1950

PROVINSIALE ADMINISTRASIE
VAN DIE KAAP DIE GOEIE HOOP

DEPARTEMENT VAN NATUUR- EN
OMGEWINGSBEWARING

NAVORSINGSEKSIE

PRIVAATSAK 5014, STELLENBOSCH 7600

PROVINCIAL ADMINISTRATION
OF THE CAPE OF GOOD HOPE

DEPARTMENT OF NATURE AND
ENVIRONMENTAL CONSERVATION

RESEARCH SECTION

PRIVATE BAG 5014, STELLENBOSCH 7600

Assistent Direkteur (Navorsing)
Dept. Natuur en Omgewingsbewaring
Privaatsak 9086
KAAPSTAD
8000

TELEGRAM Natuur
TELEFOON / TELEPHONE (02231) ~~70130~~ = 70111
NAVRAE / ENQUIRIES A Coetzer
VERWYSING / REFERENCE JNO/16/9/16/4
DATUM / DATE 1982-05-24

OLIFANTSRIVIERPROJEK

Ingeslote die verslag van die afgehandelde Olifantsrivierprojek, wat uit twee gedeeltes bestaan. Die verslag is nie vir publikasie voorberei nie, maar wel vir departementele verwysing.

Aangesien die stuk as n interne departementele verslag beskou word, is die resultate taamlik breedvoerig weergegee (tabelle) asook die chemies-fisiese parameters en faunistiese taksa wat bespreek word.

Die uwe

A COETZER

COETZER

HD

HYDROBIOLOGICAL REPORT ON THE OLIFANTS RIVER SYSTEM, WESTERN CAPE PROVINCE

A. COE

Part I. General description and physicochemical analyses of the water

Introduction

From a conservation stand point, the Olifants River System in the Western Cape is unique. Nine of South Africa's indigenous fish species occur in this system of which eight (hitherto described) are endemic. Skelton (1977) regarded three of these fishes as "rare", one as "endangered" and one as "vulnerable". According to Farquharson (1962) and Gaigher and Pott (1973) various river systems could have been interconnected during pluvial times. Fish migration probably took place from rivers to the north, with a possible connection between the Olifants River and Orange River (situated to the north) during the Pleistocene. Subsequent isolation of the Olifants River lead to speciation and the present day large proportion of endemics.

Man has had a direct and indirect influence on riverine biota by the introduction of exotic fishes and aquatic plants, the extermination of animals such as crocodiles and hippopotami, the regulation of streams and ill-considered usage of land (Chutter, 1973). Factors such as these have had an effect on the Olifants River, especially on the endemic fish species. With the prospect of further development along the west coast, the Olifants River will be further exploited as greater demands are made on water supplies.

Physicochemical and microbiological investigations are probably the most accepted methods of assessing water quality. As is frequently pointed out in literature on this subject, the results of these investigations provide inadequate criteria for maintaining healthy aquatic communities (Olive and Dambach, 1973). There being limitation they reveal conditions at the instant of sampling only. Chutter (1973) wrote that river quality should not be equated solely with water chemistry, as the flow patterns, sediment load and biota should also be considered.

Biological criteria for water quality assessment have received a great deal of attention, especially during the past few decades (Allanson, 1961; Schmitz, 1970; Chutter, 1972a; Olive and Dambach, 1973; Wilkinson, 1976; Hilsenhoff, 1977; Pratt and Coler, 1976). Resh and Unzicker (1975) divided these various methods into studies of community diversity using mathematical expressions (diversity indices) and studies on indicator organisms; in both of which the meaning of the calculated estimate is difficult to interpret (Chutter, 1975). Resh and Unzicher stressed that to apply tolerance values to groups of indicator organisms is of

1982.

2/.....

dubious value, as tolerance values could only be sought at species level. Even if identification to species level were possible (without considering time involved), little is known of the species' pollution tolerances. Tolerance values for most parameters known for aquatic organisms, are based mainly on experimental studies; situations hardly ever to be found under normal environmental conditions.

When Chutter (1972a) published his biotic index method for assessing water quality of southern African rivers, reference was made to the inherent problems of such systems. His method was adapted for Wisconsin streams by Hilsenhoff (1977) who concluded that the diversity index did not accurately assess water quality, but that the biotic index proved reliable in ranking streams to water quality. Wilkinson (1976) applied Chutter's method, tested it statistically, and concluded that "...BIV (biological index value) appears to be a good general measure of both organic and mineral pollution".

The aim of this study was to evaluate the water quality of the Olifants River System for the period April 1978 - March 1979. Chutters method being used.

Methods

The sampling locations are shown in Fig. la. Collections were intended to be made concurrently with a fish survey, which did not materialise. In selecting the locations, due consideration was therefore given to: accessibility, perennial flow and urban development. River physiography was not considered. Rainfall was low during the period of survey, and after March 1979 water flow was too low to justify further effort.

Locations were sampled at monthly intervals for macro-invertebrates from the stones-in-current biotope and partial physicochemical analyses of the water. Marginal vegetation and sandy bottom benthos not being collected because of the extensive area surveyed.

Chemical analyses were undertaken in the field, using a HACH DR-EL 2 Engineers Laboratory. Dissolved oxygen was determined with a YSI model 54 oxygen meter. The pH and conductivity were measured with a T & C model 800 pH meter and a T & C model 2000 conductivity meter.

Quantitative benthic samples of 0,3 m^2 were collected at each of the locations when stream flow permitted with a 0,1 m^2 modified Surber sampler fitted with a net of 290 micrometer mesh (vide Oliff, 1960; Chutter and Noble, 1966; Chutter, 1972b, for further information). The three Surber samples collected at each location were pooled and preserved in formalin for later laboratory analysis. The laboratory method used in counting the organisms was that described by Chutter (1963). However, the sample was washed through a sieve of 595 micrometer mesh to separate the macro and microsamples. The organisms in the macrosample were counted in toto, while one eighth of the microsample was counted. The number obtained for the microsample was multiplied by eight to determine the total organisms of the microsample.

Study Area

The Olifants River. The Olifants River (Fig. 1a) is one of the largest South African rivers draining towards the Atlantic Ocean. For most of its length it flows in a northerly direction, turning north-west and finally south-west before entering the ocean. The source of the river lies at an altitude of c. 900 m in a cultivated plateau, situated between the Kouebokkeveld Mountains to the east and the Olifants River Mountains to the west. However, some tributaries rise at altitudes of more than 2 000 m along the mountain ranges. From the plateau, the main river flows through an uncultivated gorge (c. 31 km long) with deep pools down to an altitude of about 244 m. Location 1 is situated about 2 km above the entrance, and location 2, just below the gorge. From the gorge downstream to location 4, isolated irrigation areas are found. The gradient to location 3 (Citrusdal) is roughly 3 m km^{-1}, after which there is a marked decrease in the slope towards the mouth (about 1 m km^{-1}). The mountainous areas through which the river flows are largely composed of Table Mountain Sandstone. In the lower lying areas below Bulshoek Dam, the river passes over Malmesbury formations, which are rich in soluble clorides (Harrison and Elsworth, 1958; Fourie and Steer, 1971; Fourie, 1977). These deposits are followed by Tertiary sediments and sand, which originate from the sea (Fig. 1b).

The river catchment falls within a winter rainfall zone. Annual precipitation ranges from between 900 mm in the mountainous catchment of the main river to less than 200 mm towards the river mouth. Agricultural activities in the catchment of the Olifants River include extensive mixed livestock farming and fruit farming (Fig. 1c). Irrigation schemes are well established, the two major dams being; the upper and larger Clanwilliam Dam (built in 1935) and the smaller Bulshoek Dam (constructed in 1922), about 30 km further downstream. About 500 ha below Clanwilliam Dam and 9 250 ha below Bulshoek Dam are intensively irrigated, whilst above the dams, isolated irrigation areas are to be found. The intensively irrigated areas are for most part underlain by Malmesbury formations (Fig. 1b; Fourie 1977).

The Doring River which is the main tributary of the Olifants River has a larger catchment than the Olifants River (Fig. 1a) but a lower average rainfall (130 - 180 mm yr^{-1}). The upper reaches of this river's catchment lie mainly in saline Karroo formations (Mountain, 1968 cited by Fourie, 1977).

The Sout River (not shown in Fig. 1a) lies in a semi-desert area, about 50 km downstream from the confluence of the Doring and Olifants Rivers. This river floods about once in a decade, carrying with it large quantities of silt and salt (Fourie, 1977).

Agricultural activities within the boundaries of the Doring River's drainage area consist mainly of extensive mixed livestock farming (Fig. 1c).

River Zonation

General. Three main zones can be distinguished in a river: the upper torrential eroding mountain source, the middle stable region and the lower depositing zone. These three regions are usually subdivided because of physiographical differences. Harrison (1965a) compared South African river zonation with that of Illies (1961) which was based on physical features. According to Illies a river can be divided into the mountain source, rhithronic and potamonic zones. The rhithron and potamon may be divided into epi-, meta- and hypo- subzones. Harrison concluded that the physical basis used (such as temperature and silt content) corresponded with faunal conditions, and it was therefore a useful system.

A dimensionless system used by various investigators (e.g. Kuehne, 1962; Harrell and Dorris, 1968; Haefner and Wallace, 1981) is the "Order system" of Strahler (1954, 1957). This system is adapted from Horton's (1945) analysis of drainage basins. In the order system of Strahler, the smallest fingertip tributaries are numbered 1. The channels formed by the junction of two first-order streams, are numbered 2. The junction of two second-orders form a third-order stream, and so forth. In this study stream orders were determined from topographic sheets with scales of 1:50 000 and 1:250 000.

The physiography of an area determines stream orders as well as agricultural development which in turn influences urban development, the latter two being the main contributory factors to river pollution. In addition to human involvement, the geological formations through which a river flows and the atmospheric circulation of sea salts, also effect water quality (Anderson, 1941; Fourie and Steer, 1971; Fourie, 1977).

The Olifants River. In this study the Olifants River was divided into three zones which coincided with the geology of the area, and agricultural and urban development; all of which fitted Strahler's order system.

Zone A extended from the plateau down through the gorge to a point just upstream of sampling location 2. At location 1, the stream velocity was low and it varied between 0,01 m s^{-1} during winter to 0,14 m s^{-1} by the end of spring. Small mountain streams and sponges drained into a muddy furrow which gave rise to the main stream. The furrow was partly overgrown by marginal vegetation and stones not in any real current were found to be covered with fine silt. Consequently invertebrates from the stones-in-current biotope were not collected.

This zone corresponded with the source zone of Harrison and Elsworth (1958), Oliff (1960), Illies (1961) and Chutter (1970), without considering altitude. Location 1 was situated in a third stream order according to Strahler's system (Fig. la). Although variations in chemical analysis of the water did not suggest this location as being different from the upstream locations of the next zone, it differed physically in a number of respects. It was therefore regarded as a separate zone from the downstream locations.

Zone B extended from location 2 downstream to a point between location 7 and the junction of the Doring River, at an altitude of c. 45,5 m. Mean current velocity ranged from 0,13 m s^{-1} at location 2, to 0,63 m s^{-1} at location 7. At all the locations in this zone, except 5 and 6, the river bed was stony and invertebrates were collected from the stones-in-current biotopes. Sand banks and marginal vegetation occured in the wider and shallower areas. At locations 5 and 6 only water samples for chemical analysis were collected.

This zone corresponded with Harrison and Elsworth's zone III (lower end), Oliff's rejuvenation zone, Illies' epipotamon and Chutter's unstable depositing zone. According to Strahler this river stretch falls into the fourth-order.

The irrigation dams are found in zone B. Locations 5, 6 and 7 are influenced by these dams, as reflected in the results and discussion section.

Zone C extended from above the junction of the Doring River down to a weir at Lutzville, c. 15 m above sea level. Here the river was wide and slow flowing, occasionally broken by rapids. Macro-invertebrates were collected from loose stones in these papids at locations 8 and 10.

/6........

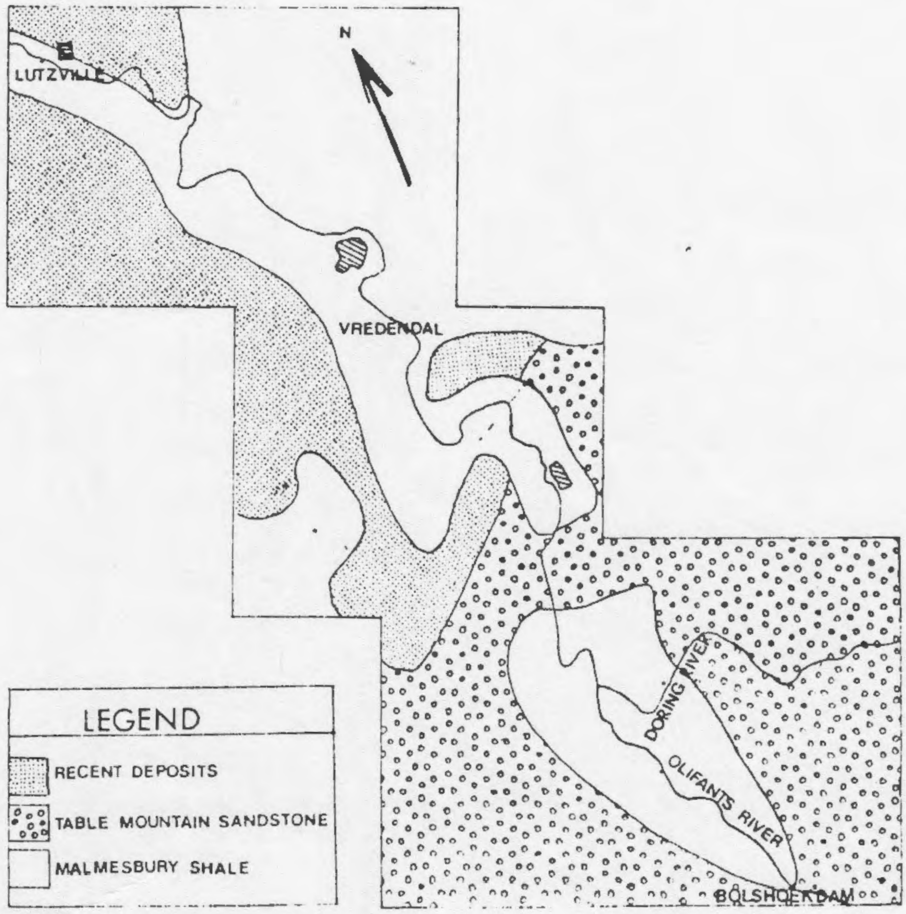


Fig. 1b. Geology of the area below Bulshoek Dam, down to sampling location 10, through which the Olifants River flows. (From Fourie, 1977)

In this stretch of river, flow varied considerably, largely due to two major influences; damming and irrigation. Below Bulshoek Dam negligible summer rain falls (Fourie, 1977), while the Doring River only flows during winter. Therefore, river flow below the dam is largely from leakage at the dam wall (30 000 m^3 day^{-1}: Fourie, 1977) and return flow irrigation water. Irrigation water regulated at Bulshoek Dam is supplied via canals at a rate of 1 220 mm water duty ha^{-1} yr^{-1} (Fourie, 1977). The river section below the confluence with the Doring River falls into Strahler's sixth-order. Because the Doring River is a sixth-order stream joining a fourth-order stream (the Olifants River); the higher stream order designation takes priority.

The tributaries which were sampled, meet up with zone B of the main river. These streams are comparable with the upper foothill of Harrison and Elsworth, the foothill sand bed of Oliff, meta-rhithron of Illies and the eroding and stable depositing zones of Chutter. Location 2a, 3a, 3c and 4a fall into Strahler's second-order, whilst 3b and 4b fall into the third-order. Macro-invertebrates from stones-in-current were collected at all these locations.

The Doring River. Along the upper reaches, the main stream of the Doring River is dry for most of the year. Therefore, the following perennial tributaries are regarded as part of the main stream: The Middeldeur River (location 11) and the Groot River (location 12) which meets the main Doring River. Because of the inclusion of tributaries as part of the main stream the zonation of this river is not as well defined as that of the Olifants River. In the upper areas of perennial tributaries, agriculture consist of orchards, vineyards and general crops. Lower downstream where river flow is intermittant, mixed livestock farming is mainly practised.

According to Strahler's system, the "main stream" can be divided into four zones. Zone DA is formed by the source of the Middeldeur River which lies in a cultivated plateau, situated between the Kouebokkeveld Mountains to the west and the Skurwe Mountains to the east. The majority of tributary streams flow from the east side of the Kouebokkeveld Mountains. The altitude of these slopes is approximately 850 m. The Middeldeur River is a third-order stream in which location 11 was situated. Pools with large boulders and rock outcrops were found at location 11, while loose stones-in-current were few, suggesting that the stream experiences very fast flowing water during heavy rains. Stream velocity ranged between 0,25 m s^{-1} during May (early wet season) to 0,40 m s^{-1} by August 1978 (wet season). Macro-invertebrates were collected at location 11.

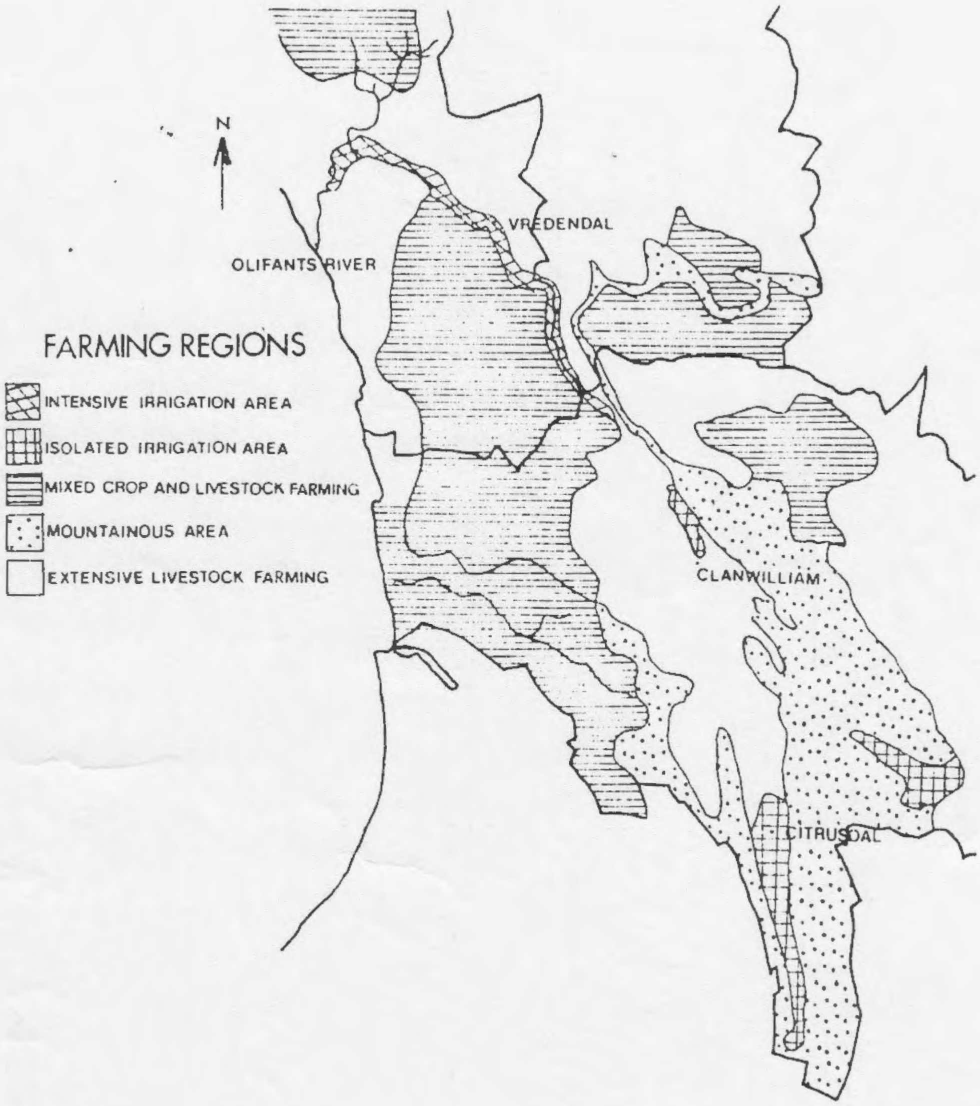


Fig. 1c. Farming regions in the Olifants River System drainage area (From Department of Planning and the Environment, 1974. Central West Coast. Regional Study).

Location 11a was situated in a third-order stretch of the Leeu River where it formed a large marshy pool. Location 11b was situated on the Lang River, a small third-order seepage stream with a sandy bottom. At both of these locations water samples for chemical analyses only were collected.

Zone DB stretched from the confluence of the Middeldeur and Leeu Rivers which forms the Groot River, down to the confluence with the Doring River. Location 12 (altitude 610 m) was situated where the Groot River broadens and is shallow (fourth-order). Numerous small stones were partly embedded in the bottom and were covered with silt and algal growth. For its width and its fairly shallow depth, the water was fast flowing (0,73 m s^{-1} during October 1978 to 0,25 m s^{-1} during February 1979) but not turbulent. Macro-invertebrates were collected at location 12.

Location 12a (first-order) and 12b (second-order) were situated in a tributary of the Groot River. At both locations macro-invertebrates were collected.

Zone DC stretched from the confluence of the Groot and Doring Rivers downstream to where the Doring and Tanqua Rivers meet. Location 13 (altitude 305 m) was situated in the Doring River, a fifth-order stream. Here the water resumed its flow during May 1978 for that year, and by June there were three main streams of fast flowing waters (0,70 m s^{-1}) which formed typical stones-in-current habitats; macro-invertebrates were collected.

Location 13a was situated in the fifth-order Tanqua River. During the period of this survey the seepage water seldom covered the gravel-like stones on the stream bed. This was an atypical stones-in-current habitat. Macro-invertebrates were collected.

Zone DD stretched from the confluence of the Doring and Tanqua Rivers downstream, and is of the sixth-order. Locations 14 and 15 were situated in this zone. At location 14 the stream flowed from June to September 1978, during which time the stones-in-current habitat was sampled, where the river formed wide shallow pools with occasional rapids and sand banks. At location 15 the river bed was composed of sand and large boulders. Flow was apparent only during July and August 1978.

Two tributaries were sampled upstream of locations 14 and 15. Locations 13b (third-order) and 13c (fourth-order) were situated in the Tra-tra River, and 13d was situated in the third-order Biedouws River. Macro-invertebrates were collected at these locations.

Because water flow in the Doring River is irregularly intermittent, no attempt has been made to relate this zonation to river zonation applied to other South African river studies.

Results and Discussion

General The Berg River studied by Harrison and Elsworth (1958) and Fourie and Steer (1971) falls in the same winter rainfall area as the Olifants River system. Fourie and Steer divided the year into a summer period, October to March, and a winter period, May to September; April was regarded as a transitional month. Their study did not include the faunistic aspects. In this study, the year was divided into four seasons of equal duration as did Harrison and Elsworth; April being the first month of the early wet season as widespread rain fell during the start of the survey. The four seasons monthly mean physicochemical analyses results are presented in Table 1, while the monthly means of the wet and dry periods are shown in Fig. 2. This procedure of presentation effected the smoothing of variations in monthly results, but brought out the long term differences.

The Olifants River. Mean alkalinity values for both wet and dry periods decreased from zones A towards B (Fig. 2 Alk). At locations 2, 3 and 4 alkalinity values remained low, but increased downstream to the impoundments at locations 5 and 6 followed by a steep increase at location 7, which continued throughout zone C. Generally, higher alkalinity values were recorded in the dry period and increased with higher stream order. In this study only bicarbonate alkalinity was encountered, due to the slightly acid to alkaline waters (cf. section on pH).

Other studies on South African rivers revealed that alkalinity increased during the dry season, and downstream (Harrison and Elsworth, 1958; Oliff, 1960; Allanson, 1961; Fourie and Steer, 1971; Fourie, 1977).

Harrell and Dorris (1968) found that bicarbonates increased while carbonates decreased with higher stream order in Otter Creek (Oklahoma), which they explained as being a result of the lower pH-values downstream. Lewis and Harrell (1978) studied Village Creek (Texas) and reported that alkalinity, pH and carbon dioxide concentrations decreased downstream. Therefore, the observed decrease in alkalinity from zone A towards zone B could be due to pH.

In both zones A and B (except location 6) the lowest mean seasonal alkalinities

9/.....

were measured during the early wet and wet seasons, while the highest were recorded during the early dry season (Table 1). In zone C, low values were recorded from the wet and early dry seasons, and high values from the early wet and dry seasons. This departure from the tendencies observed in the zones upstream, could be related to the impoundments and intensive agriculture, i.e. the pattern of water flow maintained below Bulshoek Dam for irrigation.

Hardness values were obtained for the dry season only (not shown in Fig. 2). Hardness decreased from zone A to B in which zone it increased steadily downstream with a sharp increase at locations 6 and 7. The increase continued in zone C and dropped remarkably at location 10. Hardness values exceeded bicarbonate alkalinity (the only alkalinity encountered) at all the sampling locations (Table 1). The greatest portion of hardness was therefore noncarbonate hardness.

Mean chloride values for the dry and wet periods decreased slightly from zones A to B (Fig. 2 Cl^-). In zone B chlorides increased slowly towards location 6, and increased steeply at location 7, during the wet period, continuing downstream in zone C. During the dry period, chlorides were slightly higher, except at locations 5, 6 and 7 which were downstream to the impoundments. In zone C, however, chlorides increased sharply compared to those of the wet period.

Higher chloride values during the dry period were mentioned in papers on different river systems. This was ascribed to increased concentrations because of low flow and evaporation (cf. Harrison and Elsworth, 1958; Chutter, 1963; Fourie and Steer, 1971; Fourie, 1977). Lower chloride values during the dry period at locations 5, 6 and 7 could be explained by the higher quality water received and retained by the impoundments during the rainfall season. Chemical analysis results obtained from the department of Water Affairs showed that during periods of low dam valume, chlorides increased and vice versa. This water retained by Clanwilliam Dam, was released during the dry period and passed location 5 to become available for irrigation via Bulshoek Dam. This "better quality" water diverted from the latter dam, was also reflected in results recorded from leakage water at locations 6 and 7, although the effect of seepage return was noticeable at location 7.

The high cloride measurements from locations in zone C could be related to return flow as no water from natural sources entered the river, as mentioned in

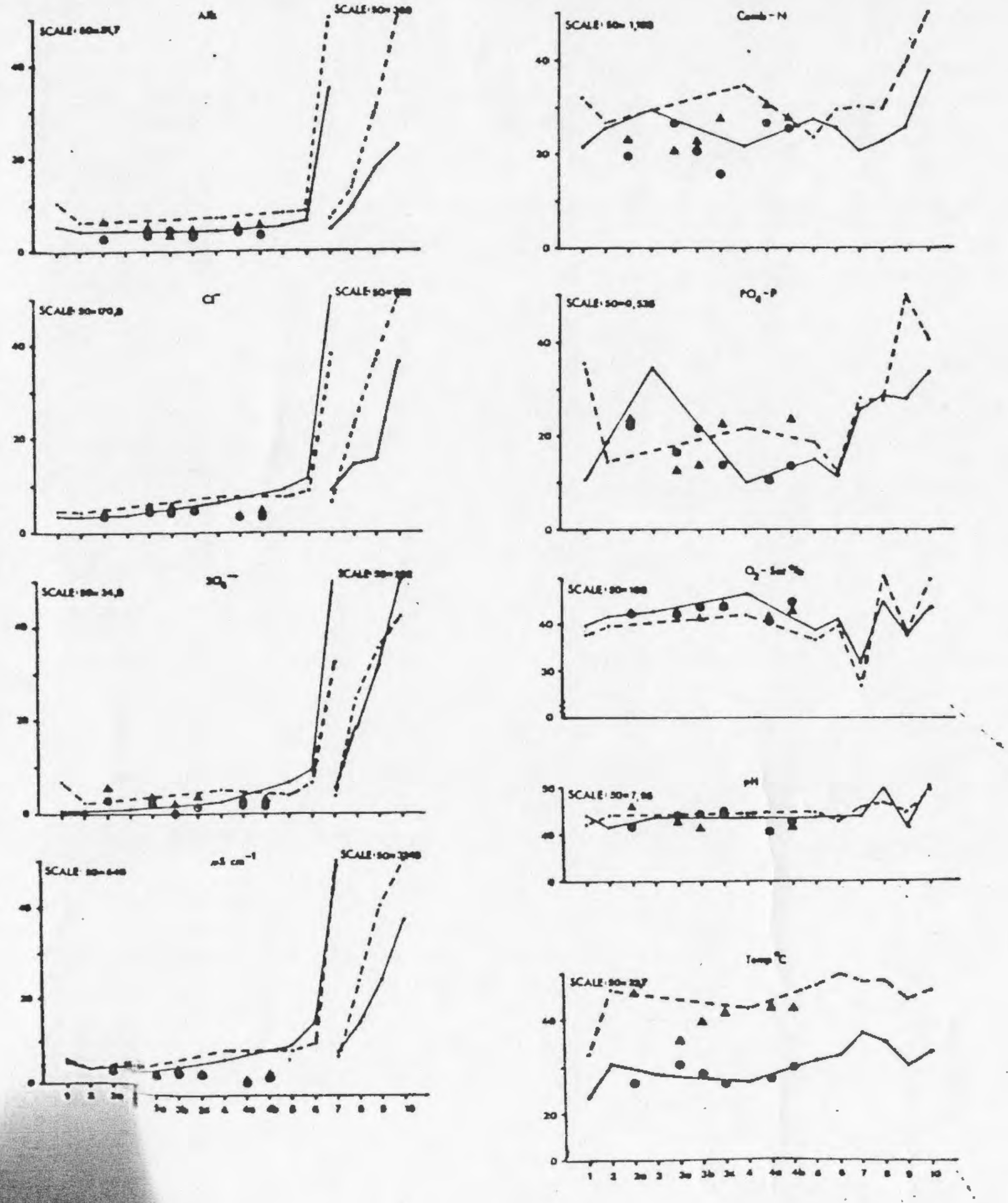


Fig. 2. Olifants River. Monthly mean physicochemical analysis results for the wet period, April - September (—— = main river locations, ⊙ = tributary locations) and the dry period, October - March (----- = main river locations, ▲ = tributary locations) 1978 - 1979. Values in mg ℓ^{-1} where applicable.

the section on river zonation. In return flow streams Fourie (1977) measured chloride values in excess of 2 000 mg l^{-1}, mainly derived from Malmesbury shale underlying irrigation soil. On average, chlorides measured during this study at locations 7 to 10, were higher than the values recorded by Fourie for 1974.

The sulphate trends for the wet and dry periods followed those of chloride and conductivity closely, and the three river zones were clearly delimited (Fig. 2 SO_4^{--}). The results obtained from locations 5, 6 and 7 correlated with their chloride tendencies, indicating the influence of the impoundments on water quality.

Intensive agriculture could result in increased sulphates from run-off (Hergenrader, 1980) and seepage water (*vide* results of Fourie, 1977). Therefore increased sulphate load of the river from location 7 downstream, could be related to agriculture. Increased sulphate measurements during low flow were also observed in other river systems (e.g. Chutter, 1973).

As conductivity is dependent on the total dissolved solids (TDS), the filterable residue can be approximated in mg l^{-1} by multiplying conductivity with a factor which depends on the nature of the water sample (APHA, 1976). In the stretch of river below Bulshoek Dam down to the weir at Lutzville (i.e. location 10) which Fourie (1977) studied, he determined the factor to be on average 0,61416 when conductance was expressed as $\mu S\ cm^{-1}$ at 25 C. Conductivity (Fig. 2 $\mu S\ cm^{-1}$) reflected the same trends as the previous parameters, increasing less sharply between locations 8 and 9, than between 9 and 10 during the wet period. This was probably caused by the lower chloride values between locations 8 and 9 (Fig. 2 Cl^{-1}). The lesser increase in sulphates between location 9 and 10 during the dry period was only partially reflected by conductivity measurements for the same period. This can be attributed to the lower electrical conductance of sulphates in solution.

The increase observed in TDS during the dry period could be due to increased seepage with high TDS content (Fourie, 1977), together with reduced flow and evaporation which increased the various chemical solutes' concentrations.

The trends during the wet and dry periods of combined nitrogen (i.e. sum total of NH_3-N, NO_3-N and NO_2-N) are shown in Fig. 2 Comb-N. During the wet season nitrogen increased from zones A to B. At location 4 the value decreased considerably because of good quality water received by the main stream from tributaries (cf. results of combined nitrogen of locations 3a, 3b and 3c; Fig.

2 Comb-N). Because of Clanwilliam Dam the water flow is reduced downstream resulting in an increase of combined nitrogen at location 5, which was incidentally supplemented by tributaries with an increased nitrogen content (cf. combined nitrogen, locations 4a and 4b). At location 6 these values decreased and dropped reasonably sharply towards location 7. The decrease observed at the former location is probably caused by the Bulshoek Dam. The available free nitrogen being trapped and utilized by aquatic plants in this man made impoundment, lowering the concentration in the leakage water below the dam wall. Bombówna et. al. (1978) found that impoundments reduced fertility of rivers further downstream; the reduction of fertility being dependent on retention time of the water.

According to Harrison and Elsworth's (1958) Berg River results, combined nitrogen values were lowest during the dry summer season when water flow was at its lowest (applicable to the middle and lower stretches). Chutter (1963) found that in the Vaal River, nitrates were highest during the summer high flow, and increased downstream. He speculated that the increase in nitrates downstream was derived from storm water drains or intensive agriculture on the banks of the river. During this study, the restricted stream flow below the impoundments, combined with a period of less intense agricultural activity during the winter period, could account for the further decrease of nitrogen measured at location 7. Downstream in zone C, nitrogen values increased because of the accumulative effect of run-off and seepage from land under irrigation along the river banks.

During the dry period combined nitrogen values were high in zone A, a plateau area with isolated irrigation, which is not shown in Fig. 1c. These values decreased towards the upper reaches of zone B, whilst it increased further downstream to reach a high at location 4. This higher value was caused by tributaries draining isolated irrigation areas, which enter the main stream (cf. dry period combined nitrogen at locations 3a, 3b and 3c; Fig. 2 Comb-N). At location 5 the dry period's combined nitrogen value was lower than that of the wet period. This was partially caused by water released from the Clanwilliam Dam (irrigation water for the Olifants River Basin), which diluted the effect of tributary water. The rise in combined nitrogen during the dry period at location 6 could, however, be explained by the through-flow of water at Bulshoek Dam into irrigation canals. The through-flow restricted the full utilization of nutrients by hydrophytes directly, and indirectly by the continuous out wash of phytoplankton. This resulted in a higher combined nitrogen value of the leakage water at location 6.

In zone C combined nitrogen concentrations increased sharply downstream in comparison with the results of the wet period. Water seepage off irrigated land and run-off probably contributed and accounted for the high increase of nitrogen values.

The high combined nitrogen values recorded during the dry period seem to contradict Harrison and Elsworth's, and Chutter's findings already mentioned. However, in the Olifants River Basin, water input was kept high during the dry (summer) period because of the irrigation scheme.

Oliff (1960) found that in the Tugela River, nitrogen compounds (as N) hardly exceeded 1 mg l^{-1}. In this study, combined nitrogen exceeded 1 mg l^{-1} at location 10 during the early wet and the whole dry period. At location 4 and 9, it exceeded this value during the early dry season.

Only ortho-phosphates (regarded as "soluble reactive phosphorus" by some, vide Rigler, 1973) were determined with the HACH-method (Fig. 2 PO_4-P). The mean wet and dry period values fluctuated widely downstream. During the wet period, ortho-phosphates increased from zones A to B and reached its highest value at location 3, decreasing towards location 4. This decrease was partially caused by water received from tributaries with lower phosphate concentrations (cf. ortho-phosphates at locations 3a, 3b and 3c). Below Clanwilliam Dam, the flow was reduced and the measured ortho-phosphates at location 5 largely reflected concentrations received from tributaries (cf. ortho-phosphates at location 4b), which caused a rise in these values. Below Bulshoek Dam the values decreased, but at location 7 and downstream along zone C, it increased. This increase could only be related to the accumulative effect of run-off and seepage from irrigated soil. There was no other apparent reason.

In the Tugela River Oliff (1960) could not detect phosphates during the dry winter season. In the Olifants River, ortho-phosphates were generally higher during periods of low flow, except at locations 2, 3a and 3b which received water from partially cultivated drainage areas. Lower combined nitrogen values were also obtained from location 3a for the same period. This phenomenon was probably caused by a better uptake of phosphates and nitrates by aquatic plants during the growth and low flow season.

Toerien et. al. (1975) found that nitrogen was the algal growth limiting factor in Clanwilliam Dam, while in Bulshoek Dam it was phosphorus. Although impoundment waters were not analysed during this study, values recorded from locations

13/....

5 and 6 during both periods, correlated with Toerien et. al.'s results. For example, at location 5 combined nitrogen decreased during the dry algal growth period in the water released from Clanwilliam Dam, while the values for ortho-phosphate were high in comparison. This indicated that ortho-phosphates could not be fully utilized by aquatic flora in this dam. Leakage water at location 6 reflected the opposite regarding combined nitrogen, where ortho-phosphates were lower, but only slightly higher than that recorded for the wet period. The "excess" of combined nitrogen during the dry period at Bulshoek Dam was caused by the through-flow of irrigation water as mentioned earlier.

Monthly visits were carried out over several days because of the extensive area to be visited. The oxygen saturation, pH and temperature were measured in the field during sampling trips. These measurements were made at the same time at the same location during each monthly visit, but never simultaneously at all the sampling locations. Therefore, these values give no indication to maximum-mimimum or diurnal variations but for broader seasonal trends observed at the different locations.

The percentage oxygen saturation for both wet and dry periods increased slightly from zone A downstream to location 4, whilst at locations 5, 6 and 7 the measurements decreased. The lowest oxygen saturations were measured at location 7 for the period of survey, an inexplicable phenomenon. Oxygen levels throughout the Olifants River were generally higher during the wet season because of more turbulent waters, except in zone C, where the levels fluctuated widely.

Water which drained from the upper mountainous reaches had neutral to slightly acidic values, reflecting the inertness of Table Mountain Sandstone formations. Fluctuations in pH of 7 ± 1 are considered biologically insignificant. Although pH values fluctuated during the wet and dry periods, values above 8 and below 6 were not recorded, though diurnal measurements were not taken. Slight seasonal variations were recorded by Chutter (1963) from the Vaal River. In the Tugela River it was found that pH tended to increase downstream and lower values were observed during summer (Oliff, 1960). In this study lower pH values were recorded during the dry period from location 6 downstream, in spite of the higher summer concentrations of dissolved solids and higher alkalinity values.

At all sampling locations dry period temperatures were higher. The lowest temperatures for both seasons being measured at location 1 (zone A). Down to location 2 temperatures increased as a result of the gorge through which the water flows, while lower temperatures were recorded further downstream to location 4.

14/.....

These lower temperatures were a result of cold water tributaries draining mountainous areas (Table 1, Fig. 2 Temp). From location 5 temperatures increased, but in zone C a downward trend was observed, caused by cooler seepage water entering the river, and the general deeper river water and cooler climatic conditions downstream from Bulshoek Dam.

Suspended solids carried to the main river by run-off water were generally higher during the wet period (Table 1). Flow figures for the tributaries are not known. Comparing physico-chemical results obtained from locations above and below their confluence with the main river, their water affected the main stream's combined nitrogen and ortho-phosphate loads (Table 1). Tributaries were low in chlorides, sulphates and TDS (as conductivity), due to their inert drainage regions.

The Doring River. Alkalinity values increased downstream, with a sharp increase in zone DD (Fig. 3 Alk). Dry period values were higher than those of wet periods except at location 15 which apparently received no water from the main stream during summer.

Stream order alkalinities for both the Olifants and Doring Rivers compared favourably with one another. But locations 11b and 13a were exceptions; both of which could be regarded as seepage streams. The former is largely effected by seepage from cultivated land, and the latter by the saline Karroo formations which it drains.

Hardness values were recorded for the dry season; a time during which many of the sampling locations had little or no water. These values were higher than the alkalinity values recorded, and were therefore mainly noncarbonate hardness (Table 2).

Chlorides increased with higher stream order. There was a sharp increase at location 14 which decreased at location 15 (Fig. 3Cl^-). Generally the values recorded for the dry period exceeded those of the wet period; location 15 being an exception. Values obtained from locations 11b and 13a were higher than the general stream order values, for reasons mentioned above. The extremely high values at location 14 could be related to causes such as reduced water flow, the apparent cessation of water flow at this point for the larger part of the year, which resulted in the build up of chlorides through evaporation. It appears that every year when flooding occurs, these accumulated salts are washed downstream. Initially, with the onset of river flow at location 15, it received water with a high chloride contents (Table 2), which became lower as flow increased, and *vice versa* before cessation. At this location there was no further input of chlorides from August 1978 until the end of the survey. The rise in chloride concentrations being due to evaporation. The lower chloride values at this location in comparison with location 14 upstream were caused by the longer input of solutes at the latter location.

Sulphates were generally low except in zone DD (Fig. 3 SO_4^{--}) where high recorded values were caused as explained above for chlorides. Sampling locations with sulphate concentrations out of phase with general stream order concentrations (of this river), were 11b, 13a and 13c. The former location reflecting the influence of agriculture (*vide* Hergenrader, 1980; Fourie, 1977), while the latter two locations reflect the geological formations through which their waters flow.

Conductivity increased downstream with a sharp rise in zone DD (Fig. 3 uS cm^{-1}). Dry period values exceeded those recorded for the wet period at locations 13 and 14, but not at location 15, for reasons already mentioned.

During the wet period combined nitrogen values decreased in zones DA to DC, whilst increasing in DD (Fig.3 Comb-N) and values recorded at location 14 were slightly higher compared with those recorded at location 15. High nitrogen values were also recorded in location 13a (Table 2) possibly caused by high TDS (13 634 and 26 171 mg l^{-1} respectively, for wet and dry periods) which could have inhibited aquatic plant growth and thus, nitrogen utilization. Combined nitrogen values for the dry period were generally higher.

Ortho-phosphate values increased during the wet period in zones DA to DB, but decreased towards zone DC and location 14 of zone DD. Values recorded in location 15 were high (Fig. 3 PO_4-P). During the dry period, ortho-phosphate values were lower along the main stream, except at location 14 and 15 in zone DD. Tributaries entering the main stream apparently having little influence on its water.

Tributaries which did not dry up during the summer months, generally had higher ortho-phosphate values compared with values recorded for the wet period, as also in most tributaries of the Olifants River.

Oxygen saturations were mostly in excess of 80%, except in the apparently standing water at location 11a. At his location low values were measured during the early wet winter (51%) and early dry summer (68%), while 85% was measured during the dry summer season; the plant growth period. There was no clear-cut pattern in the values of oxygen saturation between the wet and dry periods (Fig. 3 O_2-Sat%).

Upstream to location 13, pH values were below 7, including tributary locations, with the exception of 11b. At location 13 and downstream, the pH values were above 7, except at location 13b. The hydrogen ion activity of the waters were biologically insignificant, being in the range of pH 7 ± 1. Only at location 13a these values exceeded pH 8 (Table 2).

Water temperature of the main stream increased with higher stream order, and was higher during the dry period (Fig. 3 Temp).

Run-off water caused the values of suspended solids to rise during the wet season, except in zone DD where high values were recorded during the dry period (Table 2).

Summary:

The zonations used in this study for the Olifants River System were based on stream orders after Strahler (1954, 1957). The physicochemical analysis of the water from the different sampling locations as a whole, generally fitted the different stream orders. Exceptions were seepage streams, and those in which human involvement altered the natural environment (e.g. agriculture and impoundments). The concentrations of plant nutrients, nitrogen and phosphorus, are interrelated. The availability of one of these substances to plants, or the lack of it, influences the concentration of the other. The concentrations of these solutes were therefore not (or at most, only partially) influenced by stream order classification.

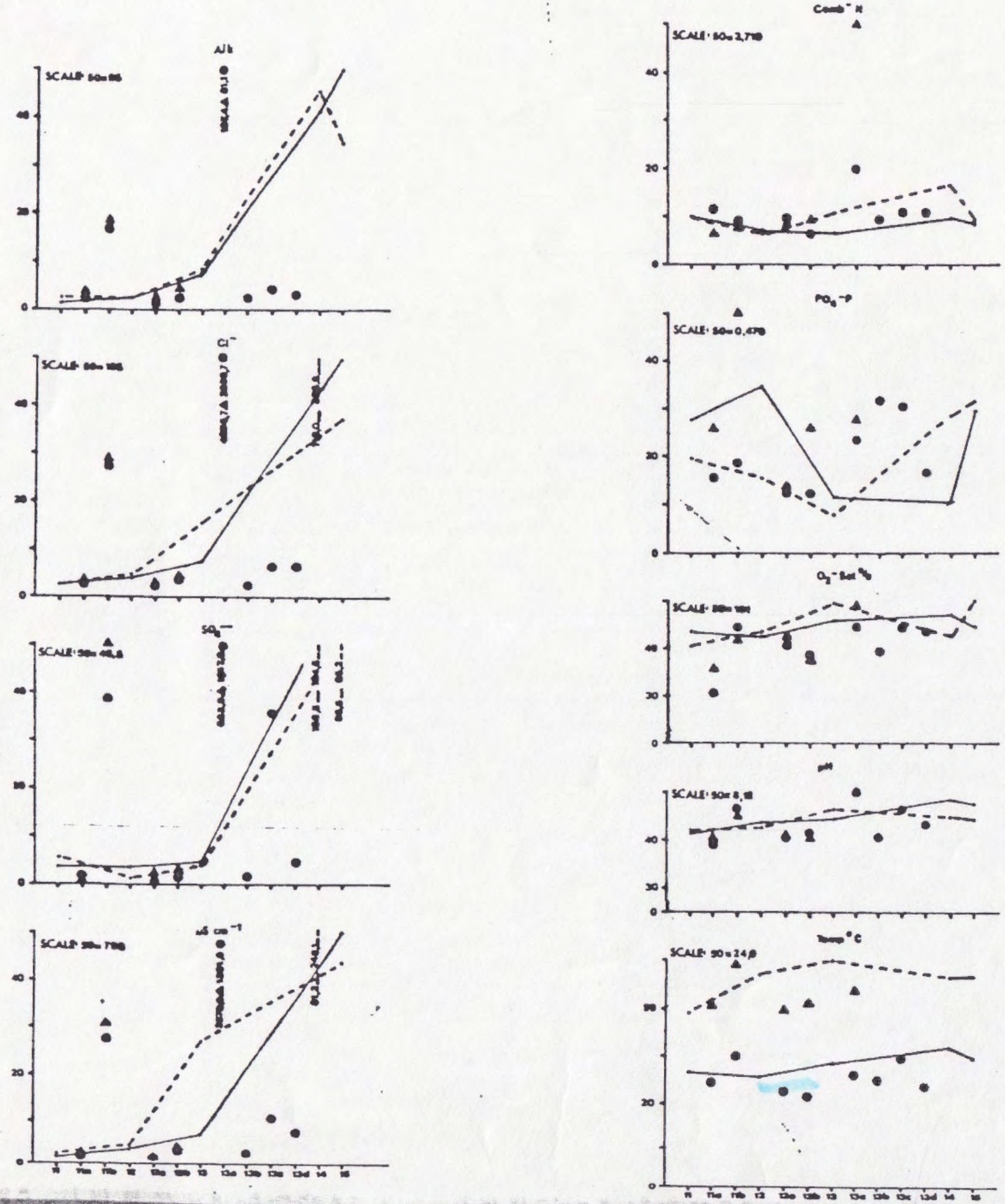


Fig. 3. Doring River. Legend as in Fig. 2.

HYDROBIOLOGICAL REPORT ON THE OLIFANTS RIVER SYSTEM, WESTERN CAPE PROVINCE

Part II. The fauna of the stones-in-current biotope and the biological quality of the water.

Introduction

In part I of this paper, a description is given of the study area and the physicochemical features of the Olifants River System. In discussing the physicochemical features, emphasis was on river zonation, based on the stream order category of the main streams, i.e. Olifants and Doring Rivers. However, in discussing the fauna, emphasis will be on the stream order category of the sampling locations. In the faunal tables, sampling locations were strictly arranged according to the stream order classification, in relation to each river zone.

Problems involved in presenting biological data from samples collected at monthly intervals, were discussed by Harrison and Elsworth (1958), Allanson (1961) and Chutter (1970). The criteria used by Chutter (1970) to recognise important taxa, were applied in this study.

The year was divided into four seasons of equal duration, namely Early wet winter (EW), Wet winter (W), Early dry summer (ED) and Dry summer (D); April being the first month of EW. Dominant taxa were those with a mean seasonal percentage of 5% or more. Significant taxa those which occured in not less than two samples when a sampling location was visited two or three times during a season, irrespective of their percentage in individual samples. When a location was visited once during a season, significant taxa were those which constituted 5% or more of the fauna in the sample. In effect, all dominant taxa were significant, but not all significant taxa were dominant. In calculating the above percentages, the numbers of cladocerans, copepods and ostracods were excluded as their numerical presence largely depended on water current speed, which affected total numbers of individuals considerably.

The monthly number of individuals per 0,1 m^2 of the insect orders Ephemeroptera, Trichoptera, Coleoptera and Diptera, collected at each location, are presented in Fig. 4. All other aquatic taxa falling under the common heading "Other taxa", as indicated in the figure. As there were large variations in numbers, each histogram represents the radius of a sphere; the size of the sphere being the total number of individuals for each taxon. The mean numbers per 0,1 m^2 for each season, and the significant taxa, are shown in Tables 3 and 4. The Baetidae has been abbreviated by combining the data for the different

PLEASE REFER TO LAST PARAGRAPH PAGE 17

Fig. 4. Monthly number of individuals per 0,1 m^2 of the different taxa during May 1978 - March 1979. (SEE TEXT)

species identified. Important changes within groups are mentioned in the text.

The fauna

The Olifants River. Invertebrates were sampled from zones B (i.e. stream order four) and C (i.e. stream order six) of the Olifants River. Tributary locations 2a, 3a, 3c and 4a were located in streams of the second-order, 3b and 4b were located in third-order streams.

In considering the different stream orders, it was found that the number of significant taxa decreased in higher stream orders and not restricted to a specific stream order, but that their seasonal significant occurrence either increased or decreased with higher stream order. To evaluate the importance of significant taxa to a specific stream order the ratio of monthly significant occurrence for all seasons at all sampling locations were determined. In the text "important" and "next important" refer to a taxon's highest and next highest ratio of significant occurrence as explained above.

Based on these determinations it was found that *Baetis harrisoni*, *B.* (*Acentrella*) sp., *Centroptilum sudafricanum* and *Pseudocloeon saxophilum* (Baetidae: Ephemeroptera) were "important" in second-order streams. Their next highest ratio of importance was in stream order three, except for *B. harrisoni*, which was "next important" in stream order four. A baetid numbered Baetid sp. 80, resembled *Centroptilum sudafricanum* and *C. parvum* in the shape of the labial palp, but differed however in having seven pairs of rather large oval shaped abdominal gills, and other features. This species had an equal ratio of significance in stream orders two and three, with its next highest ratio in stream order four. This was the only "important" baetid of stream order three. In stream order four the "important" species were *Baetis latus*, *B. bellus*, *Pseudocloeon maculosum* and *P. vinosum*. *B. bellus* reached significance only in stream order four, while *P. vinosum* was "next important" in stream order three. *B. latus* and *P. maculosum* were "next important" in stream order six. *Centroptilum excisum* was the only "important" baetid of stream order six, being "next important" in stream order four.

The ephemeropteran families Heptageniidae, Leptophlebiidae and Ephemerellidae were "important" taxa in streams of the second-order, while Tricorythidae were "important" in stream order six. Caenidae were intermediate, being "important" in stream order four with their next highest ratio in both stream orders three and six.

Important trichopteran taxa of stream order two were the eruciform larvae (regarded as a single taxon in this paper), Cheumatopsyche afra and an unidentified hydroptilid (?) species. The former two taxa were "next important" in stream order three, while the latter was significant only in stream order two. None of the trichopteran larvae reached their highest ratio of significance in stream order three, but in stream order four, C. thomasseti, Hydropsychid spp. (i.e. Hydropsychidae except Cheumatopsyche spp.), Hydroptila sp., Oxyethira sp., Ecnomidae and Philopotamidae were "important". The latter two families had their next highest ratio of significance in stream order two, and that of Hydropsychid spp. in stream order three. C. thomasseti and Hydroptila sp. had their next highest ratio in stream order six, while Oxyethira sp. was only significant in stream order four. In the sixth-order stream Orthotrichia sp. had its highest ratio, being "next important" in stream order four.

Coleopteran families "important" in stream order two were Hydraenidae, Dryopidae and Helodidae. The former two being "next important" in stream order three, while Helodidae were significant in stream order two only. Dytiscidae were significant only in stream order four, while the Gyrinidae had their highest ratio of significance in stream order six, being "next important" in stream order four.

The dipteran taxa Calopsectrini and Hydrobaeninae were about equally "important" in all the stream orders sampled along the Olifants River; the ratios being respectively 0,9, 0,9, 1,0, 1,0 and 1,0, 0,9, 1,0, 1,0. In the second stream order "important" taxa were Simuliidae, Blepharoceridae and Heleidae. Simuliidae were "next inportant" in the fourth-order stream, while the latter two taxa were "next important" in third-order streams. Rhagionidae ("next important" in stream order four) and Empididae ("next important" in stream order two) were "important" dipteran taxa of the third stream order. Tipulidae were significant in stream order four only. "Important" dipteran taxa of the sixth-order stream were Culicidae (next highest ratio in stream order three), Tendipedini and Pelopiinae (both "next important" in stream order four).

Plecoptera were "important" in stream order two with their next highest ratio of significance in stream order three. Nematoda ("next important" in stream order four) and Hydracarina ("next important" in stream order two) were significant taxa of stream order three. In stream order four, "important" taxa

20/.....

were Turbellaria, Odonata and Rhynchocoela. The first two taxa were "next important" in stream order two, while Rhynchocoela were "next important" in stream order three. Lepidoptera and Castropoda were only significant in stream order four. In stream order six Coelenterata, Annelida and Hemiptera (i.e. Corixidae) were "important" taxa. Annelida and Hemiptera (i.e. Non-Corixidae) were "next important" in stream orders three and four, respectively.

Density of the taxa varied at different locations and in different stream orders (Table 3). In stream orders two and four Ephemeroptera reached their highest numbers per unit area during EW, whilst their highest percentage composition of the total fauna was recorded during ED. In stream order three, the highest numbers per unit area coincided with the highest percentage composition of the total fauna, during ED. The lowest numbers per unit area were recorded during D in stream orders two and three, and during ED in stream order four. Unfortunately, stream order six could not be classified, as this river stretch was only sampled during the first two seasons.

Trichopterans reached their highest numbers and percentage composition of the total fauna during EW and D in stream orders two, three and four.

In stream orders two and four, coleopterans were highest in numbers and percentage composition during EW and D, while in stream order three, these values coincided only during EW.

The dipterans had their highest numbers per unit area during EW and W in stream orders two and four, and their highest percentage composition of the total fauna during W. In stream order three the highest number and percentage composition were recorded during W. In all stream orders two, three and four, these values were lowest during ED.

"Other taxa" (excluding cladocerans, copepods and orstracods) were recorded in high numbers, and formed the highest percentage of total fauna from stream orders three and four during D, whilst the lowest numbers coincided with W. In stream order two the numbers declined from season to season during the period of sampling.

Ephemeropterans, dipterans, and "other taxa" had their highest mean values for the sampling period in stream order three, whilst that of trichopterans was in stream order four. Only coleopterans reached their highest mean value in stream order two.

Dominant taxa (5% or more) common to all four stream orders sampled were Baetidae, Simuliidae, Calopsectrini and Hydrobaeninae. Dominant taxa shared by both stream orders two and three were Dryopidae, Blepharoceridae and Hydracarina; none of which was shared by stream orders four and six. Heptageniidae and Ephemerellidae were dominant taxa of stream order two. Taxa dominant to stream order three were Leptophlebiidae, Caenidae and Annelida; the latter two taxa were shared by both stream orders four and six. Except for Caenidae, Annelida and those taxa shared in common by all stream orders, stream orders four and six shared Hydroptilidae and Pelopiinae as dominant taxa. Eruciform trichopteran larvae, Hydropsychidae, Ecnomidae and Philopotamidae were taxa dominant only in stream order four. Tricorythidae and Tendipedini were dominant in stream order six only.

The Doring River. Invertebrates were collected from all four zones of the Doring River viz. Zones DA (third-order), DB (fourth-order), DC (fifth-order) and DD (sixth-order). Sampling locations of lower stream order were situated in tributaries meeting the main stream. Zone DB receives a tributary in which locations 12a (first-order) and 12b (second-order) were situated. Zone DC receives a tributary in which location 13a (fifth-order) was situated. Two tributaries meet up with zone DD in which locations 13b (third-order), 13c (fourth-order) and 13d (third-order) were located.

To evaluate significant taxa important to specific stream orders in the Doring River, the same method of ratio determination was applied as to the Olifants River, but in the Doring River, each location was evaluated separately to determine a taxon's importance to a stream order. This was decided on because locations 13b, 13d (third-order) and 13c (fourth-order), for example, formed part of zone DD, which lies in a lower latitude and drier rainfall area than locations 11 (zone DA) and 12 (zone DB). Aquatic environments of the former locations were therefore hardly comparable with those of the latter, although being of the same stream orders. Also, locations 13 and 13a were of the same stream order, but differed in water chemistry and stream flow. (cf. Part I, Table 2). Furthermore, river flow was intermittent in parts of the system, which in effect changes the stream order classification during periods of cessation, if stream flow is to be regarded as a criterium in determining stream order.

Ephemeropteran Baetidae "important" to stream order one (location 12a) were Baetis (Acentrella) sp., B. bellus, Centroptilum sudafricanum and Pseudocloeon vinosum. Stream order two shared B. (Acentrella) sp. as an "important" taxon. "Important" taxa of stream order three were B. bellus (shared by stream order one) and C. excisum. Most of the baetids were "important" in stream order four viz. C. sudafricanum, P. vinosum (both shared by stream order one), B. latus (shared by stream order five), B. harrisoni, Baetid sp. BO and P. maculosum. None of the baetids were important to the sixth-order section of the river (location 14), up to its confluence with the Olifants River.

Ephemerellidae were "important" taxa of stream orders one and three, and Leptophlebiidae and Caenidae of stream order three only. Leptophlebiidae were "next important" in stream orders one and five. Heptageniidae were only significant in stream order four, while Tricorythidae were "important" in stream order five, followed by stream order six.

Eruciform trichopteran larvae were "important" in stream orders one and three, while Macronema sp. was "important" in stream orders one and four. Orthotrichia and Oxyethira spp. had their highest ratios in stream orders two and three, while that of Hydroptila sp. was in stream order three. Cheumatopsyche afra and C. thomasseti were "important" taxa of stream order four; the former being "next important" in stream order two, and the latter in stream order five. All other hydropsychid larvae grouped, had equally high ratios in stream orders two, three and four. Ecnomidae were "important" in stream orders four and five, and Philopotamidae in stream order four.

Helodidae were "important" in stream order one, ("next important" in stream order three), Hydraenidae in stream orders one and two (next highest in ratio in stream order three), Dryopidae in stream orders one, two and three (next highest in stream order four) and the Gyrinidae in stream orders one and five. The Hydraenidae had a high ratio of significance at location 13a; a location with high TDS-water. The Dytiscidae and Hydrophilidae were recorded as "important" at location 13a only.

Blepharoceridae were significant at locations 13, 13c and 13d, with their highest ratio at location 13c (stream order four, zone DD). The Hydrobaeninae were "important" in all stream orders, except stream order five. The Calopsectrini were important in stream orders one, two and four. Simuliidae had high ratios of significance in stream orders one, two and four of zone DB, and in stream orders three and four of zone DD. Empididae was an "important"

23/.....

taxon in stream orders one, two and three, while the Dixidae were significant in stream orders one and three. Heleidae were "important" in stream order two at location 13a (stream order five), with high TDS-water. Pelopiinae were "important" in stream orders three and four, and at location 13a. Tendipedini were "important" at location 13a, being "next important" at location 13c of stream order 4.

Turbellaria, Lepidoptera, Annelida and Plecoptera had high significant ratios in stream order one. Stream orders two and three shared Annelida as an "important" taxon with the first-order, while Plecoptera were shared with a third-order stream (location 11). Rhynchocoela, Nematoda, Hydracarina and Odonata were "important" in stream order two. Third and forth-order shared the Odonata as an "important" taxon, while Hydracarina were also "important" in stream order four. Gastropoda had high significant ratios in stream order four of zone DD and stream order five (zone DC). Hemiptera (Non-Corixidae) had their highest ratio of significance at location 13a (fifth-order).

Dominant taxa (5% and more) common to all six stream orders were Baetidae, Simuliidae and Hydrobaeninae. Calopsectrini were dominant in all, except the sixth-order stream. Dominant taxa of stream orders one, two and three, were the Dryopidae and Annelida. Stream orders one and three shared the dominant taxa Ephemerellidae, Hydraenidae and Plecoptera; Hydraenidae being dominant in stream order four also. Stream order one shared the dominant taxon Leptophlebiidae with stream order five. Stream order two shared the dominant taxon Cheumatopsyche afra with stream order four. Hydracarina was a dominant taxon of stream order two only. Stream orders three and five shared the Pelopiinae as dominant, while Hydroptila sp. was dominant in stream order three only. The dominant taxon Tricorythidae was shared by stream orders four, five and six, while stream orders four and five shared Cheumatopsyche thomasseti. The Philopotamidae and Coelenterata were dominant in stream order four, while the Caenidae were dominant in stream order six.

Density of the taxa varied (Table 4). The lowest mean density of the Ephemeroptera was recorded from stream order two, and the highest from stream order five. The highest numbers usually coincided with the D and EW seasons, except in stream order five, where the highest numbers occurred during W.

The highest mean numbers of the trichopterans were recorded from stream order five. High numbers were mostly recorded from the dry season, with the highest percentage composition of the total fauna, during ED and D.

The highest mean density of Coleoptera was recorded from stream order one, while low seasonal numbers were associated with the ED season.

Diptera had their highest mean densities in stream orders one and two, while their seasonal densities were highest during EW, except in stream order one, where it was recorded during D.

All other aquatic taxa combined reached their highest numbers in stream order one, with high seasonal numbers being recorded during EW and D.

Where stream orders were comparable with the zonations used by Harrison and Elsworth (1958) and Harrison (1958), dominant taxa were comparable i.e. upper river taxa were limited to upper regions and lower river taxa were limited to lower regions, while some taxa were found throughout the system. Comparison between the number of individuals per unit area in this study and those of other published results of South African river studies (vide Harrison and Elsworth, 1958; Oliff, 1960; Allanson, 1961; Chutter, 1963, 1970) is difficult as different sampling methods were used (e.g. different mesh nets) and results were presented differently. The number of individuals per unit area was probably less in the Olifants River system.

Biological Water Quality

General: The method of Chutter (1972) was applied to the macro-invertebrate results recorded at each sampling location, to determine the biotic index value (BIV) of the water. These BIVs are shown in Table 5, for both the Olifants and Doring Rivers.

The BIV differentiate between four broad categories. Streams with a BIV of 0 - 2 are classified as clean unpolluted waters, 2 - 4 as slightly enriched waters, 4 - 7 as enriched waters and 7 - 10 as polluted waters. To arrive at the BIV, values are assigned to specific taxa. The assigned value is multiplied by the number of individuals of that taxon, totalled, and divided by the total individuals present in the sample.

The Olifants River. Mean BIVs recorded during the wet period at second-order stream locations were low on the scale of "unpolluted waters". Only at location 2a an appreciable difference between mean wet and dry period BIVs was observed. This difference was caused by BIVs measured during December and

January when normal stream flow virtually ceased. This causing drastic changes in the physical aquatic environment, e.g. a restriction in area of the stones-in-current biotope, due to human activity in redirecting what stream flow there was. The higher BIVs recorded at location 4a during September and October could also be related to human activity. This location was situated in a proclaimed wildernis area, frequented by the public during holidays. No correlation could, however, be found between BIV changes and the measured chemical parameters at second-order stream locations.

At third-order stream locations the same BIV trends were observed, as described above. High BIVs recorded at location 3b during January and February, the warmest months of summer, resulted in drastic changes of stream velocity (0,13 and 0,08 m s^{-1}, compared with 1,23 m s^{-1} during December) accompanied by physical changes as a result of reduced flow (i.e. restriction of the habitat, settling of suspended solids, higher temperatures of 21°C, etc.). During March stream flow increased and physical environmental conditions improved (stream flow 0,72 m s^{-1}, temp. 18°C) together with equilibrium adaptive community changes. These resulted in an improved lower BIV for March. There was no correlation between BIV changes and the measured chemical parameters.

In zone B (fourth-order stream) mean wet period, BIVs fluctuated within the category of "unpolluted waters" at different sampling locations. The higher mean BIV at locations 3 and 7, compared with locations 2 and 4 could be related to agricultural practises (Figs. 1a, 1c; Part I). Mean wet period values for combined nitrogen and orthophosphates were higher at location 3 in comparison with locations 2 and 4, while at location 7 there was a general increase in total dissolved solids (TDS) and ortho-phosphates. During the dry period, BIVs increased at locations 4 and 7 (sampling discontinued at location 3). These increases could be partly correlated with higher mean combined nitrogen and ortho-phosphate values, and a general increase in TDS at location 7.

At locations 8 and 10 (zone C, sixth-order stream) BIVs could be calculated for the wet period only. The mean BIV obtained for location 8 fell within the "unpolluted waters" category, while the BIV of location 10 classed it as an "enriched" water. Although the mean combined nitrogen, ortho-phosphates and TDS values at location 8 were higher in comparison with those of location 7, the BIV at location 8 was slightly lower. This indicates that other factors such as physical environmental conditions play an important role in aquatic community structure. For example, Chutter (1970) found that faunal distribution (which in fact determines faunal composition) was not regulated by temperature alone as suggested by studies on other rivers (vide Harrison, 1965a, 1965b), but that silty conditions and food requirements played a role.

Correlation between BIV (i.e. community composition) with combined nitrogen and ortho-phosphate quantities, was not borne out by individual monthly recordings, due to factors such as time of sampling; on spot water samples collected for chemical analysis do not reveal past occurrences, nor the delayed effect such substances might have on the biota. The influence of chemical and physical factors on macro-invertebrate "food" (i.e. phytoplankton, algae and micro-invertebrates) are discussed in various papers, e.g. McCombie (1953), Cholnoky (1960), Jenkin (1936) and Moore (1952). These may partly explain the seemingly superficial correlation referred to above.

The highest BIVs and mean values for physicochemical parameters were recorded at location 10.

The Doring River. At location 12a (first-order stream) BIVs varied widely on a monthly basis due to variations in the physical environment e.g. a restricted stones-in-current biotope which depended on the rapid changes in stream flow and its velocity. BIVs for both dry and wet periods fell within the category of "unpolluted waters". The dry period value was slightly lower, although mean values of the measured physicochemical parameters varied slightly.

Second-order location 12b had the highest mean BIVs for both wet and dry periods ("enriched" and "slightly enriched", respectively). Although the mean dry period value for combined nitrogen was higher, that of orthophosphates was lower. There was no apparent reason for these high BIVs as determined by the on spot water sample results. Other physicochemical parameters varied slightly.

BIVs for locations situated in third-order streams could be classed as "unpolluted". The wet period mean values were a little higher than those of the dry period. These tendencies were also observed in the fourth and fifth-order streams, except at location 13a, where the mean wet period BIV classed

27/....

it as a "slightly enriched" water. This BIV value was unrealistic compared with the physicochemical results (Fig. 3 Part I).

Summary

The calculated BIVs (Chutter's method) could not be unconditionally related to any specific physicochemical parameter, although seemingly superficial correlations could be made between some locations of a stream order and chemical parameters (e.g. fourth-order locations of the Olifants River: BIV and parameters combined nitrogen and ortho-phosphates). The BIV of first, second and third-order streams in both rivers seem to reflect effects of physical environmental instabilities which deviated from the hypothetical "normal" conditions, (e.g. stream velocity, which in turn affected scouring and deposition). Higher stream orders seem to reflect the indirect effect of chemical substances in solution (e.g. food organisms).

The relatively high and low BIVs measured at locations 12b and 13a in the Doring River could not be correlated, *per se*, with the physicochemical parameters.

Conclusion

The results discussed in Parts I and II of this paper show that the order-system of river zonation as proposed by Strahler (1954, 1957) can be applied to rivers in Southern Africa, with less bias than zonations based on physical features e.g. temperature, altitude, etc. (*vide* Harrison, 1965; Chutter, 1970). The physicochemical results indicate that the Olifants River system could be regarded as one of the less polluted rivers in South Africa. It is, however, affected by human involvement (impoundments, agriculture) and by natural geological formations in the areas which it drains.

The fauna is probably less abundant per unit area in comparison with published results of other South African rivers studies.

Table 5. Biotic index values at the different sampling locations along the Olifants River and the Doring River, May 1978 - March 1979.

Olifants River		M	J	J	A	S	O	N	D	J	F	M
Location	2a	-	0,23	0,12	0,34	0,05	0,03	0,16	2,45	2,48	-	-
	3a	0,31	0,35	0,08	0,18	0,16	0,17	0,13	0,83	0,14	0,14	0,29
	3c	-	-	-	0,19	0,14	0,09	0,12	0,34	0,16	0,43	0,20
	4a	0,09	0,07	0,05	0,15	1,21	1,01	0,03	0,01	0,34	0,10	0,27
	3b	0,36	0,08	0,05	0,06	0,39	0,13	0,09	0,07	3,36	4,26	1,23
	4b	0,38	0,12	0,19	0,04	-	-	-	0,02	0,35	-	-
	2	0,69	-	0,31	0,26	-	0,33	0,21	-	0,34	0,68	0,86
	3	0,89	0,54	1,95	0,49	-	-	-	-	-	-	-
	4	0,53	0,35	0,37	0,31	0,40	0,27	0,37	0,49	1,20	4,63	3,00
	7	0,67	0,28	1,13	2,10	-	2,15	1,48	0,31	2,52	2,87	2,89
	8	1,37	1,00	0,38	0,98	-	-	-	-	-	-	-
	10	6,81	6,98	-	-	4,27	-	-	-	-	-	-

Doring River		M	J	J	A	S	O	N	D	J	F	M
Location	11	0,43	0,85	0,08	1,84	4,81	2,18	0,38	1,81	0,57	0,69	0,53
	12a	0,08	0,35	1,90	3,06	1,64	-	1,76	0,37	0,22	0,94	2,60
	12b	3,26	4,90	3,03	4,62	5,68	2,26	0,27	0,86	5,15	3,30	2,79
	12	0,26	0,18	0,31	0,21	0,17	0,05	0,17	0,17	0,36	0,31	0,68
	13	-	0,28	0,49	0,40	0,27	0,26	0,15	0,83	0,53	-	-
	13a	5,42	3,24	4,64	2,13	-	-	-	-	-	-	-
	13b	0,43	1,80	2,56	-	-	-	-	-	-	-	-
	13d	0,12	-	0,74	0,64	-	0,05	-	-	-	-	-
	13c	1,26	-	2,30	0,03	-	0,55	-	-	-	-	-
	14	-	0,10	-	0,57	0,69	-	-	-	-	-	-

References

Allanson, B.R. 1961. Investigation into the ecology of polluted inland waters in the Transvaal. Part 1. The physical, chemical and biological conditions in the Jukskei-Crocodile River system. Hydrobiologia. 18(1-2): 1-76. Appendix: I-XXXII.

American Public Health Association. 1976. Standard methods for the examination of water and wastewater. 14 edition. 1975.

Anderson, V.G. 1941. The origin of the dissolved inorganic solids in natural waters with special reference to the O'Shannassy River catchment, Victoria. Royal American Chemical Institute Journal and Proceedings. 8:130-150.

Bombówna, M., Bucka, H. & Huk, W. 1978. Impoundments and their influence on the rivers studied by bioassays. Internationale Vereinigung Für Theoretische und Angewandte Limnologie. 20:1629-1633.

Cholnoky, B.J. 1960. The relationship between algae and the chemistry of natural waters. C.C.T.A/C.S.A. Publications. 64:215-225.

Chutter, F.M. 1963. Hydrobiological studies on the Vaal River in the Vereniging area. Part 1. Introduction, water chemistry and biological studies on the fauna of habitats other than muddy bottom sediments. Hydrobiologia. 21(1-2): 1-65.

Chutter, F.M. 1970. Hydrobiological studies in the catchment of Vaal Dam, South Africa. Part 1. River zonation and the benthic fauna. Internationale Revue der Gesamten Hydrobiologie. 55(3):445-494.

Chutter, F.M. 1972a. An empirical biotic index of the quality of water in South African streams and rivers. Water research. 6:19-30.

Chutter, F.M. 1972b. A reappraisel of Needham and Unsinger's data on the variability of a stream fauna when sampled with a Surber sampler. Limnology and Oceanography. 17(1):139-141.

Chutter, F.M. 1973. An ecological account of the past and future of South African rivers. News Letter. Limnological Society of South Africa. 21:22-34.

Harrison, A.D. 1965b. Geographical distribution of riverine invertebrates in Southern Africa. Archiv fuer Hydrobiologie. 61(3):387-394.

Harrison, A.D. & Elsworth, J.F. 1958. Hydrobiological studies on the Great Berg River, Western Cape Province. Part 1. General description, chemical studies and main features of the flora and fauna. Transactions of the Royal Society of South Africa. 35(3):125-226.

Hergenrader, G.L. 1980. Eutrophication of the Salt Valley reservoirs, 1968-1973. II. Changes in physical and chemical parameters of eutrophication. Hydrobiologia. 74:225-240.

Hilsenhoff, W.L. 1977. Use of arthropods to evaluate water quality of streams. Technical Bulletin No. 100. Department of Natural Resources. Madison. Wisconsin. pp. 1-15.

Horton, R.E. 1945. Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. Geological Society of America Bulletin. 56:275-370.

Illies, J. 1961. Versuch einer allgemeinen biozönotischen Gliederung der Flieszgewässer. Internationale Revue der Gesamten Hydrobiologie. 46:205-213.

Jenkin, P.M. 1936. Reports on the Percy Sladen expedition to some Rift valley lakes in Kenya in 1929. VII. Summary of the ecological results, with special reference to the alkaline lakes. Annals and Magazine of Natural History (London). 10(18):133-181.

Kuehne, R.A. 1962. A classification of streams, illustrated by fish distribution in an eastern Kentucky creek. Ecology. 43(4):608-614.

McCombie, A.M. 1953. Factors influencing the growth of phytoplankton. Journal of the Fisheries Research Board of Canada. 10(5):253-282.

Moore, J.E. 1952. The entomostraca of Southern Saskatchewan. Canadian Journal of Zoology. 30:410-450.

* Mountain, E.G. 1968. Geology of Southern Africa. Books of Africa (Pty) Ltd. Cape Town. South Africa.

Oliff, W.D. 1960. Hydrobiological studies on the Tugela River System. Part 1. The Main Tugela River. Hydrobiologia. 14(3-4):281-385.

Olive, J.H. & Dambach, C.A. 1973. Benthic macroinvertebrates as indexes of water quality in Whetstone creek, Morrow County, Ohio (Scioto river basin). The Ohio Journal of Science. 73(3):129-149.

Pratt, J.M. & Coler, R.A. 1967. A procedure for the routine biological evaluation of urban runoff in small rivers. Water Research. 10:1019-1025.

Resh, V.H. & Unzicker, J.D. 1975. Water quality monitoring and aquatic organisms: the importance of species identification. Journal Water Pollution Control Federation. 47(1):9-19.

Rigler, F.H. 1973. A dynamic view of the phosphorus cycle in lakes. In: Environmental Phosphorus Handbook. Ed. Griffith, E.J. et. al. Wiley & Son. New York.

Schmitz, W. 1970. General limnological and biological stream surveys as a simple means of detecting pollution and controlling their effects. Proceedings of 5th International Water Pollution Research Conference. Pergamon Press. 1971. 6 pp.

Skelton, P.H. 1977. South African red data book - fishes. South African National Scientific Programmes Report No. 14. C.S.I.R. (Pretoria). South Africa. pp. 1-39.

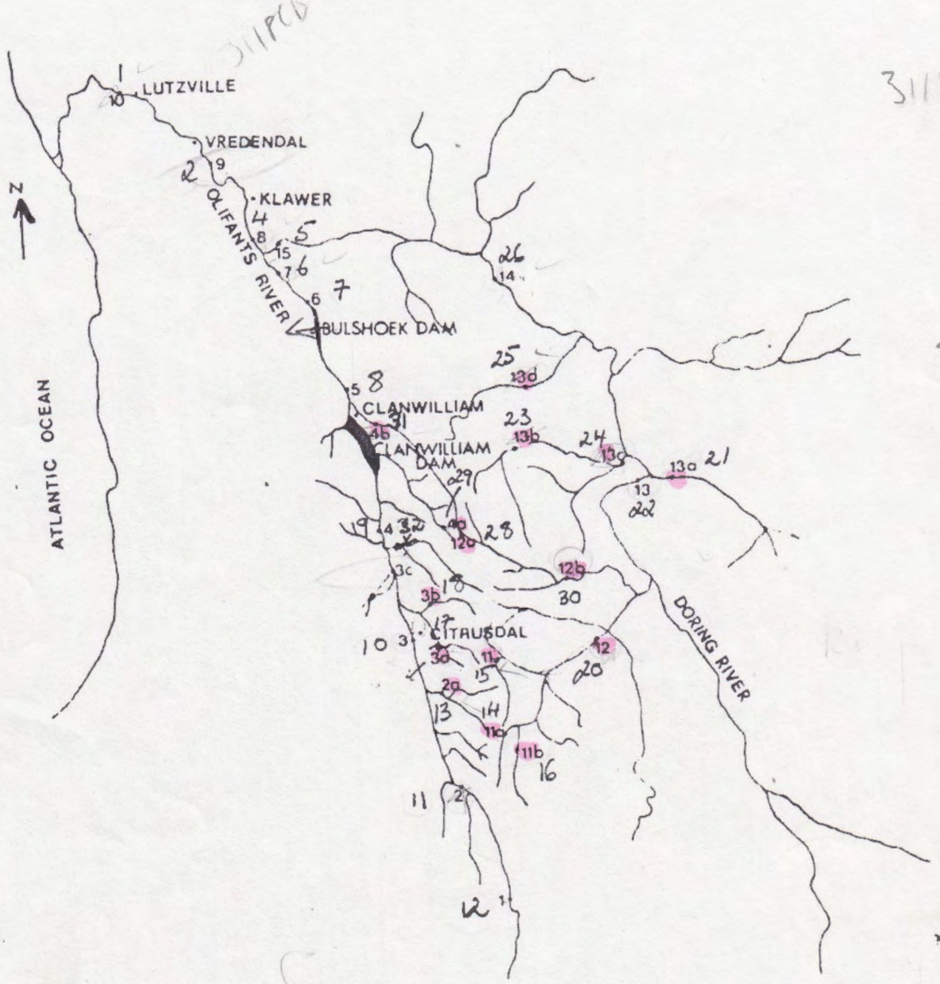
Strahler, A.N. 1954. Quantitative geomorphology of erosional landscapes. Proceedings of the 19th International Geological Congress. 13:341-354.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions American Geophysical Union. 38(6):913-920.

Toerien, D.F., Hyman, K.L. & Bruwer, M.J. 1975. A preliminary trophic status classification of some South African impoundments. Water S.A. 1(1):15-23.

Wilkinson, R.C. 1976. The indicator value of the stones-in-current faunal association in a South African river system. Paper presented: Interdisciplinary Marine and Freshwater Conference. C.S.I.R. (Pretoria). South Africa.

GROEN = OORSPRONKLIKE STASIE NOMMERS



3118 CA CB CD DA DB DC DD

3218 BA BB BC BD

Fig. 1a. Sampling locations along the Olifants River system.