Faecal coliform densities and water quality criteria in three coastal recreational lakes in the SW Cape, South Africa

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Abstract

The risk of contracting swimming-associated diseases in surface waters is currently poorly defined in the absence of epidemiological data. Site-specific and population factors, such as immunity or resistance to pathogens, complicate the universal application of a particular guideline to different lakes utilised for aquatic recreation. Data sets, covering 8 to 10 years of faecal coliform densities in 3 anthropogenically-impacted lakes in South Africa, are presented. Other hindrances to contact recreation such as dense phytoplankton populations or submerged macrophyte growth are not considered. Application of the European Community (EC) and South African National Committee for Oceanographic Research (SANCOR) bathing water criteria on an annual (non-seasonal) basis resulted in non- to marginal compliance in respect of contact recreation, despite considerable natural attenuation of faecal coliform numbers. The results show that it may be practically feasible to apply the existing criteria on a seasonal basis. All three lakes complied during the summer with a general contact faecal coliform density of 1 000 faecal coliforms per 100 mℓ.

Introduction

Ensuring that the microbiological quality of natural waters does not present a risk to human health is a priority for those responsible for the management of freshwater, estuarine or marine recreational water bodies. Surface waters, especially those within or near developed urban areas, frequently serve as conduits or sinks which receive varying amounts of treated sewage, occasional sewer overflows, storm water, industrial effluent and agricultural waste and runoff (Jones and Godfree, 1989). Swimmers in polluted water are exposed to significantly higher risks of contracting swimming-associated ear, eye, skin and gastro-intestinal illness (Stevenson, 1953; Cheung et al., 1991) than would be the case for non-swimmers or swimmers in unpolluted waters.

A variety of bathing water criteria exist, many with limits arbitrarily assigned and/or empirically derived in the absence of epidemiological studies (Brenniman et al., 1981). The historical development of bathing water criteria is reviewed by Salas (1986) and Lightfoot (1989). The universal application of bathing water criteria is precluded by local (site-specific) differences in immunity or resistance to pathogens, age composition of the user group, underlying pathogen density, transient visitor (tourist) populations, factors enhancing or prolonging microbial die-off, the presence of elevated numbers of bacteria in lake sediments, and varying types of recreational activity, each having different degrees of water contact and possibilities of water ingestion. This complexity of factors, which confounds the quantification of swimming-related disease, has been postulated as a case against the development of microbial criteria for bathing waters (Moore, 1975). With regard to the hazards to be encountered while swimming, Lacey and Pike (1989) concluded that " although there is a genuine need for guidance on issues involving recreational risks, there is no satisfactory approach to providing it. The measurement and prediction of such risks are technically difficult, and the evaluation of detriment is controversial". It is, however, arguably more beneficial to have even an arbitrary measure of health risk than none at all.

The presence of pathogens in bathing waters constitutes the greatest cause for concern, and the existing criteria incorporate safety margins. There is conflicting evidence regarding the numbers of micro-organisms in water necessary for swimmers to contract illness. According to Crockett et al., 1989, "there is little or no evidence of swimmers contracting illness from water containing less than several thousand *E.coli* per 100 mℓ, although caution should be exercised as documented evidence is scarce." Also, the presence of a pathogenic micro-organism in sewage indicates that the corresponding disease is already circulating in the population (Moore, 1975). A recent study by Lightfoot (1989), conducted at 6 Canadian freshwater beaches, found that there was no evidence to suggest that bacterial count contributed to the prediction of illness in swimmers.

Contrary to these views are the findings of Cabelli et al. (1982 and 1983) which indicate that bathers are at risk in marine waters having as few as 10 enterococci or *E.coli* per 100 mℓ (Vasconcelos and Anthony, 1985; Holmes, 1989; CMNH, 1990). The presence of *E.coli* has been shown to be highly correlated with swimming-related illness in freshwater (Dufour, 1984; USEPA, 1986) and is generally regarded as the most specific indicator of contamination with the faecal wastes of warm blooded animals (Cabelli et al., 1982). A review of research findings where statistically significant excess rates of disease have been reported in the bather group (e.g. Cabelli, 1982), has shown these to be based on poor statistical correlations (Jones et al., 1991). Methodological problems which have complicated epidemiological studies may be more satisfactorily addressed by the use of specifically directed cohort studies (Lacey and Pike, 1989; Jones et al., 1991). The methodological and analytical issues pertaining to the setting of recreational criteria have been stipulated by Fleisher (1992).

Bathing water criteria are generally expressed as an allowable average concentration and a maximum value which is not to be exceeded for more than a given per cent of the time. The maximum acceptable bacterial density for a single sample is set higher than for the mean in order to avoid unnecessary beach closings based on single samples. The simple adaptation of a particular set of criteria is considered to be inappropriate in the absence of a thorough review of local circumstances and

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TABLE 1
COMPARISON OF AVAILABLE BATHING WATER CRITERIA. ALL COUNTS REFER TO FAECAL COLIFORMS UNLESS OTHERWISE STATED

1. Australia [ANHMRC, 1987]

Primary contact:	Median not to exceed 150/100 mℓ in a minimum of 5 samples taken at intervals of no less than one month. 4/5 samples to be < 600/100 mℓ
Secondary contact:	Median not to exceed 1 000/100 mℓ in a minimum of 5 samples taken at intervals of no less than one month. 4/5 samples to be < 4 000/100 mℓ

2. Canadian [CMNH, 1990]

Geometric (log) mean of at least 5 samples per month should not exceed 200 *E. coli*/100 mℓ. Resampling compulsory if count exceeds 400 *E.coli*/100 mℓ.

3. European Community [EEC, 1976]

Guideline 'G' value (80 percentile) not to exceed 100/100 mℓ.

Mandatory 'I' value (90 percentile) not to exceed 2 000/100 mℓ.

(Standards applicable in individual EC member states are listed in [NRA 1991a; b]

4. Hong Kong [Cheung et al., 1991] – proposed 14-d grading system

Grade	Risk/1 000	Seasonal log mean *E. coli*/100 mℓ	Comment
A	0	24	Good
B	10	180	Acceptable
C	15	610	Barely acceptable
D	>15	>610	Unacceptable

5. South African coastal zone [Lusher, 1984]

Direct contact (swimming, diving, windsurfing)

Maximum acceptable counts:	100/100 mℓ (50 percentile) 400/100 mℓ (90 percentile) 2 000/100 mℓ (99 percentile)

6. United States Environmental Protection Agency [USEPA, 1968]

Primary contact:	Log mean over 30 d not to exceed 200/100 mℓ. 90 percentile (30 d) not to exceed 400/100 mℓ.
General contact:	Log mean over 30 d not to exceed 1 000/100 mℓ. 90 percentile (30 d) not to exceed 2 000/100 mℓ.

7. United States Environmental Protection Agency [USEPA, 1986]

Geometric (log) mean over 30 d not to exceed 126 *E. coli*/100 mℓ.

8. World Health Organization (WHO 1984) (Helmer et al., 1991)

Count should not exceed 100/100 mℓ (50 percentile) or 1 000/100 mℓ (90 percentile) out of a minimum of 10 samples.

local/national economic factors. Caution should be exercised in the direct application of quantitative relationships between health risk and indicator organism in other geographic areas where the general health and immunity of the population may be different (Salas, 1986).

Despite the existence of different criteria applied in different parts of the world, each having varying modes of application, either in the sampling frequency, percentile compliance limits or the use of log means or medians as the measure of central tendency, they all have very similar limits for faecal coliform compliance (see Table 1). Whereas the earlier directives (USEPA, 1968 and EEC, 1976) referred to contact (swimming) recreation only, the more recent formulations have been broadened to include a wider range of aquatic recreation types. Morris (1991) identified minimum contact recreation as angling, canoeing and rowing, occasional contact as sailing, wind-surfing and water-skiing, and total contact as swimming and diving. These groupings are similar to the classes defined by the Australian guidelines (ANHMRC, 1987) which range from primary contact (swimming), secondary contact (boating and angling) and passive contact (shoreline recreational activities requiring only aesthetically-pleasing water quality).

Bathing water criteria are continually being revised as new microbiological technologies and epidemiological information become available (Grabow et al., 1989). The most commonly utilised indicator organisms are those of the faecal coliform group, while increasing use is also being made of the confirmatory *E.coli* determination to indicate human faecal pollution.

There is increasing evidence that faecal streptococci are superior indicators of faecal pollution in sea water (Cabelli et al., 1982; USEPA, 1986). Ferley et al. (1989) showed that levels of faecal streptococci were better than those of faecal coliforms in predicting gastrointestinal illness in recreational river waters. However, the current (USEPA, 1986) United States federal bacteriological water quality criteria governing marine coastal waters, which employ enterococcus densities as the norm, have recently been shown to be questionable (Fleisher, 1991).

The existence of an inverse relationship between salinity and indicator organism density (Fleisher, 1991), and the fact that indicator organisms generally survive longer in fresh than in marine waters (Evison and Tosti, 1980; Dufour, 1984; Evison, 1988 and Cornax et al., 1991), render the applicability of marine-derived criteria to freshwater conditions doubtful. The mortality of micro-organisms in water may be caused by a variety of factors, including sedimentation, adsorption, coagulation, flocculation, solar radiation, lack of nutrients, predation, attack by bacteriophage, algal and bacterial toxins, and physico-chemical effects (Evison and Tosti, 1980). Aggregation of cells has been described as a self-protective mechanism of *E.coli* in sea water (Findlay et al., 1990). The relative significance of these factors has yet to be established in fresh and salt water, although sunlight is probably the most important in both water types. Other than sunlight, salinity probably causes the rapid coliform mortality commonly observed in sea water (Evison and Tosti, 1980).

It is beyond the scope of this paper to further consider the rationale underlying the use of different indicator organisms for monitoring bacteriological water quality, and the reader is referrred to works such as HMSO (1984), WHO (1984) or CMNH (1990) for further information.

South Africa currently makes use of the South African National Committee for Oceanographic Research (SANCOR) guidelines for bathing water quality in the coastal zone (Lusher, 1984), or the European Community (EC) directive of 1975 (EEC, 1976). There is no separate standard directly applicable to freshwaters, and the SANCOR and EC criteria are utilised to address this need. The question of bathing water criteria for recreational water use in South Africa is currently under review (DWAF 1992a and 1992b). In the light of the complexity of undertaking site-specific epidemiological investigations, it is unlikely that any new standard for South African freshwaters will amount to more than a combination of pre-existing criteria such as those formulated in North America or Australia. Importantly, a South African draft policy document (DWAF, 1992c) on water for managing the natural environment recognised that, while "water criteria for various uses can sometimes be gleaned from overseas experience, care must be taken to avoid imposing criteria which reflect western culture and criteria on essentially African environments".

This paper presents 8- to 10-year data sets of faecal coliform densities in two freshwater and one seasonally estuarine lake on the Cape Flats near Cape Town (Fig. 1). No epidemiological studies have been conducted for these lakes.

Study area

Zandvlei, Zeekoevlei and Princess Vlei are three shallow lakes situated on the Cape Flats near Cape Town (Fig. 1). All three are managed by the Cape Town City Council (CCC). These lakes are important for aquatic recreation in an area which is poor in natural inland surface waters. Recreational usage is most popular

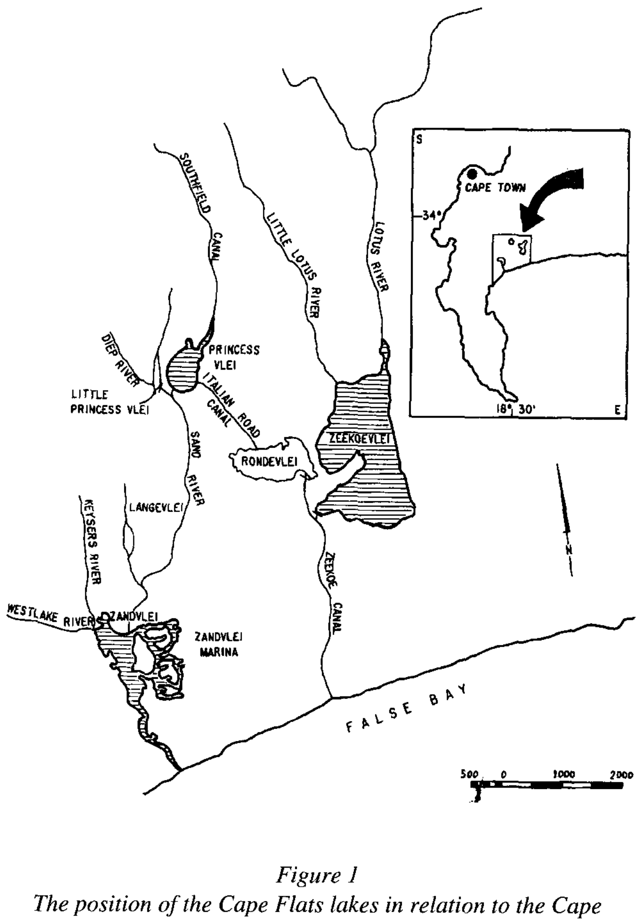

Figure 1
The position of the Cape Flats lakes in relation to the Cape Peninsula. Scale in m.

TABLE 2
COMPARISON OF ZANDVLEI, ZEEKOEVLEI AND PRINCESS VLEI

	Zandvlei	Zeekoevlei	Princess Vlei
Water type	semi-estuarine	freshwater	freshwater
Surface area, ha	56	256	29
Perimeter, km	7,9	12,6	2,4
Volume (max) m^3	793 000	5 000 000	715 000
Mean depth, m	1,5	1,9	2,5
Water level, m AMSL	0,8	5,2	6,6
Inflow, $M\ell\cdot a^{-1}$	22 000	20 000	2 000
% contribution of each river	- Sand 43% - Keysers 45% - Westlake 12%	- Lotus 85% - L.Lotus 15%	- Southfield Canal 100%
Trophic status	meso-eutrophic	hyper-eutrophic	eutrophic
Water transparency, m	0,60	0,25	0,50
Mean chlorophyll a ($\mu g\cdot\ell^{-1}$)	15	200	65
Catchment, ha	8 400	8 000	800
Land use by area(%)			
- Residential	23	33	51
- Industrial	1	10	4
- Commercial	4	1	1
- Local authority	not specified	not specified	6
- Agriculture	14	26	0
- Forestry	22	0	0
- Open space	26	30	33
- Roads	10	not specified	not specified
- Unzoned	not specified	not specified	5

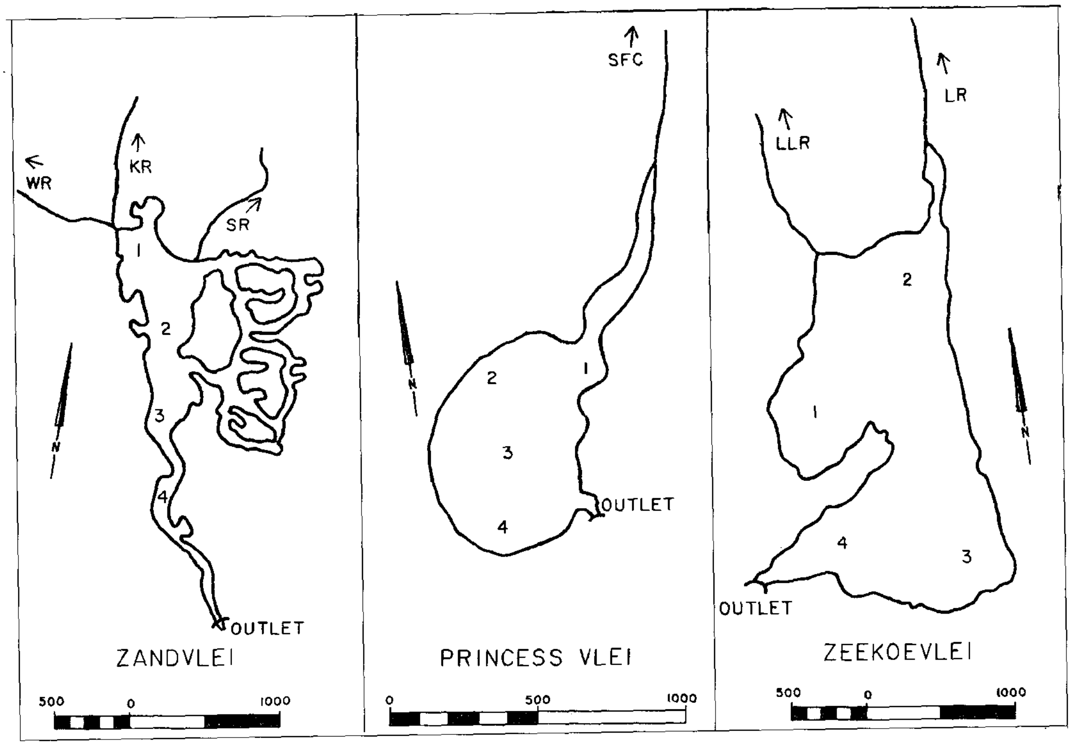

Figure 2
The position of the sampling sites on Zeekoevlei, Zandvlei, Princess Vlei and their influent rivers. WR = Westlake River, KR = Keyers River, SR = Sand River, SFC = Southfield Canal, LLR = Little Lotus River and LR = Lotus River. Scale bars denote distance in m.

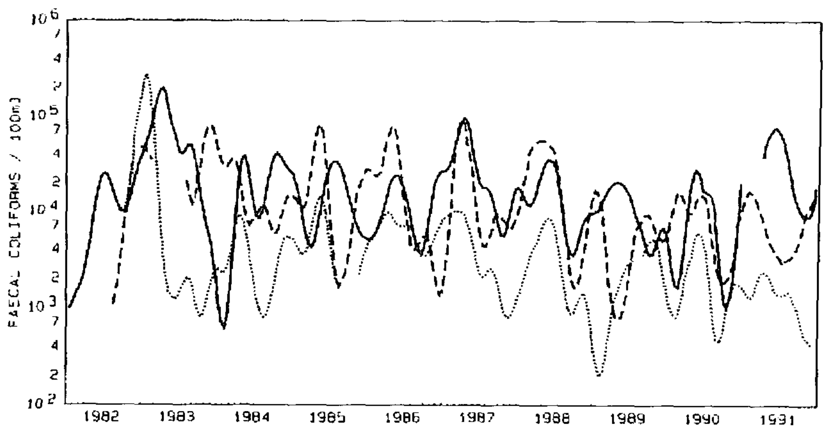

Figure 3
Smoothed, flow-weighted riverine faecal coliform loading of the Cape Flats lakes. Zeekoevlei (solid), Zandvlei (dotted and Princess Vlei (dashed)

during the dry spring and summer months of this winter-rainfall climatic region, although non-contact recreation (boating, windsurfing and skiing) continues throughout the year. The major characteristics of the lakes and their catchments are summarised below (**Study Area**) and in Table 2. Further details may be found in Harding (1991, 1992a-c). User-surveys have been conducted in the past at Zandvlei and Zeekoevlei in order to establish the user-perceptions of the water quality in each (CCC, 1988 and CCC, 1990, respectively). The lakes exhibit varying degrees of nutrient enrichment (eutrophication), ranging from meso-eutrophic (Zandvlei) to hyper-eutrophic (Zeekoevlei). Inputs from urban runoff, agricultural practices, informal settlements and occasional sewage overflows all contribute to the anthropogenic impacts on these lakes. Large portions of the urban catchments of Zandvlei and Zeekoevlei are occupied by low to sub-economic housing developments where the catchment housekeeping is below the standard desired for acceptable receiving water quality.

Materials and methods

Lake and river sampling

Water samples for bacteriological analysis were collected fortnightly from fixed sampling points, one on each river and 4 in each lake (see Fig. 2) during the periods 1982-1991 (Zandvlei), 1983-1991 (Zeekoevlei) and 1984-1991 (Princess Vlei). River and lake samples were collected in sterile 250 mℓ borosilicate (*Schott*) bottles held in a retort clamp at the end of a 2 m aluminium ranging pole. River samples were collected from the bank and lake samples from a motorboat. Samples were invariably collected between 09:00 and 11:00 and transported to the laboratory in insulated containers. Laboratory processing of samples was performed within 5 h of collection.

Determination of faecal coliforms

100 mℓ aliquots of sample, or appropriate tenfold dilutions thereof, were filtered under vacuum through sterile 47 mm, 0,45 µm cellulose-nitrate (*Millipore* or equivalent) membrane filters. Dilutions were made in 90 mℓ volumes of sterile distilled water containing magnesium chloride and phosphate buffer (Standard Methods, 1989). The membranes plus retentate were incubated on MacConkey purple agar (*Biolab* C91 or equivalent) in 65 mm disposable petri dishes at 44,5°C for 18 to 24 h. Yellow colonies were scored as positive faecal coliforms and expressed as faecal coliforms per 100 mℓ of lake water.

Because of a marked attenuation of faecal coliform numbers with increasing distance from the inflows to each lake, no attempt was made to pool the in-lake data for each system. The comparison of the faecal coliform loading of each lake was made by flow-weighting the individual rivers (Zandvlei and Zeekoevlei) according to their mean annual flows (Table 2) and plotting the results for all 3 lakes on a single set of axes (Fig. 3).

The results for each river and lake sampling point are presented as the 50, 80 and 90 percentile values for each 12-month period (Tables 4-6). Each annual set is represented by between 20 and 28 sampling occasions. The data are further considered on the basis of a 6-month winter-summer split using the periods April-September and October-March as winter and summer, respectively (Tables 7-9). The data were normalised by logarithmic transformation prior to analysis. The log-mean values for each sampling point and the variability of the log-normalised data, expressed as the log-standard deviation, p (Gameson, 1980), for the entire period covered by the data for each lake are presented in Table 3. The arithmetic mean was considered to be the best measure of central tendency, and bears a direct relationship to the geometric mean of the original data (Lightfoot, 1989). Where logarithmic or geometric means are referred to, the specific calculation is the arithmetic mean of the log-arithmically-transformed data, which are then transformed back to the original scale. Compliance with either the SANCOR or EC directives (Table 2) is indicated in each of the data tables by means of an asterisk placed alongside the relevant value (Tables 4 to 9).

Results

The concentrations of faecal coliforms (fc) entering the lakes ranged from 1 000 to 100 000 fc·100 mℓ$^{-1}$ (Fig. 3). With some exceptions, the counts demonstrated a strongly seasonal tendency, increasing along with the onset of the winter rains in April and peaking during mid-winter. Zandvlei had the lowest overall faecal coliform loading (Fig. 3). Of the rivers entering Zandvlei, faecal coliform counts were highest and lowest in the Sand River and Westlake Stream, respectively, while in the Zeekoevlei catchment, faecal coliform counts were generally highest in the Lotus River (Table 5).

There was a marked attenuation of faecal coliform numbers with increasing distance from the inlets in all three lakes (Tables 4 to 6). This feature was most marked in Zeekoevlei (Table 5). The increase in faecal coliform numbers between sampling points 3 and 4 in Zandvlei is attributed to natural factors such as roosting gulls and storm-water inputs immediately adjacent to the sampling site.

Considered on an annual basis, Zandvlei complied only at the

TABLE 3
FAECAL COLIFORM MEANS AND LOG STANDARD DEVIATIONS
Numbers indicate faecal coliforms per 100 mℓ of sample (*p* = log standard deviation ; n = number of sampling occasions)

Zandvlei

Year	Rivers			Lake sampling points				n
	Sand	Keysers	Westlake	1	2	3	4	
1983	4 300	800	750	90	60	30	60	24
1984	3 100	1 100	650	100	90	60	80	25
1985	6 400	1 500	200	120	150	70	100	27
1986	12 000	850	350	280	270	130	190	28
1987	4 500	860	380	380	190	110	130	26
1988	3 800	770	160	150	110	70	120	25
1989	1 700	460	80	140	60	30	50	22
1990	2 600	200	100	120	50	40	50	22
1991	2 100	260	120	70	40	40	80	20
p	1,22	0,36	1,43	1,74	2,30	2,20	1,62	

Zeekoevlei

Year	Rivers		Lake sampling points				n
	L. Lotus	Lotus	1	2	3	4	
1982	8 000	6 400	60	70	70	no data	26
1983	22 400	23 000	30	110	50	10	25
1984	7 400	6 300	80	190	90	120	26
1985	12 300	10 000	30	30	10	10	25
1986	5 900	9 400	20	40	10	10	26
1987	11 000	19 100	10	20	20	10	26
1988	7 900	8 900	10	40	10	10	25
1989	4 400	5 600	20	30	10	10	26
1990	no data	5 200	20	50	20	10	27
1991	5 200	12 300	30	100	40	30	23
p	1,25	1,24	2,82	3,31	2,86	2,74	

Princess Vlei

Year	River	Lake sampling points				n
	S/Field C	1	2	3	4	
1984	16 000	2 000	920	650	480	25
1985	13 000	1 600	270	210	50	24
1986	9 600	220	160	80	2	26
1987	14 000	310	190	260	1	23
1988	14 000	170	80	70	2	24
1989	4 400	130	40	20	20	22
1990	7 800	130	30	20	30	25
1991	6 400	50	30	30	10	24
p	1,22	1,82	2,31	2,45	1,57	

TABLE 4
ZANDVLEI PERCENTILE SUMMARY YEAR BY YEAR
Numbers indicate faecal coliforms per 100 mℓ of sample
***Indicates compliance with indicated criterion**

Year	Rivers			Lake sampling points				n
	Sand	Keysers	Westlake	1	2	3	4	
50 percentile – SANCOR limit 100·100 mℓ⁻¹								
1983	3 000	340	460	50*	50*	40*	40*	24
1984	4 500	980	460	100*	80*	40*	80*	25
1985	7 300	1 300	140	70*	120	40*	50*	27
1986	9 500	700	250	380	280	80*	160	28
1987	3 700	1 000	200	380	190	60*	90*	26
1988	5 000	760	80*	140	50*	40*	100	25
1989	1 600	700	95*	160	60*	50*	55*	22
1990	1 700	300	90*	240	10*	20*	20*	22
1991	2 000	330	140	90*	80*	40*	60*	20
80 percentile – EC guideline 100·100 mℓ⁻¹								
1983	20 000	6 000	4 300	2 700	830	150	350	24
1984	13 000	5 000	2 800	700	580	580	620	25
1985	15 000	5 500	460	1 050	1 350	550	300	27
1986	39 000	3 000	3 300	2 600	2 300	1 500	2 600	28
1987	27 000	3 200	3 300	2 500	1 700	900	620	26
1988	11 000	4 200	1 000	1 400	1 500	700	650	25
1989	6 000	4 300	470	1 600	710	310	150	22
1990	9 100	650	510	800	900	380	580	22
1991	6 000	750	510	280	280	190	250	20
90 percentile – SANCOR limit 400·100 mℓ⁻¹								
1983	150 000	16 000	200 000	4 500	8 200	1 400	500	24
1984	40 000	11 000	10 000	7 000	4 000	2 000	2 000	25
1985	26 000	17 000	1 500	2 700	3 700	1 000	1 300	27
1986	135 000	6 400	12 000	3 900	3 800	3 000	6 200	28
1987	39 000	9 400	10 000	4 800	7 900	6 000	1 400	26
1988	35 000	9 000	2 200	2 000	2 400	2 200	1 400	25
1989	12 000	13 000	1 000	3 100	2 000	600	230*	22
1990	14 000	1 300	840	1 200	5 700	3 000	1 100	22
1991	21 000	1 400	2 400	1 000	400*	450	370*	20

50 percentile towards the middle (sampling point 3) and southern (sampling point 5) reaches of the lake (Table 4). Zeekoevlei complied throughout the lake with the 50 percentile limit, and had marginal compliance in the south (sampling points 3 and 4) with the 80 and 90 percentiles (Table 5). The fact that marginal compliance (80 and 90 percentiles) was attained in Zeekoevlei at sampling point 1 and not 2 is attributed to the former being out of the north-south flow pattern of the lake. Sampling point 2 is immediately adjacent to the inlet of the Lotus River (Fig. 2). Faecal coliform levels in Princess Vlei complied at points 2, 3 and 4 with the 50 percentile limit throughout the 8-year period, and at sampling point 1 during 1990 and 1991. The latter sampling point does not form part of the main body of the lake, and is situated in a shallow, sheltered inlet bay (Fig. 2).

Tables 7 to 9 summarise the 6-month summer-winter split of the data for the full period covered for each lake. Good summer compliance was achieved in Zandvlei at the 50 percentile limit, with marginal compliance at the 80 and 90 percentiles (Table 7). The bacteriological water quality of Zandvlei did not comply with either the SANCOR or EC criteria during the winter. Zeekoevlei complied with all three percentile limits during the summer, and showed marginal 50 percentile compliance during the winter (Table 8). The seasonal separation of the data for Princess Vlei did not result in any improvement of the degree of compliance at any level, winter or summer.

Discussion

All 3 lakes received high loads of faecal coliforms, especially just after the onset of the winter rains. The lakes have varying, inherent capacities to attenuate the levels of bacterial pollution they receive. This was most marked in Zeekoevlei, and probably brought about by a combination of long water retention time, regular mixing of the contents of the water column through the

TABLE 5
ZEEKOEVLEI PERCENTILE SUMMARY YEAR BY YEAR
Numbers indicate faecal coliforms per 100 mℓ of sample
***Indicates compliance with indicated criterion**

	Rivers		Lake sampling points				
Year	L. Lotus	Lotus	1	2	3	4	n
50 percentile – SANCOR limit 100·100 mℓ$^{-1}$							
1982	11 000	11 000	43*	43*	46*	nd	26
1983	20 000	18 000	10*	100*	36*	7*	25
1984	8 600	7 550	72*	320	110	180	26
1985	8 800	8 000	18*	28*	10*	1*	25
1986	6 000	7 250	17*	17*	10*	10*	26
1987	11 000	16 000	10*	21*	17*	5*	26
1988	11 000	6 500	8*	20*	4*	3*	25
1989	2 650	5 500	14*	28*	6*	2*	26
1990	810	8 000	20*	20*	10*	3*	27
1991	4 900	13 000	30*	60*	20*	20*	23
80 percentile – EC guideline 100·100 mℓ$^{-1}$							
1982	34 000	30 000	410	500	440	nd	26
1983	100 000	740 000	300	2 700	900	125	25
1984	96 000	33 000	1 500	3 640	790	1 830	26
1985	51 000	40 000	330	260	170	110	25
1986	15 000	50 000	90*	335	60*	60*	26
1987	40 000	81 000	90*	410	100*	60*	26
1988	30 000	56 000	110	1 500	70*	60*	25
1989	20 000	21 000	170	300	80*	50*	26
1990	4 200	22 000	70*	550	120	50*	27
1991	24 000	63 000	220	4 900	900	330	23
90 percentile – SANCOR limit 400·100 mℓ$^{-1}$							
1982	49 000	68 000	1 700	1 500	1 900	nd	26
1983	700 000	110 000	800	54 000	2 200	840	25
1984	240 000	68 000	5 500	6 200	4 300	7 700	26
1985	85 000	70 000	2 200	1 100	500	580	25
1986	41 000	146 000	140*	3 400	140*	130	26
1987	200 000	610 000	160*	540	160*	150*	26
1988	140 000	110 000	130*	3 200	180*	1 300	25
1989	59 000	31 000	300*	3 500	170*	100*	26
1990	13 000	35 000	300*	14 000	340*	370*	27
1991	35 000	135 000	630	13 000	3 000	1 750	23

nd = no data available

light-rich zone, and high pH and hydrogen sulphide concentrations present in the lake water (Harding, 1991). In Zandvlei, light- and salinity-induced die-off are probably the most important factors causing death of bacterial populations. Princess Vlei is the smallest lake and has relatively short water retention times compared to the other two. Nonetheless, the degree of reduction of faecal coliforms was considerable.

The EC 80 percentile directive of 100 faecal coliforms per 100 mℓ of water is currently regarded by the Cape Town City Council as being the more appropriate standard to apply in assessing bacteriological water quality in both marine and fresh waters. On the basis of annually evaluated faecal coliform data and other factors such as phytoplankton and macrophyte growth, contact recreation is disallowed in all 3 lakes, while non-contact activities are permitted. Examination of the data in Tables 4 to 6 showed evidence of lower faecal coliform loads to all 3 lakes since the mid-1980s. This is attributed to improvements made to prevent and/or contain sewage pump-station overflows in the various catchments. In the absence of further significant reductions in bacterial loading it is, however, unlikely that any improvement in the degree of compliance with the bathing criteria will be achieved in any of the lakes.

All 3 lakes considered here are currently favoured by the public for non-contact recreational activities as opposed to swimming. The reasons for this are more likely to be seated in a visual perception of the water quality (algae, submerged macrophytes) than in a knowledge of the bacteriological water quality (Thornton and McMillan, 1989; Thornton et al., 1989). Seen in

TABLE 6
PRINCESS VLEI PERCENTILE SUMMARY YEAR BY YEAR
Numbers indicate faecal coliforms per 100 mℓ of sample
***Indicates compliance with indicated criterion**

Year	River S/Field C	Lake sampling points 1	2	3	4	n
50 percentile – SANCOR limit 100·100 mℓ⁻¹						
1984	11 000	1 700	940	640	400	25
1985	13 000	1 550	200	110	45*	24
1986	10 100	170	70*	90*	nd	26
1987	16 000	140	85*	250	nd	23
1988	19 500	120	70*	70*	nd	24
1989	8 500	120	20*	10*	10*	22
1990	5 000	40*	10*	10*	10*	25
1991	4 500	30*	25*	20*	10*	24
80 percentile – EC guideline 100·100 mℓ⁻¹						
1984	67 000	25 000	7 800	5 700	5 300	25
1985	43 000	12 000	1 900	1 500	370	24
1986	65 000	1 600	1 000	500	nd	26
1987	37 000	4 900	2 200	2 000	nd	23
1988	50 000	2 800	530	1 200	nd	24
1989	13 200	1 200	320	200	200	22
1990	39 000	2 800	500	200	300	25
1991	17 000	430	280	280	40	24
90 percentile – SANCOR limit 400·100 mℓ⁻¹						
1984	340 000	55 000	19 000	15 000	15 000	25
1985	110 000	23 000	8 000	9 600	1 100	24
1986	157 000	7 300	4 400	4 000	nd	26
1987	69 000	29 000	8 500	6 500	nd	23
1988	100 000	13 000	12 300	10 100	nd	24
1989	19 000	2 400	1 300	300*	750	22
1990	300 000	12 000	1 000	1 100*	720	25
1991	34 000	3 000	700	420	270*	24

nd = no data available

TABLE 7
SEASONAL COMPLIANCE IN ZANDVLEI 1983-1991
Numbers indicate faecal coliforms per 100 mℓ of sample
***Denotes compliance with indicated criterion, s**

percentile	Rivers Sand	Keysers	Westlake	Lake sampling points 1	2	3	4	s
Summer								
50	3 500	620	160	50*	40*	20*	30*	100
80	12 000	5 100	1 100	450	250	100*	140	100
90	51 000	17 000	7 000	1 000	1 200	500	350*	400
Winter								
50	5 000	700	250	430	300	150	200	100
80	15 000	3 400	1 200	3 000	2 200	1 300	1 300	100
90	35 000	9 000	8 700	5 000	8 100	4 300	2 600	400

TABLE 8
SEASONAL COMPLIANCE IN ZEEKOEVLEI 1982-1991
Numbers indicate faecal coliforms per 100 mℓ of sample
***Indicates compliance with indicated criterion, s**

percentile	Rivers		Lake sampling points				s
	L.Lotus	Lotus	1	2	3	4	
Summer							
50	5 200	5 800	5*	6*	3*	2*	100
80	25 000	24 000	40*	50*	40*	10*	100
90	110 000	101 000	140*	200*	240*	30*	400
Winter							
50	7 700	17 000	80*	290	60*	40*	100
80	44 000	70 000	400	4 000	440	325	100
90	84 000	213 000	1 100	12 000	2 000	1 000	400

TABLE 9
SEASONAL COMPLIANCE IN PRINCESS VLEI 1984-1991
Numbers indicate faecal coliforms per 100 mℓ of sample
***Indicates compliance with indicated criterion, s**

percentile	River	Lake sampling points				s
	S/Field C	1	2	3	4	
Summer						
50	11 000	90*	40*	30*	3*	100
80	36 000	2 400	500	250	130	100
90	134 000	16 000	1 700	1 400	500	400
Winter						
50	8 500	700	270	200	20*	100
80	53 000	8 000	2 400	3 600	600	100
90	98 000	18 000	11 000	10 000	2 700	400

this regard, all 3 lakes complied favourably with the limits specified for non-contact activities, ca. 1 000 fc·100 mℓ^{-1} (Table 1).

The SW Cape has 2 distinct seasons, winter and summer, with short and less well-defined autumn and spring periods. Winter rains commence annually during April and continue until September. The most intensive recreational use of the lakes in the region occurs during the summer, with peak usage during December and January, i.e. coinciding with the period of dry weather flows and highest insolation. There is thus a distinct seasonal separation of highest bacterial loading and weather conditions which are generally inconducive to aquatic recreation, from the period of greatest recreational usage. This makes practical the application of bathing criteria on a seasonal, as opposed to annual basis. Such an approach does not conflict with the EC Bathing Water Directive which stipulates its use during the "bathing season". Alternatively, the use of monthly criteria (e.g. the Canadian Standard, Table 1) could be employed in situations where the logistical and economic demands of such a routine can be accommodated.

An analysis of the chronological proximity of individual high faecal coliform counts to storm events would be illuminating for a more user-orientated analysis of the available data. This would provide an indication of how long bathing water quality remains unacceptable subsequent to runoff events. Initial estimates in this regard have shown that faecal counts remain elevated for between 2 and 5 d subsequent to rainfall of 5 mm or more (Morrison, 1992).

In the absence of site-specific epidemiological data, the continued application of the EC guidelines is recommended on a seasonal basis for primary contact recreation in the coastal lakes of the SW Cape. Similarly, the median guideline value of 1 000 fc·100 mℓ^{-1} for secondary (non-) contact activities is recommended. A recent revision of the water quality guidelines for the South African coastal zone has adopted in essence the EC guidelines for primary contact recreation, but has included allowance for determination of *Escherichia coli* in cases of high counts where the organisms may be of non-faecal origin (WRC, 1992). In general, it would be more desirable to test for *E.coli* rather than faecal coliforms. In the past cost, time and methodology restraints have precluded routine *E. coli* testing in many laboratories. Recently, short (24 h) incubation time membrane filtration media e.g. *Difco*-mTEC (Dufour et al., 1981) have become commercially available, thus alleviating this shortcoming.

A programme to determine epidemiologically-derived recreational water criteria for South African beaches is currently in progress (Von Schirnding, 1992). Once complete, the results should support the establishment of an appropriate criterion for the lakes described here, should the EC guidelines prove to be inappropriate.

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References

ANHMRC (AUSTRALIAN NATIONAL HEALTH MEDICAL RESEARCH COUNCIL)(1987) Draft Guidelines for Recreational Use of Water in Australia. 10pp.

BRENNIMAN, GR, ROSENBERG, SH and NORTHROP, RL (1981) Microbial sampling variables and recreational water quality standards. *Am.J. Publ. Health* **71**(3) 283-289.

CABELLI, VJ, DUFOUR, AP, McCABE, LJ and LEWIN, MA (1982) Swimming-associated gastroenteritis and water quality. *Am. J. Epidemiol.* **115** 606-616.

CABELLI, VJ, DUFOUR, AP, McCABE, LJ and LEVIN, MA (1983) A marine recreational water quality criterion consistent with indicator concepts and risk analysis. *J. Water Pollut. Control Fed.* **55** 1306-1314.

CHEUNG, WHS, HUNG, RPS, CHANG, KCK and KLEEVENS, JWL (1991) Epidemiological study of beach water pollution and health related bathing water standards in Hong Kong. *Water Sci. Technol.* **23** 243-252.

CCC (CITY OF CAPE TOWN) (1988) Zandvlei User Assessment Survey.Town Planning Branch. 35pp.

CCC (CITY OF CAPE TOWN) (1990) Zeekoevlei User Assessment Survey. Town Planning Branch. 43pp.

CMNH (CANADIAN MINISTRY OF NATIONAL HEALTH) (1990) Guidelines for Canadian Recreational Water Quality. Ministry of National Health and Welfare. 88pp.

CORNAX, R, MORINIGO, MA, BALEBONA, MC, CASTRO, D and BORREGO, JJ (1991) Significance of several bacteriophage groups as indicators of sewage pollution in marine waters. *Water Res.* **25**(6) 673-678.

CROCKETT, JA, HARTLEY, KJ and WILLIAMS, WD (1989) Setting and achieving water quality criteria for recreation. *Water Sci. Technol.* **21**(2) 71-76.

DUFOUR, AP (1984) Bacterial indicators of recreational water quality. *Canadian J. Publ. Health* **75** 49-56.

DUFOUR, AP, STRICKLAND, ER and CABELLI, VJ (1981) Membrane filter method for enumerating *Escherichia coli*. *Appl. Environ. Microbiol.* **41** 1152-1158.

DWAF (DEPARTMENT OF WATER AFFAIRS AND FORESTRY) (1992a) The Development of Water Quality Guidelines for Various Uses in South Africa. Draft Philosophy of Water Quality Guidelines Development for Recreational Water Use. Department of Water Affairs and Forestry, Pretoria. 13pp.

DWAF (DEPARTMENT OF WATER AFFAIRS AND FORESTRY) (1992b) The Development of Water Quality Guidelines for Various Water Uses in South Africa. Recreational Water Use. Example draft guidelines. Department of Water Affairs and Forestry, Pretoria. 11pp.

DWAF (DEPARTMENT OF WATER AFFAIRS AND FORESTRY) (1992c) Draft Policy: Water for Managing the Natural Environment. Report No DF/R-ENVIRO POLICY 00192. Department of Water Affairs and Forestry, Pretoria. 21pp.

EEC (EUROPEAN ECONOMIC COMMUNITY) (1976) Council directive of 8 December 1975 concerning the quality of bathing water. 76/160/EEC. *Official J. of the European Communities*. L31/1. 7 pp.

EVISON, LM (1988) Comparative studies on the survival of indicator organisms and pathogens in fresh and seawater. *Water Sci. Technol.* **20**(11/12) 309-315.

EVISON, LM and TOSTI, E (1980) An appraisal of bacterial indicators of pollution in sea water. *Prog. Water Technol.* **12** 591-599.

FERLEY, JP, ZMIROU, D, BALDUCCI, F, BALEUX, B, FERA, P, LARBAIGT, G, JACQ, E, MOISSONNIER, B, BLINEAU, A and BOUDOT, J (1989) Epidemiological evidence of microbiological pollution criteria for river recreational waters. *Int. J. Epidemiology* **18**(1) 198-205.

FINDLAY, JS, CURRAN, JC, MILNER, DP, CROWTHER, JM, WALTER, SG and WOOD, BJB (1990) The self-protection of *Escherichia coli* in seawater. *J. IWEM* **4**(5) 451-456.

FLEISHER, JM (1991) A reanalysis of data supporting US Federal bacteriological water quality criteria governing marine recreational waters. *J. Water Pollut. Control Fed.* **63**(3) 259-265.

FLEISHER, JM (1992) Setting recreational water quality standards: Methodology and analytical issues. Paper presented at the Institution of Water and Environmental Management International Symposium on Recreational Water Quality Standards, Cafe Royal, London, 13-14 May, 1992.

GAMESON, ALH (1980) Variability of bacterial counts in coastal waters. *Prog. Water Technol.* **12** 481-489.

GRABOW, WOK, IDEMA, GK, COUBROUGH, P and BATEMAN, BW (1989)Selection of indicator systems for human viruses in polluted seawater and shellfish. *Water Sci. Technol.* **21**(3) 111-117.

HARDING, WR (1991) The Ecology of some Urban-Impacted Coastal Lakes near Cape Town, with Special Reference to Phytoplankton Periodicity. Unpublished M.Sc. Thesis, Department of Zoology, University of Cape Town. 211pp.

HARDING, WR (1992a) A contribution to the knowledge of South African coastal vleis: The limnology and phytoplankton periodicity of Princess Vlei, Cape Peninsula. *Water SA* **18**(2) 121-130.

HARDING, WR (1992b) Zeekoevlei - Water chemistry and phytoplankton periodicity. *Water SA* **18**(4) 237-246.

HARDING, WR (1992c) Long-term data series for a seasonally-estuarine, shallow coastal lake: Zandvlei, south-western Cape, South Africa (in press).

HELMER, R, HESPANHOL, I and SALIBA, LJ (1991) Public health criteria for the aquatic environment: recent WHO guidelines and their application. *Water Sci Technol.* **24**(2) 35-42.

HOLMES, PR (1989) Research into health risks at bathing beaches in Hong Kong. *J. IWEM.* **3**(5) 488-492.

JONES, F and GODFREE, AF (1989) Recreational and amenity use of surface waters: The public health implications. *Water Sci. Technol.* **21**(3) 137-142.

JONES, F, KAY, D, STANWELL-SMITH, R and WYER, M (1991) Results of the first pilot-scale controlled cohort epidemiological investigation into the possible effects of bathing in seawater at Longland Bay, Swansea. *J. IWEM.* **5**(1) 91-98.

LACEY, RF and PIKE, EB (1989) Water recreation and risk. *J. IWEM.* **3**(1) 13-18.

LIGHTFOOT, NE (1989) A Prospective Study of Swimming-related Illness at six Freshwater Beaches in Southern Ontario. Unpublished Ph.D. thesis, University of Toronto. 275pp.

LUSHER, JA (1984) Water Quality Criteria for the South African Coastal Zone. South African National Scientific Programmes Report 94. CSIR, Pretoria. 25pp.

MOORE, B (1975) The case against microbial standards for bathing beaches. In: Gameson, ALH (ed.) *Proc. of Int. Symp. on Discharge of Sewage from Sea Outfalls*. Pergamon Press, Oxford. 103-109.

MORRIS, R (1991) The EC bathing water virological standard: Is it realistic? *Water Sci. Technol.* **24**(2) 49-52.

MORRISON, IR (1992) Personal communication. City of Cape Town, Scientific Services Branch.

NRA (NATIONAL RIVERS AUTHORITY) (1991a) Bathing Water Quality in England and Wales - 1990. Report of the National Rivers Authority, Water Quality Series No. 3. National Rivers Authority, Bristol, Great Britain. 186pp.

NRA (NATIONAL RIVERS AUTHORITY) (1991b) Proposals for Statutory Water Quality Objectives. Report of the National Rivers Authority, Water Quality Series No. 5. National Rivers Authority, Bristol, Great Britain. 99pp.

SALAS, HJ (1986) History and application of microbiological water quality standards in the marine environment. *Water Sci. Technol.* **18**(11) 47-57.

SEYFRIED, PL, TOBIN, RS, BROWN, NE and NESS, PF (1985) A prospective study of swimming-related illness. Part II. Morbidity and microbiological quality of water. *Am. J. Public Health.* **75**(9) 1071-

1075.
STANDARD METHODS (1989) Standard Methods for the Examination of Water and Wastewater (17th edn.) APHA, Washington. Various pagination.
STEVENSON, AH (1953) Studies of bathing water quality and health. *Am. J. Pub. Health.* **43** 529-538.
THORNTON, JA and McMILLAN, PH (1989) Reconciling public opinion and water quality in South Africa. *J. Limnol. Soc. South. Afr.* **13** 4-6.
THORNTON, JA, McMILLAN, PH and ROMANOVSKY, P (1989) Perceptions of water pollution in South Africa: Case studies from two waterbodies (Hartbeespoort Dam and Zandvlei). *S. Afr. J. Psychol.* **19**(4) 199-204.
USEPA (UNITED STATES ENVIRONMENTAL PROTECTION AGENCY) (1968) Water Quality Criteria. Federal Water Pollution Control Administration, Department of Interior, Washington, DC. 7-14.
USEPA (UNITED STATES ENVIRONMENTAL PROTECTION AGENCY) (1986) Ambient Water Quality Criteria for Bacteria. US EPA 44015-84-002, Office of Regulations and Standards, Washington, DC.
VASCONCELOS, GJ and ANTHONY, NC (1985) Microbiological quality of recreational waters in the Pacific Northwest. *J. Water Pollut. Control Fed.* **57**(5) 366-377.
VON SCHIRNDING, YER, KFIR, R, CABELLI, V FRANKLIN, L and JOUBERT, G (1992) Morbidity among bathers exposed to polluted seawater. A prospective epidemiological study. *SA Medical J* **81**(6) 543-546.
WRC (WATER RESEARCH COMMISSION) (1992) Water Quality Guidelines for the South African Coastal Zone (Draft Revised Edition). Water Research Commission, Pretoria. 26pp.
WHO (WORLD HEALTH ORGANIZATION) (1984) *Guidelines for Drinking Water Quality. Volume 1: Recommendations.* World Health Organization, Geneva. 130pp.