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# THE EFFECT OF URBAN RUNOFF ON THE WATER QUALITY OF THE SWARTKOPS ESTUARY

Report to the
WATER RESEARCH COMMISSION
by the
DEPARTMENT OF OCEANOGRAPHY
UNIVERSITY OF PORT ELIZABETH

WRC Report No 324/1/93

# REPORT TO THE WATER RESEARCH COMMISSION

## THE EFFECTS OF URBAN RUNOFF

## ON THE WATER QUALITY

## OF THE SWARTKOPS ESTUARY

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D A LORD
H M MACKAY

Department of Oceanography
University of Port Elizabeth

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## ABBREVIATIONS

| | |
|---|---|
| EC | Electrical conductivity, mS/m |
| OA | Oxygen absorbed from N/80 potassium permanganate in 4 hours, mg/l |
| COD | Chemical oxygen demand, mg/l |
| TSS | Total suspended solids, mg/l |
| TDS | Total dissolved solids, mg/l |
| $^{o}/_{oo}$ | Salinity, parts per thousand or g/kg |

# 1. INTRODUCTION

## 1.1 Study area

The study area is centred on the Swartkops estuary, which lies on the northern side of Port Elizabeth. The catchment is described in detail in MacKay & Eichstadt (in prep.). The estuary is about 14km long, with wide supratidal and intertidal flats. The physical, geological and biological characteristics of the Swartkops estuary have been studied over the past ten years, and the results of these studies are best summarised by Baird et al. (1988).

Fig 1.1 shows a map of the estuary up to its tidal limit at Perseverance. Much of the immediate catchment of the estuary has been undergoing rapid urbanisation, with both formal and informal settlement encroaching on the estuary's shores. Recently, concern has been expressed regarding degradation of estuarine water quality due to contaminated runoff from urban developments, since there are several such sources of pollutants which could impact on the estuary.

Pollution of the Swartkops River due to urban runoff is discussed in MacKay & Eichstadt (in prep.). As the major source of freshwater to the estuary, it is important that the

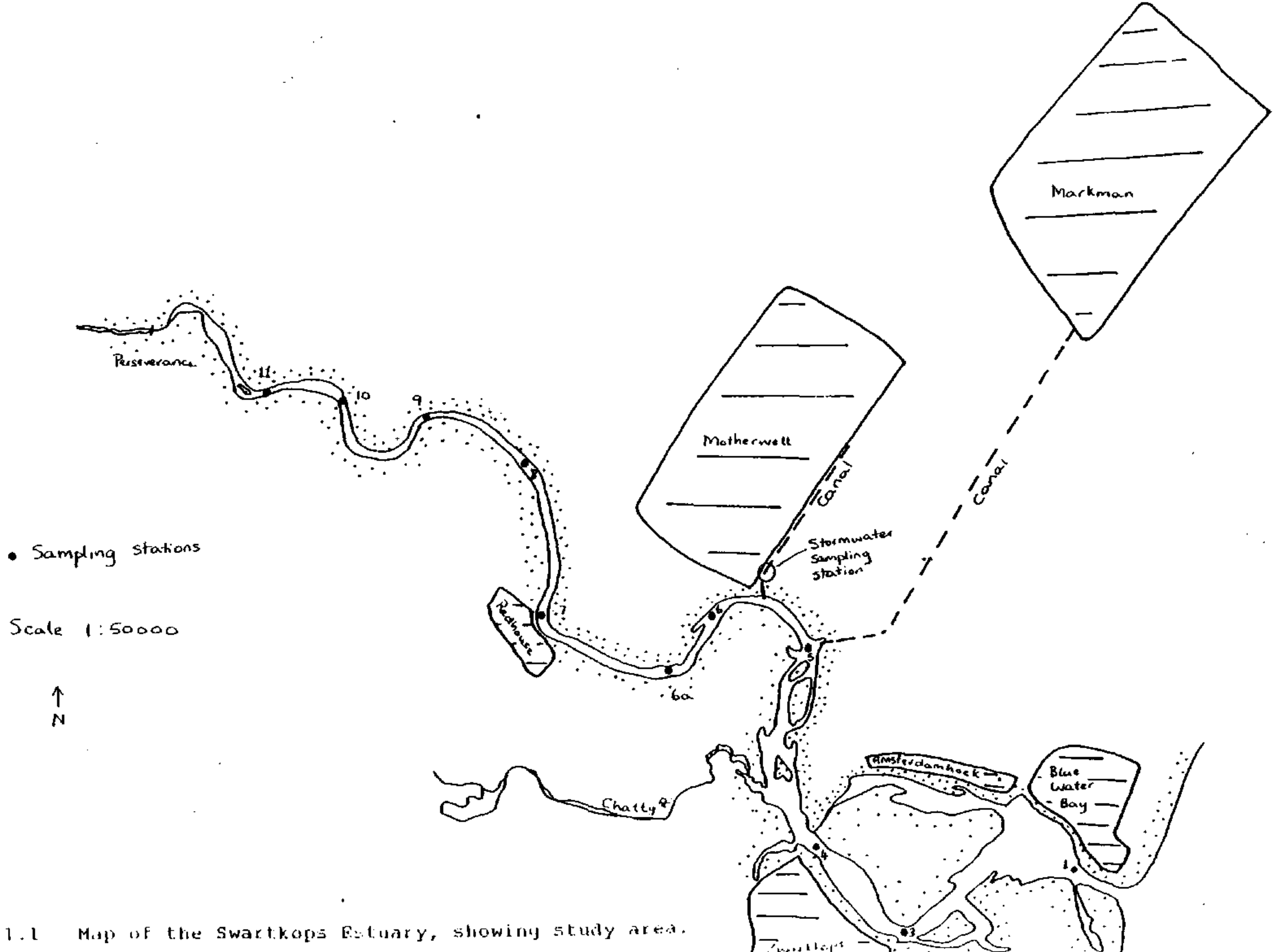



FIG 1.1 Map of the Swartkops Estuary, showing study area.

quality of the lower river be maintained at an acceptable standard. However, presently the health risk to recreational users of the estuary due to inflow from the Swartkops River is thought to be small.

In comparison, other sources are potentially serious problems :

1.1.1 Chatty River

Uncontrolled informal settlement in and above the floodplain of the Chatty River has led to severe pollution of this tributary (Fig. 1.2) by sewage and litter. Under normal flow conditions, however, the Chatty meanders through a very shallow bed for some distance before joining the estuary. Over this distance, some natural reoxygenation occurs and ultraviolet exposure probably causes die-off of many bacteria and viruses. Extremely dense algal mats remove some of the excess nutrients (Fig. 1.3). Hence the negative impact of this source on the estuary is limited. However, under high-flow conditions, serious pollution of the lower estuary by untreated faecal matter is likely to occur.

### 1.1.2 Markman Canal

This stormwater canal drains the heavy industrial township of Markman. In its upper reaches, runoff to the canal is highly polluted. However, the vegetation established in the canal bed, and the long travel time to the estuary, apparently are effective in removing most pollutants from the runoff.

### 1.1.3 Motherwell Canal

This canal carries stormwater from Motherwell Township directly to the estuary. Motherwell is a new high-density residential development. In dry weather, a small but steady flow of highly polluted water is invariably observed in the canal. The nature of this runoff has been studied in detail and the results are described in section 4.1 of this report.

The pollution problem from the canal has to a large extent been alleviated by measures taken in August 1990, but under high flow conditions, there will still be an input of pollutants to the estuary.

### 1.1.4 Settlement at Brickfields

A small settlement exists in this area, very close to the estuary bank. No sanitation is provided, since this appears to be an informal development. The potential for pollution from this source has not yet been assessed.

### 1.1.5 Other developments

The established residential areas of Redhouse, Zwartkops and Amsterdamhoek are of such a nature that, as pollution threats, they are potentially much less serious than other sources mentioned above. However, in terms of overall impact on the recreational resources of the estuary, they cannot be ignored.

## 1.2 Scope of this report

This report covers work done to ascertain the effects of urban runoff on the Swartkops estuary, the period of work being September 1989 to December 1990. In that time, an intensive field study was undertaken to investigate the quantity and quality of urban runoff from Motherwell Township via the stormwater canal which drains into the estuary. The results of this study are discussed in section 4.1.

In addition, dilution studies using Rhodamine B dye were carried out to assess the dispersion and dilution of the Motherwell runoff in the estuary. The results are described in section 4.2.

Circulation and hydrodynamics in the estuary were studied over a 14-day spring-neap tidal cycle, using salinity and temperature as tracers, and these investigations are described in section 4.3.

Detailed analysis of historic water quality data from the lower Swartkops River and the estuary has been discussed in MacKay & Eichstadt (in prep.), which has been submitted to Water S.A., a copy of which can be found in Appendix A, and MacKay et al. (in prep.). These results are covered briefly in section 4.4.

Section 5 includes a discussion of the relevance and application of results obtained so far to solution of the problem of contaminated urban runoff reaching sensitive water bodies. The proposed future research programme is also outlined in this section.

# 2. FIELD STUDIES

## 2.1 Motherwell stormwater

In October 1989, a small V-notch weir, approximately 50cm high, was constructed from steel and fixed in place in the stormwater canal, at a point near the edge of the escarpment which runs along the estuary bank (Fig 2.1).

Initially it was intended that water samples would be collected at the weir, and flow measured at the V-notch. However, the gradient of the canal bottom was so shallow that water backed up to a distance of some 500m from the weir. The resultant odour, and the danger to children or animals falling into the canal, made this unacceptable, and the weir was removed in November.

In December and January, the Motherwell Town Committee constructed instead a low brick wall in the canal, designed so that a steel plate with a V-notch could be inserted when necessary, and removed when sampling and flow measurements were completed for the day (Fig 2.2). This proved to be a satisfactory solution to the problem of standing water in the canal.

FIG. 2.1 Aerial photograph of lower section of Motherwell canal

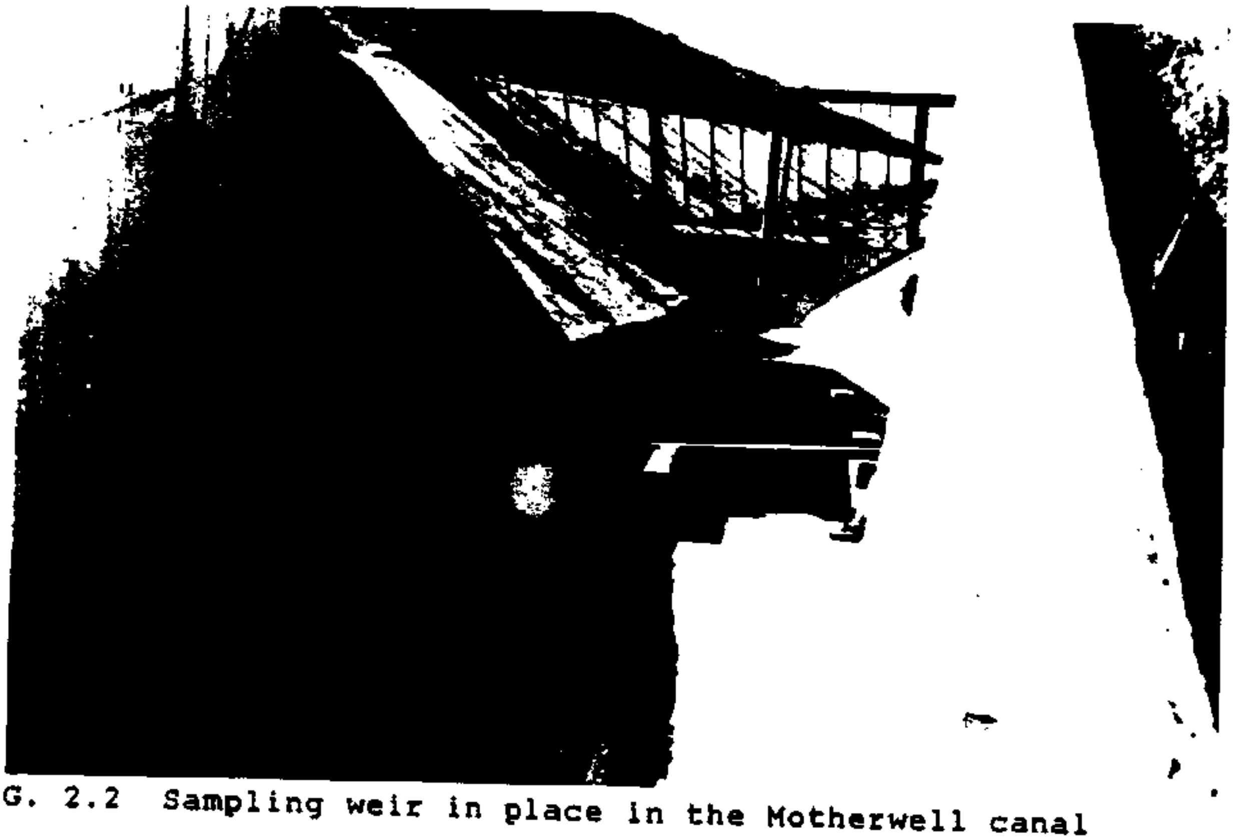


FIG. 2.2 Sampling weir in place in the Motherwell canal

Sixteen water samples were collected between 26 October and 17 November: this was really an initial settling-in period. The canal was visited on a twice-weekly basis, with additional samples collected if rain occurred in between sampling trips.

On each visit, the routine was as follows: the flow rate in the canal was measured using a bucket and a stop-watch (Fig 2.3); conductivity, temperature and dissolved oxygen content were measured in situ and recorded; weather conditions and a description of the water in the canal were also noted; a 1000ml sample of water was collected, to be delivered to the SABS laboratory; a 250ml sample was collected in a sterile bottle for bacteriological analysis at the PEM laboratory; both samples were placed on ice in a light-proof box.

The same procedure was carried out three times at hourly intervals, as close to 08h00, 09h00 and 10h00 as possible.

Sampling at the new weir commenced on 22 January 1990. The sampling procedure was the same as previously, except, that 40 - 45 minutes were required before sampling in order for the water level behind the weir, and hence the flow, to stabilise. 70 samples in all were taken on a twice-weekly basis until the end of March 1990.

FIG. 2.3  Measuring flow rate in the canal

As the sampling programme continued, it became clear that variations in flow in the canal were not always directly attributable to rainfall in the area. Hence it was decided to include several 24-hour studies in the programme. Between the end of February and the end of March 1990, eight such studies were carried out, each on different days of the week. Flow rate was measured hourly, and every two hours a water sample was collected and stored on ice for later delivery to the PEM laboratory. UPE field staff were assisted by staff of the Motherwell Town Committee.

The programme ended on March 31, but two more sampling trips were undertaken in April for the purpose of interlaboratory calibration. A total of 10 samples were collected, split, and sent to both the SABS and the PEM laboratories.

**Table 2.1**

**Schedule of analyses carried out**

1. Twice-weekly sampling

| | | |
|---|---|---|
| In situ | - | Temperature, conductivity (EC) dissolved oxygen, flow rate |
| SABS lab | - | EC; pH; TSS; TDS; nitrate N; ammonia N + nitrite N; orthophosphate P; COD; OA |
| PEM lab | - | Total coliforms; faecal coliforms; E. coli; faecal streptococci (once per week only). |

2. 24 - hour sampling

| | | |
|---|---|---|
| In situ | - | flow rate |
| PEM lab | - | pH, EC, COD, OA |

3. Calibration Samples

| | | |
|---|---|---|
| SABS lab | - | pH, EC, COD, OA |
| PEM lab | - | pH, EC, COD, OA |

## 2.2 Dye Studies

On 16 October 1990, two releases of Rhodamine B dye were made, on the ebb and flood tide, to determine the extent of influence of the plume from the Motherwell canal. Aerial photographs were taken at intervals after each release, and were scaled later in the laboratory.

A grid of marker buoys was laid both upstream and downstream of the canal mouth, in order to permit X-Y position fixing of the plume limits. The position of each buoy was fixed relative to a mark painted on the concrete bridge over the canal using theodolites. However, the orange buoys were not clearly visible in the subsequent photographs, so were not used in scaling the plume snapshots. The concrete bridge, visible in all photographs, was used as a convenient scale length of 28.3m.

The Rhodamine B dye was mixed with methanol to a density equivalent to that of the estuary water. Approximately 2 litres of the mixture was released in a plug on the estuary side of the concrete bridge. The ebb-tide dye release was made at 07h45. Records from a vector averaging current meter moored in mid-stream opposite the canal mouth show that the tide was outgoing until 10h45.

The flood-tide release was made in the same manner at 12h06, a short while before the flood current reached maximum speed.

### 2.3 Estuary circulation studies

During May 1990, five trips were made to the estuary to measure depth profiles of salinity and temperature at 11 stations between the mouth and the head (Fig 1.1) using a Valeport Series 600 Mk II CTDS meter.

The estuary was sampled at low slack water and high slack water on each trip: the boat was anchored in mid-stream at each station. Salinity and temperature were recorded at 1m intervals at stations where the water depth was 5m or greater, and at 0.5m intervals otherwise. If a halocline was observed, the depth interval was reduced to 0.25m. In most cases each slack water run began at the mouth and finished at the head within 60-75 minutes. However, on 17 May, while anchored at Station 1, we were called by police to assist in the search for a body in the Swartkops mouth area, which led to some considerable delay.

The sampling period covered one 14 day spring-neap cycle, from 17 to 30 May.

## 3. INTERPRETATION OF EXISTING DATA

### 3.1 PEM Bacteriological data

The Port Elizabeth City Engineer's Department collected samples at 9 stations along the estuary between the head and the mouth between March 1980 and September 1987. Monthly samples were analysed for faecal coliforms and E. coli per 100ml.

Staff of the Port Elizabeth City Health Department resumed bacteriological sampling at four of these stations, and at an additional station near the Motherwell canal mouth from November 1987. Initially, the stations were sampled on a fortnightly basis, later weekly, then bi-weekly. Since June 1989, sampling has continued at weekly intervals.

The data has been collated and subjected to statistical analysis (MacKay et al, in prep; MacKay & Lord, 1991), and the results are discussed in section 4.4 of this report.

### 3.2 DWA Chemical and bacteriological data

The Department of Water Affairs monitors 13 stations along the river/estuary system between Kruisriver and Amsterdamhoek, at quarterly intervals. Analyses carried out include pH, conductivity, ammonia-N, OA, COD, E. coli and faecal coliforms. Results of statistical analysis of the river water quality data have been discussed in MacKay &

Eichstadt (in prep.) and are covered briefly in section 4.4 of this report.

### 3.3 Research by the University of Port Elizabeth

In recent years, much research has been done concerning biological and geological aspects of the Swartkops system. Appendix B contains a list of all the relevant references.

### 3.4 PEM Water level records

Several water level recorders have been deployed in the river and estuary since 1987, and these are maintained by the City Engineer's department in order to provide data input for the hydrological model of the estuary (Huizinga, 1984).

Only one recorder remains in the lower river, but data is available from 4 recorders along the estuary. The recorders include shaft encoders linked to data loggers which store half-hourly water levels relative to mean sea level.

Although there are gaps in the records, they could be used to provide valuable information on the hydrodynamic behaviour of the estuary, particularly delay and distortion of the tidal signal due to constriction inside the estuary. Long-term trends in the flushing capability of the estuary could be identified, as the magnitude of the tidal prism varies with changing estuary morphology.

### 3.5 Weather data

Daily rainfall totals from Weather Bureau Stations at Swartkops Power Station, H.F. Verwoerd Airport and Uitenhage were used in interpretation of water quality data from the Swartkops River, the estuary and the Motherwell stormwater canal. Daily rainfall records from Bluewater Bay were provided by Dr A.P. Martin, the Swartkops Conservation Officer.

In addition, a rain gauge was installed in January 1990 at the house of a UPE employee resident in Motherwell township. Daily totals were recorded for approximately four weeks, but were discontinued when this person moved away from the area at short notice.

A weather station is maintained at Cape Recife by the Department of Oceanography, UPE, and hourly values of wind speed and direction, air temperature and pressure and solar radiation are recorded there.

# 4. RESULTS AND DISCUSSION

## 4.1 Motherwell Stormwater

### 4.1.1 Results from 1988 study

In 1988, the Department of Oceanography sampled runoff from Motherwell township, in the same way as during latter studies. Water samples were collected on 22 days between 9 August and 20 October 1988, and flow rates recorded (Scarr, 1988). Table 4.1 summarises the results obtained.

**Table 4.1 Results of analysis of stormwater samples from Motherwell canal.**

| Determinand | Median of 22 daily medians |
|---|---|
| Flow rate | 2 l/sec |
| Faecal coliforms | 54 000 per 100ml |
| EC | 5.45 mS/m |
| pH | 8.3 units |
| nitrate-N | 5.2 mg/l |
| O-phosphate-P | 0.28 mg/l |

**Table 4.2 Bacteriological and virological analysis of stormwater samples from Motherwell canal (from Scarr, 1988).**

| Date | Faecal coliforms per 100ml | Faecal streptococci per 100ml | Coli-farges per 10ml | Sal-monella | Viruses |
|---|---|---|---|---|---|
| 26/7/88 | 10 100 | 430 | 6 004 | POS | 6324 REO |
| 27/9/88 | 1 533 300 | 46 700 | 55 000 | POS | 93 INTRA |
| 8/11/88 | >50 000 | 37 200 | 400 | POS | - |

The results show that by soon after the commencement of development in Motherwell, a continual flow of polluted runoff was reaching the Swartkops estuary. This runoff had high levels of faecal bacteria and was nutrient-enriched. In addition, viruses had been positively identified as present in the runoff.

4.1.2 Results from 1989-90

Fig 4.1 shows box-and-whisker plots drawn as follows : for the twice-weekly sampling results of the second of three samples were extracted from the record; from the 24-hour sampling, the results of the 07h00 sample were extracted. These were then separated into wet-weather and dry-weather samples, where wet weather was defined as more than 5mm rain recorded at Bluewater Bay in the 24 hours antecedent to sampling, while dry weather was defined as less than 5mm of rain in the past 24 hours.

The results show clear differences between runoff quality in wet and dry weather. Compared to wet-weather runoff, dry-weather flow was usually between 1.5 and 2 litres per second, but never zero; pH and EC were higher; faecal coliforms per 100ml showed a similar median but greater range in values; OA, COD, orthophosphate-P and TDS were all significantly higher. In most cases, the dry-weather flow exceeded the General Effluent Standard in all determinands, although the wet-weather flow quality was usually acceptable in terms of this standard.

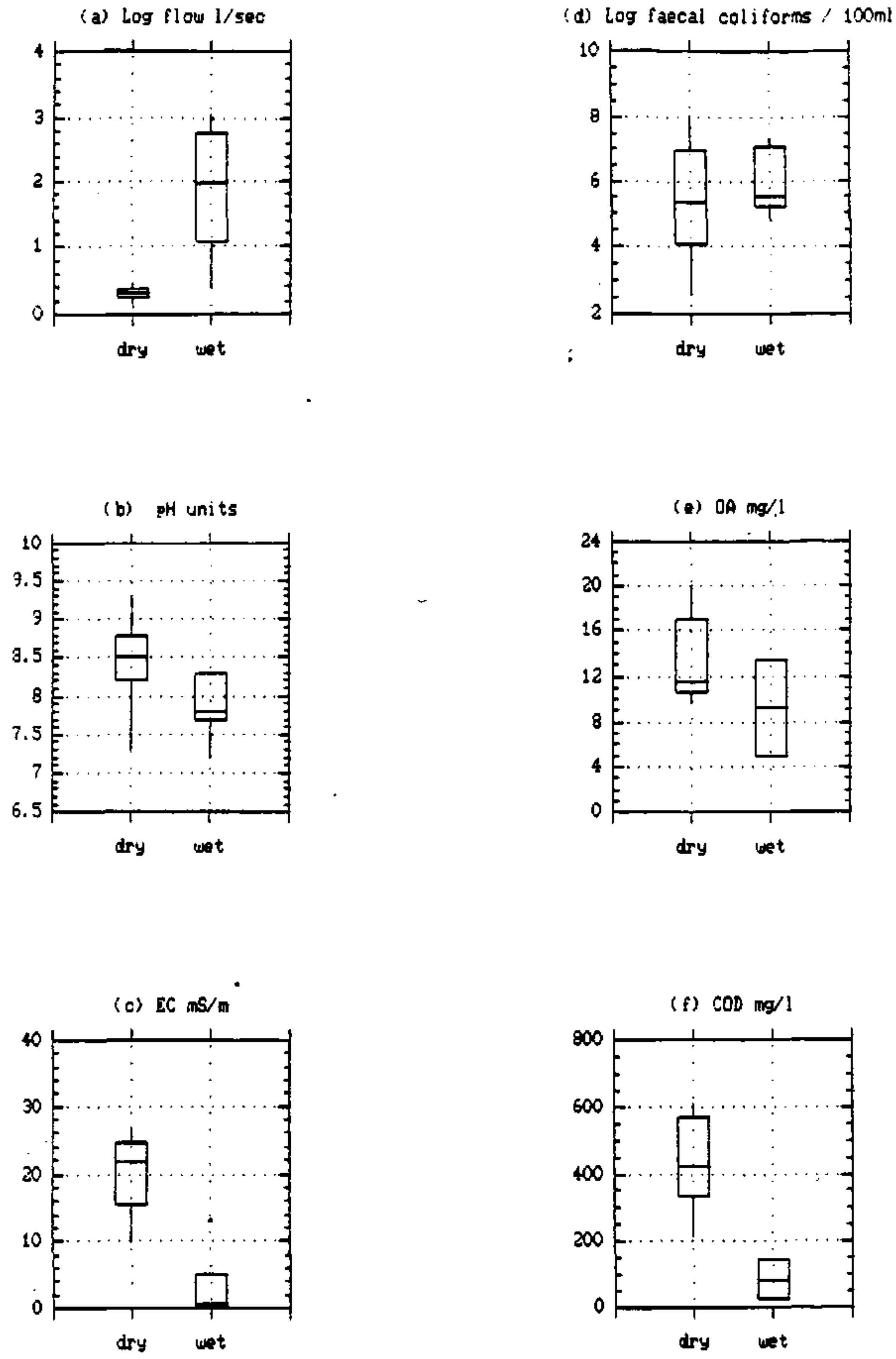



FIG 4.1 Box-and-whisker plots to show wet-weather and dry-weather runoff characteristics. Samples taken in Motherwell canal.

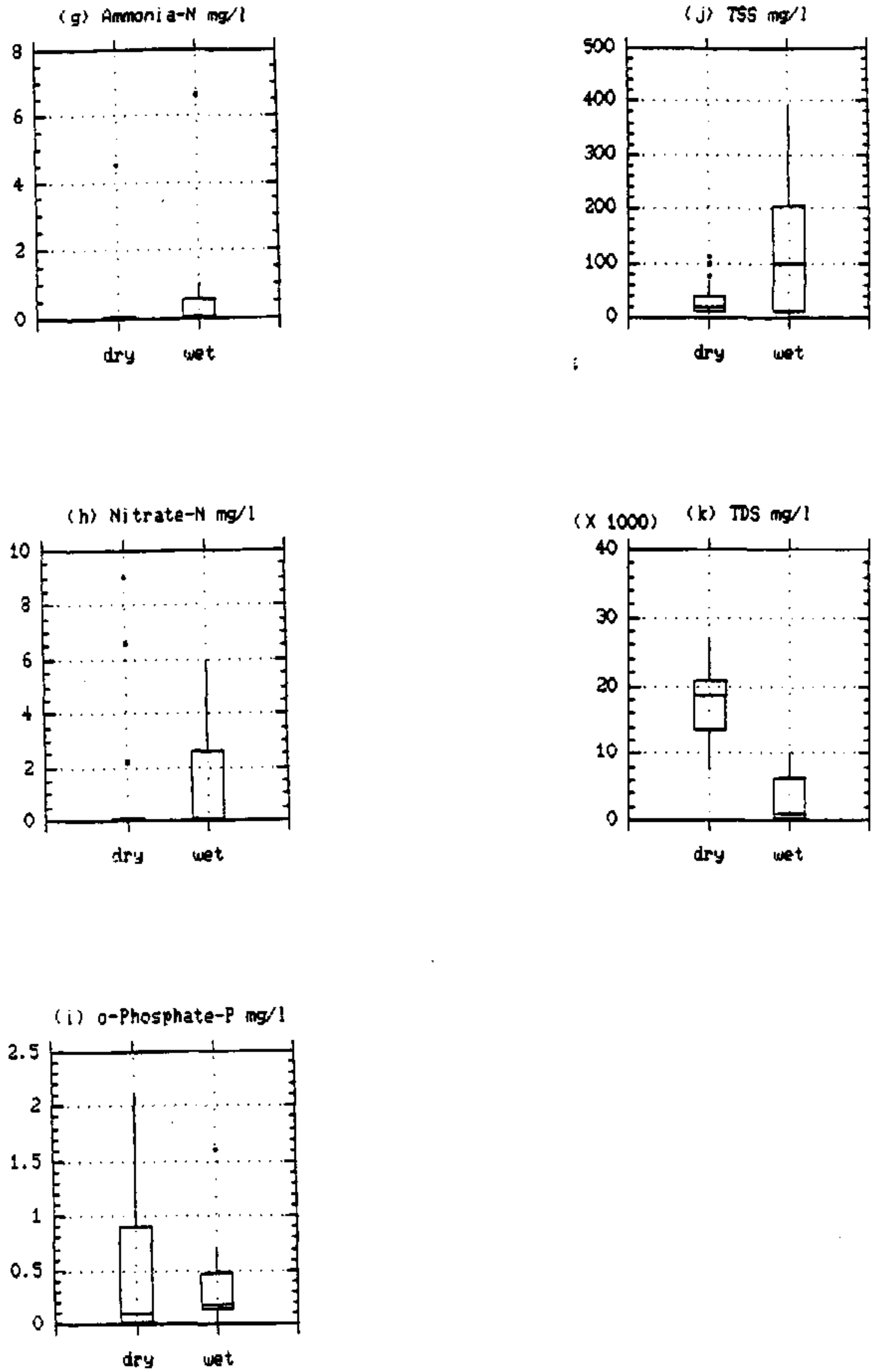



FIG 4.1 Box-and-whisker plots to show wet-weather and dry-weather runoff characteristics. Samples taken in Motherwell canal.

Invariably, dry-weather flow could be traced back to blockages of the sewerage system, often due to vandalism. Much refuse and litter was dumped in the canal and this added to pollutant loads.

A more detailed analysis of the quality and quantity of runoff from Motherwell, and its impact on the Swartkops estuary, is in preparation and will be submitted to Water SA shortly (MacKay & Lord, in prep.).

Measures were proposed to alleviate the problem of the polluted runoff, which persisted despite all attempts to maintain the sewerage system in good order and to keep the canal clean. One such proposal was the installation of an artificial reed bed at the bottom of the canal, through which dry-weather flow would pass, while bacteria and excess nutrients were removed. Wet-weather flow would pass directly to the estuary.

The solution finally adopted appears to have been successful : a sump was excavated below the floor of the canal to collect dry-weather flow, which then pumped back to the sewage system for treatment. High flows pass over the top to the estuary. The design is shown in Fig 4.2.

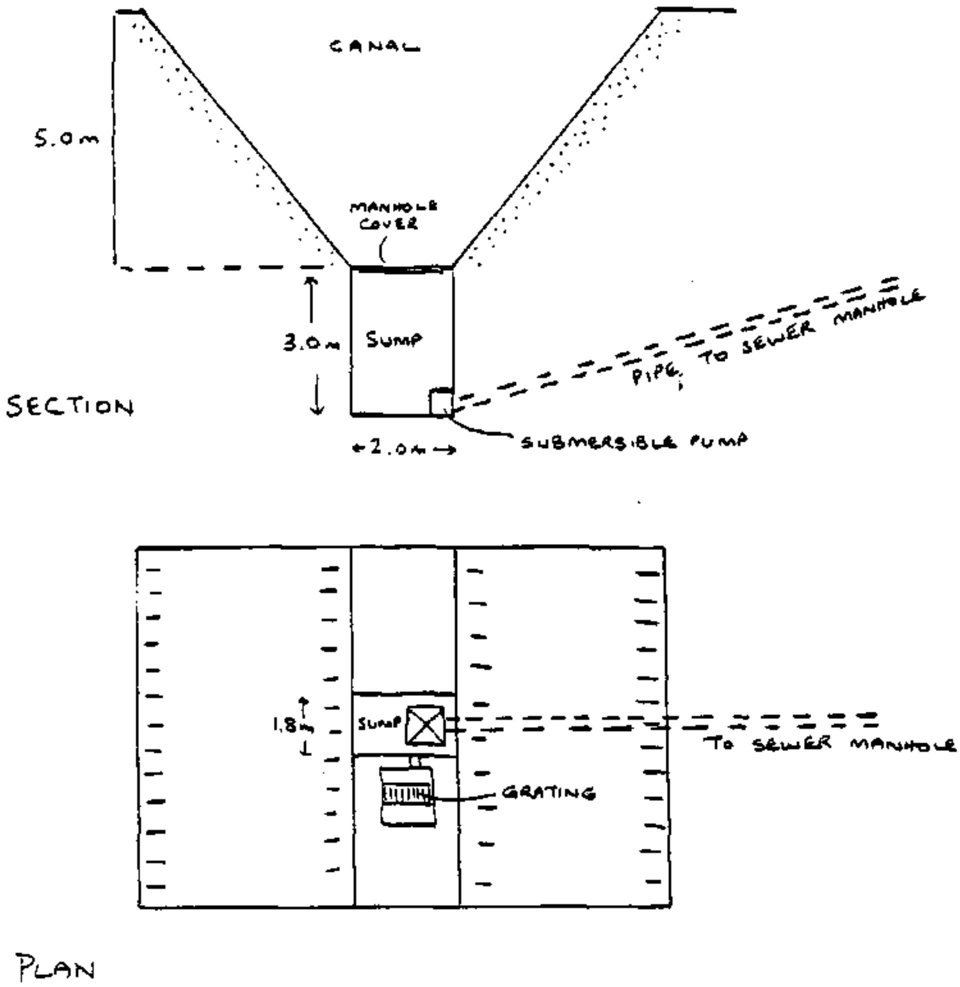



FIG 4.2 Design of the sump installed to intercept dry-weather runoff in the Motherwell canal.

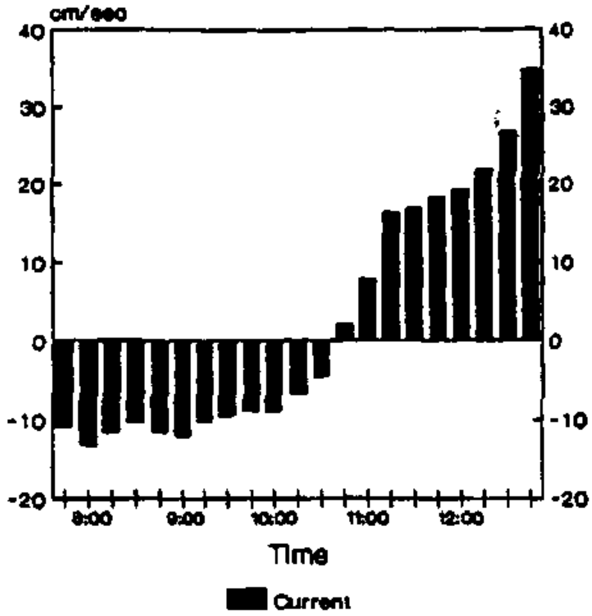
## 4.2 Dye Studies at Motherwell Canal

### 4.2.1 Ebb tide

On the day of the dye studies, the wind was a light south-westerly, and the weather partly cloudy.

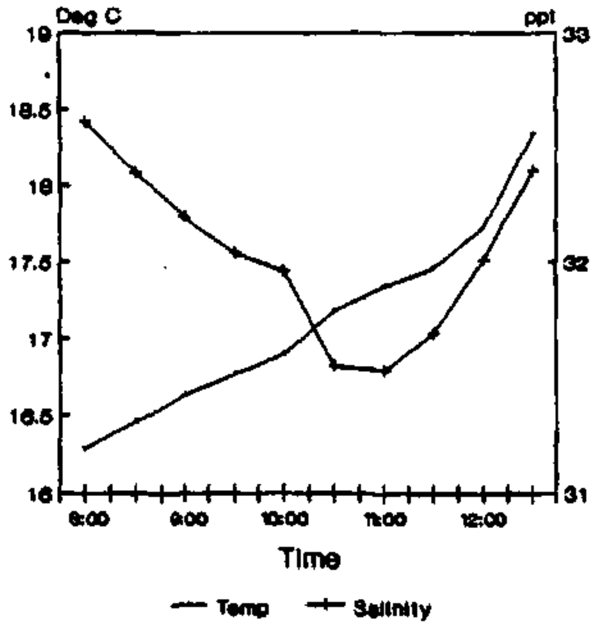
The first release was made on the ebb tide at 07h45. Fig 4.3 shows graphs of current speed and direction, depth-averaged salinity and temperature measured at the VACM mooring.

## (a) Current velocity
16/10/90




Ebb negative

## (b) Salinity / temperature
16/10/90




Depth-averaged

FIG 4.3 Graphs showing current velocity, salinity and temperature measured in the estuary during dye

Fig 4.4 shows a series of scaled drawings made from the aerial photographs. Scale length is indicated by the length of the concrete causeway over the bridge (28.3m). The downstream drift of the motorboat can be seen in drawings (c), (d) and (e).

The drawings show that most of the dispersion of the plume was in the longitudinal direction, with the plume length reaching approximately 360m by 34 minutes after release time, corresponding to a longitudinal dispersion velocity of roughly 0.2 $m.s^{-1}$ , compared to midstream measured current speeds of 0.10 - 0.13 m.s-1 . The VACM rotor was 2m below the water surface, which could have led to lower speeds being measured than at the surface, since ebb currents in estuaries tend to be concentrated in the upper layer of the water column. In addition, the plume was concentrated in the shallow region of the estuary bed, on the outside of a bend, which could also have led to higher longitudinal velocities.

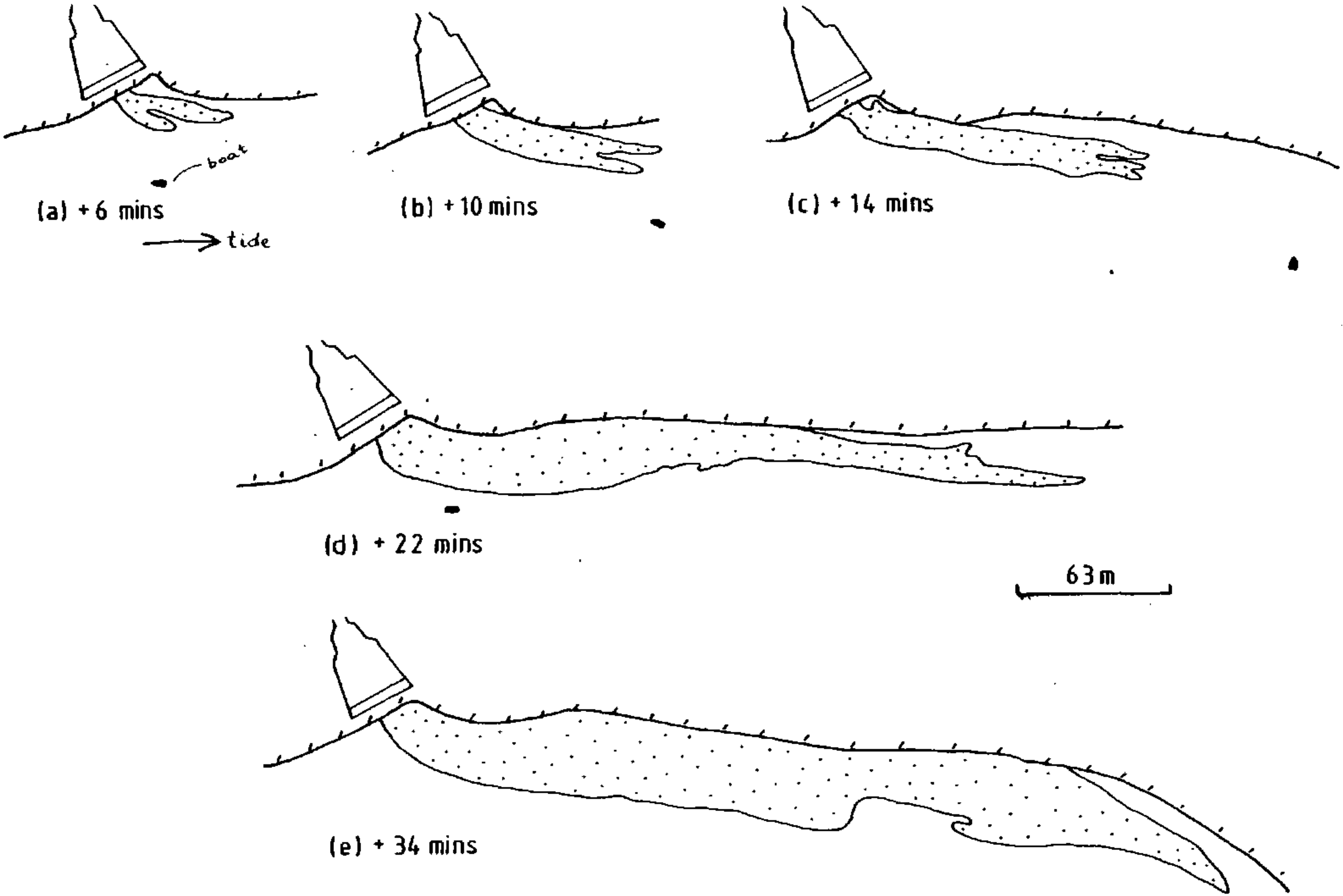



FIG. 4.4 Scale drawings of dye plume on ebb tide

Lateral dispersion was approximately 0.02 $m.s^{-1}$, averaged over the 34 minutes of observations. By the end of the observation period, the leading edge of the plume had reached the stretch of shallows and sandbanks between the Markman Canal and the Old Grahamstown Road bridge. Here the plume was mixed and diluted and could no longer be seen by eye.

The areal dispersion, estimated using a graph paper grid, was 9825 $m^2$ in 34 minutes, corresponding to a dispersion rate of 4.8 $m^2.s^{-1}$. It can be assumed that the plume mixed downward to a maximum depth of 0.5m, a reasonable estimate for fresher inflow into estuarine conditions, if little vertical turbulent mixing occurs on the ebb tide (MacKay & Schumann, 1990). Dilution calculations can be done as follows :

Total volume of plume after 34 minutes = 9825 $m^2$ x 0.5m

= 4912.5$m^3$

Canal flow on day of dye studies = $5\times10^{-3} m^3.s^{-1}$

Total canal input in 34 minutes = 10.2$m^3$

Dilution factor $\dfrac{4912.5m^3}{10.2m^3}$ = 482

Hence if the canal flow had been polluted by sewage as usual, with a count of 1 000 000 faecal coliforms per 100ml, dilution would be as follows:

Total faecal coliforms in $10.2m^3$ = $1 \times 10^{11}$

Dilution $\dfrac{1 \times 10^{11}}{4912.5m^3}$ = $2 \times 10^{7}$ per $m^3$

= 2000 faecal coliforms/100ml.

If no die-off occurred in the 34 minutes after these bacteria were released into the estuary, the count within the plume would have been 2000 faecal coliforms per 100ml. The plume remained close to the bank, where fishermen and children paddle : in such a zone, a bacteria count as high as that above is unacceptable.

The dilution estimates above are conservative, since frequently bacteria counts in the canal were of the order of $10^{6}$ per 100ml. Also, uniform dispersion across and along the plume is assumed : if the canal flow is of much lower electrical conductivity than the receiving estuary water, vertical mixing and dispersion will be reduced, leading to smaller dilution volumes.

4.2.2 Flood tide

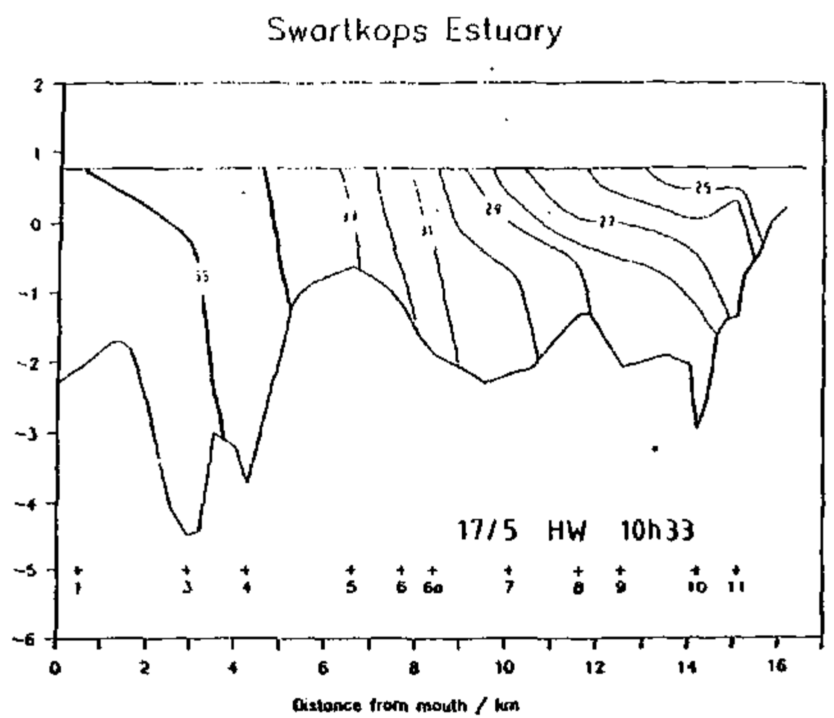
No drawings were made of flood tide dispersion, since none was observed while the aeroplane was overhead in the first 20 minutes after release. (Figs. 4.5 and 4.6). The reason for this is not clear but could be explained as follows :

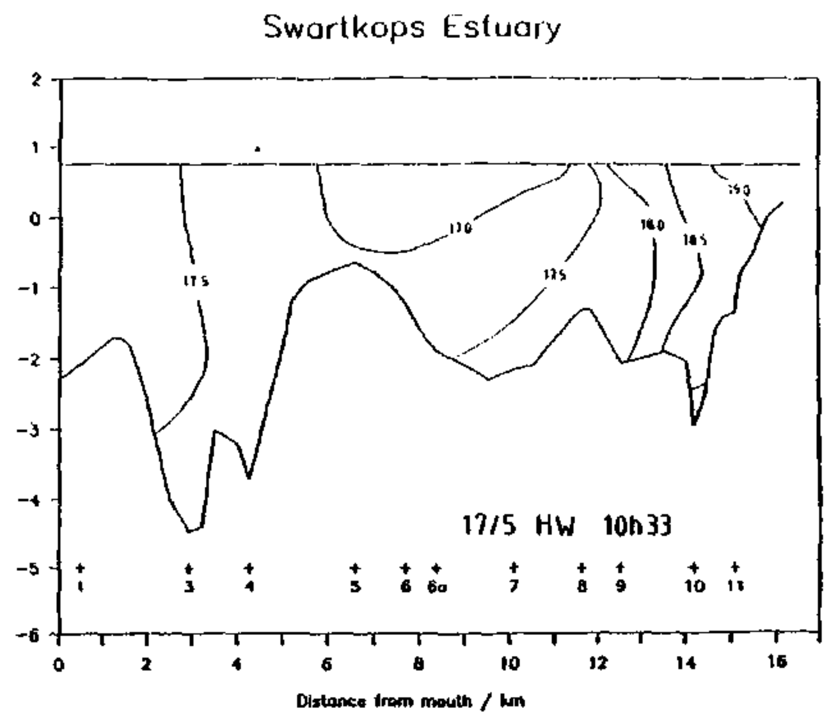
Measured flood current speed at the time of release (12h06) was approximately 0.19 $m.s^{-1}$ and increasing to a maximum of 0.35 $m.s^{-1}$ at 12h45. Flood currents in estuaries tend to be concentrated in the lower layer of the water column, and in the deepest part of the channel cross-section. Hence there was little movement of water at the dye release position, and so little dispersion.

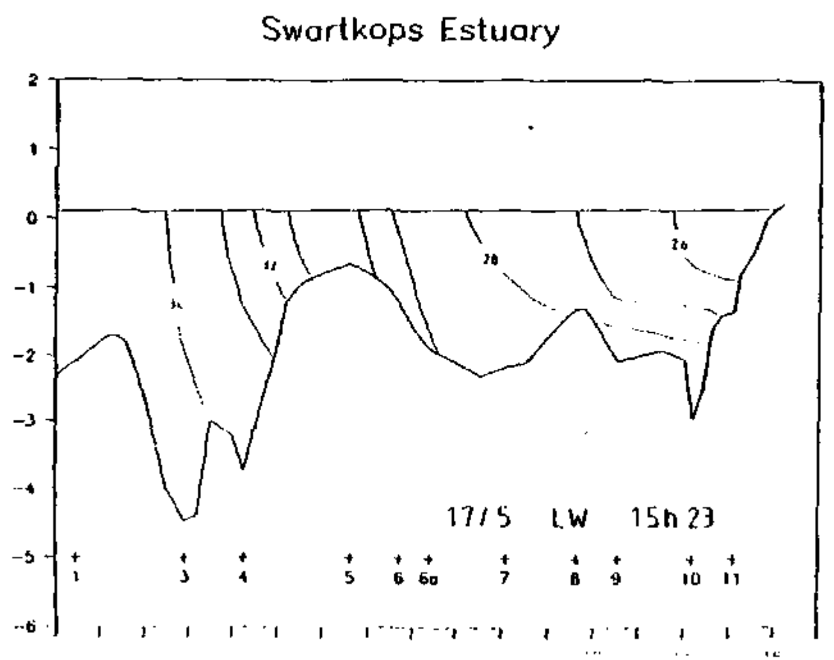
Later, once the water level rose with the incoming tide, the stagnant water at the canal mouth would have been transported upstream towards Redhouse.

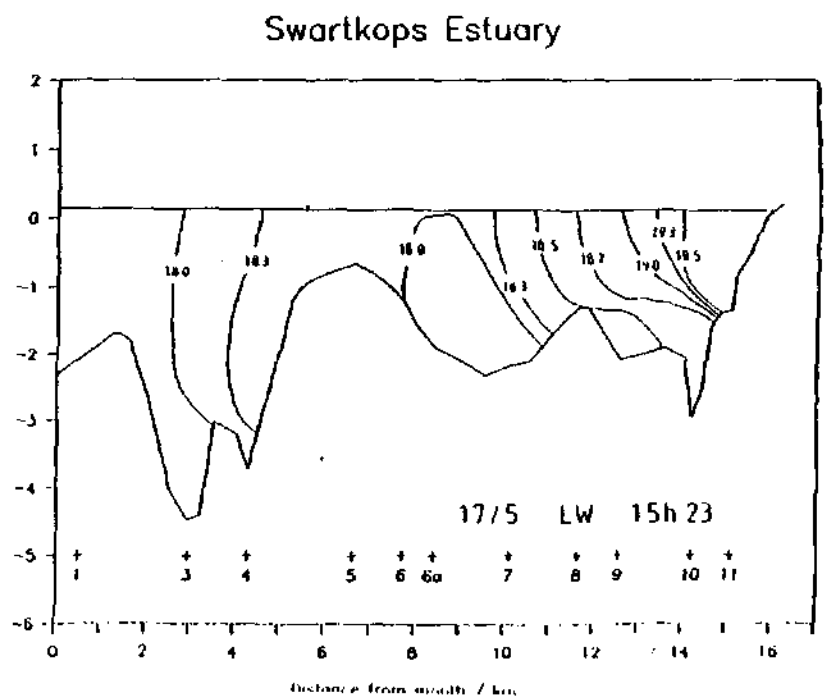
After the aeroplane landed, we returned to the canal, to find that some 85 minutes after release, the plume extended in a narrow ribbon-shape to the first bend, a distance of about 400m. The plume appeared to be considerably diluted. A similar pattern of dispersion on the flood tide was observed several times, from the air and from the top of the escarpment : even without dye, the surface of the plume was clearly visible due to the presence of scum and oils.

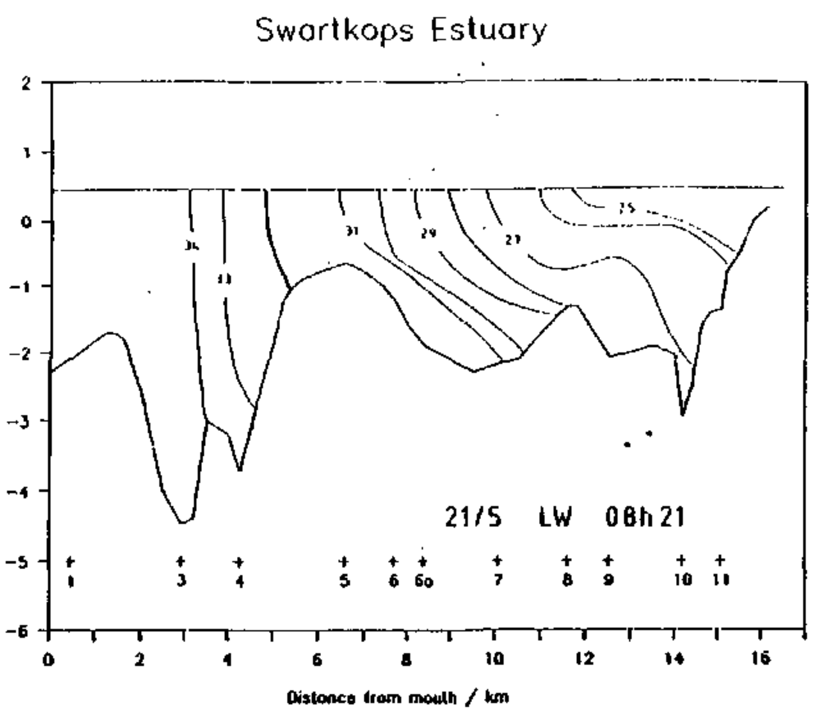
FIG 4.7 Following pages : axial contours of salinity (parts per thousand) and temperature (°C) in the estuary in May 1990.
Top and bottom left : salinity.
Top and bottom right : temperature.

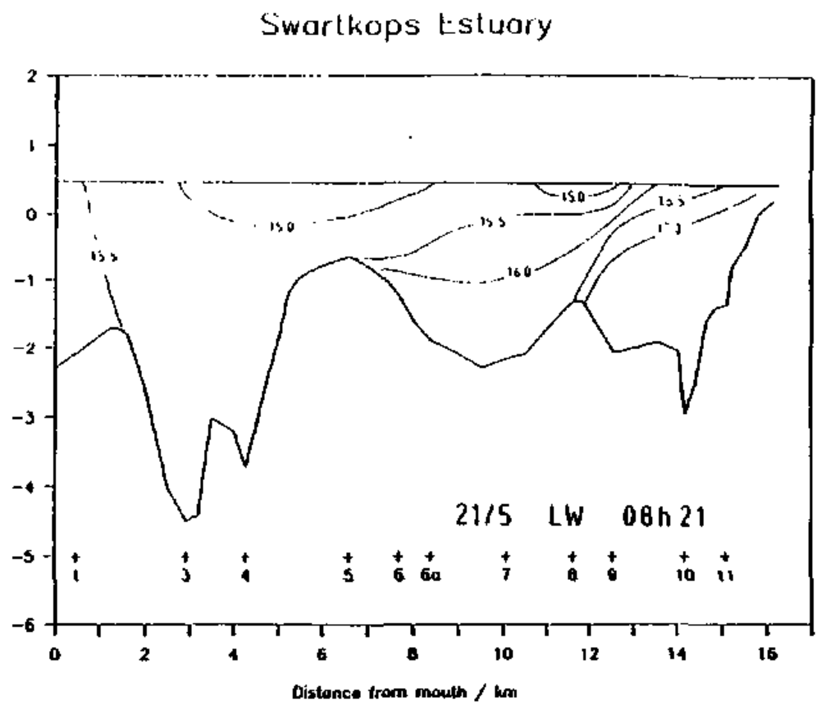

Swartkops Estuary
17/5 HW 10h33
Distance from mouth / km

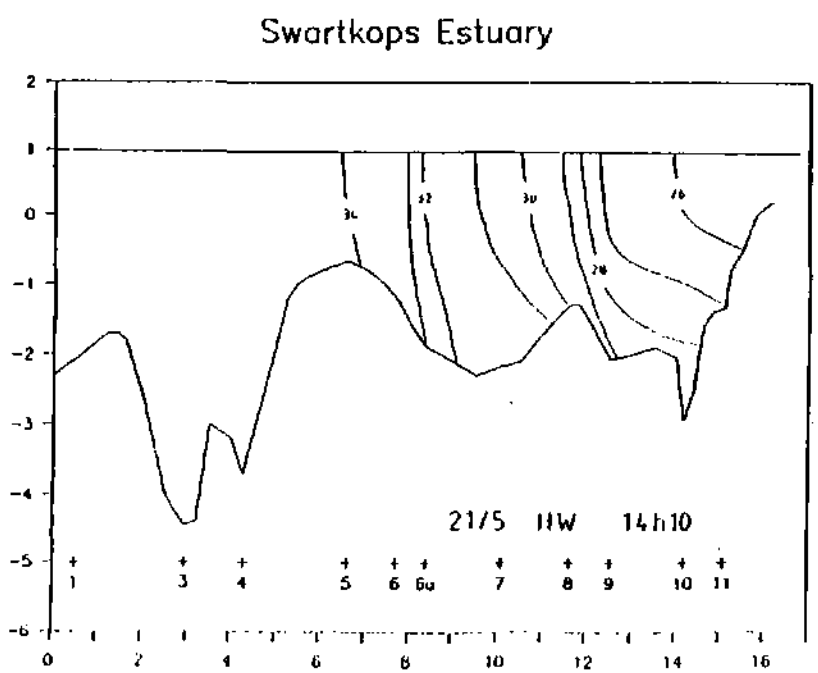

Swartkops Estuary
17/5 HW 10h33
Distance from mouth / km

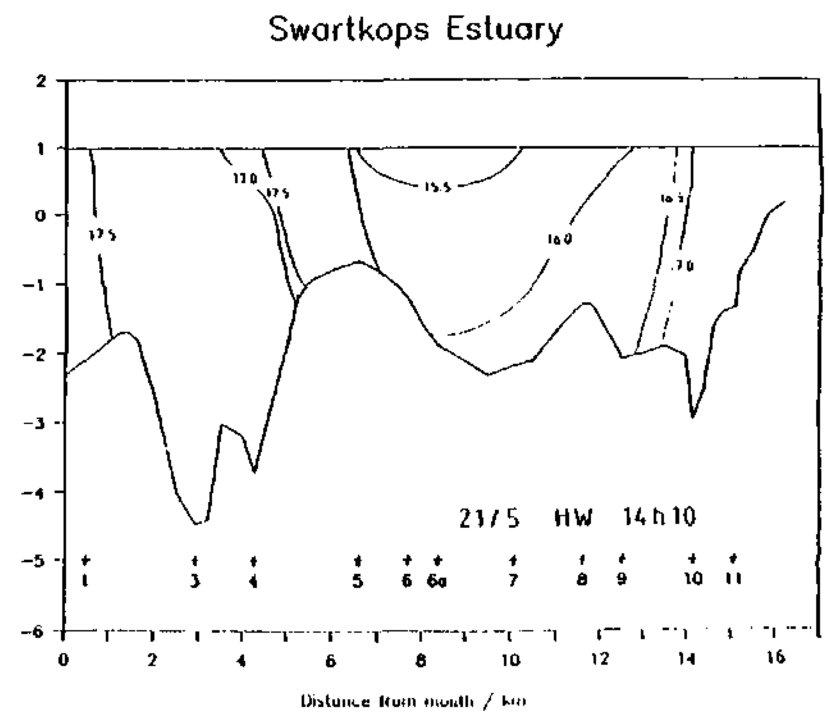

Swartkops Estuary
17/5 LW 15h23


Swartkops Estuary
17/5 LW 15h23

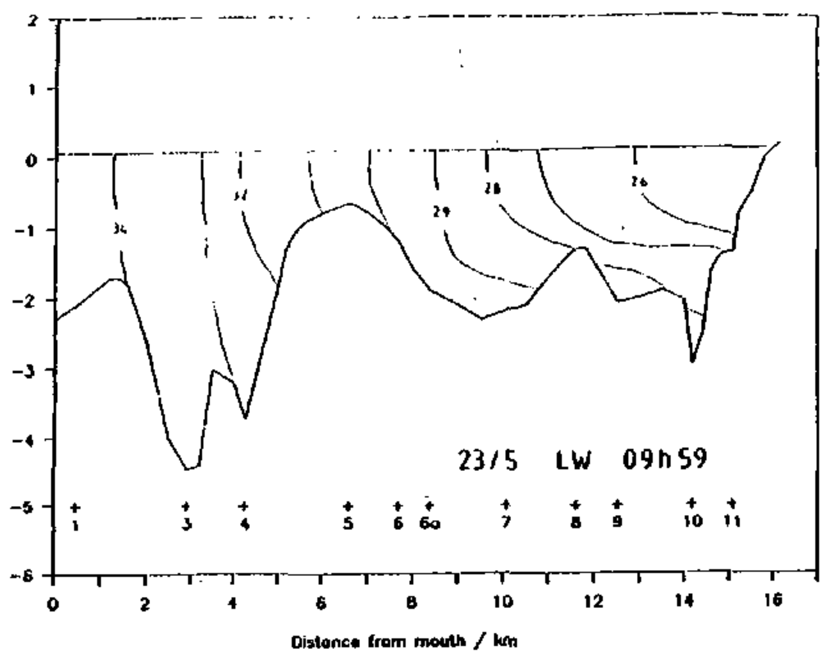

Swartkops Estuary
21/5 LW 08h21
Distance from mouth / km


Swartkops Estuary
21/5 LW 08h21
Distance from mouth / km

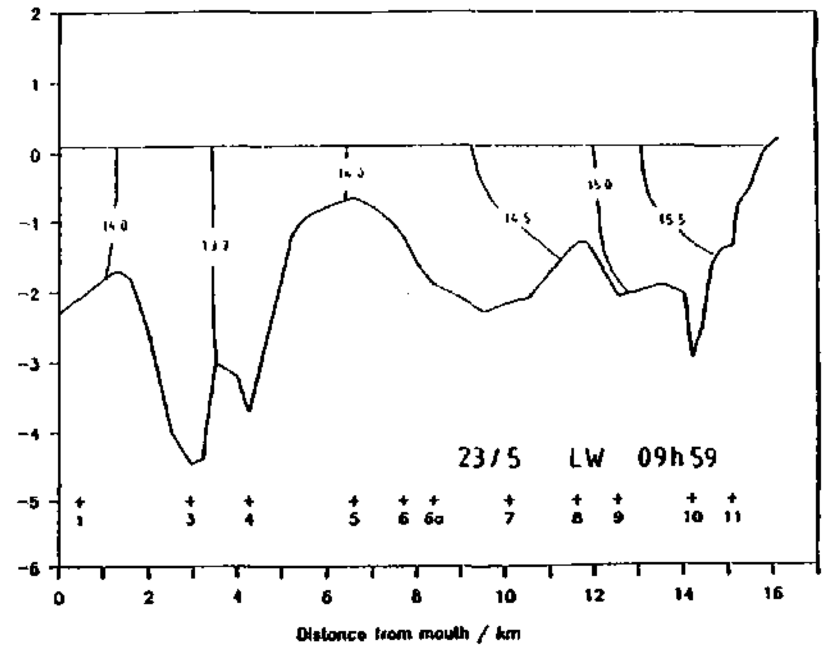

Swartkops Estuary
21/5 HW 14h10


Swartkops Estuary
21/5 HW 14h10
Distance from mouth / km

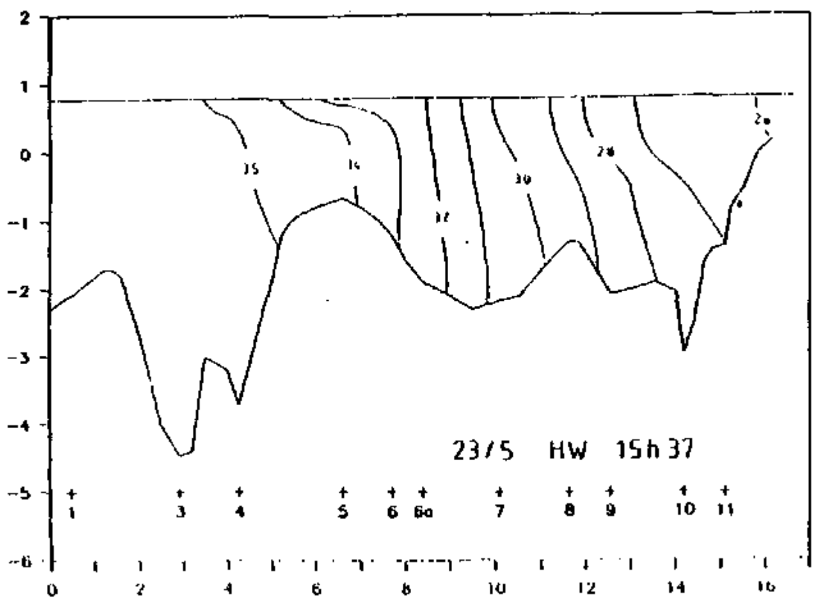
## Swartkops Estuary



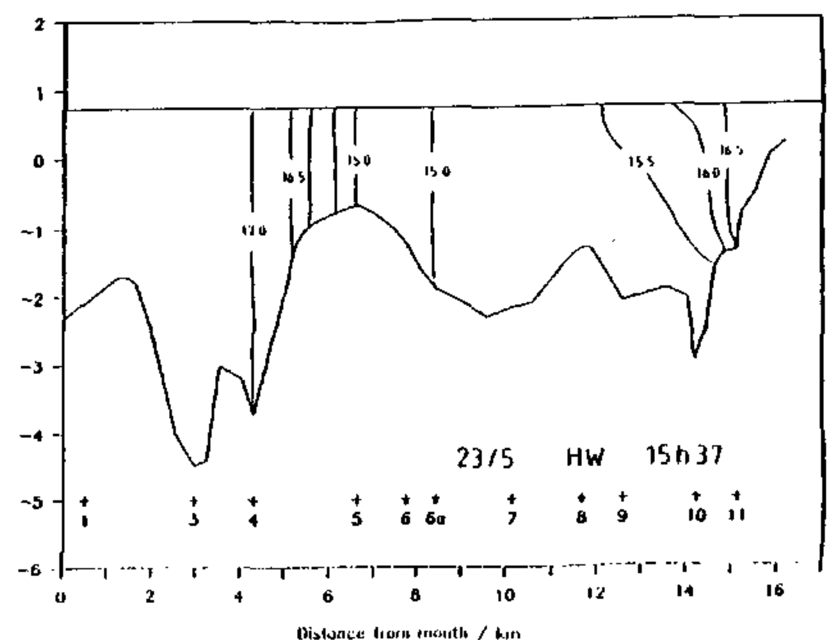

## Swartkops Estuary



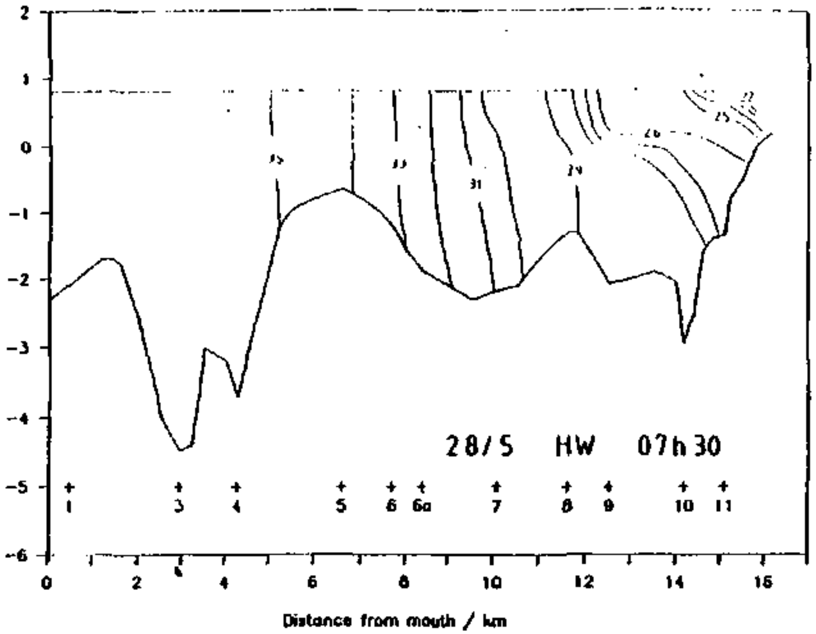

## Swartkops Estuary




## Swartkops Estuary



Swartkops Estuary

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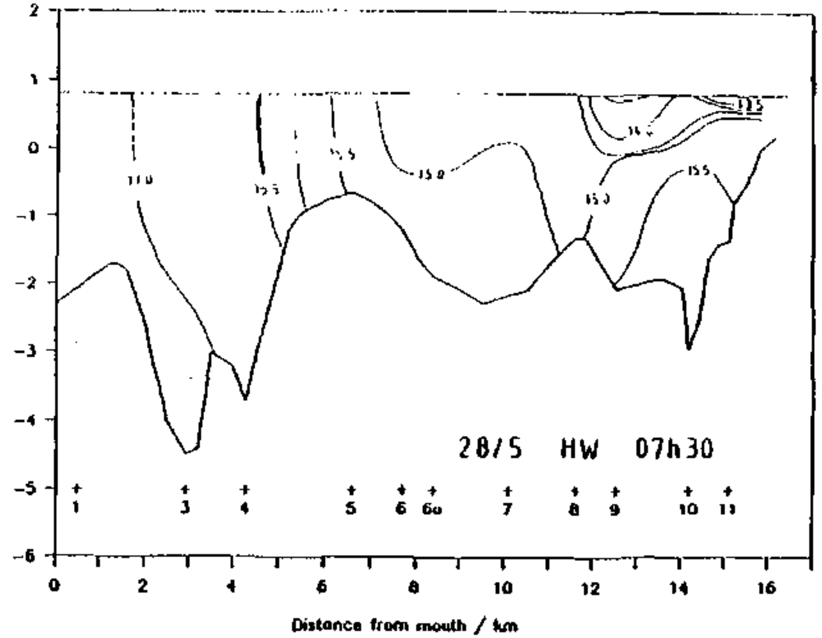


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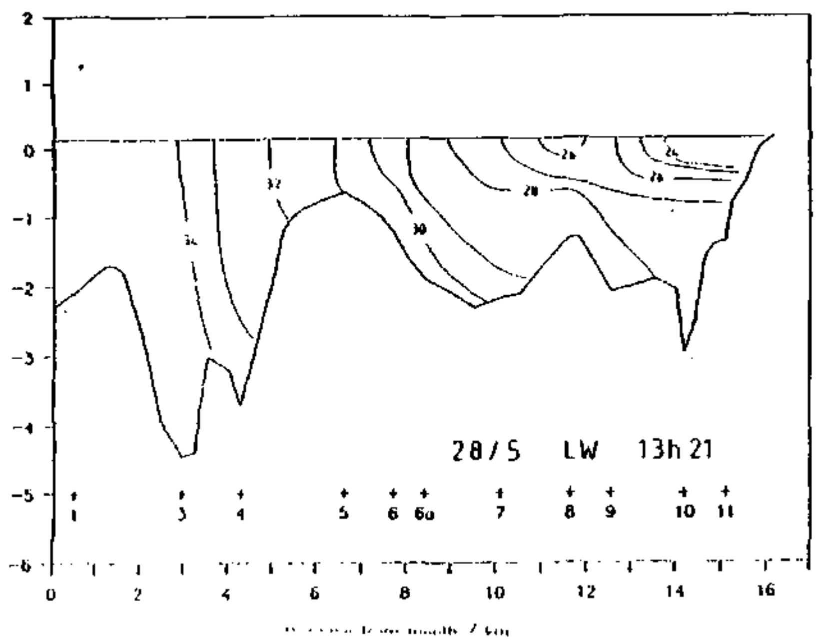


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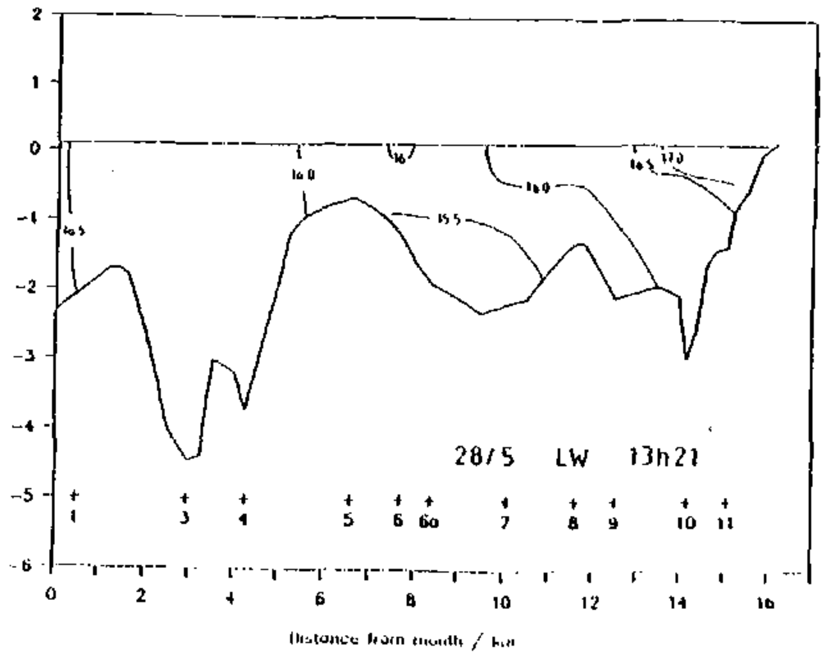

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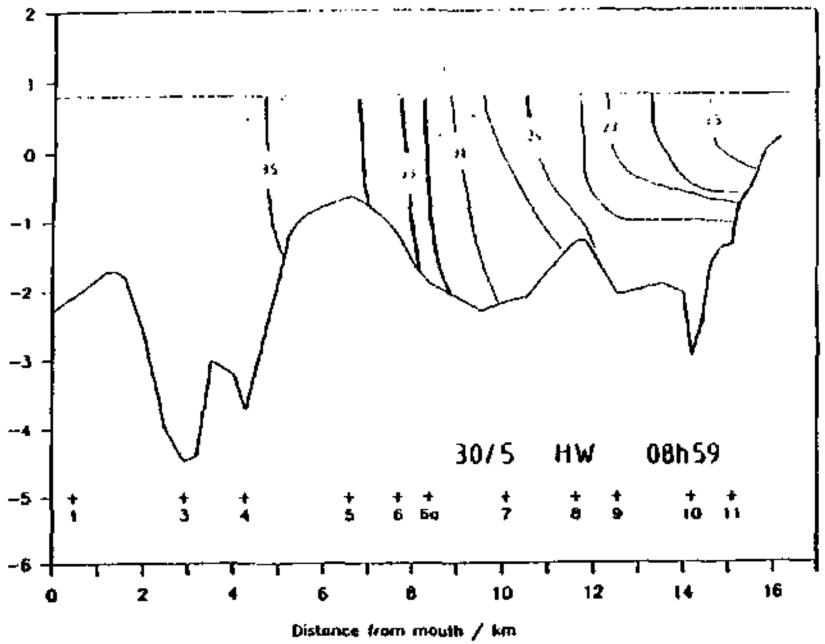


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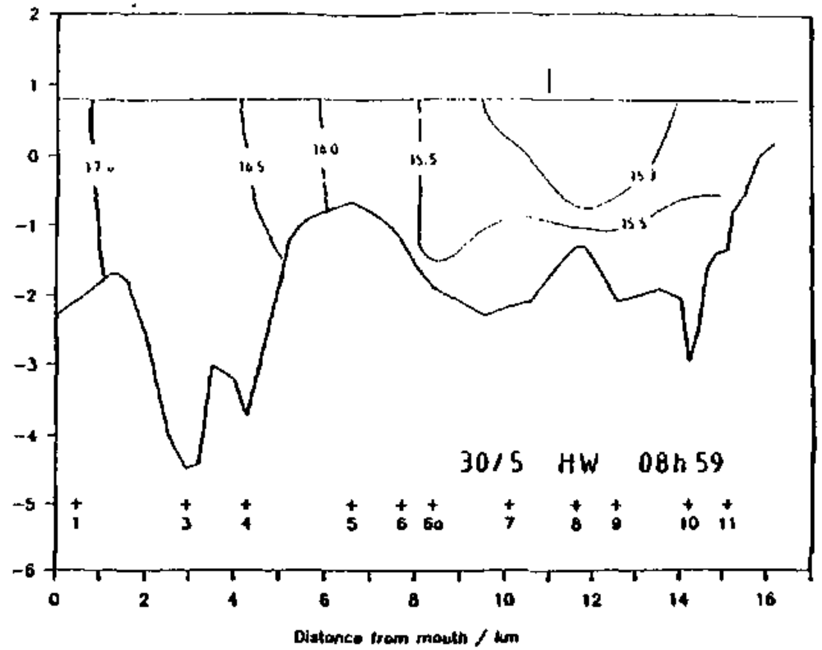
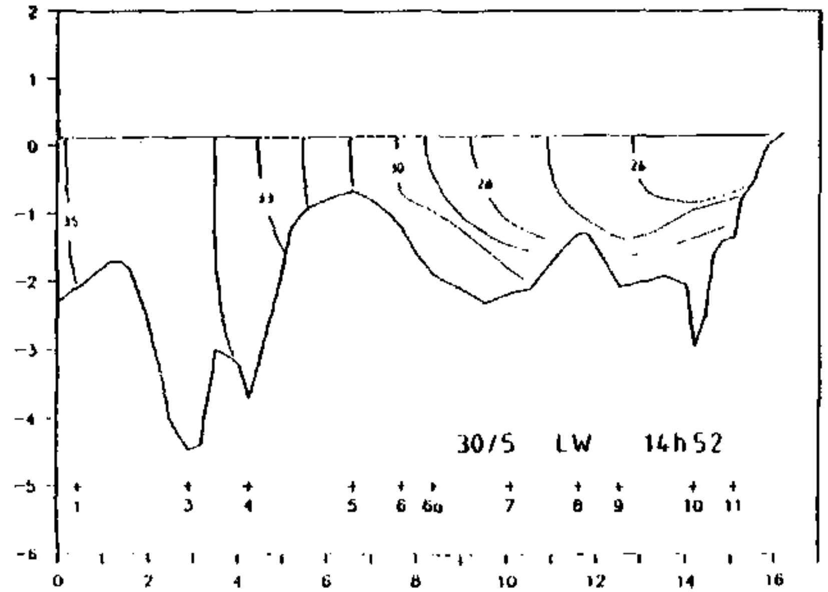
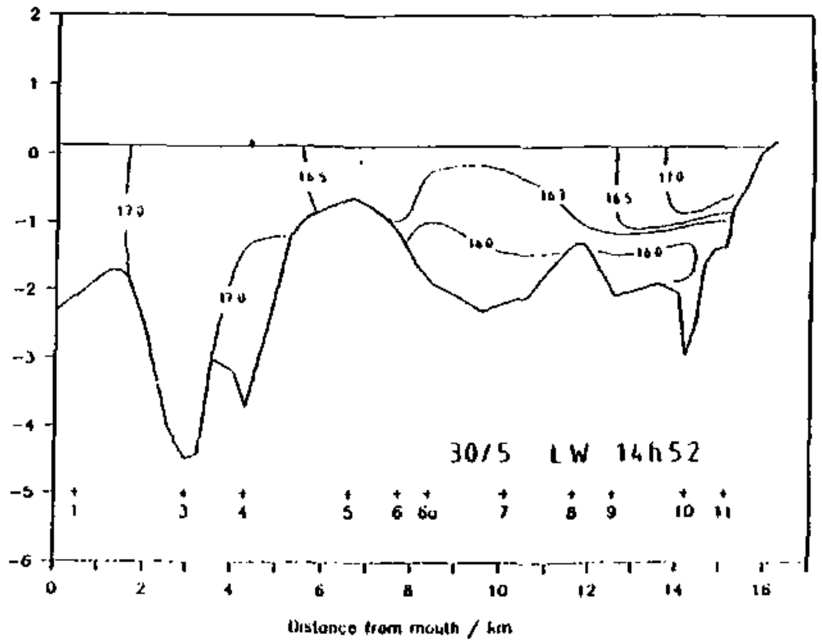



Swartkops Estuary




Swartkops Estuary



### 4.3 Salinity and temperature data

The salinity profiles (Fig 4.7) show the Swartkops to be marine-dominated almost to the head. River flow is low compared to the tidal prism, and hence salinities were consistently higher than 25 °/oo, even at station 11 near the head.

Very little stratification was observed, particularly below station 5, where the water column was well mixed on both flood and ebb tides. A small degree of stratification was observed in the upper reaches, between stations 8 and 11, which tended to become slightly more marked at neap tides.

The estuary follows the general pattern, observed in other East Cape estuaries, of tendency to stratification at neap tides or during increased river flow, and the opposite tendency to vertical mixing at spring tides (MacKay and Schumann, 1990). However the degree of stratification and the range of observed salinities are both small.

The influence of the sea on the lower and middle estuary can clearly be seen on inspection of the temperature profiles (Fig 4.7). Temperature in these regions depends more on that of the neighbouring ocean on incoming tides, but can change markedly as water from further upstream is advected seawards on the outgoing tides. This was particularly clear on 21 May and 23 May.

In the mornings, temperature inversions are common in the water column, due to the rapid cooling at night of the air layer above the water column. These inversions become more marked at neap tides when vertical mixing is inhibited due to lower tidal energy and the presence of a slight salinity stratification.

Fig 4.8 shows daily ranges of depth-averaged salinity and temperature, compared to the daily tidal range, sea temperature range measured at Humewood, and air temperature range measured at H.F. Verwoerd Airport.

The maximum daily range in salinity occurred at stations 5, 6 and 6a at neap tides, with very small ranges observed in the upper and lower estuary, again a pattern common to other estuaries. At spring tides (21 and 23 May) this pattern shifted upstream, as the larger-amplitude tides penetrated further up the estuary. By 30 May, the pattern was again returning to the neap tide situation. It would appear that very little exchange of water occurred between the upper and middle estuary, while exchange between the middle and lower estuary was adequate at spring tides, but much decreased during neap tides.

While the sea temperature remained relatively constant, that in the estuary was dependent on air temperature. Generally, estuaries can display a temperature gradient of up to 10°C, directed up-estuary in summer, and seawards in winter, as the moderating influence of the sea is felt. During the time of measurements, it is likely that the autumn transition between these two situations was under way (Fig 4.8).

In summary, the Swartkops, although behaving in a manner similar to other estuaries of its physical type, shows susceptibility to degradation via input of pollutants to its middle and upper reaches, where mixing and tidal exchange are inefficient at removing contaminants, and residence times may be longer than 14 days.

## (a) Salinity

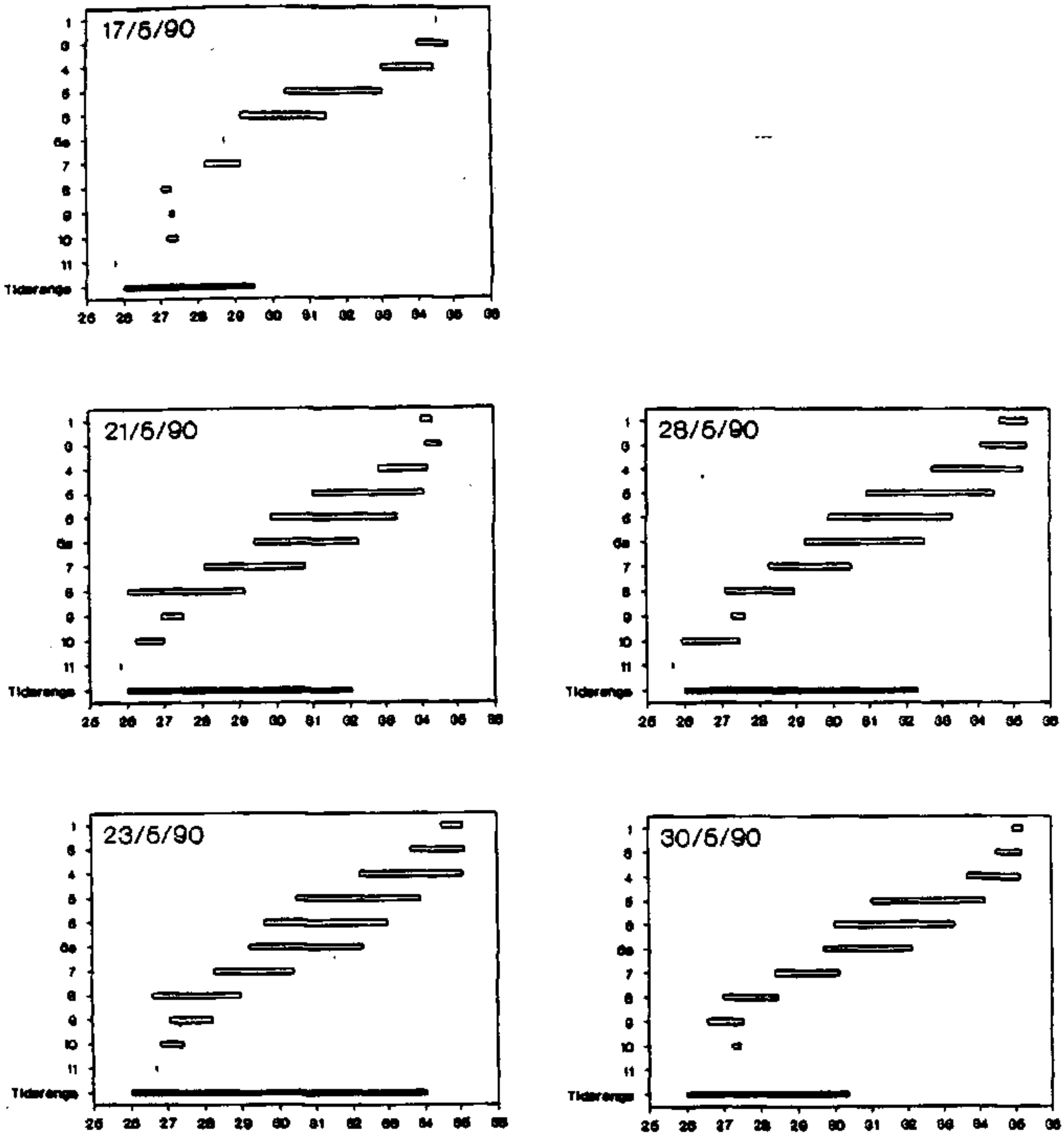
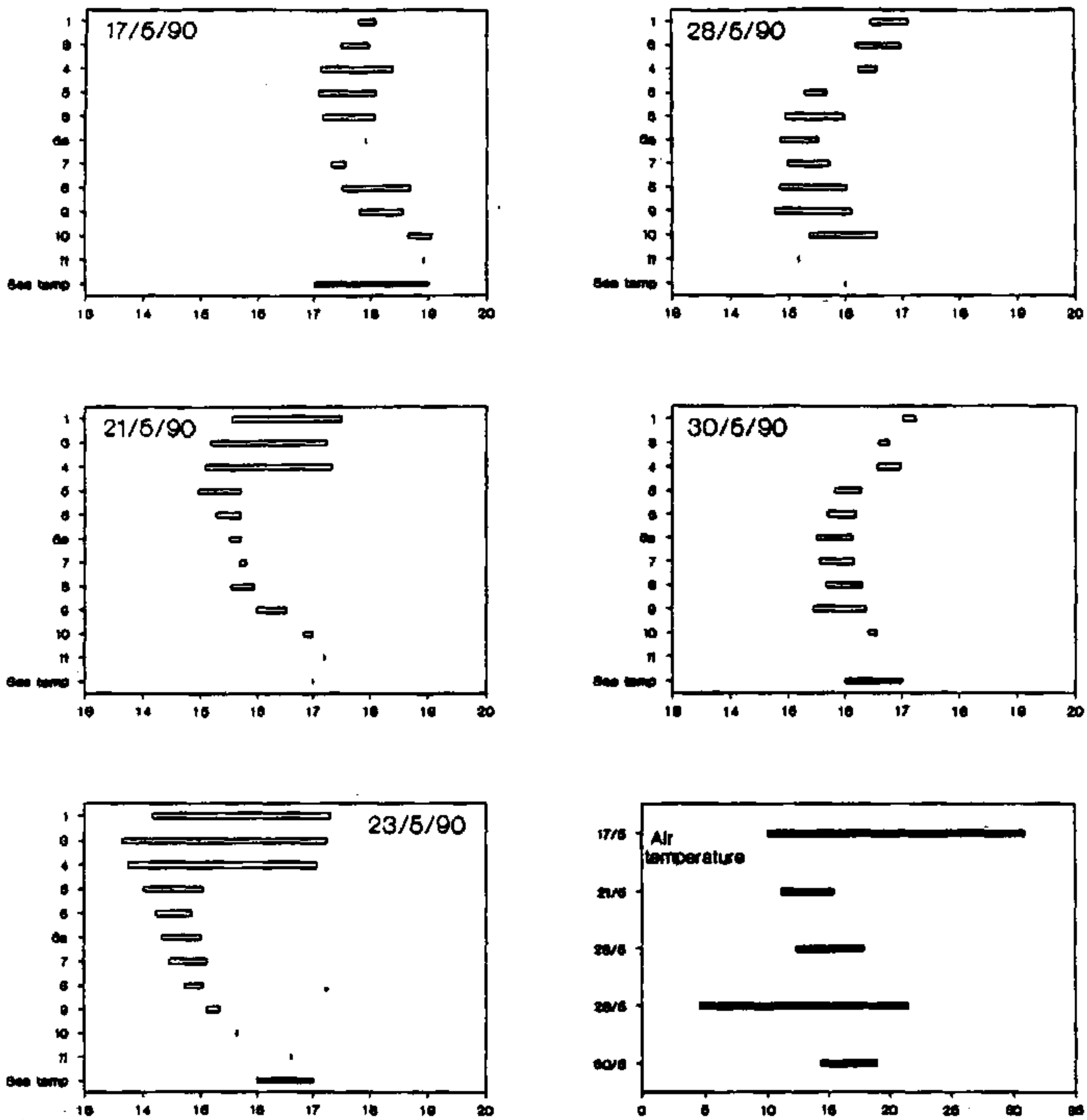



FIG 4.8 Daily salinity and temperature ranges in the estuary in May 1990.
Vertical axis : Station number
Horizontal axis : salinity ($^{o}/_{oo}$) or temperature ($^{o}$C).
Relative daily tidal range LW to HW shown.

(b) Temperature



### 4.4 River and estuary historic data

#### 4.4.1 Lower Swartkops River

The Department of Water Affairs in Port Elizabeth provided records of analysis of water samples collected in the Swartkops River between 1978 and 1991. This data was subjected to statistical analysis and interpretation in order to assess the potential for pollution of the estuary due to contaminated river inflow.

Results show that the impact of the river on the estuary presently may not be significant, compared to other inputs. However, the lower Swartkops River itself is negatively impacted by runoff from the Uitenhage-Despatch industrial complex, particularly in dry weather when little dilution occurs.

The full text of a paper by MacKay & Eichstadt (in prep.) is included in Appendix A to this report. The title of the paper is "Water Quality of the Lower Swartkops River, 1978-1991".

#### 4.4.2 Swartkops Estuary

The City Engineer's Department and the Medical Officer of Health of Port Elizabeth kindly made available results of analysis of samples taken in the estuary between 1978 and 1991. The analyses were microbiological : E. coli and faecal coliforms per 100ml.

The data has been subjected to rigorous statistical analysis, the results of which are contained in a paper entitled "Bacteriological water quality of the Swartkops Estuary 1978-1991" (MacKay et al., in prep.).

Briefly, the results show that there has been a deterioration in bacteriological water quality in the estuary during that period, particularly at Redhouse, Zwartkops and adjacent to the Motherwell canal. Levels in excess of $10^6$ faecal coliforms/100ml were frequently found in the estuary near the canal, making this area totally unsuitable for recreation. Pollution was invariably traced to contaminated runoff in the stormwater system draining Motherwell Township, as described in Section 4.1 of this report.

However the installation of the sump to intercept contaminated runoff in the canal led to an immediate and significant decrease in the levels of faecal coliforms in the estuary nearby, showing that this solution was indeed effective in reducing pollution.

# 5. CONCLUSIONS

## 5.1 Effects of stormwater on the estuary

Data from the lower Swartkops River and Motherwell canal have shown that the pollution is not linked to storm-flow runoff. During periods of high rainfall, pollutants may be brought down to the estuary, but the flushing time inside the estuary is greatly decreased, so that there may be little accumulation of contaminants under these conditions.

During the normal rainy seasons, pollutants entering with freshwater flow will remain in the upper layers of the water column due to stratification between the fresh inflow and the more saline estuary water. While stratification persists, contaminants will be removed from the estuary in the upper seaward-flowing layer on ebb tides, and accumulation within the estuarine ecosystem will be limited (Wooldridge et al., 1990).

The need to prevent highly-contaminated dry-weather urban runoff from reaching recreational water bodies such as estuaries has been demonstrated in this report : the quality of runoff from Motherwell is typical of other urban developments. The Chatty River, the Markman canal and other shoreline developments can be expected to yield similar runoff which will also enter the estuary. In dry weather, the Swartkops in its upper and middle reaches has been shown to be well-mixed with long residence times and limited flushing : in these regions, the assimilative capacity of the receiving water could well be exceeded, leading to long-term deterioration in the quality of the water and of the estuarine environment, possibly irreversible.

## 5.2 Implications for stormwater management

Large, open concrete-lined stormwater canals have been shown in the case of Motherwell, to be totally unsuitable, particularly where the canals drain into a sensitive water body. Solutions are available to existing problems, such as diversion of dry-weather flow through an artificial reedbed or to the main sewerage system for treatment.

Better still would be sensible design of major stormwater canals. For example, the Markman canal, adjacent to Motherwell, carries potentially far more dangerous contaminants sourced in runoff from heavy industrial areas. However the canal is lined with gabions in its lower reaches, and is not lined at all further up. Thick vegetation has been established in the canal and this very effectively filters out pollutants before the runoff can reach the estuary.

When designing stormwater reticulation systems in environmentally sensitive areas such as the coastal zone, provision should be made for long retention times in unlined basins, and storm drains should be covered where possible. Retention under ultra-violet light (sunlight) would help to kill off sewage-related bacteria and viruses, while natural reoxygenation would assist in removal of COD and conversion of ammonia to nitrate.

As urbanisation proceeds rapidly in South Africa, the problem of polluted runoff will be observed in many other areas, particularly the lower-income high-density formal and informal settlements. When providing infrastructure, however basic, to such areas, thought must be given to long-term maintenance of environmental quality.

## 5.3 Future research

A detailed proposal for future research was submitted to the Water Research Commission, and much of this proposal is reproduced here.

| | |
|---|---|
| **Project Title :** | The influence of urban runoff on the water quality of an estuary in an urban catchment. |
| **Project Leader :** | H. M. MacKay |
| **Duration :** | Jan 1992 - Dec 1992 |

### Introduction

It has been shown in recent studies that the Swartkops estuary is being heavily impacted by rapid urbanisation in its immediate catchment. Research indicates degradation of both chemical and microbiological water quality in the estuary, due largely to runoff from surrounding urban areas (Lord & MacKay, 1990; MacKay & Eichstadt, in prep.; MacKay & Lord, in prep.; MacKay, Lord, Devey & de Leeuw, in prep.).

Further urban and industrial development in the lower catchment may result in exceedance of the assimilative capacity of the estuary and the lower Swartkops River i.e. the estuary will no longer be able to absorb the loads of contaminants without unacceptable degradation in water quality. A balance must be maintained between two conflicting aspects, namely (i) the need for economic development and housing in the catchment area, and (ii) the high recreational value placed on the estuary by residents and tourists. Such a balance can only be achieved with adequate knowledge of the assimilative capacity of the estuary, since any changes in land use in the catchment are ultimately reflected in the sensitive estuarine environment. It is hoped that this research will break new ground in the balancing of conservation with development, particularly in the fragile coastal zone, and that viable options can be provided in order for managers to make informed decisions. The problems now evident in the Swartkops catchment, which are associated with urbanisation, are already arising in other areas of South Africa. Results of the research proposed here will have wide applicability to other river-estuary systems in the country, as economic and social development programmes proceed apace.

**Research Proposal**

A considerable amount of knowledge has been gained concerning the quality and quantity of runoff from a typical urban development in the Swartkops catchment, Motherwell township. It has been shown that options are available to minimise the risk of serious pollution in the estuary from such runoff (Lord & MacKay, 1990).

This knowledge can now be extended and applied in a holistic study of the estuary and its immediate catchment, with the aim of providing management options for the future. In this proposal, a study programme is outlined which will lead to a better understanding of the hydrodynamic and chemical processes active in the estuary, and the response of the estuary both to stormflow and to the ubiquitous dry-weather runoff typical of urban developments.

The personnel involved in the proposed project have considerable experience in estuarine research, and it is felt that the work will tie "land-based" knowledge of stormwater to its effects in the receiving water. In addition, Ms. MacKay will be registered for a Ph.D. degree in the Department of Oceanography, University of Port Elizabeth, in 1992.

**Programme Outline**

An intensive measurement programme will be undertaken over the autumn equinox period, to coincide with equinox spring and neap tides in the estuary, and the local autumn rainy season. The University of Port Elizabeth will be contracted to supply data on tidal currents, water levels, salinity and temperature in the estuary, as well as processing available weather data from the region. Sampling for key water quality determinands such as bacteria, nutrients and dissolved oxygen will take place at the same time.

Subsequent sampling will be undertaken during and after rainfall events to assess the short-term impact of stormflow on the estuary and to monitor the recovery of the estuary after such an event. Point sources of stormwater and effluent will be monitored while estuary sampling proceeds. All field work will be supervised by H. MacKay.

Chemical and bacteriological analysis of water samples will be carried out by an accredited laboratory, and it is hoped that inter-laboratory calibrations can be undertaken during the year.

The field programme should extend over approximately 9 months, to cover both wet and dry catchment conditions. Numerical modelling will play a small part in the study - programmes available from the United States Environmental Protection Agency will be used to model water quality, in particular salinity and dissolved oxygen. However, the emphasis will be on direct field measurements in the Swartkops area, since such a complex system cannot be accurately modelled.

Work initiated earlier on development of local water quality criteria (MacKay & Lord, 1990) will be continued using information gained in the proposed study.

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# APPENDIX A

**WATER QUALITY OF THE LOWER SWARTKOPS RIVER, 1978 - 1991**

**Authors: H. M. MacKay[1*] and L. A. Eichstadt[2]**

[1] Talbot & Talbot c.c.
P.O. Box 27639
Greenacres
Port Elizabeth 6057

[2] Department of Water Affairs
Private Bag X6041
Port Elizabeth 6000

* To whom all correspondence should be addressed.

**ABSTRACT**

Water quality data records, collected in the Swartkops River between 1978 and 1991, were subjected to statistical analysis. Results show that the Uitenhage-Despatch urban and industrial complex impacts significantly on the quality of the Swartkops River. The use of non-parametric statistical tests to obtain information from low-frequency data is demonstrated, and the value of long-term surface water quality monitoring programmes is highlighted.

## 1. INTRODUCTION

This paper covers two aspects of water quality management: firstly, the use of non-parametric statistics and median analysis to obtain useful information from data sets of limited length and low sampling frequency; secondly, the application of these methods to analysis of data from the Swartkops River, in order to assess the impact of industrial development on water quality and the potential for pollution of the Swartkops estuary.

The Swartkops estuary is a major resource for the city of Port Elizabeth in terms of recreation and tourism, as well as being biologically a highly productive area (Heydorn et al. 1987). Recent rapid development in the Swartkops catchment as far upstream as Uitenhage has led to concern regarding the possible degradation of water quality in the estuary and the lower river. The major threat appears to be due to contaminated runoff reaching the watercourse from the industrial areas of Uitenhage and Despatch, and from the so-called "Third-world" high-density and informal settlements which are encroaching onto the catchment area and the floodplain (Lord & MacKay, 1990). The river appears to be affected by seepage from established industrial effluent ponds in the area, and the ongoing discharge of domestic waste water from McNaughton and Rosedale Townships via the Kat Canal (Fig. 1), similar to the discharge observed from Motherwell Township (MacKay & Lord, in prep.).

As the Swartkops River is the major source of freshwater for the estuary, it is important that the quality of the river water be maintained at a level which is adequate to protect the estuary. Results of water samples collected from the river by the Department of Water Affairs show that the Uitenhage-Despatch complex does have a significant impact on water quality in the river. This implies that any further development should be planned with a view to minimising inputs of anthropogenic substances into the river/estuary system.

## 2. STUDY AREA

The Swartkops River drains a catchment area of approximately 1370 $km^2$, lying to the north and west of Port Elizabeth. The main tributaries are the Elands River, which joins the Swartkops above Uitenhage, the Brak River, and the small Chatty system, which enters the Swartkops below its tidal limit. Soils in the catchment are predominantly lithosols. Land use is limited to agriculture, with the exception of the Uitenhage-Despatch urban and industrial complex.

Mean annual precipitation varies from 706 mm in the upper catchment to 547 mm in the lower catchment. Mean annual runoff from the system is estimated to be $84.2 \times 10^6$ $m^3$ (Reddering and Esterhuysen, 1981). No flow records are kept for the Swartkops River below its confluence with the Elands

River, but normal flow at Perseverance (Fig. 1) is probably between 0.05 and 0.5 $m^3s^{-1}$ (Huizinga, 1984; Baird et al. 1986). During the 1981 floods, a peak flow of 2130 $m^3s^{-1}$ was recorded at the Niven Bridge at Uitenhage (du Plessis, 1984), a level which is thought to be close to the theoretical 100 year event (Hughes, 1987).

Industries in the Uitenhage/Despatch area include tanning, wool processing and the manufacturing of automobile components, several factories being situated within 300 m of the river banks. River stone is quarried below Perseverance. Only one industrial wastewater discharge has been permitted on this stretch of the river: the Department of Water Affairs allows the release of 35 000 $m^3$ per year of purified effluent which complies with the General Effluent Standard (DWA, 1986), except for soap, oil and grease, for which the discharge limit has been set at 5 mg/l.

There are three purified domestic effluent discharges within the study area: Kwanobuhle sewage treatment works releases 14.24 Ml per day, Uitenhage treatment works 8.83 Ml per day, and Despatch treatment works 1.68 Ml per day. Together these probably contribute significantly to the river flow measured at Perseverance. Runoff from factory premises and roads may be contaminated, and several stormwater drains lead this runoff directly into the river. A number of municipal solid waste disposal sites are located within the study area, and the effect on the river of leachates and surface runoff from these sites has not yet been established. Squatter settlements such as those at Perseverance and within the Brak and Chatty catchments are potential sources of faecal pollution.

## 3. SAMPLING AND ANALYSIS

### 3.1 Field sampling techniques

River sampling was carried out at the stations shown in Fig. 1 between 09h00 and 12h00 on sampling days, at approximately 3-monthly intervals. From 1990, samples were taken monthly. Additional sampling was undertaken only if suspected pollution was observed and reported to the Department of Water Affairs.

Station SR05 was sampled from a causeway bridge over the river but at all other stations samples were taken from the bank. The Uitenhage and Despatch sewage treatment works effluents were sampled at the point of final discharge.

A clean 1-litre plastic bottle with a screw cap was used to take a single grab sample at each station. The bottles were prior rinsed with sample at the stations before being filled, but were not pre-treated in any other way. Sample bottles were not re-used for subsequent sampling trips.

Bottles were marked appropriately, stored in a closed cooler bag without ice, and delivered to the South African Bureau of Standards (SABS) laboratory in Port Elizabeth within one hour of the last station being sampled. Thereafter, the samples were stored at 4°C for a maximum of two days before analysis.

### 3.2 Laboratory analysis

The following standard methods were used (SABS, 1984):

| Analysis | SABS method no. |
|---|---|
| pH ($\log_{10}$ units) | 11 |
| Electrical conductivity (mS/m at 25°C) | 1057 |
| Suspended solids (mg/l) | 1049 |
| Oxygen absorbed from N/80 potassium permanganate in 4 hrs at 27°C (mg/l $O_2$) | 220 |
| Free and saline ammonia as N (mg/l) | 217 |
| Chemical oxygen demand (after chloride correction) (mg/l $O_2$) | 1048 |
| Sulphates as $SO_4^{2-}$ | 212 |
| Chlorides as $Cl^-$ | 202 |

### 3.3 Data analysis

Commercial software packages, running on an IBM-compatible personal computer, were used for data analysis. The data was previously checked for accuracy by hand.

The program WQSTATII, developed by Colorado State University (1988), was run with the pre-checked data to investigate the statistical characteristics of the records such as seasonality, correlation and normality, and to check for linear trends using the Kendall Tau test.

STATGRAPHICS (Statistical Graphics Corporation, 1986) was used to plot the box-and-whisker diagrams and correlation matrices, while annual median series and other graphs were plotted with HARVARD GRAPHICS (Software Publishing Corporation, 1987).

## 4. DATA ANALYSIS

### 4.1 Data quality

Table 1 shows the length of each data set, including the years for which there were several missing values. In some years, only one value was recorded.

### 4.2 Data characteristics

It was found that for all stations, total dissolved solids (TDS), sulphate and chloride concentrations were closely correlated with measurements of electrical conductivity (EC), so that EC provided an acceptable surrogate for major ion and TDS levels. Hence only the determinands pH, oxygen absorbed by permanganate (OA) and EC will be discussed in the following sections.

Data were tested for normality by assessing the statistical significance of the skew and kurtosis parameters of each determinand at each station. In every case, all available records were used. Results showed that none of the data sets were normally distributed, at confidence levels of 80% and greater. This was to be expected, since most water quality determinands tend not to follow a normal distribution (Sanders et al., 1983).

The data showed no serial correlation, which was also as expected: the minimum sampling interval in most cases was 3 months, and temporal correlation would be unlikely at this level of sampling.

The Kruskal-Wallis test for equality of medians among seasons was used to check for seasonality. Seasons were defined in terms of the spring, summer, autumn and winter quarters. The only data set which showed significant seasonality was OA at station SR01 (75% confidence). OA levels tended to be lowest here in winter months, higher in the spring season. This may be due to the fact that the station is not impacted directly by any urban or industrial development, being upstream from Uitenhage. Hence natural hydrological cycles still predominate, where oxygen levels increase with decreased winter water temperatures. Elevated OA levels appear to coincide with the spring rainy season, as is borne out by results of correlation analysis (section 4.5).

### 4.3 Box and whisker plots

Figures 2.a, 2.b and 2.c show box and whisker plots of all available pH, EC and OA measurements at the five river stations for the period 1978 - 1989. For comparison, data from the Elands River (1970 -1979) are included, as well as results of samples of final effluent from Uitenhage sewage treatment works (UITE) and Despatch sewage treatment works (DESP) for the period 1987 -1989. The notches in the boxes of Fig. 2 correspond to the 95% confidence intervals around the median, and allow a first check for significant differences between stations. If the notches of boxes from two stations do not overlap, then there is a 95% probability that their medians are significantly different.

The pH plot (Fig 2.a) shows that there is a significant increase in pH from background levels at the Elands River and SR01 stations to SR02, SR03 and SR05, possibly due to industrial activity. Station SR02 is immediately downstream from a wool washing factory: overflow and seepage of highly alkaline water from oxidation ponds could be causing the high pH levels. Station SR04 is not significantly different from SR01, and neither are the effluents from UITE and DESP stations. Except for the occasional outliers, pH levels at all stations are within the recommended limits for protection of aquatic life and drinking water (Kempster et al., 1980).

Fig 2.b shows very clear differences in EC values. There is a marked increase in EC median values and ranges downstream of SR01, with the highest values being recorded at SR03 station. (The Brak River itself is known for its naturally high conductivity levels.)

Variations in EC with time are closely linked to rainfall and hence to river flow. The low flows commonly observed in the Swartkops River aid evaporation from pools, which may also contribute to the general downstream elevation of median EC levels. However, the increase, at SR02 in particular, is almost certainly due largely to urban and industrial development in the catchment, with an associated load of dissolved solids reaching the river via runoff from hard surfaces and factory yards, as well as the other sources mentioned above. The naturally high conductivity of input from the Brak River may mask impact downstream from the confluence.

According to the criteria of Kempster et al. (1980), the river below SR02 may be used for livestock watering, but the recommended median levels for drinking and irrigation water are exceeded at all downstream stations.

Fig. 2.c shows 4-hour OA values as compared to the general and special standards for effluents, 10 mg/l and 5 mg/l $O_2$ absorbed respectively. (DWA, 1986). OA values are significantly higher at SR02 and downstream than at the

baseline station SR01. The Uitenhage works discharge exceeded the general standard on 75% of the samples, but levels downstream at SR04 and SR05 show a decrease in median OA, implying some recovery due to the river's self-cleansing ability.

**4.4 Annual median series**

Where data are too sparse for annual box-and-whisker plots to be drawn, and trends may be masked by high natural variability, graphs showing annual medians, with the maximum and minimum values plotted in a box around the median, are often useful for qualitatively assessing long-term data characteristics. Figs. 3.a, 3.b, and 3.c show annual pH, EC and OA medians from station SR01, SR02 and SR04 as examples. The series from SR05 is very similar to SR04, but shows greater variability around the medians, while SR03 is similar in trend to SR01 (note the change of vertical scale for SR01).

In all cases, annual medians appear to be linked to the annual total of rainfall measured at Uitenhage (Weather Bureau). The drought years of 1989 - 1991 are reflected in the upward trend in EC levels at all stations during that time.

An interesting anomaly can be seen: at SR01, high OA values are measured in years of high rainfall. In dry years, OA levels decrease while higher EC values are recorded. At SR02, OA levels are generally much higher, as seen in the box-and-whisker plots, but follow the opposite trend: elevated levels in dry years, followed by lower levels in wet years. A possible explanation could be the natural increase of decaying detrital material at SR01 in wet years, leading to greater oxygen demand as the material decomposes. In dry years, the river at SR02 is impacted by contaminated runoff, leading to higher OA levels, while during good rains, increased river flow causes dilution of this polluted input. Elevated OA levels at the downstream stations do not appear to follow the flow-dependent pattern so closely, and variability may be linked with more certainty to urban or industrial activity than to natural hydrological cycles.

## 4.5 Correlation analysis

Correlation analysis can be used both qualitatively and quantitatively in different ways: (i) between several stations along a river reach to assess the spatial extent of pollution or impact; (ii) between determinands at a single station to isolate the possible character of the pollution; (iii) between determinands and rainfall to assess the effect of river flow or storm flow where few records are available.

For each of the above three cases, Spearman-rho rank correlation coefficients were calculated for Swartkops River stations on two levels: firstly each data point was used and correlated with the 7-day antecedent rainfall total, and secondly annual medians were correlated with annual rainfall totals. When testing for spatial correlation, improved confidence levels were attained using all available data points matched according to sampling days, rather than annual medians. However, when testing at individual stations for correlation between water quality and rainfall, use of annual values yielded more significant results. This perhaps reflects the complex nature of the relationships between rainfall, runoff and water quality in any catchment, and shows that to quantify this relationship adequately, either sampling should be more frequent then three-monthly, or the data set should be at least ten years in length.

The same relationships that were observed in the box-and-whisker plots and median series can now be quantified with some confidence in the correlation matrices. Spearman correlation coefficients are scaled to fall between -1.0 and +1.0; if the absolute value of the coefficient is greater than 0.6, significant correlation is indicated, which may be positive or negative, depending on the sign. Absolute values between 0.4 and 0.6 indicate a possible relationship, but this may not be statistically significant. Values less than 0.4 mean little or no correlation exists.

### 4.5.1 Spatial correlation

Matrices of spatial correlation coefficients can be found in Tables 2.a to 2.c.

Generally, correlation between upper stations SR01-SR03 and lower stations SR04-SR05 is poor, indicating that different processes are active in the upper reaches compared to those in the lower reaches. SR04 and SR05 are well correlated in terms of pH, EC and OA, showing that whatever process leads to water quality variability in this section of the river acts at both stations, so that the impact is likely to originate upstream of SR04 but downstream of the confluence with the Brak River.

SR01 and SR03 are similar to each other in terms of EC trends, showing that SR03, like SR01, is impacted more by natural hydrological processes than by runoff from industrial areas.

The negative correlation in OA between SR01 and SR02, and the lack of correlation downstream, is striking, though not strong. However, it does indicate that water quality at SR02 depends much more on the nature and extent of runoff from urban areas than it does on any hydrological cycles, and that it is not generally linked to water quality either upstream or downstream, suggesting a localised, possibly point source of pollution.

4.5.2 Correlation between determinands

Matrices of correlation coefficients can be found in Tables 3.a to 3.e.

Tables 3.a to 3.e highlight both the strengths and weaknesses of correlation analysis. Where river flow records are not available, rainfall can be used as a reasonable surrogate since the Spearman procedure is based on the ranks of the data rather than absolute values, and generally increased rainfall can be expected to lead to increased river flow, although the relationship is not linear.

Where data are closely grouped around a median value, for example EC at SR01 and pH at most stations, sampling error, laboratory error and the random nature of variability of most water quality determinands tend to make the correlation test less powerful, and more data is needed to increase the significance of results. Hence the correlation between EC at SR01 and annual rainfall is positive, which is opposite to natural trends. There may be a physical explanation to be found on further field investigation, but it is more likely to be due to the small range of EC values compared to those downstream, leading to loss of power in the Spearman test.

**4.6 Trend testing**

Another non-parametric procedure, the Kendall Tau test for linear trend, was used with all available data to check for positive, zero or negative trends at the 95% confidence level. The Sen slope estimate can be used in conjunction to quantify the magnitude of the trend. At least five years of quarterly data is required for best results.

Table 4 shows the significant trends and Sen slope estimates. Long-term trends in pH levels are small, but oppositely signed upstream and downstream of the Uitenhage-Despatch area, indicating that different factors are affecting water quality in these regions.

There is a strong positive trend in EC at SR02, which is evident before the drought years and is not shown at the other stations, so is likely to be linked to development. The downward trend in EC at SR03 is also relatively large, although the data set extends only from 1978 to 1986 and excludes the recent drought. This may be due to increased urban runoff from Kwanobuhle township, as has been observed from Motherwell township further down in the catchment (MacKay & Lord, in prep.).

## 5. CONCLUSIONS

The analysis shows clearly that the Uitenhage-Despatch urban industrial complex has a significant effect on the water quality of the lower Swartkops River. The impact on the river includes an increase in pH and EC levels and a decrease in dissolved oxygen content reflected in the elevated OA levels in the water compared to upstream measurements. Occasional extreme values of OA were recorded, such as 39 mg/l $O_2$ absorbed at SR02 in one sample, and thus sporadic acute pollution of the river may occur.

This degradation in water quality is not directly linked to rainfall, since the presence of polluted runoff appears to be common to both wet and dry weather. At station SR02 however, stormflow appears to lead to improvement in water quality due to dilution.

Water quality in this case was defined only in terms of pH, conductivity and oxygen levels, a definition which is limited since it gives no indication of faecal pollution, toxic substances, or of the concentrations of excess nutrients which lead to eutrophication. Such measurements are important in assessing possible effects on the riverine and estuarine aquatic ecosystem.

Long-term routine monitoring of surface water has been shown to be a valuable and worth-while activity. However, the need to use available financial and manpower resources efficiently in well-designed monitoring programme has been highlighted. Careful choice of water quality determinands is most important in order to make best use of the information gathered.

## ACKNOWLEDGEMENTS

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**Table 1**

**Number of records in the data base**

| | SR01 | SR02 | SR03 | SR04 | SR05 |
|---|---|---|---|---|---|
| pH | 60 (1,0) | 60 (1,0) | 24 (1,5) | 58 (1,0) | 55 (2,0) |
| EC | 60 (1,0) | 60 (1,0) | 25 (1,5) | 58 (1,0) | 55 (2,0) |
| $Cl^-$ | 54 (1,0) | 55 (1,0) | 23 (1,5) | 50 (1,1) | 51 (2,0) |
| $SO_4^{2-}$ | 52 (0,0) | 50 (2,0) | 20 (1,6) | 46 (1,1) | 46 (2,0) |
| TDS | 18 (1,6) | 16 (0,9) | 16 (0,9) | 16 (0,9) | 15 (0,9) |
| OA | 60 (1,0) | 59 (1,0) | 25 (1,5) | 57 (1,0) | 54 (2,0) |
| Data period | 1978-91 | 1978-91 | 1978-91 | 1978-91 | 1978-91 |

Note: (x,y) where x = number of years for which there was only 1 sample;
y = number of years for which there were no samples.

**Table 2.a**

**Correlation of pH between stations** (all values)

| | SR01 | SR02 | SR03 | SR04 | SR05 |
|---|---|---|---|---|---|
| SR01 | 1.00 | | | | |
| SR02 | 0.19 | 1.00 | | | |
| SR03 | 0.29 | 0.27 | 1.00 | | |
| SR04 | 0.03 | 0.34 | 0.69 | 1.00 | |
| SR05 | 0.13 | 0.42 | 0.39 | 0.72 | 1.00 |

**Table 2.b**

**Correlation of EC between stations** (all values)

| | SR01 | SR02 | SR03 | SR04 | SR05 |
|---|---|---|---|---|---|
| SR01 | 1.00 | | | | |
| SR02 | 0.01 | 1.00 | | | |
| SR03 | 0.80 | 0.40 | 1.00 | | |
| SR04 | 0.06 | 0.81 | 0.37 | 1.00 | |
| SR05 | 0.06 | 0.69 | 0.37 | 0.77 | 1.00 |

**Table 2.c**

**Correlation of OA between stations** (all values)

| | SR01 | SR02 | SR03 | SR04 | SR05 |
|---|---|---|---|---|---|
| SR01 | 1.00 | | | | |
| SR02 | -0.43 | 1.00 | | | |
| SR03 | 0.29 | -0.04 | 1.00 | | |
| SR04 | 0.36 | -0.16 | 0.18 | 1.00 | |
| SR05 | 0.44 | -0.10 | 0.33 | 0.70 | 1.00 |

**Table 3.a**
**SR01 - correlation between water quality and rainfall** (annual values)

| | PH | EC | OA | RAIN |
|---|---|---|---|---|
| PH | 1.00 | | | |
| EC | 0.15 | 1.00 | | |
| OA | -0.13 | 0.43 | 1.00 | |
| RAIN | -0.05 | 0.39 | 0.75 | 1.00 |

**Table 3.b**
**SR02 - correlation between water quality and rainfall** (annual values)

| | PH | EC | OA | RAIN |
|---|---|---|---|---|
| PH | 1.00 | | | |
| EC | 0.28 | 1.00 | | |
| OA | 0.27 | 0.34 | 1.00 | |
| RAIN | -0.37 | -0.80 | -0.41 | 1.00 |

**Table 3.c**
**SR03 - correlation between water quality and rainfall** (annual values)

| | PH | EC | OA | RAIN |
|---|---|---|---|---|
| PH | 1.00 | | | |
| EC | 0.47 | 1.00 | | |
| OA | 0.07 | -0.51 | 1.00 | |
| RAIN | 0.13 | -0.48 | -0.03 | 1.00 |

**Table 3.d**
**SR04 - correlation between water quality and rainfall** (annual values)

| | PH | EC | OA | RAIN |
|---|---|---|---|---|
| PH | 1.00 | | | |
| EC | 0.18 | 1.00 | | |
| OA | 0.02 | 0.26 | 1.00 | |
| RAIN | 0.12 | -0.63 | 0.07 | 1.00 |

**Table 3.e**
**SR05 - correlation between water quality and rainfall** (annual values)

| | PH | EC | OA | RAIN |
|---|---|---|---|---|
| PH | 1.00 | | | |
| EC | 0.52 | 1.00 | | |
| OA | -0.18 | -0.20 | 1.00 | |
| RAIN | -0.30 | -0.69 | 0.31 | 1.00 |

**Table 4**

**Kendall Tau trends at 95% CI,** Sen slope estimate in data units/year

| | PH | EC | OA |
|---|---|---|---|
| SR01 | -0.05 | -1.75 | -0.07 |
| SR02 | NS | +17.25 | +0.42 |
| SR03 | +0.05 | -24.75 | NS |
| SR04 | NS | +2.43 | -0.19 |
| SR05 | +0.07 | NS | -0.09 |

**FIGURE CAPTIONS**

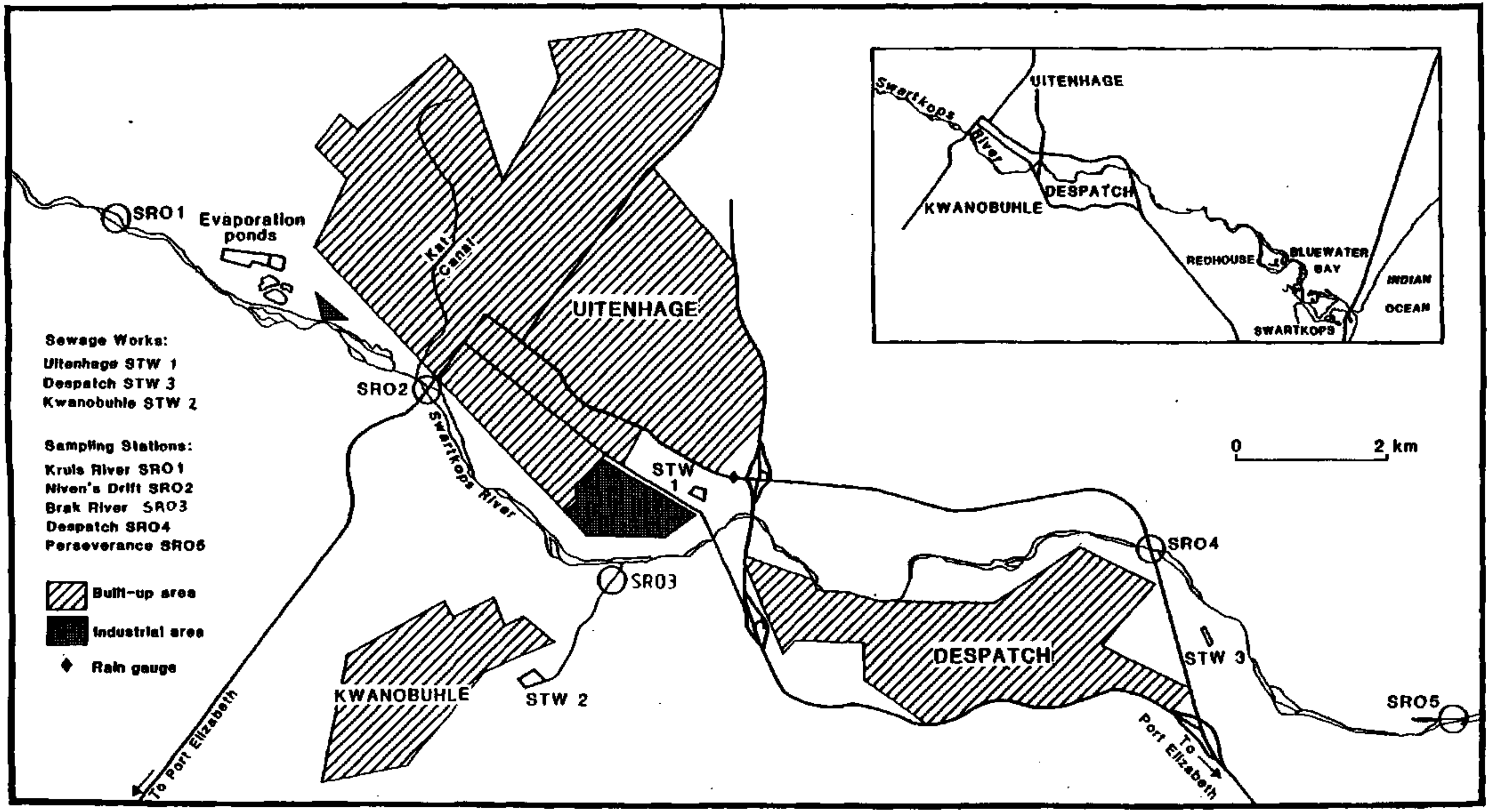
Figure 1. Map of the lower Swartkops River showing the study area in relation to the Uitenhage-Despatch complex.

Figure 2. Box-and-whisker plots of water quality determinands for the period 1987-1991. (a) pH; (b) EC; (c) OA.

Figure 3.a Time series of annual medians from station SR01.

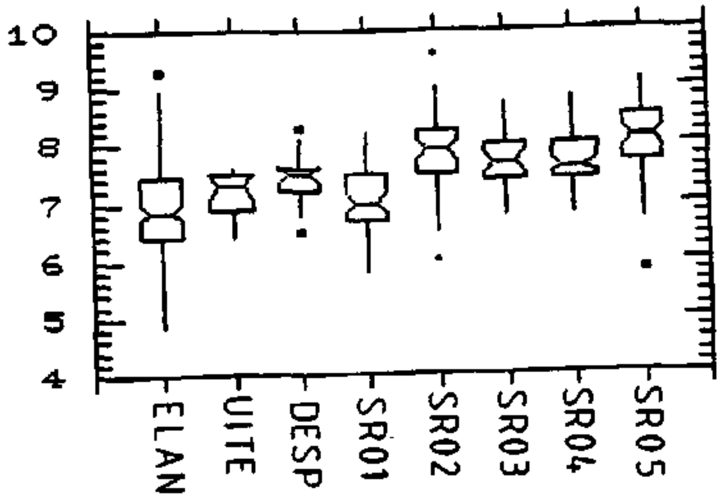
Figure 3.b Time series of annual medians from station SR02.

Figure 3.c Time series of annual medians from station SR04.

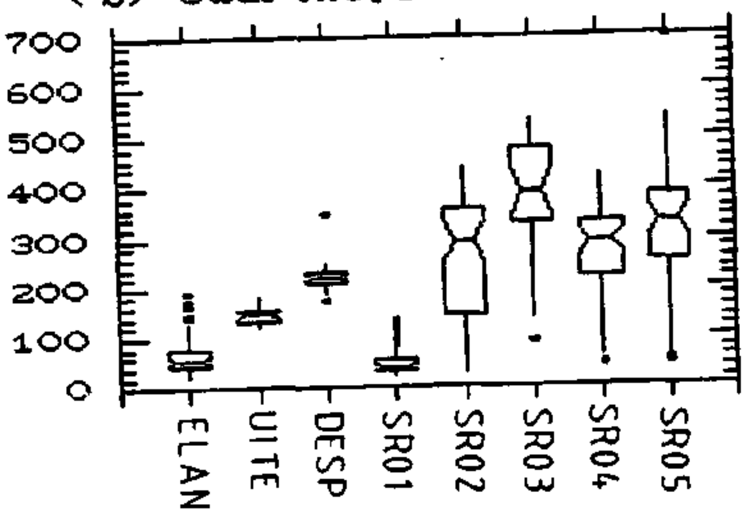


SRO1
Evaporation ponds
Kat Canal
UITENHAGE
Sewage Works:
Uitenhage STW 1
Despatch STW 3
Kwanobuhle STW 2
SRO2
Swartkops River
Sampling Stations:
Kruis River SRO1
Niven's Drift SRO2
Brak River SRO3
Despatch SRO4
Perseverance SRO5
STW 1
SRO3
Built-up area
Industrial area
Rain gauge
KWANOBUHLE
STW 2
To Port Elizabeth
DESPATCH
SRO4
STW 3
SRO5
To Port Elizabeth
0 2 km
Swartkops River
UITENHAGE
KWANOBUHLE
DESPATCH
REDHOUSE
BLUEWATER BAY
INDIAN OCEAN
SWARTKOPS

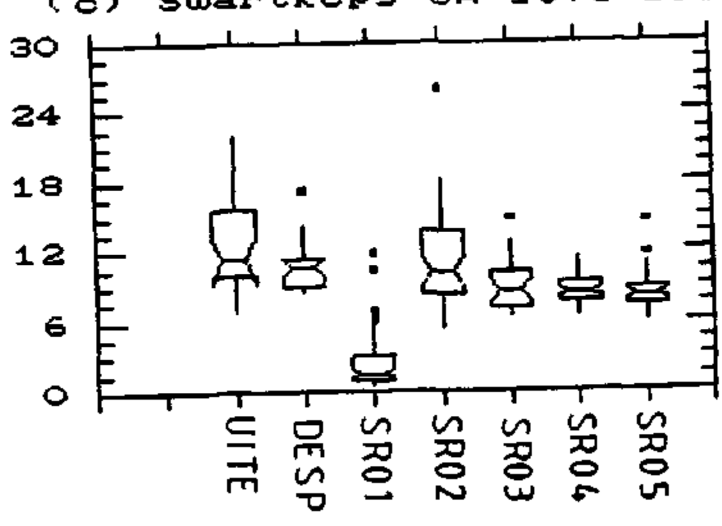
(a) Swartkops pH 1978-1991



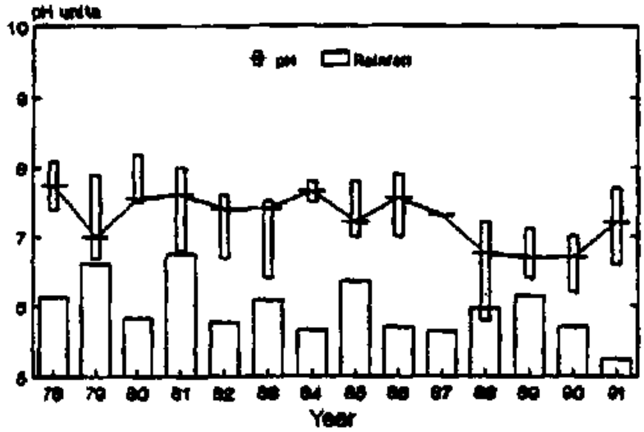

(b) Swartkops EC 1978-1991



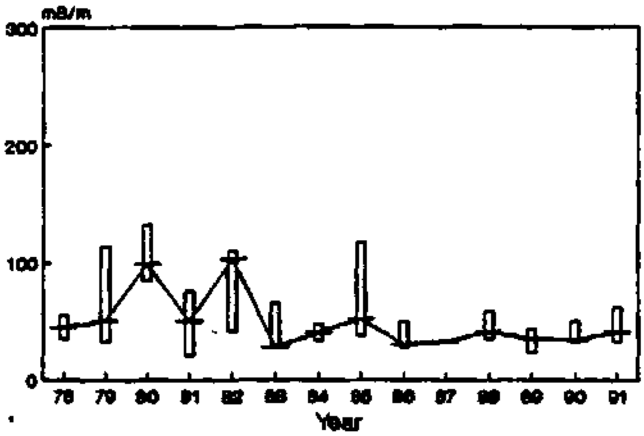

(c) Swartkops OA 1978-1991



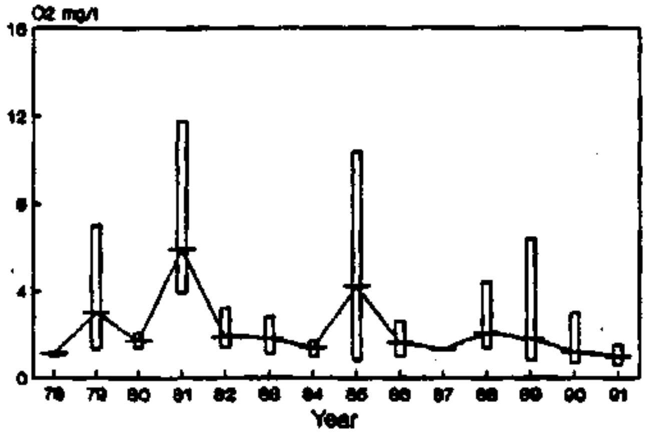
## SR01 pH



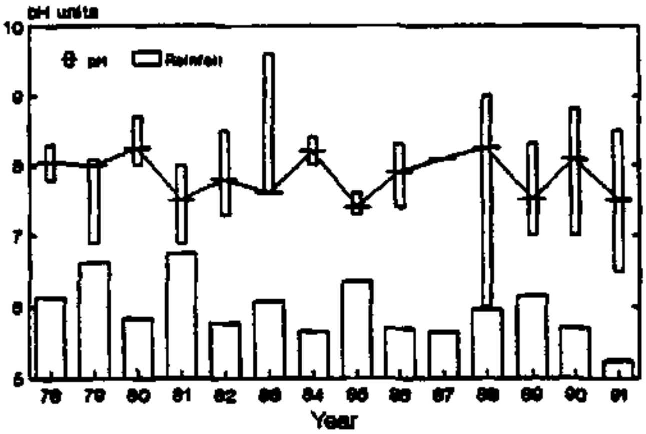

## SR01 EC



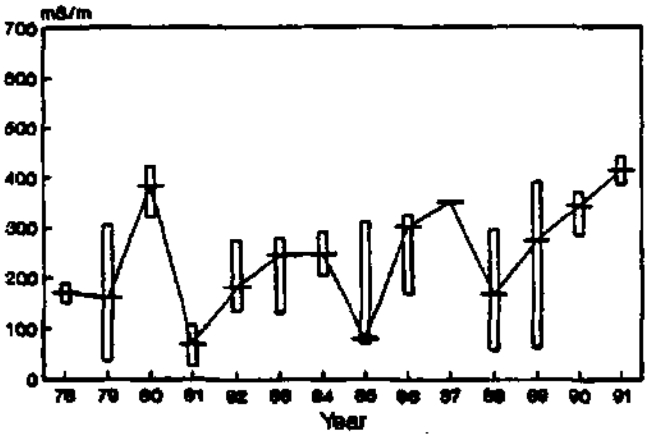

## SR01 OA



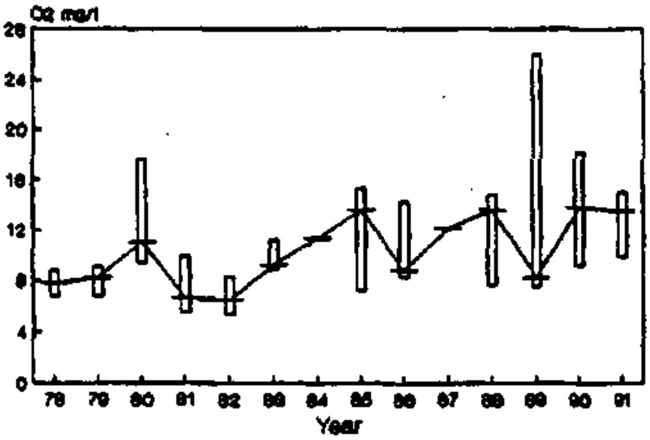
## SR02 pH



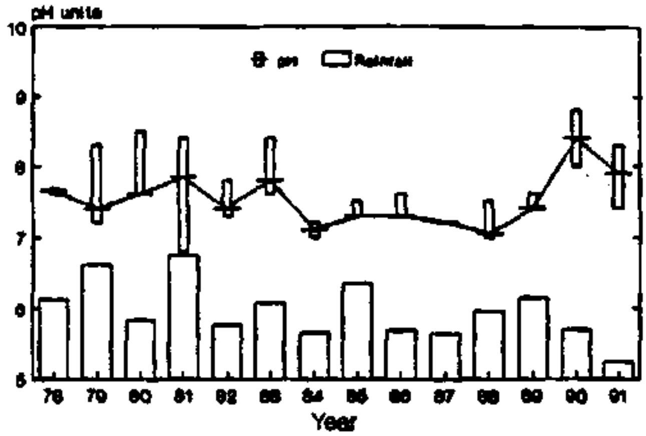

## SR02 EC



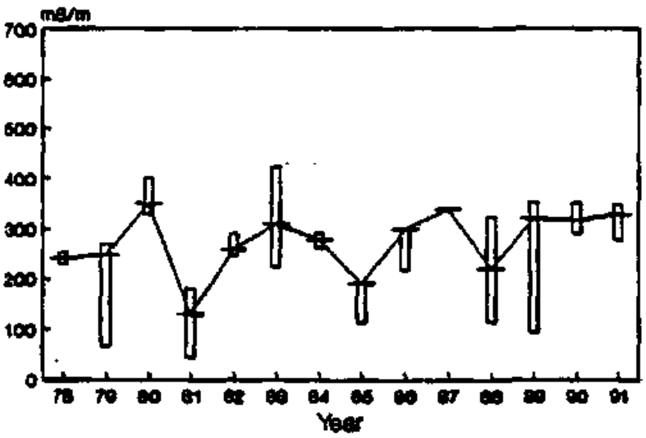

## SR02 OA



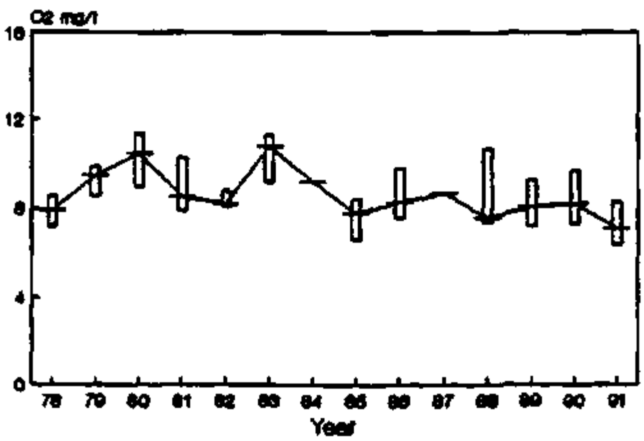
## SR04 pH




## SR04 EC




## SR04 OA



# APPENDIX B

**REPORTS AND REFEREED PAPERS FROM THE UNIVERSITY OF PORT ELIZABETH**

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