The nutrient status of the Swartkops River estuary, Eastern Cape

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Abstract

Surface and bottom water samples were taken along the length of the Swartkops River estuary at selected intervals during a two year period to ascertain the levels and distribution of the following parameters: temperature, salinity, pH, dissolved oxygen, total ammonia, nitrite, nitrate, soluble reactive phosphate (SRP), *total phosphorus, silicate and faecal E. coli.* Temperature, salinity and dissolved oxygen readings fell within the expected range. Sewage pollution in the upper reaches of the estuary resulted in the lowering of dissolved oxygen and pH levels and an increase in ammonia, nitrite, nitrate, phosphate and total phosphorus levels. Total ammonia (NH_3 - N + NH_4 - N) and nitrite (NO_2 - N) levels were generally below 30 $\mu g.\ell^{-1}$, but periodic high values at the head of the estuary caused these means to rise to 204 $\mu g.\ell^{-1}$ and 13 $\mu g.\ell^{-1}$ respectively. Mean nitrate (NO_3 - N), phosphate (PO_4-P,), total phosphorus (tot. P) and silicate ($HSiO_3$) levels were high (516, 1 324, 1 498 and 1 943 $\mu g.\ell^{-1}$ respectively). *E. coli* levels were generally low, but periodic pulses associated with heavy runoff and sewage overflow raised the mean value to 6,4 x 10^2 . 100 $m\ell^{-1}$. Nitrite, nitrate, phosphate, total phosphorus and silicate values were significantly higher at the head of the estuary than at the mouth. In the headwaters of the estuary only nitrate was significantly correlated with rainfall, while nitrite, nitrate and *E. coli* were positively correlated with river flow and phosphate was negatively correlated to river flow. Two 24h sampling series were conducted at the Swartkops mouth. Nutrient levels oscillated with the tide, with phosphate, silicate, ammonia, *nitrite and nitrate peaks at the end of the ebb-tides.* Nett exports were registered for ammonia, nitrite, nitrate, phosphate and silicate with total nutrient exports of 4,7 to 6,8 $t.d.^{-1}$.

Introduction

Estuaries are ecosystems of high productivity as nutrients are flushed into them (Naiman and Sibert, 1978). Such ecosystems form nutrient "traps" or "sinks" (Hobbie *et al.*, 1975; Day, 1981a) as these nutrients are adsorbed or absorbed and later released by sediments (Nedwell, 1982) and estuarine flora (Taft, 1975; Smith, 1978). As nutrients form the basis to productivity through the food web (Odum, 1971) and because estuaries are known to be subject to seasonal pulsation in nutrient loads and concentrations (Fraser and Wilcox, 1981; Mulholland *et al.*, 1981), it is essential to have a knowledge of the composition, levels and tempo-spatial dynamics of these nutrients in estuarine systems.

A two year study was undertaken on three Eastern Cape estuaries namely the Swartkops, Sundays and Kromme in order to better understand the nutrient status and dynamics of these locally important systems. This paper deals with the first system, namely the Swartkops River estuary.

The Swartkops is one of the largest and best known estuaries of the Eastern Cape. It is 155 km long with a catchment area of 1 438 km^2 (Heydorn and Tinley, 1980), with a mean annual precipitation of 636 mm and a mean annual runoff (MAR) of 84,15 x $10^6 m^3$ (*Noble and Hemens*, 1978). The only impoundment on the Swartkops is the Groendal Dam which supplies the industrial area of Uitenhage with water and governs the inflow of freshwater into the Swartkops estuary.

Although the estuary has been periodically sampled fo nutrients by Oliff (1976) and Vail (1983), little information has been published on its nutrient status. Day (1981b) noted that faecal *E. coli* counts were fairly low and that the nutrient concentrations were of the order of 700μg PO_4-P.ℓ^{-1} and 1 300μg NO_3 - N.ℓ^{-1}.

In this paper various physico-chemical parameters including faecal *E.coli* levels of Swartkops estuarine water were examined over two years. In addition two 24h sampling studies were conducted at the Swartkops mouth in order to obtain information on the flux of nutrients between the estuary and adjacent coastal waters.

Material and methods

The Swartkops River discharges into Algoa Bay via its 16km long estuary, just north of Port Elizabeth (34°00'S, 24°30'E). Five sites were selected along the length of the estuary for regular bi-monthly sampling from June, 1979 to October, 1981 (Fig. 1). Surface and bottom water samples were taken during spring low tide and introduced into 250 $m\ell$ polyethylene bottles. The following parameters were measured on site: temperature (mercury thermometer), salinity (refractometer) and dissolved oxygen (YSI model 57 field instrument). Samples were then stored in crushed ice during transportation to the laboratory. pH was measured on return to the laboratory using a Metrohm E396B pH meter. All instruments were calibrated prior to use. Total ammonia (as NH_3 - N + NH_4 - N), nitrite (as NO_2 - N), nitrate (as NO_3 - N), phosphate (as soluble reactive phosphate, SRP) and total phosphorus (all measured as $\mu g.\ell^{-1}$) were analysed using the methods of Solorzano (1969), Bendschneider and Robinson (1952), Wood *et al.* (1967), Strickland and Parsons (1972) and Menzel and Corwin (1965) respectively, measured as absorption on a Pye Unicam model SP6-550 spectrophotometer set to the appropriate wavelengths. From October, 1980, silicate (as $HSiO_3$) was analysed on a Tecnicon Auto Analyser using the standard Tecnicon method. Samples for faecal *E. coli* I were collected in sterile wide-necked glass bottles and enumerated in the laboratory using the indole test (South African Bureau of Standards, 1971)

All data resulting from these measurements and analyses were stored on computer. For presentation, data was rationalised by combining surface and bottom values into winter (April

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to September) and summer (October to March) groups. Three-dimensional diagrams were interpolated using a Tectronix plotting terminal which relayed to a Tectronix plotter.

Two 24h sampling studies were conducted, the first during a spring tide on the 28/10/80 and the second during a neap tide on the 8/10/81. A sampling station was established in mid-channel in the Swartkops mouth (station 1; Fig. 1) by securing a buoy to a heavily weighted anchorage. Surface and bottom water samples were collected every 1,5h from a boat and temperature, salinity, pH and current velocity (calibrated OGAWA SEIKI model OSK861 current meter) recorded. Water samples were stored on ice and analysed for total ammonia, nitrite, nitrate, phosphate and silicate as previously described. Nutrient flux was estimated after Boon (1978) and Kjerve and McKellar (1980). The cross-sectional areas for each sampling interval were computed from a programme using tidal height from the Port Elizabeth harbour.

Results

Temperature

Recorded temperatures ranged from 10,9°C in winter to 25,7°C in summer (Table 1) with an overall mean of 19,6°C (n = 150, S.E. = 0,3) for the estuary. During summer the headwaters were

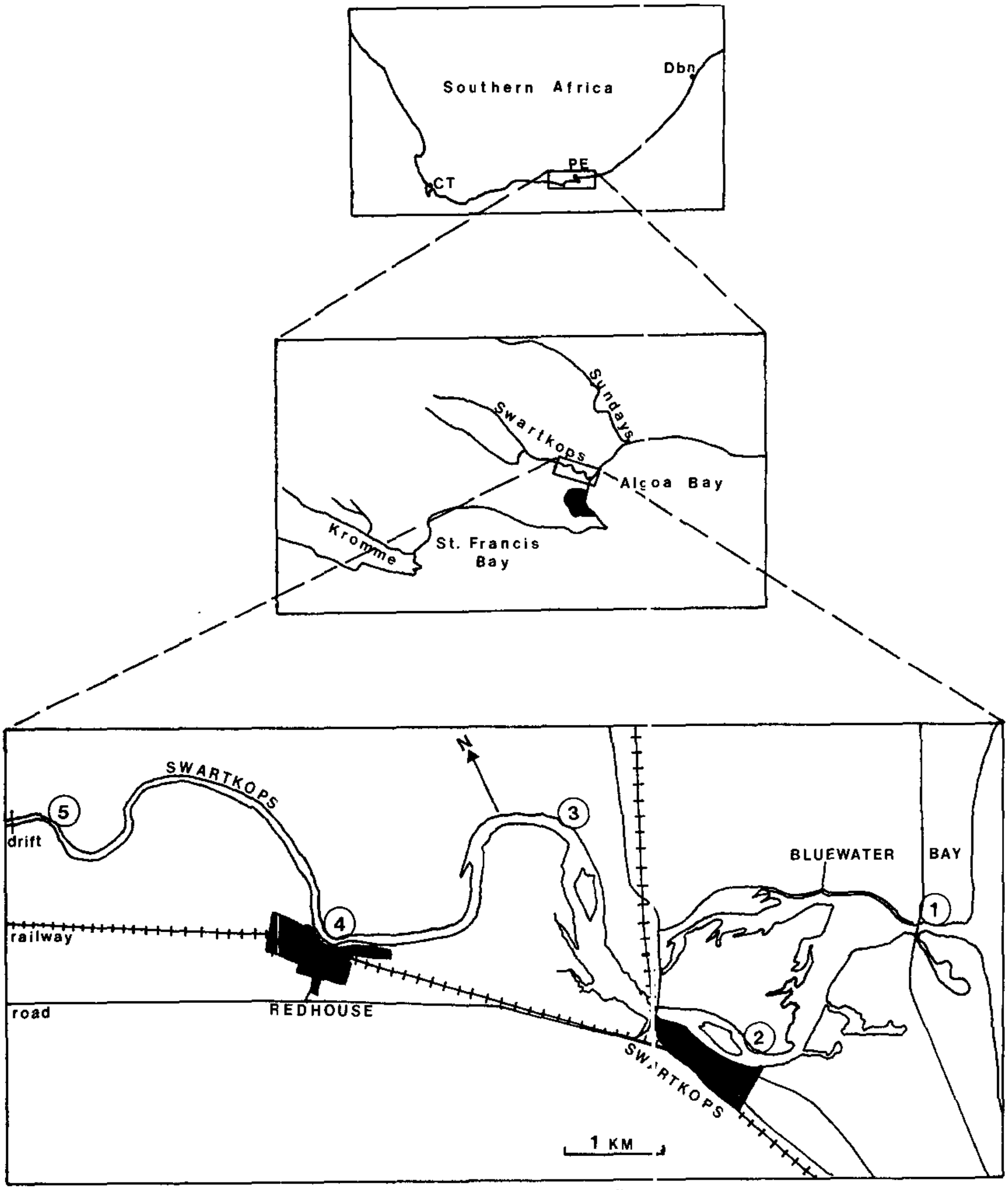

Figure 1
Location of sampling sites along the length of the Swartkops River estuary.

TABLE 1
A SYNOPSIS OF SUMMER AND WINTER PHYSICO-CHEMICAL DATA FOR 5 STATIONS ALONG THE SWARTKOPS RIVER ESTUARY FROM JULY 1979 TO OCTOBER, 1981. MEANS ($\bar{x}$), STANDARD ERRORS (S.E.) AND RANGES ARE GIVEN. ASTERISK DENOTES PEAK LEVELS INDICATING POINT-SOURCE POLLUTION

		Station																			
		1				2				3				4				5			
		$\bar{x}$	S.E.	range	n	$\bar{x}$	S.E.	range	n	$\bar{x}$	S.E.	range	n	$\bar{x}$	S.E.	range	n	$\bar{x}$	S.E.	range	n
TEMPERATURE °C	Summer	21,1	0,5	18,2-23,3	14	22,7	0,6	18,8-25,1	14	22,6	0,6	18,0-25,0	14	22,3	0,6	18,1-25,0	14	23,2	0,5	20,4-25,7	14
	Winter	17,3	0,7	11,5-20,7	16	18,4	0,7	12,6-21,9	16	16,8	0,8	11,7-21,1	16	16,2	0,7	10,9-19,8	16	16,6	0,7	11,8-19,5	16
SALINITY $^0/_{oo}$	Summer	34,1	0,3	32-36	14	31,0	1,9	9-37	14	26,4	3,2	0-37	14	26,6	2,4	0-35	14	20,5	2,8	0-30	14
	Winter	26,7	3,3	0-36	16	24,1	3,6	0-36	16	17,6	3,3	0-33	16	14,6	3,2	0-32	16	10,8	2,9	0-30	16
pH	Summer	8,1	0,1	7,9-8,3	14	8,1	0,0	8,0-8,3	14	8,1	0,0	7,9-8,3	14	8,0	0,1	7,8-8,2	14	8,0	0,1	6,7-8,6	14
	Winter	8,0	0,1	7,8-8,4	16	8,0	0,1	7,6-8,6	16	8,1	0,1	7,7-8,9	16	8,1	0,1	7,6-9,1	16	8,1	0,2	7,6-9,2	16
TOTAL AMMONIA $\mu g.\ell^{-1}$	Summer	13,1	7,9	0,3-90,0	14	24,2	13,2	0,5-140	14	26,5	14,9	0,8-180	14	36,2	20,1	0,3-240	14	1170	118,4	0,4-15700*	14
	Winter	32,4	19,1	1,3-290,0	16	24,4	12,6	1,3-180,0	16	23,4	11,2	0-160	16	40,3	26,8	0-430	16	680,4	623,0	0-10000	16
OXYGEN $mg.\ell^{-1}$	Summer	6,8	0,2	5,3-7,8	14	6,4	0,1	5,9-6,9	14	6,4	0,2	5,6-7,6	14	6,3	0,3	4,3-8,0	14	6,0	0,3	3,5*-7,7	14
	Winter	8,0	0,2	6,8-10,2	16	7,4	0,3	4,7-9,8	16	7,9	0,4	5,9-10,6	16	8,0	0,4	6,0-10,5	16	8,0	0,5	1,8-11,0	16
NITRITE $\mu g.\ell^{-1}$	Summer	2,8	0,4	1,0-5,5	14	7,0	1,5	2,2-20,0	14	8,1	2,9	3,3-45,0	14	11,5	4,7	1,8-70,0	14	24,9	14,2	2,7-208,0*	14
	Winter	6,6	1,0	0,4-12,0	16	8,7	1,2	2,4-17,0	16	11,2	2,3	2,0-29,0	16	13,8	3,4	1,4-50,0	16	33,1	9,6	2,2-123,0	16
NITRATE $\mu g.\ell^{-1}$	Summer	37	8	10-110	14	83	20	20-282	14	179	66	29-990	14	275	110	2-1430	14	386	138	8-1752	14
	Winter	434	170	5-2120	16	501	167	106-2324	16	823	165	200-2230	16	913	157	208-2153	16	1255	245	217-3240*	16
PHOSPHATE $\mu g.\ell^{-1}$	Summer	236	20	160-360	14	614	58	290-1100	14	1217	113	850-1900	14	2019	291	1000-4950	14	4210	796	2200-13150*	14
	Winter	318	35	37-450	16	494	49	90-760	16	891	97	380-1600	16	1228	172	350-2650	16	2227	498	320-6750	16
TOTAL PHOSPORUS $\mu g.\ell^{-1}$	Summer	339	32	190-500	14	763	65	320-1150	14	1335	93	710-2060	14	2096	269	1140-5100	14	4436	861	1860-13900*	14
	Winter	463	38	185-740	16	631	47	320-960	16	1051	89	630-1720	16	1445	175	642-3120	16	2602	488	516-7000	16
SILICATE $\mu g.\ell^{-1}$	Summer	538	57	270-700	8	1085	106	750-1450	8	1631	304	520-2905	8	1940	339	950-3545	8	2241	372	820-3850	8
	Winter	1292	462	500-3050	6	1967	585	650-3750	6	2950	564	1150-4150	6	3275	628	1150-4750	6	3275	608	1200-4450	6
FAECAL *E. coli* $n.100m\ell^{-1}$	Summer	29	13	2-70	5	63	34	2-190	5	71	35	2-198	5	165	100	2-500	5	872	522	2-2790	5
	Winter	1083	569	0-6020	11	1163	891	6-9900*	11	723	540	4-6000	11	417	359	2-4000	11	721	311	7-3000	11

warmer than the mouth region, while in winter there was a temperature reversal with the mouthwaters generally warmer than the headwaters. Surface and bottom temperatures were very similar. At station 2 temperatures were generally 1 - 3 °C higher than station 1.

Salinity

Salinity ranged from 0 to 37 °/ooS. A permanent salinity gradient existed between the head and the mouth of the estuary indicating a continuous input of freshwater into the system. Salinities at the head (station 5) never rose above 30 °/ooS (Table 1). During 1980 salinities were relatively stable and high, but in July 1979 and January, March and June 1981, heavy rainfall and subsequent riverflow caused the estuary to become more fresh (Table 1), lowering the overall mean salinity for the estuary to 22,9 °/ooS ($n = 150$; S.E. = 1,1). Mean winter salinities were generally lower than those for summer.

pH

A mean pH value of 8,1 ($n = 150$; S.E. = 0,02) was obtained for the estuary, with a range of 6,7 to 9,2. A variation in pH value was found between the mouth and the head. Values were generally higher at the head although reversals in pH values were recorded during summer (Table 1). A greater difference in pH value was observed between surface and bottom waters in the upper reaches of the estuary (Table 1).

Dissolved oxygen

The Swartkops appears to be generally well oxygenated with an overall mean of 7,2 $mg.\ell^{-1}$ ($n = 150$; S.E. = 0,12; range = 1,8 to 11,0 $mg.\ell^{-1}$; Table 1) for the estuary. Oxygen levels displayed a seasonal pattern with high winter values and lower summer values, a pattern which reciprocated temperature (Table 1). Bottom values were usually slightly lower than surface readings, especially at station 5 where bottom values were low during November 1979, August 1981 and October 1981. A pulse of poorly oxygenated water was also recorded locally at station 2 during July 1979.

Total ammonia

Ammonia levels were generally low ($< 30 \mu g\ell^{-1}$), but high values, in bottom waters at station 5 during August and October 1981 (Table 1), elevated the overall mean for the estuary to 204 $\mu g.\ell^{-1}$ ($n = 150$; S.E. = 124; range = 0 to 15 700 $\mu g.\ell^{-1}$). Little difference was found between surface and bottom values except when organic decay on the bottom was evident (cf. station 5; Table 1).

Nitrite

Nitrite levels were generally below 10 $\mu g.\ell^{-1}$. However, high values at the head of the estuary during September 1979, August 1981 and October 1981 caused the overall mean level to be elevated to 12,9 $\mu g.\ell^{-1}$ (n = 150; S.E. = 1,9; range = 0,4 to 208 $\mu g.\ell^{-1}$). There was little seasonal difference, or difference between surface and bottom waters near the mouth, but towards the head of the Swartkops, surface values were slightly higher (Table 1) especially during periods of strong nutrient influx.

Nitrate

Nitrate levels ranged from 2 to 3 240 $\mu g.\ell^{-1}$ (Table 1) with a mean of 516,4 $\mu g.\ell^{-1}$ (n = 150; S.E. = 55,5) for the estuary. Summer values were generally lower than winter ones (Table 1; Fig. 2). A consistent nitrate gradient existed between the head and the mouth of the Swartkops estuary (Table 1) which steepened during winter (Fig. 2). After flooding and strong riverflow, high nitrate values were found throughout the estuary. There was little difference in $NO_3 - N$ between surface and bottom waters, except at stations 4 and 5, where surface values were generally slightly higher.

Phosphate

Phosphate levels were generally high, with a mean of 1 320 $PO_4 - P$ (n = 150; S.E. = 133) and a range 37 to 13 150 (Table 1). A phosphorus gradient predominated between the head and the mouth (Table 1), as was found for nitrate, and appeared to steepen during spring (Fig. 3). During flood conditions and high river discharge, however, phosphate levels declined throughout the estuary (Fig. 3). Discernable differences in phosphate were measured between surface and bottom waters. At the top of the estuary (stations 4 and 5) surface phosphate levels were higher than levels at the bottom; in the middle reaches (station 3) surface and bottom values were similar; while in the lower reaches near the mouth phosphate levels were generally higher in bottom waters. Mean $PO_4 - P$ values were higher during summer than during winter (Table 1).

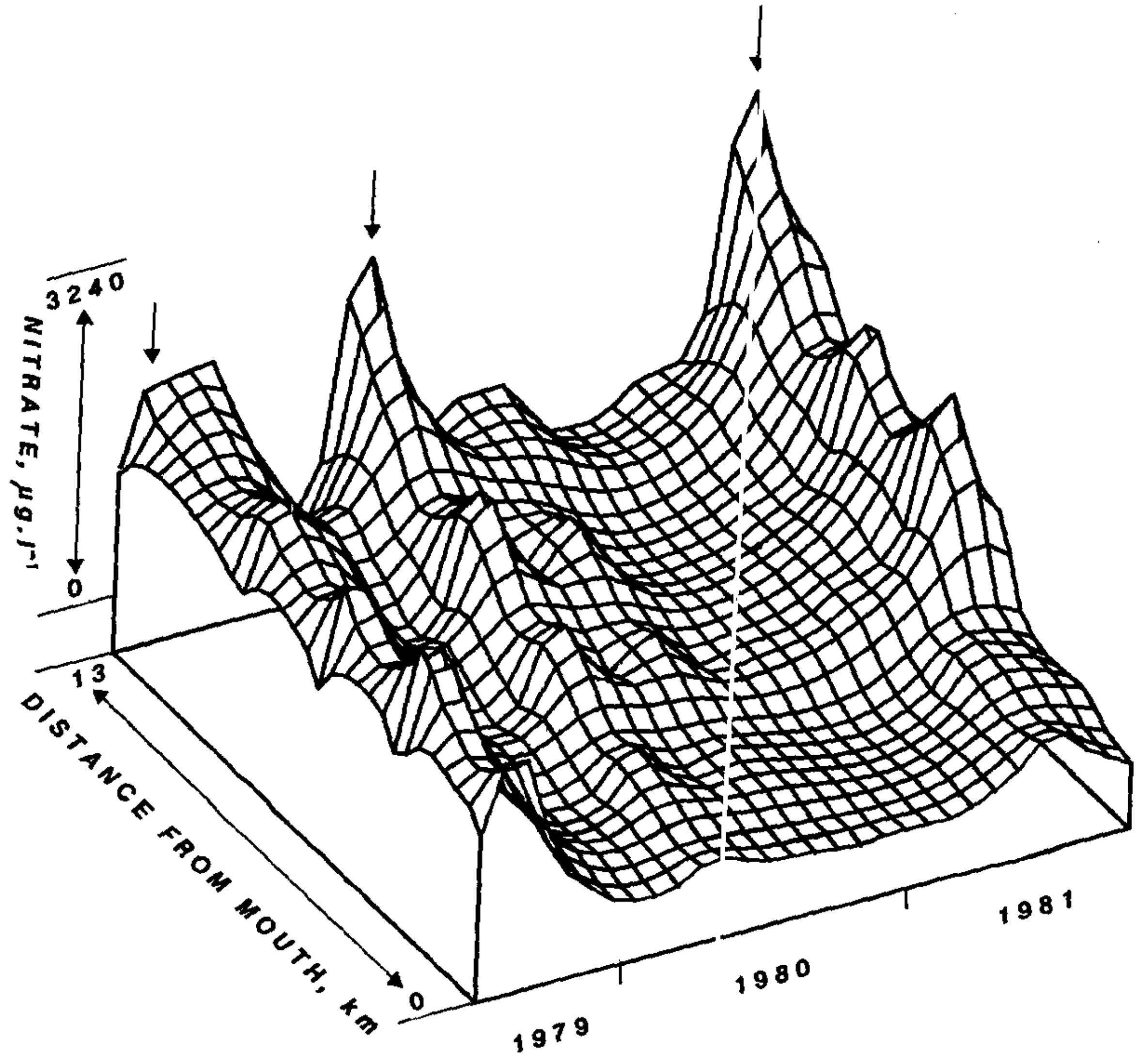

Figure 2
Surface nitrate ($\mu g.\ell^{-1}$ $NO_3 - N$) along the Swartkops estuary from July 1979 to October 1981. Arrows indicate periods of high river discharge.

Total phosphorus

The same trends that were found for phosphate were reflected for total phosphorus which had a mean of 1 498 $\mu g.\ell^{-1}$ (n = 150; S.E. = 138) and a range from 185 to 13 900 $\mu g.\ell^{-1}$ (Table 1). Total phosphorus levels were generally higher in surface waters from station 2 through to station 5, while there was little difference between surface and bottom phosphorus levels at the mouth, station 1. As with phosphate, total phosphorus levels were higher in summer than during the winter (Table 1).

Silicate

A range from 270 to 4 750 $\mu g.\ell^{-1}$, with a mean value of 1 843 $\mu g.\ell^{-1}$ (n = 70; S.E. = 159) was recorded for silicate in the estuary. A silicate gradient extended down the estuary from head to mouth (Table 1). Surface and bottom values were similar throughout the estuary, with surface readings generally slightly higher. Mean winter silicate values were higher than the mean summer levels (Table 1).

Faecal *E. coli*

Levels of faecal *E. coli* were spatially and temporally highly variable with counts ranging from 0 to 9 900.100$m\ell^{-1}$ (Table 1) with a mean of 640.100 $m\ell^{-1}$ (n = 80; S.E. = 177) for the estuary. Eighty-one per cent of the readings (65 out of 80) were lower than this mean showing that the readings were generally low and that the mean was weighted by sporadic pulses of *E. coli* into the estuary. These pulses were associated with heavy runoff, especially on the 25/7/79 and the 7/8/81 resulting in higher mean winter coliform counts than in summer (Table 1). Values were generally highest at the head of the estuary, but occasionally a higher reading was registered at the mouth (Table 1).

Nutrient gradients and input into the estuary

As gradients extended down the estuary for most of the nutrients measured, nutrients and *E. coli* at the mouth station (1) and the head station (5) were compared using a paired student's t-test. Nitrite, nitrate, phosphate, total phosphorus and silicate values were significantly higher ($p < 0,05$) at the head of the estuary, while ammonia and faecal *E. coli* levels were not significantly different ($p > 0,05$) (Table 2). As most of the nutrients appeared to be entering the estuary via the Swartkops River, these parameters were correlated with rainfall and riverflow (Table 3). Only nitrate levels were significantly correlated with rainfall ($p < 0,05$). Nitrite, nitrate, phosphate and *E. coli* were, nevertheless, significantly ($p < 0,05$) correlated with riverflow; nitrite, nitrate and *E. coli* positively and phosphate negatively, (Table 3). A high correlation coefficient (r = 0,784) was obtained for silicate, but it was not significant (p = 0,67) due to a small number of points. If mean head and mean mouth nutrient values are compared it can be seen that most of the nutrients are absorbed in the estuary, the percentage absorption ranging from 67,5% for silicate to 90,8% for phosphate, (Table 2), while the balance is exported. High *E. coli* levels at the mouth resulted in little difference between head and mouth stations (Table 2).

TABLE 2

PAIRED T-TESTS BETWEEN THE MOUTH (STATION 1) AND THE HEAD (STATION 5) OF THE SWARTKOPS RIVER ESTUARY FOR SURFACE SAMPLES FROM JULY 1979 TO OCTOBER 1981 TO INDICATE ANY DIFFERENCES IN NUTRIENT AND FAECAL *E. coli* LEVELS. DEGREES OF FREEDOM (d.f.) = n − 1. PERCENT ABSORBED IS THE MEAN PERCENTAGE DIFFERENCE BETWEEN THE HEAD AND THE MOUTH INDICATING ABSORPTION ALONG THE ESTUARY AS A NETT GAIN. PERCENT EXPORTED IS THE DIFFERENCE INDICATING A NETT LOSS FROM THE ESTUARY. NS = NOT SIGNIFICANT; S = SIGNIFICANT AT THE 95% LEVEL (p = 0,05).

Parameter	t	d.f.	Significance	p	% Absorbed	% Exported
Ammonia	1,52	14	NS	0,12	80,2	19,8
Nitrite	2,36	14	S	0,03	88,4	11,6
Nitrate	2,63	14	S	0,02	73,4	26,6
Phosphate	5,08	14	S	<0,01	90,8	9,2
Total phosphorus	5,34	14	S	<0,01	88,1	11,9
Silicate	4,25	14	S	<0,01	67,5	32,5
E. coli	0,05	14	NS	0,39	2,0	98,0

Nutrient flux at the Swartkops mouth

During the first 24h series (spring-tide) current velocity, temperature, and to a slight extent, salinity changed with the tide, as has already been reported by Emmerson (1983). Generally pH values increased with the flood-tides and declined with the ebb-tides. Phosphate, silicate, ammonia, nitrite and nitrate values changed with the tide to peak at the end of the ebb-tides and decline with the incoming flood-tides (Fig. 4). Only slight differences were found between surface and bottom waters due to turbulent mixing in the mouth.

During the second 24h series (neap-tide) current velocities were lower, but temperature, salinity and changes in pH values, were marked (Emmerson, 1983). Nutrient levels oscillated with the tide, as was observed previously, with high phosphate, silicate, ammonia, nitrite and nitrate peaks at the end of the ebb-tides which subsequently declined during the ensuing flood-tides (Fig. 5).

The flux of these nutrients in and out of the Swartkops mouth during both the spring-tide and neap-tide series was calculated in Table 4. Nett exports were registered for ammonia, nitrite, nitrate, phosphate and silicate, with total nutrient exports of 6,83 tonnes per day during spring-tide and 4,71 tonnes per day during neap-tide.

From the mean nitrate and mean phosphate levels a N:P ratio of 0,39 : 1 is obtained. If total inorganic nitrogen (ammonia, nitrite and nitrate) is compared with total phosphorus an N:P ratio of 0,49 : 1 is obtained.

Discussion

General

Temperatures at station 2 were generally 1 to 3 °C warmer than station 1. This was due to warm water effluent from the Swartkops power station which discharges into the estuary approximately 1,5 km above station 2. As the estuary was sampled during spring low tide, the plume was directed downstream past station 2.

The Swartkops experiences regular flooding from which it recovers fairly quickly, as the mouth is permanently open (Day, 1981b) and it has a relatively large tidal prism (Uncles, 1983). There was little difference between surface and bottom salinities in the lower and middle reaches of the estuary due to wind and tidal mixing, but some stratification occurred in the upper reaches, as was also reported by Day (1981b). In the lower reaches of the estuary pH values were comparatively stable due to continual tidal flushing with fresh seawater which also has a buffering capacity (Day, 1981a), whereas in the fresher upper reaches the pH value variation was considerably higher. Cliff (1982) investigating the physico-chemical parameters of the Lourens estuary in the Western Cape similarly found that pH was generally higher in the headwaters. The mean pH value of 8,1 was considerably higher than that reported for Swartvlei (pH = 5; Howard-Williams, 1977) as the Swartkops does not carry as much humic material. The Uitenhage sewage works, tanneries and wool-washing plants periodically discharge organic pollutants into the Swartkops lowering the pH at station 5 (Table 1). The rapid decomposition of organic detritus on an estuary bed has been shown to lead to changes in pH values (Day, 1981a). A decline in the pH level was also recorded locally at station 2 during July 1979 as a result of anti-fouling chemicals discharged with the power station effluent. This discharge of chemicals also caused severe local oxygen depletion at station 2.

Nutrients

Organic pollution and subsequent bacterial activity at the head of the Swartkops estuary, especially during November 1979, August 1981 and October 1981 caused severe oxygen depletion in the head waters (Table 1). Day (1981a) observed that polluted water flowed into the Swartkops, but that deoxygenated water seldom reached the estuary. This pollution also resulted in extremely high levels of ammonia (Table 1), nitrite (Table 1), nitrate (Tabel 1; Fig 2), phosphate (Table 1; Fig 3) and total phosphorus (Table 1). Although fertilizer (Kollenbrander, 1977) and industrial waste water (Watling and Emmerson, 1981) are sources of nutrients as water pollutants, the cause of this incident of pollution was probably the overflowing of the Uitenhage sewage works following heavy rainfall as *E. coli* levels were also high during this period (Table 1). Decomposition of organic material could then maintain these high nutrient levels, especially ammonia. Eppley *et al.* (1979) for example found that 90% of the ammonia in coastal Southern Californian waters originated through decomposition of organic material, while human imports accounted for only 10%. High ammonia levels (760 $\mu g.\ell^{-1}$) have also been reported for the Mgeni estuary near Durban which also receives sewage effluent (Day, 1981a).

Nitrates

Levels of nitrate in the Swartkops were generally high (mean 516 $\mu g.\ell^{-1}$). Of ten Southern African estuaries, Day (1981a)

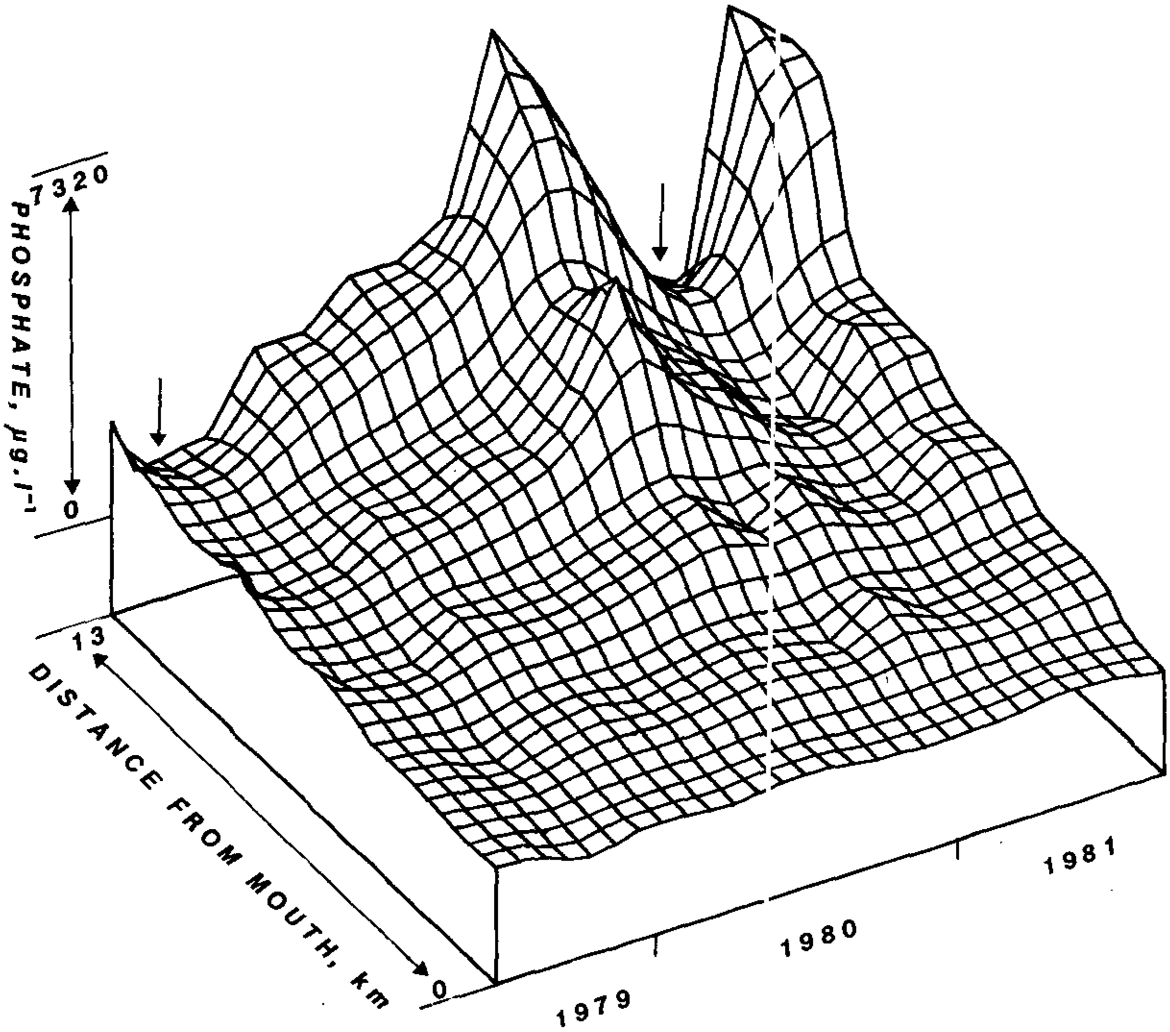

Figure 3
Surface phosphate ($\mu g.\ell^{-1}$ PO_4-P) along the Swartkops estuary from July 1979 to October 1981. Arrows indicate periods of high river discharge.

listed the Swartkops third after the Mgeni (winter, 1 400 – 1 455 $\mu g.\ell^{-1}$) and the Olifants (summer, 379 – 485 $\mu g.\ell^{-1}$). As mentioned previously, sewage is also pumped into the Mgeni, while upwelling affects the Olifants (Day, 1981a). Nitrate levels at the head of the Swartkops estuary were positively correlated with both rainfall and runoff (Table 3) and not just flood conditions suggesting that this nutrient has both a point source (e.g. from the sewage works) and a diffuse or non-point source (Omernik, 1977) as runoff from the catchment. Nitrate in urban runoff from areas such as Uitenhage probably also made a contribution (Roberts *et al.*, 1977).

Phosphates

Phosphorus levels were generally high in the Swartkops, especially at the head of the estuary (Table 1). Oliff (1976) obtained phosphate values of 157 – 593 $\mu g.\ell^{-1}$ for the Swartkops which Day (1981a) listed as the highest of 13 Southern African estuaries sampled. Phosphate removal during sewage treatment requires a special anaerobic phase (McLaren, 1979) which is not used at the Uitenhage sewage works (Vail, 1983). The high levels of phosphorus at the estuary-head could thus be attributed to the inflow of river water rich in phosphorus containing material. Phosphate rich material flocculates and is adsorbed onto particles of clay, silt and organic matter under saline conditions in estuaries (Day, 1981a). This could account for phosphate and total phosphorus being higher in surface waters than bottom waters at the head of the Swartkops and higher in bottom waters than surface waters in the lower reaches of the estuary. A significant exception was found during August and October 1981 when extremely high phosphorus levels (13 900 $\mu g.\ell^{-1}$ PO_4-P) were encountered in bottom waters at station 5 (Table 1), coinciding with conditions of low oxygen (3,5 $mg.\ell^{-1}$; Table 1). In Swartvlei, Silberbauer (1982) showed that phosphorus was only released from the sediment during anaerobic conditions.

A phosphate and total phosphorus gradient were found to exist along the length of the estuary (Table 1; Fig 3). Day (1981a) also noted this and observed that this was the only Southern

TABLE 3
CORRELATION BETWEEN VARIOUS NUTRIENT PARAMETERS AND FAECAL *E. coli* LEVELS AT THE HEAD OF THE SWARTKOPS ESTUARY WITH RAINFALL DURING THE PERIOD JULY, 1979 TO OCTOBER, 1981 AND WITH RIVERFLOW FROM JULY, 1979 TO NOVEMBER, 1980. DEGREES OF FREEDOM (d.f.) = n−1. NS = NOT SIGNIFICANT; S = SIGNIFICANT AT THE 95% LEVEL (p = 0,05).

	Parameter	Correlation		d.f.	F	Significance	Best Fit	p
		r	+/−					
RAINFALL	Ammonia	0,375	+	14	2,1	NS	Linear	0,17
	Nitrite	0,272	+	14	1,0	NS	Log	0,33
	Nitrate	0,554	+	14	5,8	S	Linear	0,03
	Phosphate	0,377	−	14	2,2	NS	Exponential	0,16
	Total phosphorus	0,383	−	14	2,2	NS	Exponential	0,16
	Silicate	0,418	−	14	1,1	NS	Log	0,31
	E. coli	0,431	+	14	3,2	NS	Power	0,10
RIVERFLOW	Ammonia	0,367	+	10	1,4	NS	Log	0,26
	Nitrite	0,669	+	10	7,3	S	Log	0,02
	Nitrate	0,859	+	8	19,7	S	Linear	<0,01
	Phosphate	0,599	−	10	5,0	S	Exponential	0,05
	Total Phosphorus	0,544	−	10	3,8	NS	Exponential	0,08
	Silicate	0,784	+	2	1,6	NS	Linear	0,67
	E. coli	0,725	+	9	8,9	S	Power	0,02

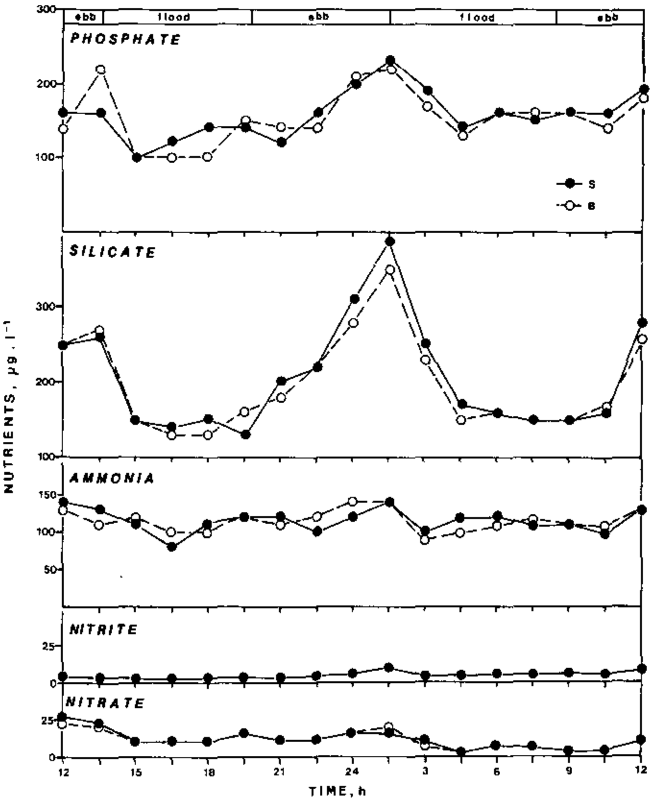

Figure 4
Surface (S) and bottom (B) phosphate, silicate, ammonia, nitrite and nitrate levels ($\mu g.\ell^{-1}$) in the Swartkops mouth during the first 24-h study (spring-tide).

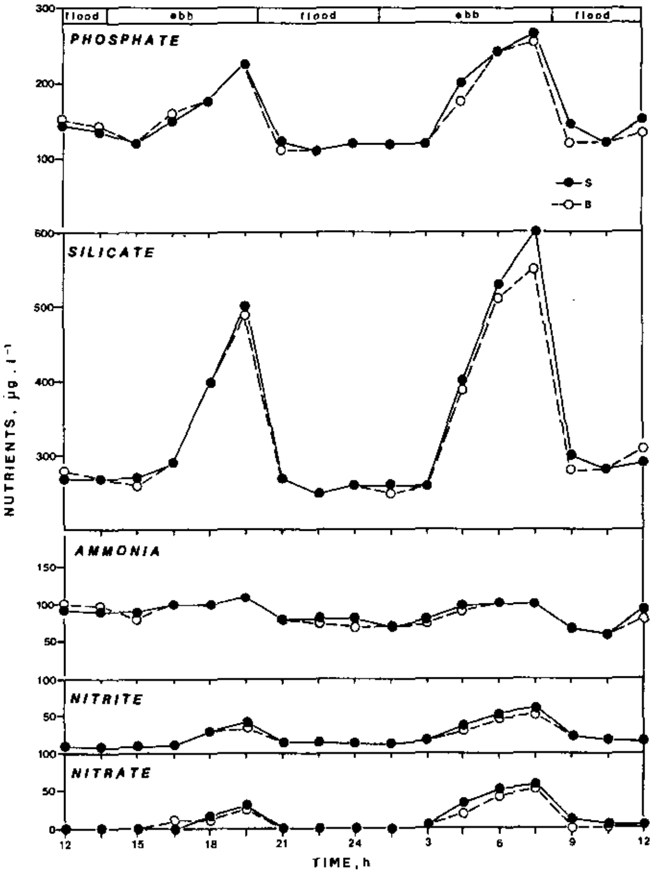

Figure 5
Surface (S) and bottom (B) phosphate, silicate, ammonia, nitrite and nitrate levels ($\mu g.\ell^{-1}$) in the Swartkops mouth during the second 24-h study (neap-tide).

TABLE 4
FLUX OF NUTRIENTS ($t.d.^{-1}$) IN AND OUT OF THE SWARTKOPS MOUTH DURING SPRING-TIDE (1st SERIES) AND NEAP-TIDE (2nd SERIES)

		NH_3-N	NO_2-N	NO_3-N	PO_4-P	$HSiO_3$	Total
1st Series	Out	11,15	0,36	1,03	14,99	20,87	
	In	*10,98*	*0,32*	*0,83*	*13,55*	*15,88*	
	Nett Export	0,17	0,04	0,20	1,43	4,99	*6,83*
2nd Series	Out	4,13	1,15	0,81	7,66	16,38	
	In	3,90	0,75	0,11	6,50	14,17	
	Nett Export	0,23	0,40	0,70	1,16	2,21	*4,71*

African estuary which displayed this pattern as although phosphate concentrations differ between estuaries, they are generally fairly constant within a particular estuary. Although phosphate levels were not correlated with rainfall they were negatively correlated with riverflow (Table 3) suggesting an accumulation of organic pollutants and phosphorus released during periods of low riverflow which is subsequently diluted during periods of high runoff.

Silicates

Silicate concentrations were shown to be higher in the headwaters of the Swartkops estuary than at the mouth (Tables 1 and 2) although no correlation was found with rainfall or riverflow (Table 3). Estuarine enrichment has, however, been shown to occur through seasonal pulses of nitrogen, phosphorus and silica associated with the summer wet season and riverflow (Fraser and Wilcox, 1981). Working on the dissolved silica (DS) distribution in San Francisco Bay, Peterson *et al.* (1975) similarly found that DS modulated seasonally with river discharge and DS utilization. Although silicate was only monitored in the Swartkops for approximately a year a seasonal cycle was apparent (Table 1) despite no correlation with rainfall or riverflow (Table 3). Given more data, a positive correlation could possibly have been obtained ($r = 0,78$; Table 3).

Faecal *E. coli*

Although no correlation was found between rainfall and *E. coli* levels in the estuary (Table 3), a significant positive correlation ($p = 0,023$) was obtained with riverflow (Table 3). Levels were particularly high during winter floods e.g. 25/7/79 and 7/8/81 (Table 1) when the Uitenhage sewage works overflowed. *E. coli* gradients were often seen in the Swartkops (Table 1) which may be explained in terms of distance from the source, tolerance and survival of the coliforms. High readings were occasionally encountered in the mouth (Table 1) and could be pollution from the sea. The Fishwater Flats sewage treatment works on the Swartkops flats discharges effluent from a pier pipeline approximately 2 km south of the Swartkops mouth. Although Emmerson *et al.* (1983) found *E. coli* levels to be acceptable here, this could change with treatment efficiency, effluent discharge volume and the direction of prevailing inshore currents.

Changes along length of the estuary

A significant difference ($p<0,05$) was found between head and mouth waters for 5 out of the 7 parameters tested (Table 2), *with 80% of the ammonia, 88% of the nitrite, 73% of* the nitrate, 91% of the phosphate, 88% of the total phosphorus and 68% of the silicate being absorbed by the estuary (Table 2). Hill (1979) found that nitrate disappeared downstream mainly as a result of adsorption/absorbtion and denitrification in the sediment, with only 7% being exported, while De Groot (1981) has significantly correlated phosphate exchange between the sediment and the supernatant water with gross loading. Large amounts of nitrogen, phosphorus *and carbon are also accumulated by aquatic macrophytes* (Howard-Williams, 1977). Nutrient accumulation in the Swartkops could be considerable as the saltmarsh is dominated by macrophytes (Day, 1981c).

Comparisons with Northern Hemisphere systems are relative. Levels of nitrate in rivers ranging from 10 to 34 $mg.\ell^{-1}$ were considered by Hill and Wylie (1977) to be high. By Southern African standards the nutrient loading in the Swartkops (mean NO_3-N, 516 $\mu g.\ell^{-1}$; mean PO_4-P, *1 324* $\mu g.\ell^{-1}$) *is high due to sewage pollution, as is the* Mgeni. Other systems like the Lourens River estuary experience only periodic high nutrient loads (NO_3-N, 6 507 $\mu g.\ell^{-1}$; PO_4-P, 197 $\mu g.\ell^{-1}$; Cliff, 1982) due to chemical plant overflows. These levels are seen in perspective when compared with unpolluted systems such as Swartvlei (NO_3-N, 26 $\mu g.\ell^{-1}$; PO_4-P, up to 21 $\mu g.\ell^{-1}$; Howard-Williams, 1977), the Berg (NO_3-N, 90 - 250 $\mu g.\ell^{-1}$; PO_4-P, 1 - 50 $\mu g.\ell^{-1}$; Harrison and Elsworth, 1958), the Bashee (NO_3-N, 13 $\mu g.\ell^{-1}$; PO_4-P, 2,5 - 20 $\mu g.\ell^{-1}$; Day, 1981a) and Kosi Bay (NO_3-N, 4,5 - 47 $\mu g.\ell^{-1}$; PO_4-P,6 - 7,5 $\mu g.\ell^{-1}$; Day, 1981a).

Apart from rainfall and riverflow, other factors which influence the distribution of nutrients in an estuary are wind (De Groot, 1981) and tide (Webb and D'Elia, 1980). In this present work, nutrient levels were found to fluctuate with the tide, with the highest levels in the Swartkops mouth coinciding with the end of the ebb-tide (Figs. 4 and 5). Similar results have been reported elsewhere. In the Shimizu estuary, Japan, for example, dissolved components, especially silicate and phosphate displayed a tidal variation, with nutrient plumes being produced at ebb-tide (Fukui and Okabe, 1981).

Conclusion

Two important points have emerged from this study. Firstly from the nutrient distribution patterns in the Swartkops over two years sampling, a significant nutrient gradient was shown to dominate between the head and the mouth of the estuary for nitrite, nitrate, phosphate, total phosphorus and silicate (Table 2). Secondly, from both of the 24h series at the mouth of the Swartkops a nett export was found for ammonia, nitrite, nitrate, phosphate and silicate (Table 4). Odum's (1968) "outwelling" theory is no longer in vogue (Nixon, 1980) as there are marine-dominated systems which import nitrogen and phosphorus from the nearshore region. Most estuaries, however, are fluvially-dominant such as the mangrove systems in Australia (Boto and Bunt, *1981*), *the* Pamlico River estuary (Hobbie *et al.*, 1975) and the Swartkops (present work) and generally supply more nitrogen to the sea than they gain (Day, 1981a). There are many references to fluvial nutrient input, which show that systems with a dominant fluvial input have the river as the estuary's main source of nutrients. Hobbie *et al.* (1975) found that the nutrient input from the Pamlico River into its estuary was abundant and while 60% of the total phosphorus and 50% of the nitrate was retained in the estuary the balance was exported (cf. 88% and 73% respectively for the Swartkops). If Strickland's (1965) growth-limiting nitrogen value of 20 $\mu g.\ell^{-1}$ and Ketchum's (1939) growth-limiting phosphorus value of 15 $\mu g.\ell^{-1}$ are applied to the Swartkops, it is doubtful whether either would limit plant growth in the estuary as both nitrogen and phosphorus levels were high. So although the Swartkops is polluted with high nutrient and faecal *E. coli* levels, most is absorbed along the length of the estuary enhancing the estuary's general productivity. A N:P ratio of 0,39 – 0,49 : 1 was obtained for the Swartkops. Published N:P values range from 3,6 or 4,9 : 1 for the Pamlico estuary (Hobbie *et al.*, 1975) to 12 – 55 : 1 in Chesapeake Bay (Taft and Taylor, 1976). Phosphorus levels were thus actually higher than nitrogen levels in the Swartkops, as was found for four degraded Natal estuaries (Day, 1981a) and is indicative of sewage pollution. With its high nutrient loading and good flushing the Swartkops could be classified as a conservative estuary (McCarthy, 1981), with little recycling and some export (4,7 – 6,8 tonnes of nutrient per day). More 24h studies spread throughout the year are required to quantify any seasonal changes in nutrient flux (Nixon and Lee, 1981).

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