numbers dropped accordingly at Tilby Point to < 1 per 100 ml and Otumoetai foreshore to 2 per 100 ml.

Compliance also improved at other sites where effluents were removed from receiving waters such

Table 4 Median enterococcal numbers from river swimming hole sites (see Fig. 1).

			Enterococci per 100 ml		
Site	River/stream	Description	1992	1993	1995
Median Bathing Suitability Guideline (freshwaters) = 33					
R1	Haparapara River	Omaio d/s SH35 Bridge	10	**39**	7
R2	Otara River	d/s SH35 Bridge	**60**	**44**	**93**
R3	Waioeka River	SH2 Bridge	**45**	**72**	**77**
R4	Waioeka River	bend near Waioeka Pa	17	1	7
R5	Tauranga River	Eight Acres	23	16	15
R6	Waimana River	Waimana Gorge Picnic Area	17	24	**120**
R7	Whakatane River	Landing Road Bridge	**61**	**43**	32
R8	Rangitaiki River	above Murupara raft exit	4	5	13
R9	Rangitaiki River	Edgecumbe	9	21	33
R10	Rangitaiki River	Thornton Domain	**72**	**72**	**41**
R11	Tarawera River	Boyce Park	11	17	17
R12	Ruruanga Stream	Cricket Pavillion	**46**	**52**	**70**
R13	Waitangi Springs	Lake Rotoehu	3	3	6
R14	Ohau Channel	SH 33 Bridge	1	3	4
R15	Puarenga Stream	Whakarewarewa	**107**	**110**	**210**
R16	Utuhina Stream	Pukehangi Road	31	**68**	**63**
R17	Utuhina Stream	Lake Road	**106**	**130**	**140**
R18	Ngongotaha Stream	Railway Bridge	**72**	**190**	**270**
R20	Awahou Stream	Glouster Road	19	**61**	**90**
R21	Kaituna River	Trout Pool Rd	6	**3**	2
R22	Kaituna River	Maungatangi Road	15	19	30
R23	Kaituna River	Te Matai Rail Bridge	19	**62**	**87**
R24	Waimapu River	SH 29 Bridge	**202**	**220**	**240**
R25	Ngamuwahine River	at Reserve	26	19	**43**
R26	Wairoa River	below McLaren Falls Dam	**38**	26	**40**
R27	Wairoa River	Bethlehem	24	**48**	**45**
R28	Te Rereatukahia Stream	at Pa	**90**	**96**	**120**
R29	Uretara Stream	Katikati	**130**	**130**	30
R30	Tuapiro Stream	McMillan Road	**98**	**67**	**93**
R31	Ngongotaha Stream	SG Site SH Road			190

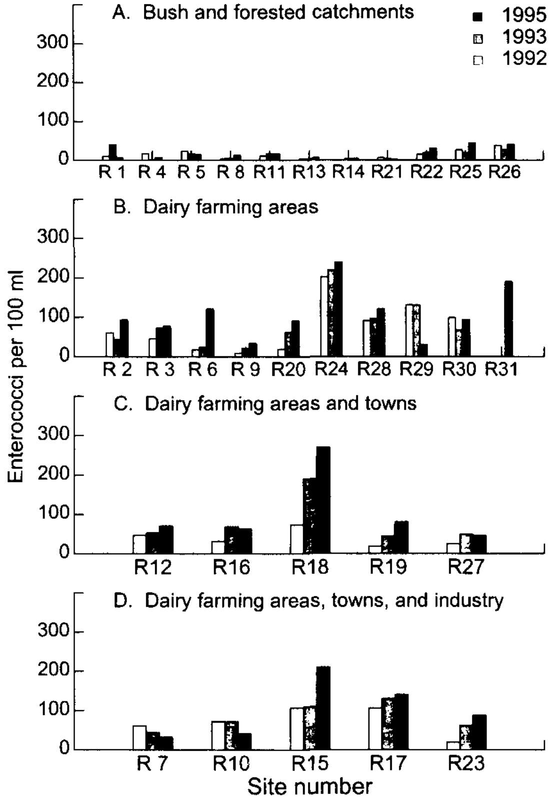


Fig. 2 Enterococcal numbers recorded at river swimming sites and grouped according to the major influences on the catchment areas immediately upstream of the sites (site number key in Table 4, location in Fig. 1).

as Ongare Point (Site 32). Bacterial numbers of 100 enterococci per 100 ml recorded here in 1993 probably originated from an upstream piggery effluent. After the piggery closed down in June 1993, enterococcal numbers dropped to 3 per 100 ml (Table 2). High enterococcal numbers recorded occasionally at Whakatane Heads (Site 12) and Waihau Bay (Site 1) were probably derived from intermittent discharges from diary sheds and to a lesser extent in Whakatane from industrial and urban discharges.

Sites such as Otarawairere Bay (Site 11) and Ohope Beach (Sites 9, 10) which recorded high enterococcal numbers in the first two surveys (60 and 145 enterococci per 100 ml in 1993, respectively) recorded 1 and 11 enterococci per 100 ml in 1995, respectively. Reasons for such a significant improvement could be

1. lower rainfall than in previous seasons;

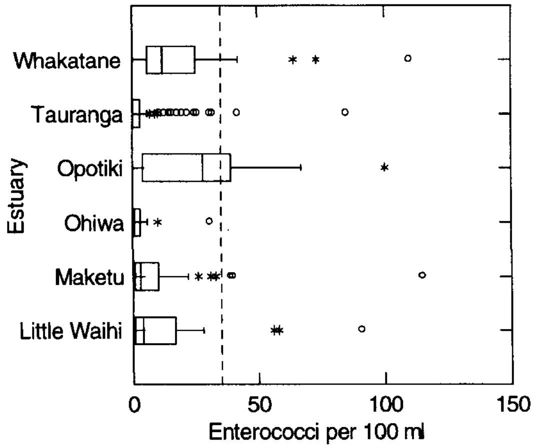


Fig. 3 Boxplots of enterococcal numbers from waters in Bay of Plenty estuaries and harbours from mid 1990 to mid 1994 (J. Deely and J. McIntosh, Environment BOP unpubl. report 94/23). The vertical dashed line indicates the median of 35 enterococci per 100 ml permitted for bathing in sea waters. Each box represents 50% of the data set with the dividing line indicating the median value ($n = 24$). The medians for Tauranga, Maketu, and Ohiwa estuaries include data from 8 ($n = 192$), 2 ($n = 16$), and 2 ($n = 16$) sites, respectively. The * and ° symbols represent outside values and extreme outside values, respectively.

2. the slightly later sampling period in 1995 compared to 1991 and 1993; and
3. overall good-quality waters in the Bay of Plenty.

Rainfall

Warmer weather during the 1994/95 summer with lower rainfall may have led to lower run-off in 1995 than in either 1991 or 1993 and hence lower enterococcal numbers entering coastal areas. However, the design of this study was focused on avoiding the effects of rainfall during sampling. As far as possible all sampling was undertaken during dry periods. Consequently, when enterococcal numbers were plotted against mean rainfall for 3 days before and including the day of sampling, no relationship was found for any site over the three sampling seasons. This finding was supported by the river enterococcal distributions which are discussed below.

Time of sampling

Bathing and increased human activity close to beaches during holiday periods may be a source of

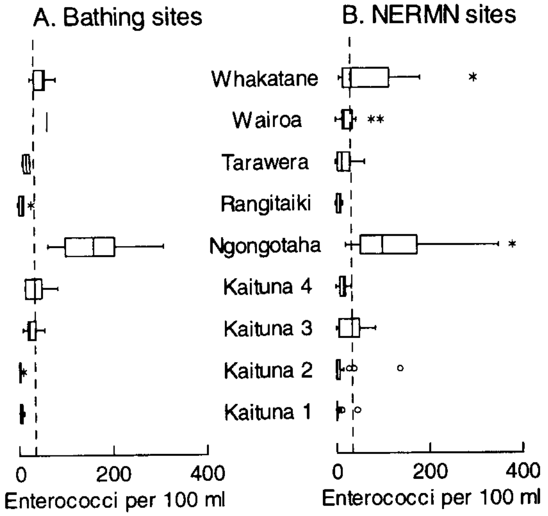


Fig. 4 Boxplots (cf. Fig. 3) comparing median enterococcal numbers at nine river swimming hole sites of this study (Bathing) with medians of Natural Environmental Regional Monitoring Network (NERMN) data from sites close to the bathing sites. The bathing medians are from data collected in the 1992, 1993, and 1995 surveys (Table 1). The NERMN medians are from data collected bimonthly from 1990 to 1994 (n = 28) (J. Deely and R. Donald, Environment BOP unpubl. report 95/7). Kaituna 1 is at Okere Falls, Kaituna 2 at Ohau Channel, Kaituna 3 at Paengaroa, and Kaituna 4 at Te Matai.

enterococci to bathing beaches. In 1995, sampling started a month later than in the previous two surveys, after the holiday period. Consequently, lower bathing populations may have contributed to the reduced enterococcal numbers in 1995. This situation could be expected for sites along Ohope Beach where large numbers of people bath. From 26 December to early February, the population of Whakatane and Ohope (normally 16 000 combined) swells by 70–80% with holiday makers, most of whom are resident in Ohope (Tony Kirby, Whakatane Public Relations, pers. comm.). After the school holidays, the population drops back almost to normal in early February.

However, data from a bathing survey at Ohope Beach in early 1995 suggest that changes in the size of the bathing population did not impact on enterococcal numbers. From 2 January to 19 February 1995, 65 composite water samples were taken at Ohope Beach from the Surf Club (Site 10) to the Holiday Park (Site 9) as part of a national epidemiological survey (Bandaranayake et al. 1995). The median enterococcal density of these samples was 12 per 100 ml, near-identical to 11 per 100 ml recorded in this study during February and March 1995. Only on two occasions did values exceed the single sample limit of 96 per 100 ml. The low enterococcal counts for Ohope indicate that bacterial numbers were low throughout January and February and that for this site (in 1995) there was no relationship between enterococcal numbers, period of sampling, and numbers of bathers and holiday makers.

Long-term marine water quality

A summary of water quality in Bay of Plenty estuaries from Waihi to Opotiki from August 1990 to July 1994 is presented in Fig. 3 (J. Deely & J. McIntosh, Environment BOP unpubl. report 94/23). The long-term median values (n = 24) of most estuaries are below the guideline value of 35 enterococci per 100 ml. The estuary median data suggest that the low enterococcal numbers recorded in beach bathing waters in 1995 are representative of long-term good-quality marine bathing waters in the Bay of Plenty region. Higher median values reported for some sites in 1991 and 1993 probably represent short-term fluctuations in enterococcal numbers but in the long-term, bathing waters comply. High-quality marine bathing waters may be a national phenomenon (Bandaranayake et al. 1995).

Diurnal variation in enterococcal numbers at marine swimming sites

In a 1995 survey (Environment BOP unpubl. data) of the effect of Mt Maunganui Outfall on waters close to the shore between Papamoa and Omanu (Tauranga), enterococcal numbers varied markedly within several hours depending on the wind direction. During calm conditions bacterial numbers were either low or nil, but, when the winds moved to south-easterly and easterly, bacterial numbers rose to 100s and 1000s at some sites (Environment BOP unpubl. data). Similar patterns were noted for other Tauranga Harbour beach sites. Where beaches were protected from prevailing onshore winds by landforms such as spits, bacterial numbers remained low regardless of wind direction. In the 1995 epidemiological survey of New Zealand marine swimming waters, Bandaranayake et al. (1995) also noted diurnal variability in enterococcal densities, with the highest enterococcal counts recorded either in mornings and/or in shallow waters (approximately knee depth).

The above findings indicate that enterococcal numbers are variable at marine bathing sites and may not comply for several hours on a particular day if any or a combination of the following conditions prevail

1. onshore winds;
2. incoming tide; and
3. nearby outfalls discharging.

Lake beaches

A large proportion of the inflowing water to the Bay of Plenty lakes is filtered through porous volcanic material, which may explain why lake water enterococcal counts were generally below the guideline value of 33 per 100 ml. Lake Rotorua is the only lake to receive significant inflows, although many of these inflow streams have riparian margins.

In 1991, median enterococcal numbers at Ngongotaha (Site L20: 38 per 100 ml) and Motutara Point (Site L18: 230 per 100 ml) of Lake Rotorua exceeded the guideline value. Motutara also exceeded the single sample limit of 101 enterococci per 100 ml occasionally with values greater than 800 per 100 ml. These high numbers were probably influenced by the nearby discharge of Rotorua's treated sewage effluent, which had a geometric mean of 3500 enterococci per 100 ml (F. Power, Environment BOP unpubl. report 91/ 3). In 1993, the dramatic reduction of enterococci numbers to 7 per 100 ml, at Motutara Point, was probably caused by the removal of the treated sewage effluent to land disposal in Whakarewarewa Forest.

The occasionally high enterococcal numbers at some lake sites (such as Ngongotaha in 1991 and 1993 and Hamurana (Site L21) in 1993 of Lake Rotorua) may have originated from intermittent run-off from farms.

In 1995, enterococcal densities were low, with only Lake Rotoiti at Otaramarae (Site 9) equalling the guideline value of 33 per 100 ml. However, as the number of rural subdivisions is increasing in the Rotorua lakes area (N. John, Environment BOP pers. comm.), future single sample exceedences at various sites around Lake Rotorua may relate to septic tank seepage.

River sites

Catchment type

The three groups of river sites affected by dairy farming, towns, and industry all contain enterococcal numbers in the range 50–250 per 100 ml (Fig. 1 and Fig. 2B-D). Dairy farms are the most likely source of high enterococcal numbers. There is no indication that either urban or industrial run-off are significant sources of enterococci at any particular site.

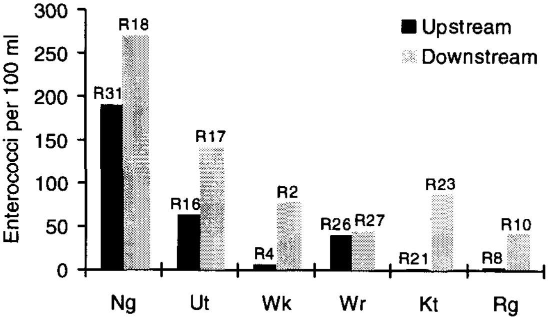


Fig. 5 Enterococcal numbers recorded at upstream and downstream sites on the same rivers in 1995. The rivers are ranked in order from smallest to largest flow: Ng, Ngongotaha (1700 l s^{-1}); Ut, Utuhina (2000 l s^{-1}); Wk, Waioeka (32 000 l s^{-1}); Wr, Wairoa (36 000 l s^{-1}); Kt, Kaituna (39 000 l s^{-1}); Rg, Rangitaiki (71 000 l s^{-1}).

Influence of river size/flow

Figure 5 suggests an inverse relationship between river size/flow and increase in enterococcal numbers between upstream and downstream sites in rivers flowing through intensive dairying catchments. In small streams such as Ngongotaha and Utuhina (< 2000 l s^{-1}), the impact of agricultural run-off on enterococcal numbers is greater than in large-volume rivers such as the Rangitaiki (> 50 000 l s^{-1}). This probably relates to dilution which would be greater in the larger rivers. Consequently, the most significantly impacted swimming sites are in small streams and rivers with agricultural and dairying activity in their catchments.

The percentage of river sites that complied each year dropped from 55% in 1992 to 39% in 1993 and 36% in 1995. There was insignificant variability in temperature at each site between seasons. An examination of flow variability revealed that almost all sites had slightly lower relative flows in 1995 than in 1992. However, the differences in flow were significant only for rivers with lower flows. For streams such as Tuapiro and Waimapu (< 1000 l s^{-1}), when the flows increased the number of enterococci also increased noticeably but dropped rapidly as the flows returned to normal. Higher enterococcal numbers during rising flows were probably derived from land surfaces during periods of rainfall. For large rivers such as Whakatane and Rangitaiki (> 20 000 l s^{-1}), there appeared to be no significant relationship between flow and enterococcal numbers in the waters. Presumably, increases in enterococcal numbers would be diluted to insignificance in the large volumes of water in these two rivers.

Trends in enterococcal numbers from 1992 to 1995

The river data were tested for normality using the Lillifors test and an analysis of variance was performed on the data using ANOVA (normally distributed data) and Kruskal-Wallis (non-parametric data). Of the 31 river sites studied, 11 showed significant variability between the three seasons. Table 5 lists these sites indicating whether or not enterococcal numbers increased or decreased over the three surveys. Three sites showed a significant drop in enterococcal numbers from 1992 to 1995: of these both Haparapara (Site R1) and Tauranga (Site R5) rivers are in forested catchments and had median enterococcal levels below the guideline value of 33 per 100 ml. The Uretara Stream (Site R29) is in an area where effluent disposal is slowly being diverted from water to land and this stream also had enterococcal densities below the guideline value in 1995. Of the eight sites that significantly increased in enterococcal numbers from 1992 to 1995, six sites were in the western catchment area of Lake Rotorua. All sites that displayed increased enterococcal numbers were affected by agricultural run-off, particularly dairy effluents.

Rotorua's treated sewage effluent ceased to influence Motutara Point (Site L18) when it was diverted to spray irrigation in Whakarewarewa Forest in November 1991. Leaching from the spray site may account for the high enterococcal numbers in Puarenga Stream (Site R15). Whether or not the increase in median enterococcal numbers, from 110 to 210 per 100 ml from 1993 to 1995, is related to the effluent spraying is to be determined by ongoing compliance monitoring.

Table 5 List of river sites whose enterococcal numbers changed significantly between 1992 and 1995 (see Fig. 1). Significance: *, $P < 0.05$; ** $P < 0.01$ (ANOVA, except R6 and R9: Kruskal Wallis); Trend: +, increase and -, decrease in enterococcal numbers.

Site	River	Significance	Trend
R1	Haparapara	*	–
R5	Tauranga	*	–
R6	Waimana	*	+
R9	Rangitaiki	*	+
R12	Ruruanga	*	+
R15	Puarenga	**	+
R18	Ngongotaha	*	+
R19	Waiteti	*	+
R16	Utuhina	*	+
R20	Awahou	**	+
R29	Uretara	**	–

Although the Rangitaiki River at Edgecumbe (Site R9) is influenced by an upstream dairy catchment, which may be responsible for the increasing enterococcal numbers at this site, the median value in 1995 was just on the guideline value. In contrast, the median value at the Waimana River bathing site (Site R6) rose from 24 in 1993 to 120 per 100 ml in 1995. More intensive dairy farming in the upstream catchment may explain this trend.

Recent work has yielded enterococcal numbers as high as 500 per 100 ml in leaf litter adjacent to streams in New Zealand (G. D. Lewis, Environmental Science Department, University of Auckland, pers. comm.). Such non-faecal sources may cause fluctuations in enterococcal distributions in sites in upstream bush and forested catchments, but are less likely to have a significant effect on downstream impacted sites.

Origin of enterococci in catchment areas west of Lake Rotorua

Widespread sections of the western catchment areas adjacent to Lake Rotorua are used for dairy farming. In recent years, land use in this area has changed from dry stock lamb and beef farming to dairy farming, with a corresponding increase in cattle numbers and reduction in sheep numbers. (N. Johns and W. Esler, Environment BOP, Rotorua, pers. comm.). Although most of the dairy effluents have been discharged onto land since 1991 and the margins of many streams have been retired from grazing for several years, the growing cattle numbers have resulted in erosion and loss of top soils surrounding small tributaries in the area. Most of the riparian retirement is on steep slopes and is effective for soil conservation but less effective in protecting water quality. Thus dairy farms are probably the main source of enterococci to the streams of this area.

Our ongoing study of enterococci in the Ngongotaha, Waiteti, and Awahou Streams has not yet identified all the specific sources of high enterococcal numbers in this area. The 1995 results indicated that alternative sewage dispersal methods were required at an agricultural tourist farm (W. Esler, Environment BOP pers. comm.). Owing to the subdivision of the Ngongotaha catchment into "lifestyle blocks", the number of land owners has increased from 24 to 40 in the area in the last few years (N. Ngapo, Environment BOP, pers. comm.). Therefore, another source of the increasing enterococcal numbers in swimming holes of this area could be seepage from septic tanks.

MANAGEMENT OPTIONS

Bacterial contamination of river waters on the regional scale identified in the Bay of Plenty is probably common to dairying areas elsewhere. Environment BOP is reducing the amount of agricultural discharge to rivers through its consenting and compliance process. Policy guidelines have been prepared for Whakatane, Ohiwa, Opotiki, Eastern Tarawera/Rangitaiki, and Tauranga to progressively remove agricultural effluents from surface water disposal to land disposal over the next few years (R. B. Gardner Environment BOP, unpubl. agenda reports); a similar approach is being followed for Rotorua, Kaituna, and Pongakawa districts. If land disposal fails to produce a significant reduction in bacterial numbers and nutrient concentrations in the rivers, then more extensive riparian management may be required. Lake Rotorua inflows at Ngongotaha and Waiteti already have riparian strips retired from grazing.

Over the next 5 years, enterococcal numbers are expected to drop in the rivers as a consequence of the proposed management strategy. Riparian strip management of the smaller streams may also reduce the impact of stock drinking on water quality. With most rivers discharging into lakes and coastal waters, these measures are also expected to reduce enterococcal numbers down stream.

CONCLUSION

The three surveys showed that most marine, lake, and upstream river swimming sites comply with the median guidelines of 35 and 33 enterococci per 100 ml for marine and fresh waters, respectively, recommended by McBride et al. (1992). Owing to the exposed nature of most marine sites, there was considerably more short-term variability in enterococcal numbers at these sites than either lake or river sites. In the mid reaches of most rivers, high enterococcal numbers were found in the bathing waters. These bacteria were thought to be derived from agricultural run-off, primarily dairy farming. The highest enterococcal numbers were observed in small rivers and streams. Urban and industrial run-off are apparently insignificant sources of enterococci to Bay of Plenty rivers.

The results of this study suggest that the water quality of bathing beaches is generally good in the Bay of Plenty. However, at river swimming sites that have low volumes and/or low flows and which receive animal faecal input from farming operations, the quality may not always be satisfactory. Different management options such as land disposal of farm wastes and planting of riparian strips along small rivers and streams may help to improve water quality at these sites.

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REFERENCES

(Copies of unpublished reports are available from Environment BOP.)

Anon 1976: Council Directive of 8 December 1975 concerning the quality of bathing waters. *Official journal of the European communities, L 31, 5 Feb 1976*: 1–7.

Anon 1994a: *Proposal for a Council Directive concerning the quality of bathing water.* COM (94) 36 Final Brussels, 16 Feb 1994. 44 p.

Anon 1994b: Proposal for a Council Directive concerning quality of bathing water. *Official journal of the European communities, C 112, 22 Apr 1994*: 3–10.

APHA 1992: Standard methods for the examination of water and wastewater, 18th edition. American Public Health Association, American Water Works Association, Water Environment Federation. 949 p.

Bandaranayake, D.; Salmond, C.; Turner, S. J.; McBride, G. B.; Lewis G. D.; Till, D. G. 1995: Health effects of bathing at selected New Zealand marine beaches. Ministry for the Environment report. 98 p.

Bonde, G. J. 1977: Bacterial indication of water pollution. *Advances in aquatic microbiology 1*: 275–364.

Burman, N. P.; Stevens, J. K.; Evans, A. W. 1978: Streptococci as indicators in water supplies. *In*: Skinner, F. A. *ed*. Streptococci. Society for Applied Bacteriology. *Academic Press Symposium series 7*: 335–347.

Cabelli, V. J. 1978: New standards for enteric bacteria. *In*: Mitchell, R. *ed*. Water pollution microbiology 2, pp. 233–271. John Wiley, New York.

Cabelli, V. J.; Dufour, A. P.; McCabe, L. J.; Levin, M. A. 1982: Swimming-associated gastroenteritis and water quality. *American journal of epidemiology 115*: 606–616.

Cabelli, V. J.; Dufour, A. P.; McCabe, L. J.; Levin, M. A. 1983: A marine recreational water quality criterion consistent with indicator concepts and risk analysis. *Journal the of Water Pollution Control Federation 55*: 1306–1324.

Calderon, R. L.; Mood, E. W.; Dufour, A. P. 1991: Health effects of swimmers and nonpoint sources of contaminated water. *International journal of environmental health research 1*: 21–31.

Fleisher, J. M. 1991: A re-analysis of data supporting the US Federal bacteriological water quality criteria governing marine recreational waters. *Journal of the Water Pollution Control Federation 63*: 259–264.

Kay, D.; Fleisher, J. M.; Salmon, R. L.; Jones, F.; Wyer, M. D.; Godfree, A. F.; Zelenauch-Jacquotte, Z.; Shore, R. 1994: Predicting the likelihood of gastroenteritis from sea bathing: results from a randomised exposure. *The lancet 344*: 905–909.

McBride, G. B.; Cooper, A. B.; Till, D. G. 1992: Provisional microbiological water quality guidelines for recreational and shellfish-gathering waters in New Zealand. Public Health Services, New Zealand Department of Health, January 1992, 17 p.

McBride, G. B. 1993: Discussion of Health effects of swimmers and nonpoint sources of contaminated water, by Calderon, R. L.; Mood, E. W.; Dufour, A. P. 1991. *International journal of environmental health research 3*: 115–116.

Sinton, L. W.; Donnison, A. M. 1994: Characterisation of faecal streptococci from some New Zealand effluents and receiving waters. *New Zealand journal of marine and freshwater research 28*: 145–158.

Sinton, L. W.; Donnison, A. M.; Hastie, C. M. 1993: Faecal streptococci as faecal pollution indicators: a review. Part 11: Sanitary significance. *New Zealand journal of marine and freshwater research 27*: 117–137.

USEPA 1986: Ambient Water Quality Criteria for Bacteria–1986: USEPA Report No. EPA440/5–84–002. United States Environmental Protection Agency, Washington, DC.

Wilkinson, L.; Hill, M.; Miceli, S.; Birkenbeuel, G.; Vang, E. 1992: *SYSTAT for windows: graphics, version 5 edition*. Evanston, IL: SYSTAT, Inc., 1992. 636 pp.