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Modelling water quality in the upper Klip river

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6.2 Sampling surveys

Three separate sampling surveys were undertaken with the assistance of students and technical staff of the University as well as staff of the Hydrological Research Unit when required.

6.2.1 Location of sampling points

The number of sampling points differed for each of the sampling surveys. Initially only 3 points were used for the pilot survey but for the intensive surveys of 18 July 1978 and 21 March 1979 eight and four points were used respectively. All these sampling stations, designated A to H and H(a), are indicated on figure 6.1 and described below. Note that stations A to D were included before it was decided to confine the study reach to downstream of the Golden Highway bridge.

Station A - In the Klip River at the Lenasia Road bridge, upstream of the confluence with the Klipspruit.

Station B - In the Klipspruit at the Potchefstroom Road bridge upstream of the sewage works outfall.

Station C - In the Klipspruit works final effluent channel approximately 100 m before the outfall into the Klipspruit.

Station D - In the Olifantsvlei final effluent channel the sewage works.

Station E - (Chainage 0,00 m) In the Klip River at the old bridge next to the Golden Highway.

Station F - (Ch. 1 850 m) In the Klip River at the Golden Highway Pleasure Resort.

Station G - (Ch. 3 400 m) In the Klip River in the Olifantsvlei Nature Reserve.

Station H - (Ch. 5 800 m) In the Klip River 500 m downstream of the Misgund Road causeway.

Station H(a) (Ch. 5 300 m) In the Klip River at the Misgund Road causeway.

As can be seen from figure 6.2 the locations of stations E, F, G and H (H(a)) correspond roughly to the three subreaches of the study reach.

6.2.2 Sampling procedures

(a) Samples for chemical analysis

Samples for chemical analysis were collected in wide mouthed glass or plastic jars in sizes ranging from 250 ml to 500 ml. 250 ml jars were only used where BOD tests were not required. Each jar was numbered and the sampling personnel were instructed to take samples from as far into the main stream as possible but without wading into the river and thereby disturbing the river bed.

The sample bottles were then tightly sealed and stored under wet sacks until being taken to the laboratory. An inevitable time delay of up to 26 hours in some cases occurred between time of sampling and the chemical analysis.

Samples were taken at specified intervals and the time of sampling noted on the sampling sheet.

(b) Dissolved oxygen and temperature measurements

Dissolved oxygen concentrations and temperatures were taken using a YSI 54 R portable dissolved oxygen meter calibrated according to the manufacturer's directions just before the

sampling period. The calibration was checked again at the end of the sampling period, and in the case of the survey of 21 March 1979, also once during the survey. Readings were taken at the same time as sampling, the dissolved oxygen meter probe being attached to a long stick and agitated gently approximately 30 centimetres below the surface of the water. Between observations the probe was kept immersed in water or in the specially designed plastic cap containing a damp sponge.

(c) Flow estimations

In order to estimate the flow at each sampling point surface velocities were taken at 3 points across the river. Floats were timed over distances of four to ten metres depending on the station and at the same time the water level read off a gaugeplate inserted in the river at the beginning of the sampling period. The gaugeplate levels were referenced to the bench marks used during the cross-section surveys for each station.

6.2.3 Chemical analyses

The chemical analyses were carried out at the Celna Laboratories of the Johannesburg Municipality Health Department. The following tests were undertaken on the samples:

5-day BOD - selected samples only
20-day BOD - five selected samples only
COD
pH
Conductivity
Ammonia
Ortho-phosphate
Nitrite
Nitrate
Chloride
Alkalinity
Suspended solids

The BOD and COD tests were carried out according to the procedure set out in 'Standard Methods for Water and Wastewater Analysis' published by Americian Water Works Association. The chemical analyses were carried out using a Technicon Autoanalyser II.

Unfortunately, BOD_5 tests could not be carried out on all samples due to a lack of storage space in the laboratory's incubators. For the same reason, BOD_{20} tests could only be carried out on a few selected samples.

6.2.4 Pilot sampling survey - 31 May 1978

Objective: The objective of this survey was a trial run to obtain a feeling for the data to be collected as well as the problems likely to be encountered in the sampling and analysis procedures.

Sampling stations: E, G, H.

Personnel: 2 Final year undergraduate students plus the writer.

Duration: 07h45 to 16h15 (8,5 hours).

Sampling frequency: 1,5 hours.

Analyses performed: All analyses under 6.2.3 except BOD_{20} nitrite and alkalinity.

This survey brought to light a number of small practical problems, particularly with regard to personnel requirements. A minor accident with one of the vehicles resulted in a number of samples having to be omitted.

The results of this survey are shown in Table C1 in Appendix C.

6.2.5 Intensive sampling survey - 18 July 1978

Objective: Intensive collection of data for use with a BOD - dissolved oxygen mathematical model.

Sampling stations: A,B,C,D,E,F,G and H.

Personnel: 2 technicians
2 laboratory assistants
2 final year undergraduate students
1 engineer (supervising)

Duration: 06h00 to 22h00 (16 hours).

Sampling frequency: 2,5 hours
7 samples per station giving a total of 56 samples.

Analyses performed: All analyses under 6.2.3 except BOD_{20}, nitrite and alkalinity. BOD_5 analyses were performed on alternate samples only.

The personnel were organised so that one person covered two stations with the exception of stations C and D where one sampler was allocated to each. No dissolved oxygen measurements were made at these two points as the DO concentrations in the final effluent of the sewage works was considered to be small. (This assumption was later shown in tests undertaken by undergraduate students to be in error; dissolved oxygen values of 5-6 mg/l being obtained. However as these points were later omitted from the study it was of no consequence). The writer plus one of the laboratory assistants supervised and assisted where required.

The results of this survey are shown in Table C2 in Appendix C.

6.2.6 Intensive sampling survey - 21 March 1979

Objective: Further intensive collection of data for use with a BOD-dissolved oxygen simulation model.

Sampling stations: E, F, G and H(a).

Personnel: 3 technicians
2 engineers (one supervising)
2 undergraduate students.

Duration: 06h00 (21/3/1979) to 06h00 (22/3/1979) - 24 hours.

Sampling frequency: Hourly.
25 samples per station giving a total of 100 samples plus a few additional samples where required.

Analyses performed: All analyses under 6.2.3 except suspended solids.
BOD_5 analyses were carried out on one sample in three. BOD_{20} analyses were carried out on 5 additional samples taken.

The personnel were organised into two twelve-hour shifts. During the day one sampler would cover two stations whereas at night the number of samplers was doubled, two samplers covering two points. The writer supervised throughout the full 24 hours.

A problem was experienced when one of the two dissolved oxygen meters being used gave trouble during the night shift and from about 21h00 on, one DO metre had to be used for all four points. This meant that DO readings could only be taken at alternate sampling times at each point (Difficulties experienced in obtaining DO meters had resulted in there being no spare). Some light rain also occurred during the night but was not considered sufficient to have a significant effect on the results of the survey.

Light and dark bottle tests as described under paragraph 6.3.1 below were also undertaken during this 24 hour period.

The results of this survey are shown in Table C.3 in Appendix C.

6.3 Additional tests undertaken

6.3.1 Light and dark bottle tests

In order to estimate the photosynthesis effect on dissolved oxygen a simple light and dark bottle test was performed at a point in the river around chainage 450,0 m on 6 January 1979.

Two 2-litre glass preserve jars were used for the experiment. One jar was completely covered in masking tape and sprayed with matt black paint so that no light could enter the jar. At the sampling point a bucket was filled with water from the river and the dissolved oxygen concentration and the temperature of the water in the bucket measured with a DO meter. Each jar was then carefully filled with water from the bucket. The jars were sealed beneath the surface of the water to ensure no air was trapped. The two jars were then suspended in the river, away from the side and about 30 centimetres below the surface of the water. Twenty four hours later the bottles were removed from the water and the dissolved oxygen concentration and temperature measured in each. The difference between the two dissolved oxygen levels gives an indication of the effect of photosynthetic production of dissolved oxygen by suspended algae in the water, since no photosynthesis would have occurred in the dark bottle.

Similar light and dark bottle tests were also carried over the twenty-four hour period of the sampling survey on 21 March 1979 at all four sampling stations.

The results of all the above tests are shown in Table C4 in Appendix C.

6.3.2 Benthal oxygen demand tests

A very crude test to determine the order of magnitude of benthal oxygen demand in the river was carried out at the same time and location as the light and dark bottle test on 6 January 1979.

A bucket of river water was obtained and the temperature and dissolved oxygen concentration determined with a dissolved oxygen metre. Two 2-litre glass preserve jars, one about a quarter full with mud obtained from the bottom of the stream, were carefully filled with water from the bucket. The jars were sealed underwater to ensure no air was trapped inside. The two jars were then lowered by means of a length of wire so that they rested on the river bottom at a depth of about 1,2 metres. After twenty four hours the bottles were removed from the water and the temperature and dissolved oxygen concentration measured in each. The results, although very crude, gave an idea of the order of benthal oxygen demand to be expected. These results are given in Table C5 in Appendix C.

6.3.3 Time of passage and dispersion tests - 2 May 1979

Doubts about the time of passage for each reach calculated from flow and channel geometry led to the decision to perform dye tracer measurements for a more accurate estimate. The same tests were used to estimate the longitudinal dispersion coefficients.

Five kilograms of fluorescein dye were dissolved in two buckets of water. The contents of each bucket were then poured simultaneously into the river from the bridge at station E, attempting to pour the dye as evenly across the width of the river as possible. 50 millilitre samples were collected in brown glass bottles at fifteen minute intervals at stations F and G. Lack of staff meant that station H(a) could not be sampled. Samples were also taken at midstream by means of long poles every half hour in order to assess the effect of taking

samples near the side and not in the middle of the stream. The frequency of sampling at station G was increased to every 7½ minutes as the dye peak came past in order to have a better definition of the peak.

Sampling continued for over three hours after the last visible signs of tracer had passed to be sure of sampling the tail of the distribution. Float velocity measurements and stage readings were also taken at points E, F and G to estimate the flows.

Dye concentrations in the samples were determined by the Hydrological Research Institute laboratories of the Department of Water Affairs, Forestry and Environmental Conservation in Pretoria, using a Turner Spectrofluorometer model 430. The results of the analyses are presented in Table C6 in Appendix C and discussed in chapter 7.

6.4 Survey of river channel geometry

In order to calculate the flow at the sampling stations and to estimate the time of passage through each reach, a knowledge of the channel cross-sections was required.

Cross-sections of the river channel were determined in the field at the following locations marked in figure 6.2:

E	-	chainage 0 m
E1	-	chainage 160 m
E2	-	chainage 500 m
E3	-	chainage 1 350 m
F	-	chainage 1 850 m
F1	-	chainage 3 000 m
G	-	chainage 3 400 m
H(a)	-	chainage 5 300 m
H	-	chainage 5 800 m

Details of these cross-sections are shown in figure 6.3.

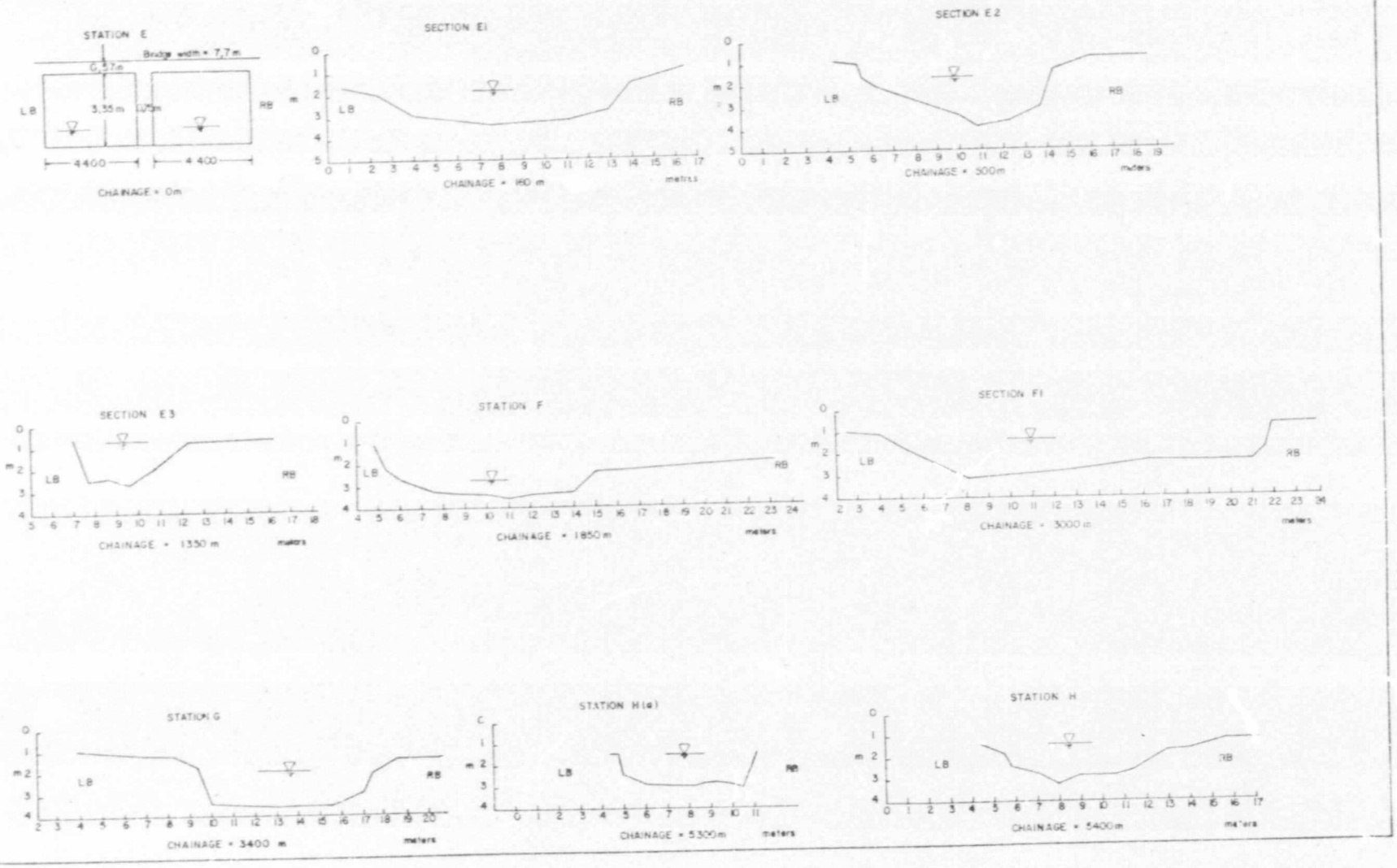


Figure 6.3 River Channel Cross Sections.

The cross-sections were obtained using a tacheometer and staff, use being made of a rubber dinghy when the water was too deep for wading.

No accurate channel cross-sections could be taken in the vlei area in reach 3 although one section could be obtained in the vlei in reach 1 at E3. Very rough channel cross-sections through the vlei in reach 3 could however be obtained from the engineering contractors for the highway. These were at the following locations:

G3 - chainage 4 500 m
G4 - chainage 4 800 m
G5 - chainage 4 850 m

No further cross-section information could be determined directly but from knowledge of the river channels, obtained by two trips down the river in a dinghy, it was possible to approximate cross-sections in other parts of the river to similar known cross-sections.

CHAPTER 7

ANALYSIS AND DISCUSSION OF FIELD DATA

The results of the field surveys outlined in the previous chapter are listed in Appendix C, and are analysed and discussed in the following sections:

7.1 Intensive sampling survey - 18 July 1978

In this investigation, the data obtained from sampling stations A to D were not used; the reason for this was the problem of combining the inputs of the Klip River, Klipspruit and the sewage works. Inadequate knowledge of the channel geometry at the confluence, compounded by the problem of the pond'd portion of the flow and the natural vlei, meant that modelling of this area would have been extremely difficult. For this reason, the study reach as described in paragraph 6.1 included only the Klip River downstream of the Olifantsvlei sewage works and the confluence with the Klipspruit, that is, from sampling station E.

7.1.1 Oxygen balance data

Graphs of the measured BOD_5, COD and dissolved oxygen concentration against time for the sixteen hour period of study are shown in figure 7.1. The BOD data is very sparse particularly at stations G and H where only two determinations were made. This shortage of data for BOD was a result of a lack of laboratory facilities as mentioned in section 6.2.3. Chemical oxygen demands were determined for all samples.

Clearly the considerable variability in BOD and COD at each sampling station indicates that the sampling interval of two and a half hours was inadequate to describe the time variations. In addition the small number of analyses, even for the COD, makes it impossible to decide if certain outliers should be rejected from the data.

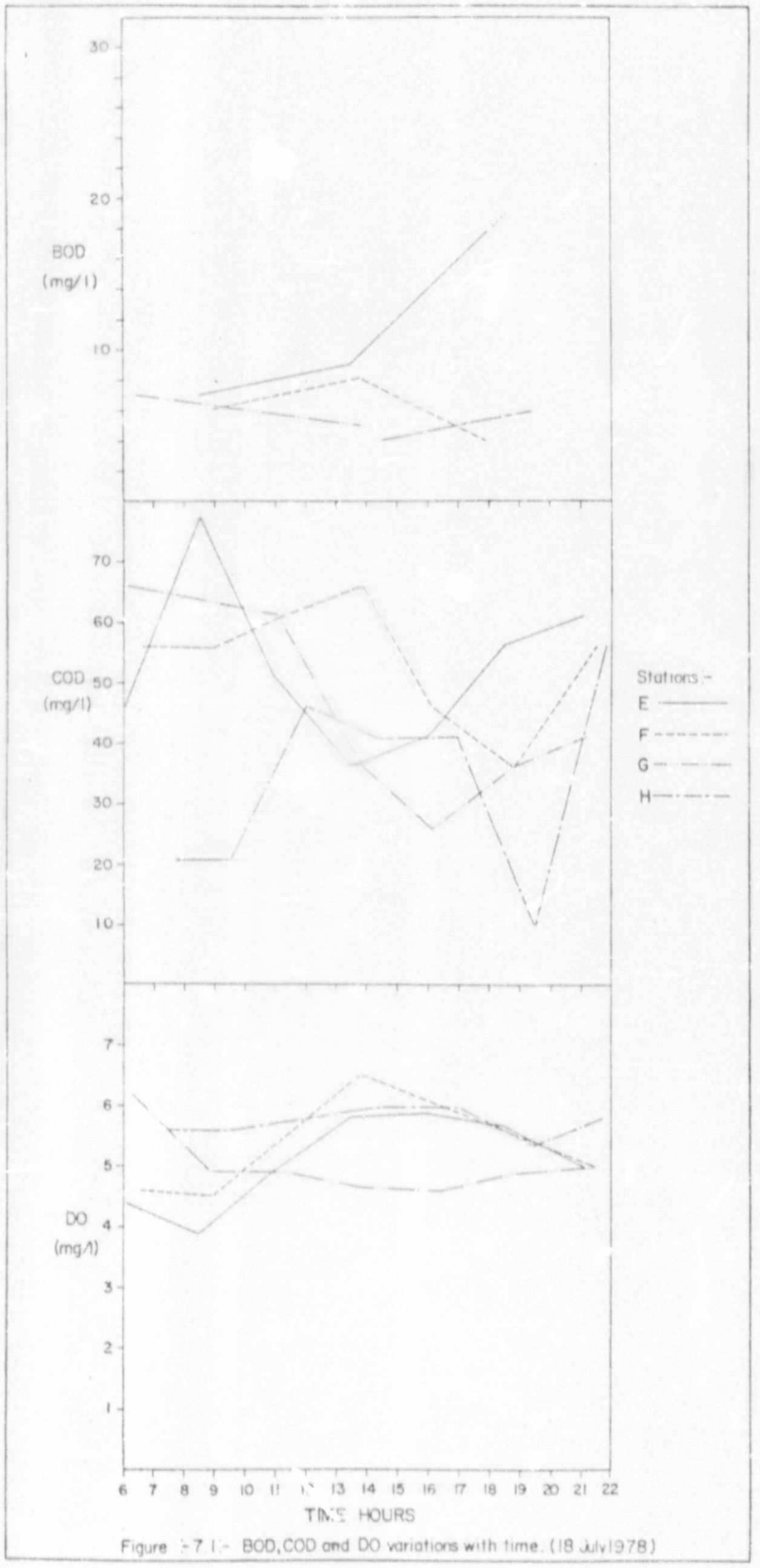
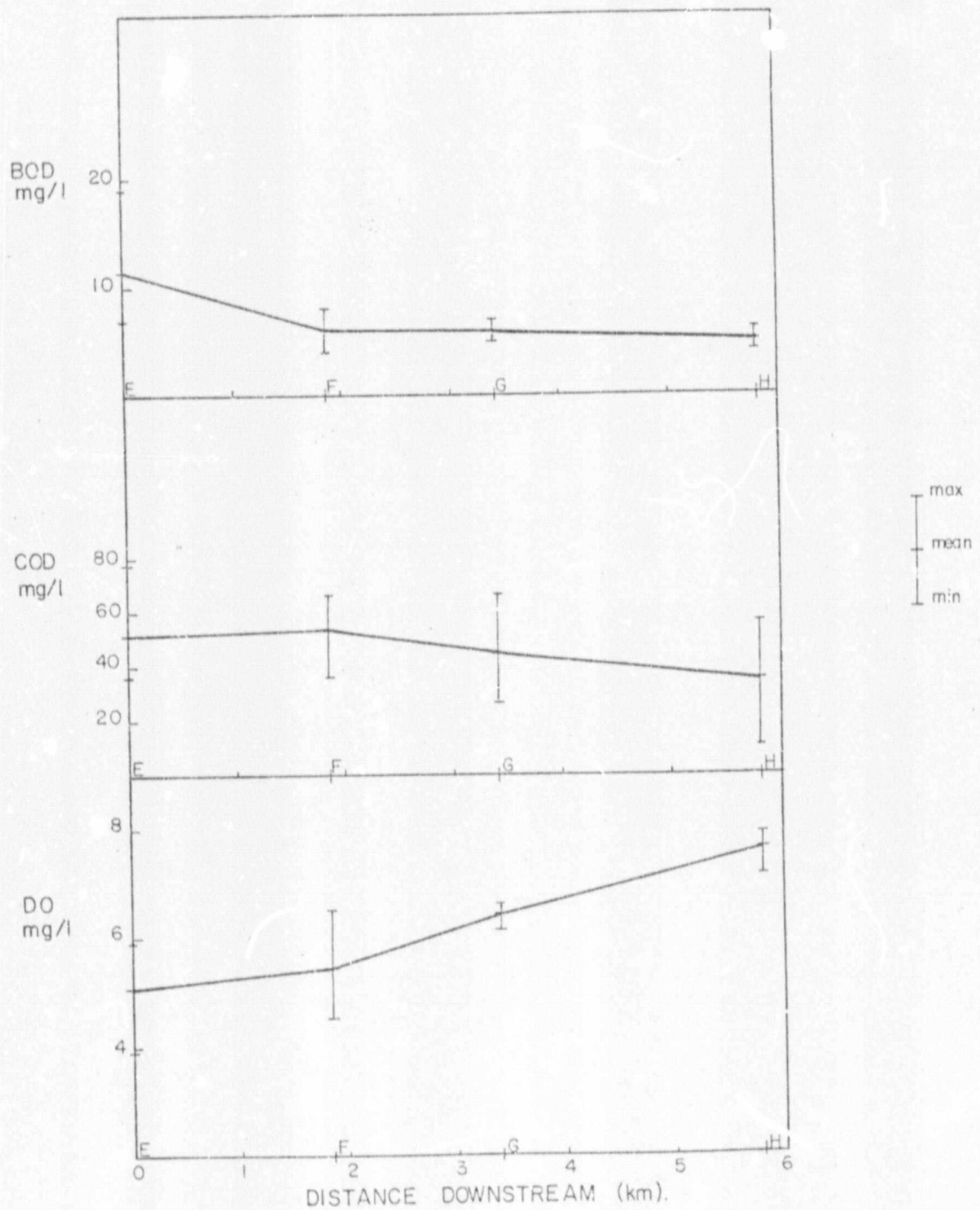


Figure :-7.1:- BOD, COD and DO variations with time. (18 July 1978)



Figures :- 7.2 :- BOD, COD and DO variation with distance down-stream. (Sampling survey 18 July 1978.)

The data clearly shows decreasing BOD concentrations with distance downstream; the average COD, however, shows an increase slightly in reach 1 before beginning to drop (figure 7.2). The corresponding increasing dissolved oxygen concentrations are also very clear, indicating that the study reach is located within the recovery limb of the dissolved oxygen sag curve below the sewage works outfall. This would be expected if it is realised that considerable self-purification takes place in the vlei and ponded areas of the river at the confluence with the Klipspruit.

7.1.2 Flow determinations

The river flow at each station was determined by means of the surface velocities and the cross-sectional areas of flow. Since surface velocities were obtained at three points across the river, it was possible to divide the cross-section into three segments as shown in figure 7.3. The mean velocity for each segment was obtained by multiplying the surface velocity by a factor, the latter being estimated from open channel velocity distributions given in Chow (1959).

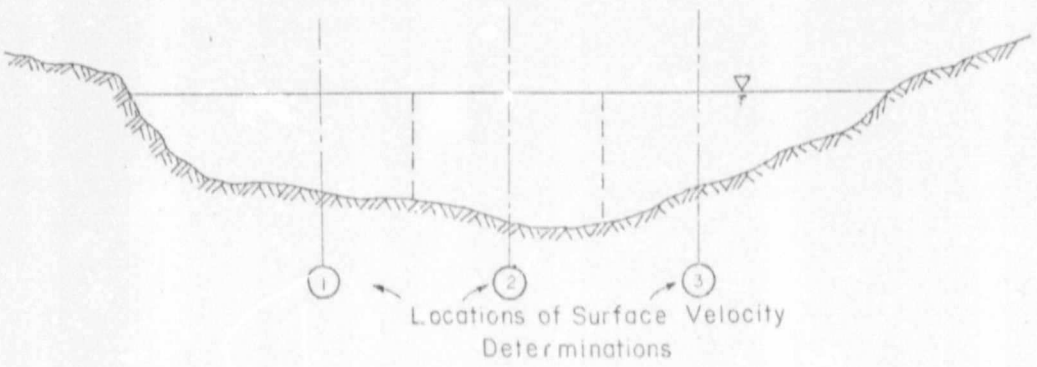


Figure 7.3 Typical segmentation of river cross-section for flow estimation

The results of the flow estimates for each station are given below.

Station	Average flow over period of survey (m^3/s)
E	4,19
F	4,26
G	4,14
H	4,25

A mean value of 4,2 m^3/s was assumed for the simulation.

7.1.3 Estimated time of passage

In order to calculate the times of passage through the first two reaches, these were further subdivided into shorter reaches of roughly uniform cross-sectional area and roughness characteristics. Since cross-section surveys could not be taken for all the sub-reaches, it was necessary to approximate some of the sub-reaches to those known to have similar cross-sections.

Due to the fact that the surveys of the cross-sections not at sampling stations were not taken on the same day as the sampling, it was necessary to correct the cross-sectional area of flow to that for the sampling day by means of the relation:

$$\frac{R_1^{\,2}\, A_1^{\,3}}{R_2^{\,2}\, A_2^{\,3}} = \left(\frac{Q_1}{Q_2}\right)^3$$

which is derived from Manning's equation,

with R = hydraulic radius of cross-section
A = cross-sectional area
Q = flow

and the subscripts referring to the values on the two different days.

Having subdivided the reach into smaller reaches and calculated the relevant cross-sectional areas of flow for each section, the times of passage applicable to the day of sampling could be determined by dividing the occupied channel volume by the flow.

The calculated times of passage and average velocities were:

	Time of passage	Average velocity
Reach E to F	1,27 hours	0,40 m/s
Reach F to G	1,37 hours	0,31 m/s

Lack of data due to the inaccessibility of reach G-H meant that no estimate could be made of the time of passage for that reach. It could reasonably be presumed that the flow would be much slower through this vlei due to the spreading out of the stream into the reed beds, and consequently a time of passage of 2,67 hours with an average velocity of 0,25 m/s was assumed for this reach.

The above results would appear to be somewhat unreliable as intuitively one would expect that the average velocity along reach F to G would be higher than that through the heavily reeded reach E to F. This was in fact shown to be the case with the tracer tests which are discussed in section 7.4, and the above values were not used in the final simulation.

7.2 Intensive sampling survey - 21 March 1979

7.2.1 Oxygen balance data

With the elimination of the sampling points A to D from the field of interest it was possible to sample at a greater frequency and over a longer period than in the earlier survey. From figure 7.4 it is again evident that the BOD data was too variable to be adequately represented by a BOD determination at three-hourly intervals but, as before, this was restricted by

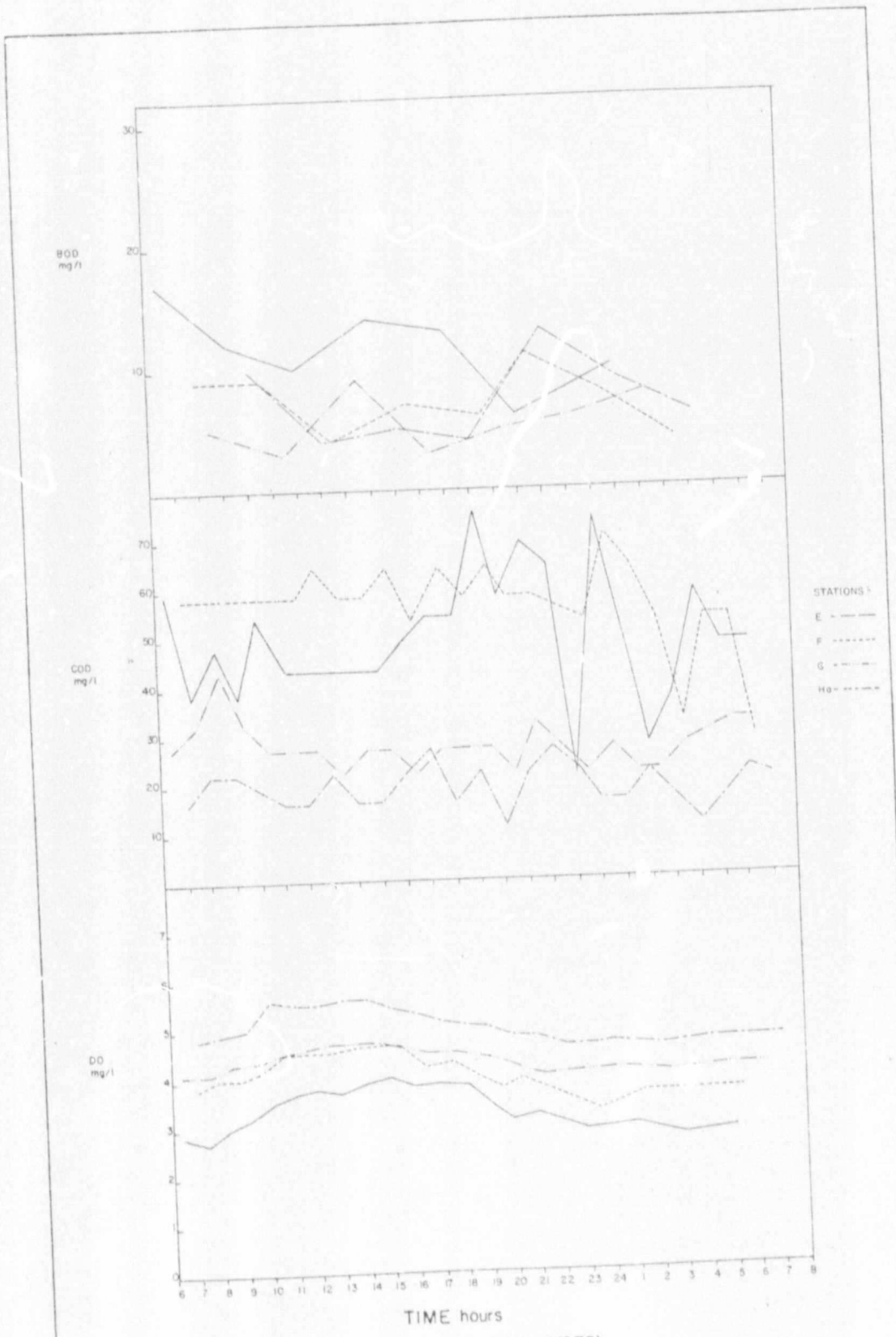


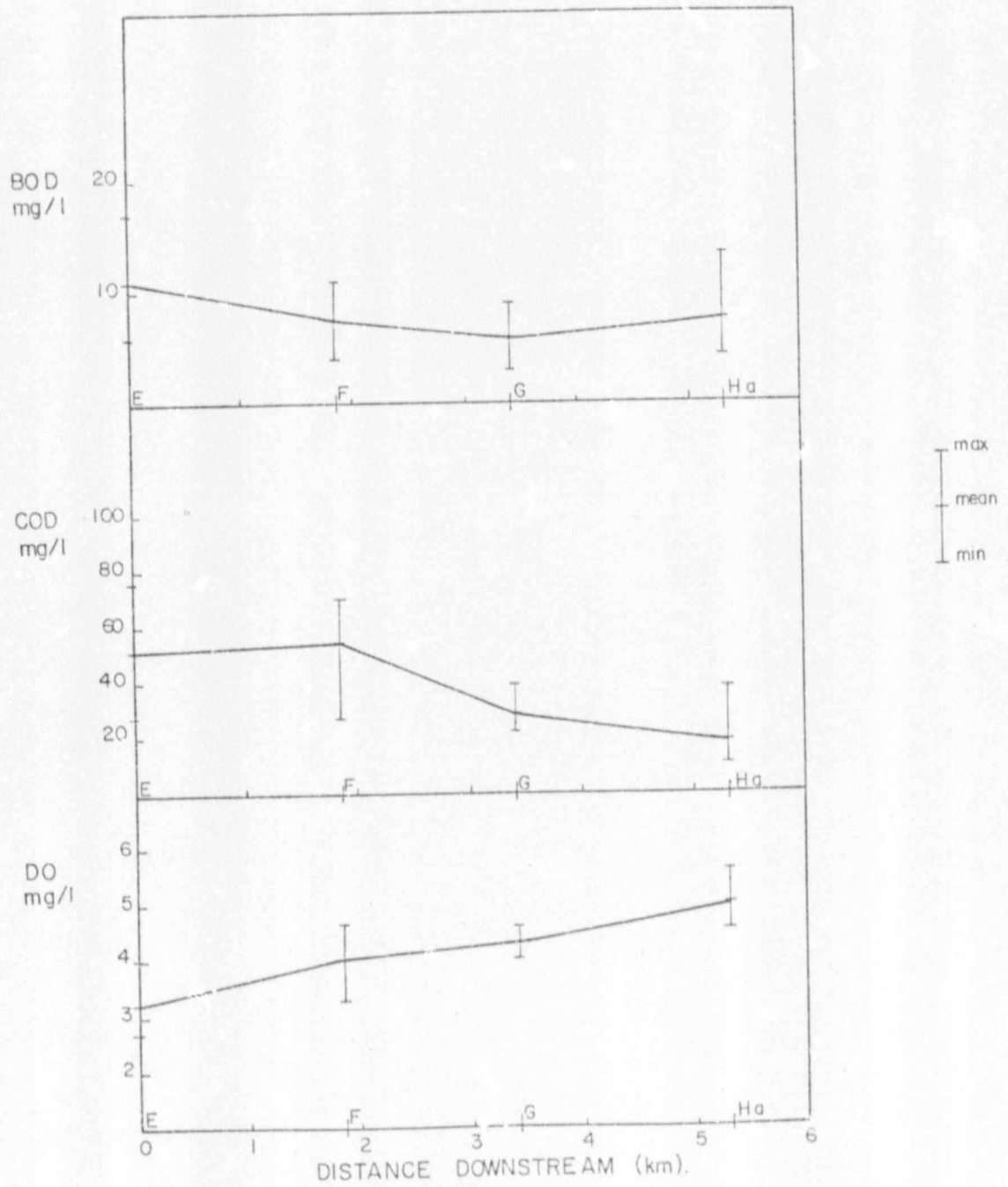
Figure : 7.4 :- BOD, COD, DO Variations with time (21 March 1979).

laboratory facilities. The COD analyses were performed on hourly samples and the data so obtained is clearly an improvement on the previous survey. The greater number of COD determinations means that certain outlying values obtained could be rejected but this was still not possible for the BOD data. The rejection of outlying COD values was done purely by observation and not through statistical tests of significance (the values concerned are indicated in table C3 of Appendix C).

A problem with the reliability of the data at station F arises from the fact that the COD values apparently remain fairly constant for approximately twenty hours, and then become highly variable. Further investigation found that the sampler had noted at the time that after nineteen hours he had moved his sample point four metres upstream because of difficulties being experienced in taking the samples at the original point. This is apparently the reason for the change in variability as the initial sample point had been in a slightly more secluded area of the river flow.

The variation in concentrations with distance downstream is indicated in figure 7.5. It is interesting to note here the increase in BOD in the last reach; the reason for this is unclear as there were no apparent sources of BOD along this reach. A comparison with the BOD from the previous survey is not possible because of the totally inadequate data at stations G and H in the earlier survey. The COD graph again indicates an increase in concentration in the first reach and the dissolved oxygen level is seen to be increasing as before.

In comparing the results of this survey with those of the previous survey it must be borne in mind that the two surveys were taken at very different times of the year hydrologically. The survey of the 18 July 1978 was taken in the middle of the dry season whereas the survey of 21 March 1979 was at the end of the summer rainy season.



Figures :- 7.5 BOD, COD and DO variation with distance downstream. (Sampling survey 21 March 1979.)

Algal blooms vary from season to season and the effect of higher temperatures on DO levels in the March survey are obvious from the data. In addition, in between the two surveys, construction work for a new highway resulted in an embankment being built across the vlei area in reach 3. This was bound to have a marked effect on the characteristics of that reach.

BOD_5 - COD correlation

A means of supplementing the BOD data would be to obtain a correlation between the BOD and the COD levels. It is obvious by observation of the data however, that there is little such correlation and in fact this is borne out by the following linear correlation coefficients calculated from the data at each station:

Station	BOD_5 - COD Correlation coefficient
E	-0,36
F	0,45
G	-0,47
H(a)	0,23

Determination of ultimate BOD (BOD_{20})

The four results of the twenty-day BOD tests were insufficient to obtain a satisfactory correlation between the ultimate BOD and the COD; the results of one test even indicated a higher BOD_{20} and had to be rejected completely. From the other three tests a mean non-biodegradable fraction of sixty percent was obtained and used in the simulations.

Only two BOD_{20} tests could be compared with BOD_5 tests, and these yielded an average BOD_5/BOD_{20} ratio of 0,5.

7.2.2 Flow determinations

Flow estimates were made as described in paragraph 7.1.2 and are listed below:

Station	Average flow over period of survey (m^3/s)
E	3,38
F	3,35
G	3,43
H(a)	5,25

The above determination at H(a) is unacceptable due to the fact that the sampling point was located just downstream of two concrete pipes through which the water flowed under the Misgund Road causeway. This resulted in a high velocity near the surface and consequently an overestimation of flow rate. It therefore had to be assumed that, as in the earlier sampling survey, the flow between G and H(a) did not change.

A mean estimate of the flow rate for the simulation was taken as 3,4 m^3/s.

7.2.3 Estimated time of passage

The time of passage through the first two reaches was calculated by dividing the occupied channel volume by the flow as discussed in paragraph 7.1.3, with the following results:

	Time of passage	Average velocity
Reach E to F	1,34 hours	0,38 m/s
Reach F to G	1,51 hours	0,29 m/s

A time of passage of 2,3 hours for an average velocity of 0,23 m/s was assumed for reach G to H(a).

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A time of passage of 2,3 hours for an average velocity of 0,23 m/s was assumed for reach G to H(a).

Again the relative average velocities calculated do not correspond to what would be expected and it was for this reason that tracer tests were carried out to get a better estimate of the average velocities (see section 7.4).

7.3 Light and dark bottle tests and benthal demand tests

In the light and dark bottle tests, the difference between the oxygen consumed in the light bottle and that consumed in the dark bottle is assumed to be due to the production of DO by the microscopic suspended algae in the water. This is because the process of photosynthesis, as described in section 4.5.2, requires light as a source of energy in order to produce oxygen; in the dark bottle therefore, no photosynthetic oxygen can be produced.

In the tests carried out on 6 January 1979, a difference in DO consumed of 3,1 mg/l was measured and this is attributed to photosynthesis. In the tests conducted on 21 March 1979 over the twenty-four hour period, two of the results indicated a lower consumption of DO in the dark bottle whilst the other two indicated a lower consumption in the light bottle. The possibility of carelessness on the part of the sampler, resulting in some air being trapped in the bottles, must be considered here. However, these results were not used directly in the simulation, but only as guidelines.

It should also be borne in mind that DO production by photosynthesis is not confined to free-floating algae, but in a relatively shallow stream such as the Klip River, fixed bottom algae, benthal algae and even other aquatic plants can contribute. Bruwer (1980) has indicated that free-floating algae are not generally abundant in South African rivers.

The benthal oxygen demand test performed on 21 January 1979 was very crude. The sample of bottom mud could not be considered to be representative of the entire reach and was considerably

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