Nutrient status and water quality assessment of the Marina Glades canal system, Kromme Estuary, St. Francis Bay

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Abstract

This paper presents results on the inorganic nutrient and coliform bacterial concentrations in a tide dominated marina canal system, situated in the Kromme Estuary, St. Francis Bay. Results show an increase during the December holiday season in the concentration of NO_3-N of up to one to two orders of magnitude higher than during non-season periods. Concentrations in the marina were also found to be much higher during the holiday season than in the Kromme and other eastern Cape estuaries. It is suggested that the increased nutrient load is due to ground-water seepage from septic tanks during the holiday season when the human population in the marina increases fivefold. Other chemical and physical parameters do not show significant seasonal variations. It is concluded that the water quality in this marina is good, with the exception of high NO_3-N levels, which is a function of an increase in the human population during the summer holiday season.

Introduction

A marina (the Marina Glades) has been developed on the west bank in the mouth region of the Kromme Estuary, and consists of a network of canals connected originally to the main estuary by two access canals (Baird et al., 1981). Excavations began in 1959 and at present about 12 km of canals have been constructed, comprising an area of approximately 0,13 km^2. The erection of waterfront housing was the prime objective of this development and so far about 220 houses have been built along the banks of the canals.

During the pas decade or so significant changes in the general patterns of sedimentation have occurred in the lower reaches and mouth area of the estuary due to both the upstream and downstream migration of sand bars (Anon, 1990). This has resulted in the closing of the seaward access canal (Baird et al., 1981) and thus has affected the efficiency of water circulation in the canals as well as the rate of water exchange between the estuary and the marina. Restricted tidal circulation has raised concern about the water quality of the marina canals and the possibility of pollution from non-point sources such as the seepage of domestic effluents from septic tanks and fertiliser runoff from waterfront gardens (Bickerton and Pierce, 1988). Domestic sewage is being disposed of by septic tanks at about 70% of the marina dwellings, and the total waterfront area under horticulture is about 23 ha. The possible pollution threat is thought to be particularly high during the summer holiday period ("in-season") when the population in the marina increases to more than about 2 000, as opposed to a "non-season" population of about 120 people.

The objective of this study was to assess the water quality of the marina canal system with special reference to the inorganic nutrient load of the canal waters and the presence of indicators of sewage pollution. The concentrations of nutrients, particularly nitrogen and phosphorus, are important indicators of the presence of enriched discharges from, for example, sewage inputs, fertiliser runoff from farmlands, industrial effluent discharges and storm water. The presence of sewage-derived wastes can be detected by determining the presence of total faecal and *E. coli* bacteria, and is a convenient means of evaluating sewage related contamination in water (Lord and Thompson, 1988). The nutrient status of the waters in the canal system is compared with that of the Kromme Estuary and other eastern Cape estuaries for which comparable data exist, whilst comments on the general environmental conditions of the marina canals are made.

The Kromme River estuary is one of the largest in the eastern Cape. It is 13,7 km long with an approximate surface area of 3 km^2. The Kromme River rises in the Tsitsikama mountains and is approximately 95 km long. It has a catchment area of 936 km^2 and a virgin mean annual runoff of about 105,5 x 10^6 m^3 (Reddering and Esterhuysen, 1983). Two dams have been built in the river catchment, namely the Churchill Dam (completed in 1943) and the CW Malan Dam (completed in 1982). Both these dams provide water to the Port Elizabeth metropolitan area and the catchment area of these two dams combined is about 840 km^2, which represents about 90% of the total catchment area of the river.

Studies on various aspects of the ecology of the Kromme Estuary have been conducted during the past decade. Emmerson and Erasmus (1987) and Emmerson (1989) commented on the nutrient status and abiotic characteristics in the estuarine waters; Bickerton and Pierce (1988) and Hanekom and Baird (1988) reported on botanical aspects; and Hecht (1973); Baird et al. (1981); Hanekom (1982); Hanekom and Baird (1984) and Marais (1983; 1984) on zoological aspects. Studies on the sedimentation in the Kromme Estuary have been conducted by Reddering and Esterhuysen (1983) and more recently by the CSIR (Anon, 1990). Baird et al. (1981) conducted the first study on the water circulation, water quality, and species diversity and abundance of the marina. Much of the available information on this estuary was summarised by Bickerton and Pierce (1988).

Material and methods

Water samples were collected from 6 stations (Stations 2 to 7) in the canal system, and from 1 (Station 1) in the estuary

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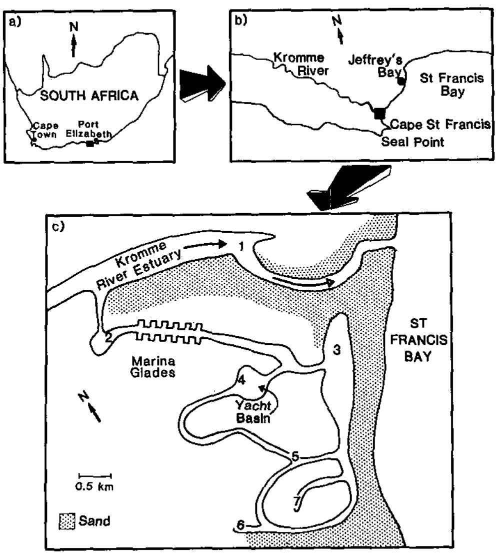

Figure 1
Map of the Marina Glades canal system in the Kromme Estuary showing the study area and sampling stations in this study

proper. Stations 2, 3, 4, and 5 were situated in the main canals and Station 6 and 7 in two blind ones (see Fig. 1). Sampling took place on 20 November and on 11 and 12 December 1989, prior to the summer holiday season, and again on 19 February and on 9 March 1990, just after the holidays, providing a total of 7 sets of data. Five of these were obtained during ebb tides, and 2 (on the mornings of 12 December 1989 and 9 March 1990) during flood tide. All samples were taken during the day, with the exception of the fourth set (on 11 December 1989), which was taken during the night. Duplicate water samples were collected at all stations from approximately 30 cm below the surface in sterilised 50 mℓ glass containers and stored at <5°C in cool-bags filled with ice. All samples were analysed in the laboratory within 8 h. At Stations 6 and 7 duplicate samples were collected respectively from 30 cm below the surface and approximately 50 cm above bottom as these stations were situated in blind canals (see Fig. 1) where the exchange of water with the rest of the system was thought to be weak. The average depth in the canals is approximately 2 m at high water spring tide and approximately 1,3 m at low water spring tide.

Water samples were filtered through Whatman CF/C filters and analysed for total ammonia as NH_3-N (Nessler method), nitrite as NO_2-N (diazotisation method), nitrate as NO_3-N (cadmium reduction method) and phosphorus as soluble reactive phosphorus (PO_4-P) (ascorbic acid method) using a Hach Model DREL/1c Colorimeter. The test procedures for the analysis of the various nutrient constituents by the Hach colorimeter were according to Standard Methods (1980); (Anon, 1984).

The detection range for each of the nutrients was as follows: NH_3-N: 0 to 2 $mg \cdot \ell^{-1}$; NO_2-N: 0 to 0,2 $mg \cdot \ell^{-1}$; NO_3-N: 0 to 30 $mg \cdot \ell^{-1}$ and PO_4-P: 0 to 3 $mg \cdot \ell^{-1}$ (Anon, 1984). The concentration of a particular nutrient at a particular station was determined from the mean of 2 samples only if the difference between the individual results was less than 10%. If not, a third (or fourth if necessary) aliquot was analysed. The standard additions technique was performed during the analyses of the samples for the various nutrients (Anon, 1984) to check the performance of the reagents, instrument and procedure.

Water samples to assess the levels of faecal coliform and *E. coli* bacteria were collected in sterile wide-necked bottles at all stations and enumerated (number per 100 mℓ) by the Port Elizabeth Municipality Water Quality Monitoring Laboratory using a slightly modified indole test (South African Bureau of Standards, 1971, Method 221). Temperature (°C) and salinity ($g \cdot kg^{-1}$, Valeport CTD Series 600 field instrument), dissolved oxygen concentration ($mg \cdot \ell^{-1}$, YSI model 57 field instrument and pH (Crison Model 566, portable pH meter) were measured on site at each station.

Results

Results of the water analyses are summarised in Table 1, which shows the concentrations of inorganic nutrients, dissolved oxygen (in $mg \cdot \ell^{-1}$ and per cent saturation), pH, salinity and temperature at each station for the different dates and tides.

Physical and chemical characteristics of the water column

Salinity and temperature in the marina canals were relatively uniform during the sampling period. Salinity remained close to that of the sea, varying between 32,5 and 35,0 $g \cdot kg^{-1}$. Slightly hypersaline conditions (>35,00 $g \cdot kg^{-1}$) were measured at Station 7 during February and March 1990, and marked salinity stratification occurred on the afternoon of 20/11/89 between the surface and the bottom at Stations 6 and 7 (Table 1). Temperatures of the canal waters increased consistently into the marina away from its connection with the estuary with the largest difference of 6,5°C found between Station 1 (estuary main channel) and Station 6 on 19/02/90. A temperature stratification occurred on the morning of 20/11/89 and on the afternoon of 11/12/89 between top and bottom of Stations 6 and 7.

The pH was also relatively uniform and close to that of sea water, with a slight tendency of the waters to become more alkaline at Stations 5, 6 and 7 (Table 1).

Dissolved oxygen

The concentrations of dissolved oxygen in the waters of the canal were uniform on most occasions, varying between 6,0 and 7,5 $mg \cdot \ell^{-1}$ and within about 21% of saturation (Table 1). Highest dissolved oxygen concentration values (>100% saturation) were recorded during midday on 11/12/89 at Stations 1, 2 and 3. On this date a strong south-easterly wind was blowing and the estuary and canal waters were choppy. The lowest concentrations (<6 $mg \cdot \ell^{-1}$ and <70% saturation) were measured during the evening of 11/12/89 at Stations 6 and 7 in the blind canals (Fig. 1).

Inorganic nutrients

Levels of soluble reactive phosphorus (SRP) were uniformly <1,0 $mg \cdot \ell^{-1}$) (Table 1) although sharp differences in concentration were recorded among stations during the morning of 20/11/89, and on 19/02/90 and 09/03/90. The SRP concentrations in the marina canal varied during the study period between 0,030 and 1,800 $mg \cdot \ell^{-1}$, with an overall mean of 0,299 $mg \cdot \ell^{-1}$ (n=51, SE=0,043). The relatively high concentration values at some stations in the marina canals seem to be episodic events, since no pattern of variation is evident from the data. The same also applies to day and night samples, high and low tide samples, and samples before and after the December holidays.

TABLE 1
NUTRIENT CONCENTRATIONS AND OTHER ABIOTIC PARAMETERS MEASURED IN THE WATERS OF THE MARINA CANALS

STATIONS	PO_4-P	NO_3-N	NO_2-N	NH_4-N	diss.O_2	%O_2 saturation	pH	Salinity	Temperature		
	mg·ℓ^{-1}							g·kg^{-1}	°C		
1	0,606	0,22	0,006	0,002	7,2	78,3	8,0	34,0	17,9	Sampling date:	20/11/89
2	0,438	0,81	0,005	0,005	7,2	78,9	8,0	30,5	18,4	Sampling time:	morning
3	0,738	0,61	0,004	0,003	7,0	76,3	8,0	33,7	18,0	High tide:	09:36
4	n.d	1,40	0,009	0,002	7,4	81,9	8,0	32,3	18,9	Low tide:	16:10
5	0,219	0,81	0,007	0,003	7,2	81,5	8,5	31,5	20,1	State of tide:	ebb
6T	n.d	0,81	0,007	0,003	6,8	79,7	8,4	27,5	22,0		neap
6B	0,699	0,50	0,008	0,002	7,1	83,2	8,6	31,9	19,5		
7T	0,630	0,90	0,004	0,003	6,9	81,2	8,6	32,4	22,2		
7B	0,399	0,90	0,000	0,003	7,2	82,2	8,8	32,3	20,5		
1	n.d	0,30	0,016	0,005	7,0	80,4	8,8	33,2	20,8	Sampling date:	21/11/89
2	0,480	0,90	0,010	0,008	7,0	81,5	8,7	31,1	21,6	Sampling time:	morning
3	0,198	0,50	0,007	0,003	6,8	76,3	8,8	32,8	19,6	High tide:	09:58
4	0,438	1,00	0,007	0,002	6,8	77,4	8,3	32,8	20,4	Low tide:	16:24
5	0,210	0,70	0,008	0,003	7,0	83,0	8,7	31,4	22,7	State of tide:	ebb
6T	0,180	0,50	0,005	0,003	6,5	78,6	8,7	23,3	23,8		neap
6B	0,399	0,50	0,004	0,002	6,5	75,4	8,3	31,8	21,4		
7T	0,558	0,90	0,003	0,003	6,7	79,1	8,8	23,9	22,4		
7B	0,120	0,50	0,003	0,003	6,9	80,9	8,8	32,6	22,0		
1	1,068	0,61	0,025	0,007	9,8	112,5	8,7	34,3	20,8	Sampling date:	11/12/89
2	0,150	1,50	0,025	0,007	9,5	116,3	8,7	33,5	24,6	Sampling time:	midday
3	0,078	1,80	0,025	0,005	9,2	110,6	8,6	34,1	23,5	High tide:	08:15
4	0,549	1,80	0,026	0,005	7,9	95,3	8,7	34,0	23,7	Low tide:	14:30
5	0,150	1,60	0,024	0,004	8,8	107,6	8,8	34,1	24,5	State of tide:	ebb
6T	0,060	1,60	0,025	0,010	7,8	96,4	8,8	33,6	25,2		spring
6B	0,030	2,10	0,014	0,012	7,6	93,5	8,8	33,9	24,9		
7T	0,060	1,50	0,025	0,006	7,2	89,9	8,8	34,1	25,8		
7B	0,150	1,90	0,020	0,010	7,5	92,5	8,8	34,0	25,0		
1	0,099	0,56	0,005	0,002	6,7	75,5	8,6	34,3	19,8	Sampling date:	11/12/89
2	0,159	1,00	0,005	0,005	6,7	76,5	8,7	32,6	20,5	Sampling time:	evening
3	1,180	1,10	0,004	0,002	6,0	68,1	8,7	32,8	20,2	High tide:	20:54
4	0,168	1,20	0,005	0,002	6,0	69,8	8,6	34,1	21,6	Low tide:	04:12
5	0,150	1,10	0,004	0,003	6,5	74,6	8,7	33,7	20,8	State of tide:	ebb
6T	0,120	1,10	0,003	0,003	5,8	69,3	8,8	32,9	23,1		spring
6B	0,228	1,30	0,003	0,003	5,4	62,7	8,8	33,8	21,5		
7T	0,099	1,30	0,005	0,006	5,5	66,6	8,7	32,6	23,9		
7T	0,090	1,30	0,002	0,005	5,3	62,1	8,7	34,2	22,0		
1	0,069	0,50	0,025	0,003	6,6	75,1	8,5	34,5	20,3	Sampling date:	12/12/89
2	0,159	1,20	0,023	0,007	6,6	82,6	8,7	33,5	26,0	Sampling time:	morning
3	0,168	1,90	0,022	0,004	6,9	82,1	8,6	34,1	22,9	High tide:	15:18
4	0,129	1,70	0,024	0,003	5,7	72,1	8,6	34,3	26,6	Low tide:	09:03
5	0,108	1,50	0,024	0,005	6,5	78,4	8,6	34,1	23,7	State of tide:	flood
6T	0,210	1,80	0,027	0,006	5,8	71,5	8,6	33,6	25,0		spring
6B	0,009	1,70	0,025	0,007	5,6	68,5	8,7	34,1	24,5		
7T	0,090	1,40	0,025	0,005	5,9	72,2	8,7	34,0	24,6		
7B	0,129	1,80	0,024	0,007	6,0	73,0	8,8	34,1	24,2		
1	0,999	0,82	0,004	0,003	7,3	81,7	8,8	35,0	19,5	Sampling date:	19/02/90
2	n.d	1,00	0,000	0,005	6,3	75,2	8,3	35,5	23,0	Sampling time:	afternoon
3	0,369	1,40	0,002	0,004	6,9	82,3	8,1	34,5	23,0	High tide:	10:18
4	0,219	1,50	0,003	0,004	6,2	75,2	8,1	37,0	24,0	Low tide:	18:11
5	n.d	1,50	0,002	0,005	6,3	76,4	7,8	35,0	24,0	State of tide:	ebb
6T	0,168	1,50	0,000	0,004	6,7	83,9	7,8	32,5	26,0		neap
6B	0,228	1,50	0,050	0,006	6,2	76,4	7,9	35,0	25,0		
7T	n.d	1,20	0,000	0,005	6,1	75,8	7,9	37,0	25,5		
7B	0,360	1,30	0,003	0,005	6,7	82,6	8,3	36,0	25,0		
1	0,234	0,58	0,005	0,006	7,3	81,0	8,7	35,5	19,0	Sampling date:	09/03/90
2	0,390	1,76	0,002	0,003	6,3	72,6	9,1	35,0	21,0	Sampling time:	morning
3	0,060	1,80	0,003	0,004	6,9	79,5	9,0	35,0	21,0	High tide:	15:04
4	n.d	1,50	0,002	0,029	6,2	72,7	8,9	35,0	22,0	Low tide:	08:59
5	0,219	1,60	0,003	0,005	6,3	73,2	9,0	35,0	21,5	State of tide:	flood
6T	0,168	2,00	0,003	0,005	5,7	67,4	8,9	34,5	22,5		spring
6B	0,408	1,50	0,005	0,006	6,2	73,3	9,0	35,0	22,5		
7T	0,249	1,70	0,005	0,007	6,1	71,5	9,0	36,0	22,0		
7B	0,489	1,60	0,001	0,009	6,7	79,2	9,0	36,0	22,5		

Nitrogen values as nitrites and ammonia were uniformly low (<0,027 and <0,029 mg.ℓ^{-1} respectively) in the marina canal stations during the study period (Table 1). This is usually the case in well oxygenated waters in which the reduced forms of inorganic nitrogen are rapidly oxidised to nitrate. NH_4-N concentrations in the marina canals ranged between 0,002 and 0,029 mg.ℓ^{-1} with a mean of 0,005 mg.ℓ^{-1} (n=56, SE=0,001), whilst NO_2-N levels ranged from 0 to 0,027 mg.ℓ^{-1} with a mean of 0,011 mg.ℓ^{-1} (n=53, SE=0,001). Highest values of nitrite were recorded at all sampling stations on the morning of 11/12/89, which corresponds with relatively high values of nitrates (Table 1). Although ammonia and nitrite levels fluctuated spatially and temporally no clear pattern of variation is evident from the results.

Nitrogen concentrations as nitrate show a different picture. The lowest nitrate concentrations in the marina (<1,0 mg.ℓ^{-1}) were recorded during November prior to the holiday season, but increased during December and remained above 1,4 mg.ℓ^{-1} in February and March. No clear pattern of variation is evident among the sampling stations in the marina canals. NO_3-N concentrations varied between 0,50 and 2,00 mg.ℓ^{-1}, with an overall mean of 1,300 mg.ℓ^{-1} (n=56, SE=0,058) in the marina canals. The results also indicate consistently lower nitrate levels at Station 1, situated in the estuary (Fig. 1) in comparison to those measured results also indicate consistently lower nitrate levels at Station 1, situated in the estuary (Fig. 1) in comparison to those measured at the stations in the marina canals.

Coliform bacteria

Total faecal coliform and *E. coli* counts in the marina canals are summarised in Table 2. Coliform concentrations in the water were consistently low in all cases, with the exception of Station 2 where a total count of 140 faecal coliform·100 mℓ^{-1} was recorded on 12/12/89. All the coliform concentration values obtained during this study were within the range of coliform counts recorded in the Kromme and Sundays Estuaries by Emmerson and Erasmus (1987) and Emmerson (1989) respectively, but much lower than those in the Swartkops River which drains the densely populated areas of Uitenhage and Port Elizabeth (Emmerson, 1985).

Discussion

The temperature and salinity recorded in the marina during the study period fall within annual ranges measured in the Kromme (Hanekom and Baird, 1984), Swartkops (Emmerson, 1985) and Sundays Rivers (Harrison and Whitfield, 1990) respectively. The mean summer temperature in the marina (21,7°C) falls within the summer temperature range recorded by Emmerson and Erasmus, 1987) for the entire Kromme Estuary. There also appears to be little difference between the mean pH measured in the marina and at the above-mentioned estuaries (Emmerson, 1989).

The annual salinity range in the Kromme Estuary and in the marina is higher than in the Swartkops and Sundays Estuaries, mainly due to reduced fresh-water inflow into the Kromme Estuary since the construction of the Charlie Malan Dam in 1983 (Anon, 1990), whilst no fresh-water streams discharge into the marina system.

There appears to be little difference between the dissolved oxygen concentrations, which are within 20% saturation at the respective mean temperatures in the three estuaries. Oxygen saturation levels during the study period ranged in the marina between 62% and 116% (Table 1), with a mean saturation of 75% (at a mean temperature of 21,7°C which is slightly lower than in the other 3 estuaries. Lower oxygen saturation levels in the marina can be ascribed to slower current velocities and less dynamic mixing in particularly the upper reaches of the canal system (Baird et al., 1981), and possibly to decaying plant material which was observed on the bottom of some stations in the marina. Signs of widespread anaerobic conditions such as the release of H_2S and the absence of macro-invertebrates from the sediment were, however, not observed.

The mean total ammonia concentration of 0,005 mg.ℓ^{-1} in the marina is very similar to the mean value of 0,003 mg.ℓ^{-1} determined for the entire estuary by Emmerson and Erasmus (1987). Both these values are, however, lower than the mean values of 0,100 mg.ℓ^{-1} obtained in the mouth of the Swartkops Estuary (Baird and Winter, 1990), 0,204 mg.ℓ^{-1} for the entire estuary (Emmerson, 1985), and 0,041 mg.ℓ^{-1} for the Sundays Estuary (Emmerson, 1989). The ranges of ammonia concentrations of 0,023 to 0,1921 mg.ℓ^{-1} measured in the Bot River estuary (Koop et al., 1983) and in the Tamar Estuary, England, of 0,001 to 0,300 mg.ℓ^{-1} (Morris et al., 1985) are also higher than those recorded in the marina and the Kromme Estuary.

The mean NO_2-N concentration in the marina of 0,011 mg.ℓ^{-1} is much higher than the mean for the estuary of 0,005 mg.ℓ^{-1} (Emmerson and Erasmus, 1987), but is in the same order as the mean values of 0,013 mg.ℓ^{-1} and 0,018 mg.ℓ^{-1} reported for the Swartkops (Emmerson, 1985) and Sundays Estuaries (Emmerson, 1989) respectively. It also falls in the same range of 0,005 to 0,035 mg.ℓ^{-1} measured in the Tamar Estuary (Morris et al., 1985)

The mean nitrate level in the marina (1,300 mg.ℓ^{-1}) is substantially higher than the mean concentration of 0,064 mg.ℓ^{-1} determined by Emmmerson and Erasmus (1987) for the Kromme Estuary. It is also higher than the mean concentration values reported for the Swartkops Estuary (0,516 mg.ℓ^{-1}; Emmerson, 1985) and the Sundays Estuary (0,630 mg.ℓ^{-1}; Emmerson, 1989).

The mean concentration of 0,229 mg.ℓ^{-1} of soluble reactive phosphorus in the marina is approximately the same as the mean concentration of 0,233 mg.ℓ^{-1} recorded for the Sundays Estuary (Emmerson, 1989), but higher than that of the Kromme Estuary (0,121 mg.ℓ^{-1}; Emmerson and Erasmus, 1987). It is, however, much lower than the mean concentration of 1,320 mg.ℓ^{-1} measured in the Swartkops Estuary, which is ascribed to phosphorus enrichment from sewage inputs (Emmerson, 1985).

It has been shown that nutrient concentrations vary considerably in the waters of eastern Cape estuaries and in the marina as discussed above. The generally low concentrations in the Kromme Estuary (Emmerson and Erasmus, 1987) are most probably due to the absence of industrial and large-scale agricultural activities in the catchment (Bickerton and Pierce, 1988), as well as to the fact that the largest geological substrate in the Kromme River catchment is quartzite which is well leached, giving the soil a low nutrient content (Reddering and Esterhuysen, 1983). High levels of nitrates and phosphates could be expected in the estuaries of rivers which drain agricultural farmland where chemical fertilisers are applied to crops, as in the case of the Sundays Estuary (Forbes and Allanson, 1970), or in the Swartkops Estuary which receives also sewage and industrial effluents in addition to fertiliser runoff (Day, 1981; Lord and Thompson, 1988). The anomalously high levels of nitrate and phosphate concentrations in the marina canals as compared to the Kromme Estuary must thus be of local and anthropogenic origin for the following reasons:

- firstly, nitrate concentrations at Station 1, situated in the estuary, were consistently lower than those in the marina canals, which implies a limited riverine or marine nutrient input and;
- secondly, nitrate values were relatively low in the canals in November, before the onset of the summer holidays, but increased rapidly during December and remained high during February and March, during and after the 1989/90 holiday season.

The increase in population in the Marina Glades during these months is therefore likely to be largely responsible for the increase in nitrogen levels.

Two possible sources of nitrogen to the water in the canals are:

- chemical fertilisers applied to the gardens of water-front houses; and
- the seepage of organic nitrogen from septic tanks into the canals or transported by the underground phreatic layer.

Chemical fertilisers, which are commonly used in gardens, would

TABLE 2
CONCENTRATIONS OF TOTAL FAECAL COLIFORM AND *E. COLI* BACTERIA (n·100 mℓ⁻¹) IN THE MARINA CANAL WATERS, 1 NOVEMBER 1989 - MARCH 1990

	Stations								
	1	**2**	**3**	**4**	**5**	**6T**	**6B**	**7T**	**7B**
22/11/89									
Total faecal:	8	12	<10	3	1	4	7	<10	<10
E. coli:	3	12	5	2	0	4	5	4	7
12/12/89									
Total faecal:	10	140	2	5	6	5	7	12	3
E. coli:	1	53	2	2	3	2	7	9	3
20/02/90									
Total faecal:	0	14	0	0	0	6	0	1	0
E. coli:	0	3	0	0	0	5	0	1	0
09/03/90									
Total faecal:	3	8	0	0	2	4	0	3	4
E. coli:	0	5	0	0	0	1	0	0	4

TABLE 3
COMPARISON OF MEAN VALUES OF SOME ABIOTIC CHARACTERISTICS IN EASTERN CAPE ESTUARIES

Parameters	Kromme* mean	Swartkops+ mean	Sundays• mean	Marina# mean	
Temperature (°C)	17,8	19,6	19,3	21,7	(summer)
				17,8	(annual
Salinity (g·kg⁻¹)	25,8	22,9	20,5	32,4	
pH	8,0	8,1	8,2	8,3	
Oxygen (mg·ℓ⁻¹)	7,4	7,2	7,7	6,5	

* Emmerson and Erasmus (1987)
+ Emmerson (1985)
• Emmerson (1989)
This study

enter the canals through direct surface runoff. Nitrogen in domestic sewage is usually in the form of organic nitrogen, or in reduced form. Organic nitrogen is mineralised by bacteria to nitrate while ammonia and nitrites are also rapidly oxidised to nitrate, giving rise to the high nitrate concentrations in the marina.

Inorganic nutrients are not pollutants *per se,* and are not toxic in the concentrations measured in the marina canals. However, high nutrient levels (particularly nitrates) may facilitate the formation of phytoplankton blooms as well as the growth of macro-algae in the canals. Subtidal vegetation has increased dramatically in the last few years and dense beds of *Caulerpa filiformis, Codium* spp. and *Zostera capensis* occur in some canals; the growth of these algae may be the result of nutrient-enriched ground water entering the canals (Baird et al., 1981; Talbot and Knoop, 1989). A complex and diverse community of fauna is usually associated with these macro-algae which possibly provide an excellent nursery ground for juvenile fish (Hanekom and Baird, 1984). Phytoplankton blooms have not been observed during the study period.

Coupled with inefficient water exchange in the canals and thermal or saline stratification of the water column, decaying plant material could give rise to anoxic conditions and subsequently to the mortality of fish and benthic animals. Macro-algae also trap sand particles and contribute to the accretion of sediment in the canals.

Faecal coliform and *E. coli* bacteria are convenient indicators of sewage contamination as they are mainly derived from the digestive tracts of warm-blooded animals (Lord and Thompson, 1988). Ninety-six per cent of the total faecal coliform values (in Table 2) do not exceed 100 faecal coliform.100 mℓ⁻¹ whereas the water quality criteria for the South African coastal zone stipulate that 50% of the values should not exceed 100 bacteria.100 mℓ⁻¹ (Lusher, 1984). It would thus appear that the concentrations of faecal coliform bacteria in the marina are well within the limits established for recreational use of sea water and for edible filter-feeding organisms (Lusher, 1984).

The mean number of 4 *E. coli*.100 mℓ⁻¹ in the marina is also lower than the mean values of 26, 640 and 18 (all.100 mℓ⁻¹) reported for the Kromme (Emmerson and Erasmus, 1987), Swartkops (Emmerson, 1985) and Sundays (Emmerson, 1989) Estuaries respectively. The low coliform levels in the marina would indicate that the septic tank system employed in the area is capable of disposing of the domestic sewage at the peak of the holiday season, and that raw sewage does not leach into the canals. Also, foul odours and the accumulation of floating detritus, which are characteristic of this type of pollution, were not encountered during the study period.

The biotic communities of the marina canals have been studied in some detail by Baird et al. (1981)and more recently by Heymans (1990), Groeneveld (1990) and Cloete (1990). These results showed that the biota do not seem to have been affected by changes in the system, when compared to the earlier work of Baird et al. (1981). The Marina Glades in the Kromme Estuary is primarily a marine-dominated system and functions essentially as an integral part of the estuary (Baird et al., 1981; Bickerton and Pierce, 1988). It is also clear that, with the exception of elevated nitrate and phosphorus levels in the marina, most of the abiotic measurements fall within the same range as for the whole Kromme and other eastern Cape estuaries.

In the absence of obvious sources of external pollutants, the stability and viability of biological communities in artificial canal systems, which are tidally dominated, will ultimately depend on two factors:

- firstly, an efficient turnover and flux of water through the canals; and
- secondly, the presence at all times of well oxygenated water (IAWPRC and AWWA, 1988).

In the case of the Marina Glades canals this is a subject of concern. Although net sedimentation in the mouth region of the Kromme Estuary appears to be insignificant (Anon, 1990), the redistribution of sand in this area has caused the closure of the seaward access canal during recent years. This had led to a less effective tidal flushing of the marina waters and an increase in the residence time of water in the canals. It has been determined by means of a hydrodynamic simulation model of the marina (Anon, 1990) that the concentration of a pollutant, released for example at Stations 2, 4 and 7 (Fig. 1), will be diluted by 100%, 68% and 25% respectively after about 11 tidal cycles (or 5,25 d). When both inlets of the marina are open to the estuary, the dilution rate at Stations 4 and 7 then increases 97% and 50% respectively. These results clearly indicate the vulnerability of the marina to pollution and to the importance of maintaining good water quality in coastal marina systems.

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