

A Preliminary Pollution Survey of the Papenkuils River, Port Elizabeth

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Abstract

The concentration and distribution of nutrients (ammonia, nitrite, nitrate, phosphate and total phosphorus), faecal *Escherichia coli* I and heavy metals (copper, lead, zinc, iron, manganese, cobalt, nickel, cadmium, chromium and mercury) have been studied during a preliminary survey of the Papenkuils River undertaken in November 1980. Areas of pollutant input to the river have been identified from the results. These pollutants have caused extensive ecological modification in the river, which represents one of the more serious sources of pollutants in the coastal marine environment of the south-eastern Cape.

Introduction

The Papenkuils River, with a catchment area of approximately 600 km², enters Algoa Bay 5 km north of Port Elizabeth on the south-eastern coast of South Africa. For the last 3 km of its course, the river flows through the industrial areas of North End and Deal Party and for this entire region the river bed and banks have been canalized with concrete. The urban areas of Gelvandale and Algoa Park, together with the municipal rubbish dump, are situated at the head of the river, while industrial effluents contribute to the flow in the region of the mouth.

The early establishment of local industry earned the river the appropriate title of "Smelly Creek" but conditions improved after canalization in 1965. However, the increase in the number and diversity of industrial concerns in the area and the introduction of a 20 Ml/d outfall at the river mouth in 1976 have caused considerable environmental stress in the system. Although every effort is made to monitor and control the quality of effluent entering the river, this is an almost impossible task and the final 4 km of the river are subject to a high pollutant load which has led to the complete loss of macrofauna. The aim of the present survey was to determine the concentration of nutrients, bacteria and metals in this river and where possible, to locate and identify pollutant sources.

Materials and Methods

Water and Effluent Samples

Nutrients: Samples were collected in 250 ml high-density polyethylene bottles which were stored in crushed ice during transportation to the laboratory. The analyses of total ammonia, nitrite, nitrate, phosphate and total phosphorus were undertaken using the methods of Solorzano (1969), Bendschnei-

der and Robinson (1952) and Wood *et al.*, (1967) as described in Strickland and Parsons (1972) and Menzel and Corwin (1965) respectively.

Bacteria: Samples were collected in previously sterilized wide-necked glass bottles which were stored in the dark at approximately 10°C for transport to the laboratory. Faecal *E. coli* I were enumerated using the indole test (South African Bureau of Standards, 1971, Method 221).

Oxygen and pH: Dissolved oxygen was measured on site using a YSI model 57 field instrument while pH was measured immediately upon return to the laboratory using a Metrohm E 396B pH meter.

Metals: Samples were collected in 2,5 l high-density polyethylene bottles and two sub-samples separated from the bulk. These were:

- (a) a 500 ml sample acidified with 2 ml redistilled nitric acid, for the determination of mercury; and
- (b) a 1000 ml sample for the determination of zinc, cadmium, copper, lead, iron, manganese, nickel, cobalt and chromium. A sample of 10 ml buffered solution of sodium diethyldithiocarbamate was added immediately to this sample which was then shaken for 5 min.

On returning to the laboratory, the chelated metals were extracted into chloroform. The organic phase was then separated, acidified with 2 ml nitric acid and evaporated to dryness. This organic residue was dissolved in 10 ml 1M nitric acid for atomic absorption analysis (Watling and Watling, 1976).

Ten millilitres of a 25% m/v low-mercury potassium permanganate solution and 2 ml of concentrated sulphuric acid were added to the 500 ml acidified sample and the mixture left for 24 h to oxidise all organically-bound mercury to inorganic mercury. The excess permanganate in the prepared mercury-absorbing solutions was reduced using 10% m/v hydroxyl-ammonium chloride in 20% v/v hydrochloric acid. Mercury concentrations in these samples were determined using an amalgamation trap and cold-vapour atomic absorption spectrometry (Watling, 1978a).

Surface Sediments

Metals: Samples were collected from the main channel and from effluent channels and were stored in sealed polyethylene bags. On returning to the laboratory, the samples were trans-

ferred to pads of filter paper and air-dried, disaggregated and sieved through a 1 mm screen to remove large particles and plant debris. The fraction which passed through the screen was reserved for analysis.

Samples of 2 g were transferred to 50 ml conical flasks, 10 ml concentrated nitric acid added and the solutions evaporated to dryness at 120°C. A volume of 10 ml of a 4 : 1 nitric:perchloric acid mixture was added and these solutions were fumed to dryness at 140°C. After cooling, the residue was dissolved in 10 ml 1M nitric acid for atomic absorption analysis.

Composite standards were prepared to contain major and trace elements at concentrations similar to those of the sample solutions. A Varian Techtron AA5 with AA6 readout module and BC6 background corrector was used for all measurements. Background correction was employed for the determination of zinc, lead, cadmium, cobalt and nickel, and the slotted tube (Watling, 1978b) was used for the determination of lead and cadmium.

Samples were also prepared for mercury analysis using a simple oxidation procedure; 2 g of each sample were weighed into a ceramic boat which was then placed inside a combustion tube in a tube furnace preheated to 700°C. Oxygen was passed over the sample at a rate of 650 ml/min. The exhaust gases were bubbled through a solution containing 25 ml 5% potassium permanganate and 50 ml 14% sulphuric acid until combustion was complete (about 3 min). All the mercury evolved from the sample was absorbed by this solution (Watling, 1978a). The excess permanganate in the prepared mercury-absorbing solutions was reduced using 10% m/v hydroxylammonium chloride in 20% v/v hydrochloric acid. Mercury concentrations in these samples were determined using an amalgamation trap and cold-vapour atomic absorption spectrometry (Watling, 1978a).

Ash content: Air-dried samples were further dried at 90°C for 24 h and a known quantity transferred to a previously weighed silica crucible. The sample was then placed inside a muffle furnace and the temperature increased to 700°C over a 24 h period. Final oxidation of the sample took place during a further 8 h period at 700°C. The sample was then removed from the furnace, cooled in a desiccator and reweighed, and the ash content calculated.

Results and Discussion

The location of sampling stations is shown in Figure 1. The physico-chemical, nutrient and faecal *E. coli* I results are listed in Table 1.

Temperatures were stable at approximately 21°C with the exception of station 8 where temperatures greater than 10°C above local ambient were recorded. The effluents at stations 7 and 12 were alkaline, being pH 8,9 and pH 8,8 respectively.

Faecal *E. coli* I concentrations were generally low (<9000/100 ml) upstream of the railway bridge (stations 1–14). However, an exceptionally high count of $4,76 \cdot 10^6/100$ ml was obtained at the railway bridge (station 15) and this was accompanied by a dissolved oxygen concentration of 5,4 mg/l. Effluent from the Fishwater Flats sewage works, which enters the river at station 17, was also low in dissolved oxygen (3,0 mg/l) and had an elevated faecal *E. coli* I count of $6,9 \cdot 10^5/100$ ml. Faecal *E. coli* I counts remained greater than $10^5/100$ ml between the effluent input at station 17 and the mouth of the river and a significant drop in dissolved oxygen concentrations was also recorded for this region.

The source of the exceptionally high *E. coli* I levels found

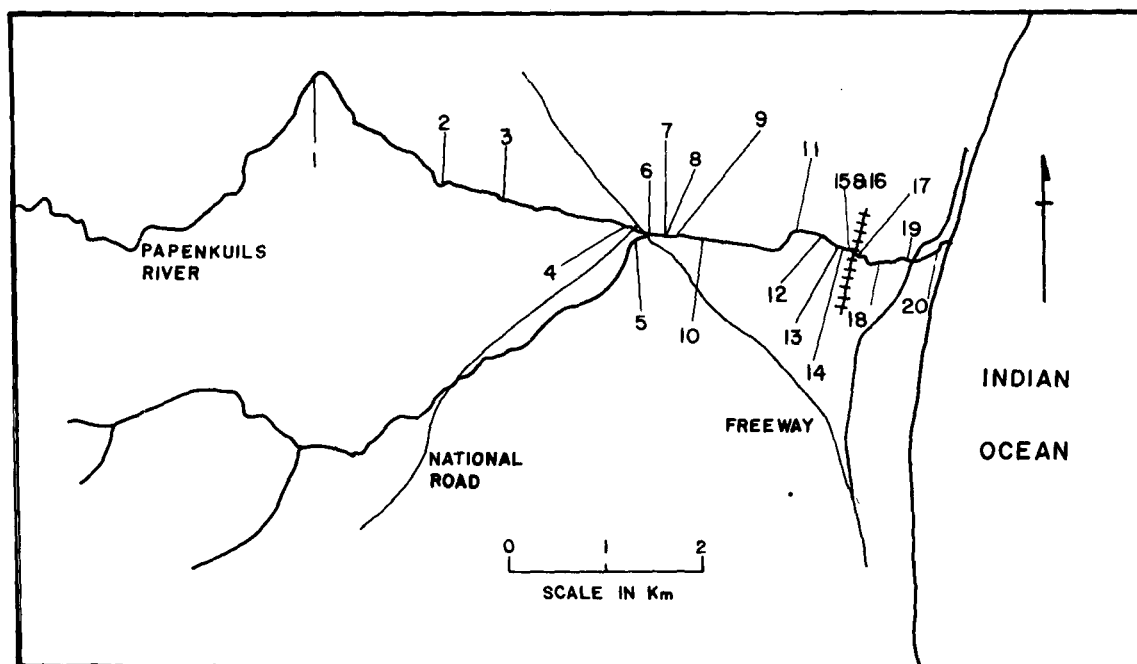


Figure 1
Map of the Papenkuils River, Port Elizabeth, showing sample locations

TABLE 1
PHYSICO-CHEMICAL AND FAECAL *E. COLI* CONCENTRATIONS IN WATER SAMPLES FROM
THE PAPENKUILS RIVER, PORT ELIZABETH

| Station | Temp °C | O ₂ mg/l | pH | Total Ammonia µg/l | NO ₂ -N ₁ µg/l | NO ₃ -N ₁ µg/l | PO ₄ -P ₁ mg/l | Total Phosphorus mg/l | <i>E. coli</i> I /100 ml |
|---------|---------|---------------------|-----|-----------------------|---|---|---|--------------------------|-----------------------------|
| 1* | 18,0 | 6,4 | 8,1 | 540 | 73 | 470 | 0,30 | 0,45 | 1400 |
| 2* | 20,2 | 5,0 | 8,0 | <1 | 1 | 13 | 0,30 | 0,60 | <10 |
| 3* | 19,8 | 7,8 | 7,8 | 2 | 4 | 350 | 0,05 | 0,25 | 40 |
| 4* | 20,5 | 9,8 | 7,9 | 100 | 1 | 17 | 0,15 | 0,60 | 20 |
| 5* | 22,5 | 6,5 | 8,1 | 160 | 22 | 720 | 0,50 | 0,80 | 2000 |
| 6§ | 19,2 | 9,2 | 8,0 | <1 | 10 | 100 | 8,0 | 8,4 | 7000 |
| 7* | 23,2 | 8,0 | 8,9 | <1 | 77 | 49 | 0,50 | 0,80 | 190 |
| 8§ | 33,4 | 9,0 | 7,6 | 29 | 11 | 790 | 0,05 | 0,30 | 50 |
| 9§ | 26,2 | 8,2 | 8,2 | <1 | 15 | 1500 | 0,90 | 3,4 | ** |
| 10§ | 20,6 | 6,4 | 7,9 | 60 | 7 | 71 | 3,5 | 4,3 | 4200 |
| 11* | 24,0 | 4,5 | 7,7 | 430 | 62 | 250 | 0,60 | 1,0 | 50 |
| 12§ | 20,2 | 7,8 | 8,8 | 3 | 120 | 3080 | 2,0 | 2,8 | ** |
| 13§ | 18,4 | 10,0 | 7,8 | 23 | 70 | 2200 | 0,70 | 1,0 | 9000 |
| 14§ | 17,9 | 10,4 | 8,0 | 33 | 140 | 2400 | 2,2 | 2,7 | 600 |
| 15§ | 17,0 | 5,4 | 7,7 | 33 | 1100 | 120 | 9,5 | 11 | 4,8.10 ⁶ |
| 16* | 21,5 | 9,6 | 7,8 | 53 | 790 | 1500 | 0,90 | 1,1 | 2000 |
| 17§ | 20,9 | 3,0 | 7,7 | 27 | 590 | 2100 | 6,1 | 7,8 | 6,9.10 ⁵ |
| 18* | 20,6 | 6,0 | 7,3 | 30 | 600 | 1800 | 22 | 30 | 1,3.10 ⁵ |
| 19* | 19,2 | 4,2 | 7,8 | 37 | 700 | 1700 | 11 | 11 | 1,3.10 ⁵ |
| 20* | 19,1 | 5,4 | 7,8 | 41 | 780 | 1600 | 5,0 | 6,8 | 2,3.10 ⁵ |

§ Drain sample

* Main stream sample

** Unable to be enumerated due to confluent growth of interfering non-lactose fermenting bacteria

at station 15 was found to be a double stormwater drain with a flow of about 0,029 Ml/d while the main effluent outfall at station 17 delivered from 19–20 Ml/d. In spite of these differences in flow, the daily *E. coli* I contribution from station 15 ($1,4 \cdot 10^{12}$ faecal *E. coli* I per day) may be only 100 times less than from station 17 ($1,4 \cdot 10^{14}$ faecal *E. coli* I per day).

The *E. coli* I level recorded at the river mouth during this survey was $2,25 \cdot 10^5/100$ ml while in September 1979 and 1980 counts of $2,0 \cdot 10^5$ and $1,2 \cdot 10^5/100$ ml respectively were obtained. It is worth noting that the Brighton Beach bathing area is only about 3 km downshore of the Papenkuils River mouth and that an inshore current flows in the direction of this beach. There is also another effluent discharge from the Fishwater Flats plant through a pipe under the pier at Brighton Beach.

Counts of <100 and 14/100 ml were recorded for Brighton Beach in September 1979 and 1980 respectively which are well under the "recommended" level of 100/100 ml for *E. coli* I in water. Therefore there must have been considerable dilution, dispersion and mortality of the faecal *E. coli* I in the area between Papenkuils River and Brighton Beach. Nevertheless this could be affected significantly by current patterns and the situation must be monitored to ensure that these levels remain low.

Ammonia levels remained below 100 µg/l in all samples except those collected from stations 1, 4, 5 and 11. These stations were situated in the main stream rather than in effluent channels. Nitrite levels are generally low above station 15 but in-

crease markedly towards the mouth in both main stream and effluent channel samples. Nitrate concentrations show a similar trend although concentration fluctuations between samples are greater, particularly in the upper reaches of the river. Phosphate concentrations also increase in the lower reaches of the river, the highest value being recorded at station 18 just below the railway bridge. A three-fold increase in phosphate concentrations is observed between the effluent outfall at station 17 which is the main source of phosphate in the river, and station 18. This result is surprising and leads to the suggestion that there is an accumulation of sludge downstream of the outfall and that bacterial degradation of this sludge releases phosphate into the water column. Phosphate and total phosphorus concentrations decrease between station 18 and the mouth of the river.

In South Africa there is a "Special Standard" which limits the soluble ortho-phosphate levels in wastewater draining into "relatively unpolluted rivers or portions of rivers" or into "eutrophication-sensitive catchments" to a maximum of 1 mg/l (expressed as P). The "General Standard", however, places no such limitations on phosphate levels (Zunckel *et al.*, 1979) and this is clearly the standard which applies to the Papenkuils River. Both nitrate and ammonia concentrations are relatively low in all samples collected during this survey. The maximum nitrate concentration recorded here is 3 mg NO₃-N/l which is well below the WHO recommended limit of 11,3 mg NO₃-N/l for drinking water (Porter, 1977). These low nitrate levels may be ex-

TABLE 2
METAL CONCENTRATIONS IN WATER FROM THE PAPENKUILS RIVER, PORT ELIZABETH
 (concentration $\mu\text{g}/\text{l}$)

| Station | Cu | Pb | Zn | Fe | Mn | Co | Ni | Cd | Cr | Hg |
|---------|----|-----|------|-------|-----|------|-----|------|----|-------|
| 1* | 5 | 3 | 169 | 950 | 790 | <0,1 | 2 | 0,14 | 1 | 0,084 |
| 2* | 1 | 1 | 191 | 1260 | 320 | 0,7 | 2 | 0,10 | 1 | 0,009 |
| 3* | 19 | 69 | 184 | 24400 | 290 | 6,1 | 7 | 0,36 | 35 | 0,032 |
| 4* | 11 | 7 | 31 | 2800 | 650 | 1,6 | 3 | 0,16 | 3 | 0,032 |
| 5* | 6 | 20 | 28 | 560 | 41 | <0,1 | 5 | 0,13 | 4 | 0,029 |
| 6§ | 18 | 7 | 470 | 730 | 510 | 0,7 | 4 | 0,49 | 83 | 0,009 |
| 7* | 4 | 16 | 38 | 540 | 41 | <0,1 | 6 | 0,02 | 5 | 0,016 |
| 8§ | 13 | 5 | 17 | 360 | 208 | 0,2 | 3 | 0,17 | 1 | 0,082 |
| 9§ | 9 | 7 | 690 | 440 | 33 | 0,1 | 2 | 0,17 | 14 | 0,026 |
| 10§ | 9 | 10 | 75 | 1160 | 82 | 0,3 | 2 | 0,16 | 4 | 0,021 |
| 11* | 3 | 9 | 29 | 850 | 185 | 0,1 | 4 | 0,08 | 15 | 0,035 |
| 12§ | 17 | 33 | 62 | 160 | 14 | <0,1 | 2 | 0,57 | 6 | 0,153 |
| 13§ | 67 | 212 | 2190 | 1480 | 87 | 1,6 | 13 | 0,88 | 30 | 0,068 |
| 14§ | 42 | 326 | 3600 | 880 | 78 | 1,4 | 16 | 0,72 | 18 | 0,026 |
| 15§ | 26 | 104 | 800 | 1780 | 223 | 1,2 | 8 | 0,71 | 22 | 0,015 |
| 16* | 20 | 32 | 56 | 1340 | 191 | 0,8 | 5 | 0,15 | 6 | 1,047 |
| 17§ | 3 | 8 | 144 | 550 | 224 | 1,1 | 106 | 0,03 | 8 | 0,032 |
| 18* | 2 | 7 | 150 | 230 | 221 | 0,8 | 106 | 0,02 | 5 | 0,044 |
| 19* | 9 | 26 | 390 | 440 | 169 | 0,8 | 44 | 0,18 | 7 | 0,126 |
| 20* | 11 | 41 | 430 | 680 | 170 | 0,8 | 52 | 0,22 | 9 | 0,215 |

§ Drain sample
 * Main stream sample

TABLE 3
METAL CONCENTRATIONS IN SEDIMENT FROM THE PAPENKUILS RIVER, PORT ELIZABETH
 (concentration $\mu\text{g}/\text{g}$)

| Station | Cu | Pb | Zn | Fe | Mn | Co | Ni | Cd | Cr | Hg | % Ash |
|---------|-----|------|--------|--------|------------------|-----|----|-------|--------|------|-------|
| 1* | 9 | 150 | 137 | 95 800 | 896 | 1,5 | 6 | 0,14 | 42 | 0,26 | 82,5 |
| 2* | 1 | 5 | 7 | 1 150 | 7 | 0,3 | 1 | 0,19 | 7 | 0,04 | 97,1 |
| 3* | 8 | 31 | 61 | 10 100 | 31 | 3,0 | 5 | 0,16 | 17 | 0,07 | 97,2 |
| 4* | 16 | 36 | 86 | 17 900 | 91 | 4,1 | 9 | 0,24 | 33 | 0,08 | 93,9 |
| 5* | 107 | 290 | 900 | 21 700 | 202 | 5,4 | 25 | 1,30 | 130 | 0,68 | 38,0 |
| 6§ | 740 | 360 | 22 400 | 27 500 | 253 | 4,9 | 96 | 15,00 | 40 000 | 2,00 | 37,9 |
| 7* | 150 | 250 | 755 | 16 000 | 68 | 4,4 | 23 | 1,40 | 210 | 0,62 | 83,3 |
| 8§ | | | | | <i>No Sample</i> | | | | | | |
| 9§ | 64 | 2400 | 436 | 25 900 | 207 | 2,7 | 12 | 0,47 | 60 | 0,08 | 96,8 |
| 10§ | 205 | 140 | 1 640 | 13 800 | 178 | 6,0 | 40 | 3,40 | 830 | 0,14 | 66,7 |
| 11* | | | | | <i>No Sample</i> | | | | | | |
| 12§ | 109 | 290 | 890 | 18 800 | 465 | 5,9 | 26 | 1,10 | 200 | 0,56 | 81,9 |
| 13§ | 172 | 1200 | 162 | 15 400 | 443 | 5,8 | 32 | 1,70 | 330 | 0,26 | 80,0 |
| 14§ | 87 | 420 | 1 390 | 7 440 | 97 | 2,4 | 20 | 1,40 | 110 | 1,80 | 85,5 |
| 15§ | 48 | 88 | 202 | 1 400 | 126 | 3,5 | 13 | 0,27 | 46 | 0,24 | 94,1 |
| 16* | | | | | <i>No Sample</i> | | | | | | |
| 17§ | 155 | 450 | 1 820 | 9 090 | 162 | 2,9 | 68 | 2,00 | 320 | 3,47 | 85,6 |
| 18* | 7 | 33 | 95 | 2 240 | 24 | 0,1 | 2 | 0,07 | 14 | 0,12 | 35,3 |
| 19* | 3 | 8 | 20 | 2 040 | 17 | 0,1 | 1 | 0,06 | 5 | 0,03 | 86,0 |
| 20* | 2 | 10 | 9 | 1 980 | 23 | 0,1 | 1 | 0,06 | 10 | 0,01 | 83,9 |

§ Drain sample
 * Main stream sample

plained by the fact that at the Fishwater Flats sewage treatment plant, the aerators are switched off routinely and anaerobic denitrification with the consequent lowering of nitrate levels can occur (J. Vail, personal communication). Furthermore, as a completely anaerobic zone is required for the bacterial (Davelaar *et al.*, 1978) or chemical (McLaren, 1979) removal of phosphate, and as the Fishwater Flats plant is not designed for biological phosphate removal this would explain the high phosphate and total phosphorus levels recorded during this survey.

The concentrations of ten elements in water samples are listed in Table 2. Metal concentrations are elevated along the entire length of the river. In the canalized section of the river the introduction of large amounts of copper, lead, zinc and nickel via drains at stations 12–15 and 17 is partly responsible for the absence of invertebrate macrofauna. Zinc concentrations are more than 500 times greater than the highest concentration of 8 $\mu\text{g}/\ell$ found in the nearby Swartkops River while lead and nickel concentrations are more than 50 times higher (Watling and Watling, 1981). With the exception of nickel, metal concentrations in the effluent entering the river at station 17 are not elevated for this type of medium. However, nickel concentrations in this effluent are high, as are those in all the remaining samples collected downstream.

Sediment samples were collected from the same locations as the water samples with the exception of stations 8, 11 and 16 where no sediment was available. The ash contents of the dry samples varied between 37.9 and 97.2% (Table 3). No recognisable pattern in this variation could be discerned but in the lower regions of the canalized zone the loss in mass of these samples could be attributed almost entirely to the oxidation of sewage sludge.

Metal concentrations in sediment samples are also shown in Table 3. These concentrations are elevated along the entire length of the river, but notably between stations 10 and 17. Exceptionally high concentrations of zinc (2%) and chromium (4%) were recorded for station 5, these being the highest found in the sediments of any of the south-eastern Cape rivers so far studied. In general, the concentrations of copper, zinc, lead, cadmium and mercury are considerably higher than those determined for the nearby Swartkops River (Watling and Watling, 1981). Sedimentation occurs to a greater extent in the lower reaches of the Papekuils River, below station 17 and the results presented here indicate that metals are absorbed onto and coprecipitated with this sediment. Therefore, metals which are currently being introduced into this river will be present for a considerable period of time and could represent a long-term pollution threat to the biota.

Conclusions

Urban effluent and run-off usually contain a high pollutant load (Roberts *et al.*, 1977) and the Papekuils River is no exception to this generalization.

Nutrient input is relatively small, with the exception of that from the Fishwater Flats outfall near the mouth (station 17). In addition, all industrial effluent should be processed at the Fishwater Flats plant. However, there are obviously considerable quantities of different metals entering the river via the many drains which are to be found both in and above the canalized section.

Industrial and urban developments are abundant within the comparatively small catchment and, although every effort is made by local authorities to limit misuse of the river, nevertheless significant pollution is occurring along its entire length.

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