HYDROBIOLOGICAL STUDIES ON THE VAAL RIVER AND SOME OF ITS TRIBUTARIES, INCLUDING AN INTRODUCTION TO THE ECOLOGY OF SIMULIUM IN ITS LOWER REACHES

by

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PREFACE

This dissertation has been bound in two parts to facilitate reference to the Plates and Tables while the text is being read. The Figures have been bound in with the text as near as possible to the pages on which reference is first made to them.

As readers of this dissertation may not be familiar with the South African aquatic invertebrate fauna a systematic list of the animals mentioned has been prepared to supplement the list given by Chutter (1963). The supplement is given in an Appendix on taxonomy at the end of the text.

In terms of the University regulations collateral evidence has been handed in with this dissertation for the examiners' consideration. It is in the form of the following published papers:-

Chutter, F.M. (1961) Certain aspects of the morphology and ecology of the nymphs of several species of *Pseudagrion* Selys (Odonata). Arch. Hydrobiol. 57 (4) : 430 - 463

Chutter, F.M. (1963) Hydrobiological studies on the Vaal River in the Vereeniging area. Part 1. Hydrobiologia 21 (1-2):1-65 (Note. Part 2 of this paper has also been handed in, though it is not the candidate's work, because the publisher printed two of the tables belonging to Part 1 with Part 2).

Chutter, F.M. & Noble, R.G. (1966) The reliability of a method of sampling stream invertebrates. Arch. Hydrobiol. 62 (1) : 95 - 103

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All the work included in this dissertation was undertaken for the National Institute for Water Research of the South African Council for Scientific and Industrial Research. The author thanks the Director of that Institute, Dr. G.J. Stander, for his kind permission to use it for thesis purposes.

The early stages of the planning of the work in the Vaal Dam Catchment were carried out under the direction of Professor A.D. Harrison (then of the National Institute for Water Research; now at the University of Natal). The late Professor S.E. Cruise of Rhodes University gave freely of his time in advising the author on the statistical analysis of data from Warrenton, while many fruitful discussions were held with Dr. K.M.F. Scott of the National Institute for Water Research. The author gratefully acknowledges the assistance and encouragement of these people.

Mr. A. Lagendijk and Mr. L.P. Prinsloo of the National Institute for Water Research made the water and sediment analyses for the Vaal Dam Catchment study, while Mr. E. Braune of the same institute carried out the water analyses at Warrenton. Mr. Braune also rendered considerable assistance in the collection of faunal samples in the field. To these three people the author expresses his thanks.

Mrs. M.V. Eksteen, Miss J. Grant-MacKenzie, Mr. J.D. Agnew, Mr. P.B. Botha and Mr. M.H. Mason gave the author much assistance in sorting the biological samples from the Vaal Dam Catchment and the author is greatly indebted to them for the cheerful and uncomplaining way in which this monotonous task was carried out.

Grateful thanks are due to the following specialists for their aid in the identification of specimens:-

Dr. R.O. Brinkhurst, Toronto	- Oligochaeta
Mr. R.S. Crass, Pietermaritzburg	- Pisces
Dr. R.W. Crosskey, London	- Simuliidae
Dr. J. Delève, Brussels	- Elmidae
Professor J.A. van Eeden, Potchefstroom	- Mollusca
Dr. D.J. Lewis, London	- Simuliidae
Dr. (Mrs.) J. Omer-Cooper, Grahamstown	- Dytiscidae
Professor R. Poisson, Paris	- Hemiptera
Professor I. Sciacchitano, Firenze	- Hirudinea
Dr. K.M.F. Scott, Grahamstown	- Trichoptera
Dr. K.O. Viets, Wilhelmshaven	- Hydrachnellae
Dr. B.J. Cholnoky, Pretoria	- Algae and diatoms

The author wishes to thank Mrs. P.M. Eva who typed the manuscript and also his wife for her assistance in the preparation of the figures.

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INTRODUCTION

The fauna of South African rivers has been intensively studied in the recent past. Harrison and Elsworth (1958) worked on the Great Berg River in the Western Cape Province. They showed that this river could be divided into a number of physical zones from its source down to its estuary and that the fauna changed with these zones. They suggested (p. 220) that temperature and silt were important factors restricting the upper river communities to the upper river and that certain lower river species were limited to the lower river by their food requirements. Seasonal changes in the fauna were ascribed mainly to differences in flow characteristics, turbidity, silt load and temperature. However, the Western Cape Province is a winter rainfall area and in this important respect it differs from the rest of Southern Africa, where the summer is the rainy season. Oliff (1960a) also found a succession of communities down the course of the Tugela River, which lies in the summer-rainfall area. He suggested that this succession depends mainly upon physical features, such as temperature, rate of flow of water, gradients and altitude. The greatest differences in conditions between zones were those of temperature. The Tugela River has a profile very different from the Great Berg River, the most striking differences being that the Tugela falls steeply all the way to its mouth and in addition has what Oliff termed a Rejuvenated Zone. This zone occurred in the middle reaches of the river and had a very much steeper gradient than the zones above and below it.

The Tugela and Great Berg River studies were essentially pioneering, aimed mainly at establishing the natural fauna of rivers and the factors governing its distribution in widely separated parts of South Africa. The reasons why these extensive studies were necessary have been described by Harrison (1961), who in addition reviewed what had at that time been found about the effects of various types of pollution on river faunas under South African conditions.

Since the time when Harrison wrote his 1961 paper, the effect of pollution on South African rivers has been further studied (Allanson 1961, Oliff 1963) and knowledge of the zoogeography of the aquatic fauna of Southern Africa has been considerably extended (Harrison and Agnew 1962, Harrison 1965b). Harrison (1965a) suggested that South African rivers fit into the system for the universal zonation of rivers, suggested by Illies (1961).

It is now generally agreed by workers on river faunas that severe organic pollution is easily detected by changes in the biota (Hynes 1960, Allanson 1961) and that such changes are broadly speaking similar all over the world. Such pollution is often also readily detected by chemical means. However the biological effects of the addition of small amounts of organic matter to lentic waters are much more variable, and may only be understood from a thorough knowledge of the normal variation of the biota. Hynes (1960, Chapter 13) argued strongly against the development of formal methods and systems, such as the Kolkwitz and Marsson 'Saprobiensystem', for the interpretation of the effect of pollution on stream biotas. Hynes himself says "In nature little is simple and straightforward, and a rigid system can lead only to rigidity of thought and approach. Each river or stream and each effluent is different, so the pattern of pollution varies from place".

The studies on the Vaal River and its tributaries presented here, were carried out for a variety of reasons. Prominent among them were several of immediate practical importance, such as the need to know the pollution status of waters which ultimately form the major supply for the Witwatersrand urban and industrial complex, and the need for background data on a stretch of the river which was to be

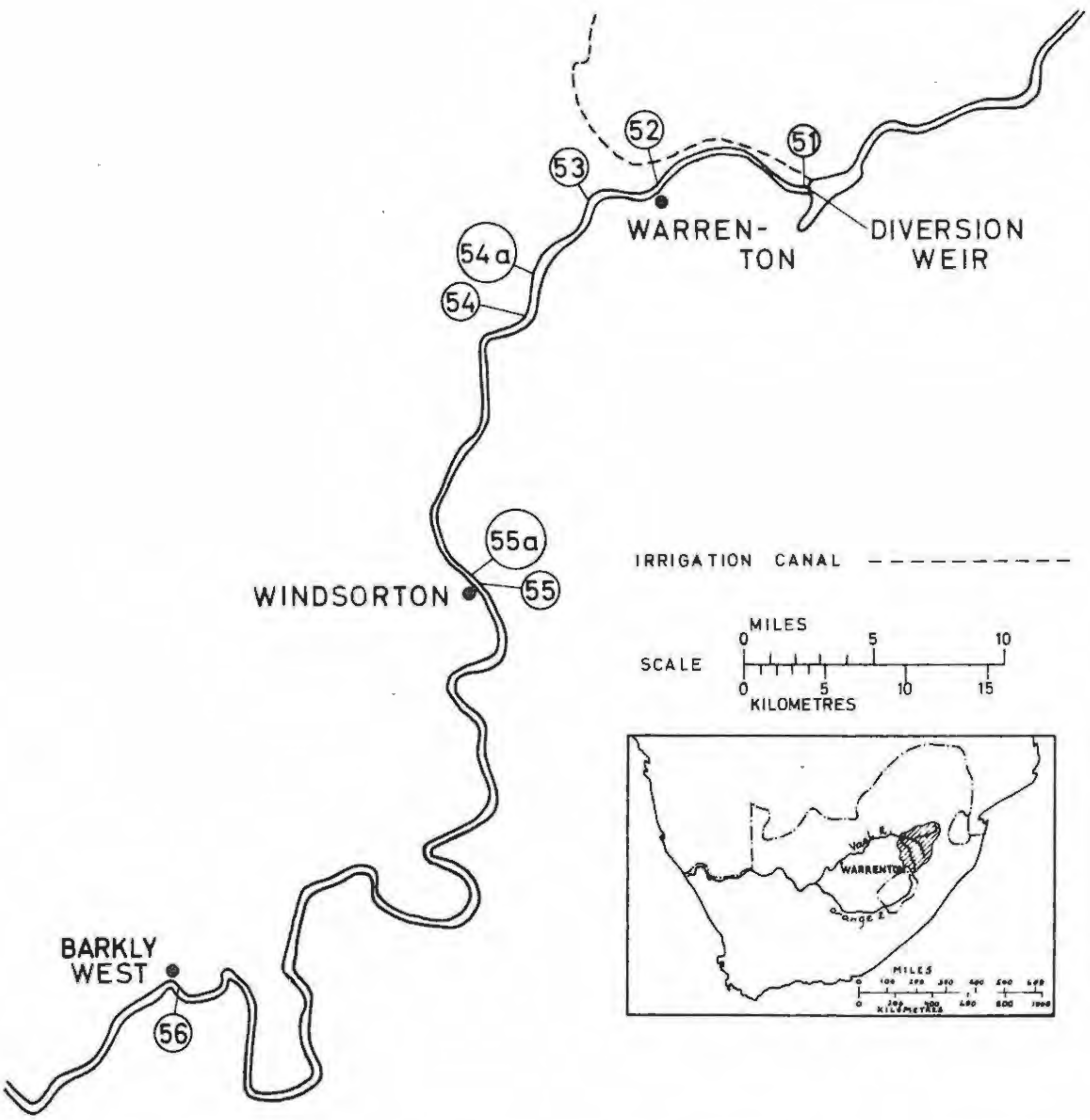


Figure 1 The Vaal River, showing sampling points in the Warrenton area. Inset showing this area and the Vaal Dam catchment.

insecticided to control a Simulium pest. However the results of such work can often be used for wider purposes. In this thesis they are used to examine the major factors thought to govern the distribution and abundance of the invertebrate Metazoa in the river. In some ways this would seem to be a repetition of the type of work carried out by Harrison and Elsworth and Oliff. The work is, however, justified by the fact that the Vaal differs in some important ways from both the Great Berg and the Tugela Rivers, and so further advances our understanding of the relationship between aquatic fauna and environment.

This work on the Vaal River is presented in two contrasting parts. The first is a detailed study, mainly of the stones in current fauna, of a comparatively short stretch of the lower Vaal River. The second is a study of the streams and rivers of the catchment of Vaal Dam. As will be seen the methods with which these two studies were carried out differed greatly and so did the type of result they yielded. However the results do complement one another and together make for a greater understanding of river ecology than either would alone.

PART 1

STUDIES ON THE VAAL RIVER FROM WARRENTON TO BARKLY WEST

The background to the studies

There is a very large population of Simulium chutteri in the Vaal River at and below Warrenton. The female of this species attacks man, cattle and horses and had become a pest when the studies described here were made. The first aim of the studies was to record the density of the larvae and also of the other invertebrate animals in the river at different times of the year from Warrenton down to Barkly West (Fig. 1). This was done so that when measures are taken to control the fly by insecticiding the larval stages, there will be a background of fact about the river fauna against which the effect of the insecticide on the Simulium larvae and also on the other invertebrates may be assessed. The planning of the work was very much influenced by this first aim, as will be described later. However faunal changes may be ascribed to insecticides more reliably if the major factors which influence the composition and density of the fauna under natural conditions are known. The studies in the Warrenton area were therefore expanded by the measurement of important environmental variables and the relationship between the animals collected and these has been investigated. Naturally one of the most important considerations was whether there was any factor with which the occurrence of such unusually large numbers of Simulium larvae could be associated.

Methods and apparatus

Planning the study

A preliminary survey of the area showed that the main sites of larval attachment of S. chutteri were in the stones in the current. There was seldom vegetation trailing in the current, which in other Simuliidae is often the main larval habitat. The stones in current fauna was studied at several sampling points spaced out between Warrenton and Barkly West, so that when insecticides are applied to the river it might be possible to establish how far downstream the fauna is affected. A marginal vegetation community was studied in the river near Warrenton, and it is hoped that these data will be useful when the insecticide programme is in full operation.

As the first aim of the study was to obtain quantitative data on the fauna, several small samples from each selected sampling point were taken. The fauna collected in each sample was compared and an estimate of the faunal density arrived at. The alternative would have been to take fewer large samples which singly would yield an estimate of the faunal density more reliable than single small samples, but which at the same time would not reveal anything about the variability of the faunal density at single sampling points. The advantage of having many analyses of the fauna density at a sampling point,is that statistical techniques may be used to confirm whether differences in sample mean densities of animals at different places or times are likely to represent population density differences,or are the spurious outcome of the variability of the density of the animals in the biotopes. In the event it turned out that the numbers of animals collected in individual samples varied so irregularly that it was necessary to use non-parametric statistics in order to compare mean densities of animals, or to investigate the correlation between the occurrence of various pairs of species. Because numerous small samples were to be analysed the frequency of field trips had to be curtailed. The river was visited four times in a year at quarterly intervals corresponding more or less with the four seasons.

The investigation of water chemistry was planned so that the results were not based on single snap samples, as snap samples can be misleading, particularly when there were to be only four sampling occasions during the course of a year. However transport capacity placed a severe limit on the number of water samples which could be collected.

Field methods and apparatus

The stones in the Vaal River in the Warrenton area are generally speaking large, making it virtually impossible to use several of the more usual quantitative sampling methods for stony biotopes in the current. The stones were too large for the Surber square foot sampler (Surber, 1936) and for samples based on the shovel principle (Macan, 1958). "Kicking" methods of sampling (Hynes, 1961) and sampling for a standard period were not acceptable because many of the animals adhere closely to the stones. The *Simulium* pupae would not be collected by kicking and they would disrupt the comparison of data collected in standard times because a much smaller area would be sampled when animals which have to be picked off stones, rather than rubbed off, were abundant. Sampling methods such as the cone (Wolfe & Peterson 1958) and polythene strip "traps" (Williams & Obeng 1962) were not suitable as they reveal only the *Simulium* populations. Moreover the sampling area was some 800 km from the laboratory and was to be visited only four times, the visits each being of only four days duration.

In view of these shortcomings of the more usual sampling methods it was decided to collect the fauna of single stones and to treat the animals collected from each stone as a separate sample. Initially the fauna of 20 stones was collected at each sampling point, though in one instance there were so many Simuliidae on the stones that there was time to sample 16 stones only. Later the number of stones sampled at each station was reduced to 10. The selection of the stones was important and, on account of the turbidity of the water, it had to be carried out largely by touch. The procedure followed was to feel about among the stones until one reckoned to be small enough to be lifted with one hand was found. Really small stones, which were easily encompassed by the fingers were rejected, but all others that could be lifted were taken. Stones were never taken from parts of the sampling area disturbed by previous sampling on the same day and in this way samples were taken from a large area. Each stone was lifted from the water with the hand net held close behind it and then carried to the bank with the net held below. There it was placed in a bucket of water and the fauna washed and picked off into the bucket until a three minute inspection revealed no further animals. The contents of the bucket were then poured through the hand net and the collection of animals transferred to a preserving jar and pickled in formalin. Finally, rough measures of the surface area and volume of each stone were made. For surface area measurements, each stone was placed on the ground with its greatest flat surface downwards, and the length and breadth of the rectangle which most nearly fitted its size, measured. It was then turned on its side and the height measured. The measurements were made with a centimetre cloth tape. The volume of the stone was estimated to the nearest 100 cc by displacement of water in a bucket graduated in half-litres. It will be appreciated that neither the surface area nor the volume measurements are very accurate. However, surface area or volume of the stone sampled are only two of the numerous factors likely to influence the number of individuals collected on the stone, and it was felt that the time used in making accurate measurements, particularly of surface area, would be largely wasted.

Replicate samples were also drawn from the marginal vegetation biotope. In order to make sure that the samples were taken without reference to small changes in the fringe of vegetation the first step was to place the sample jars in a line along the bank of the river, each being a little over a metre from its neighbours. The biological samples were then collected by sweeping the hand net from the outer fringe of the vegetation in to the bank exactly opposite each sample jar.

The hand net used in sampling both the stony run and marginal vegetation consisted of a net 35 cms deep on a strip brass ring 3 cm deep of 25.4 cm (10") diameter mounted on a handle about 2 metres long. The net was bolting silk with 23 meshes/cm (58 meshes/inch) and an average distance between the meshes of 0.29 mm.

There were several important factors which guided the decision on how the current speeds were to be measured. First of all it was obvious, on account of the turbidity of the water, that it would not be possible to measure the current speed in the vicinity of a particular stone with any accuracy. Secondly it is extremely doubtful whether such measurements would be at all meaningful because of the great variation in current speed around a stone in a rapid. It was therefore decided that the current should be measured in a large number of places in the rapid to give some idea of the average speed of the water. Differences in the speed from sampling point to sampling point might account for some of the differences in the fauna, but differences in current speed could not be used to account for the differences between the fauna of individual stones at single sampling points. The next consideration was whether to measure the current before or after taking the biological samples. Ideally it should be measured before the run is disturbed by taking stones from it, but the walking through the run involved in measuring the current speed would disturb the fauna. The current speed was therefore measured after the biological sampling had been completed. Current speeds were measured with an Ott Laboratory Minor propellor driven current meter.

Water samples for mineral analysis were collected separately from those for analysis of combined nitrogen. The latter were preserved with mercuric chloride according to the method of Hellwig (1964). The water sample for mineral analysis was collected in a 4.5 litre plastic container. This was filled by a quarter at roughly equal intervals which were estimated to cover the whole time that it took to collect the biological samples. Each time water was added to this large plastic bottle a $\frac{1}{2}$ litre bottle with mercuric chloride was filled and the pH and temperature of the water were measured. At Station 51 (see below), where only water samples were collected, the interval between sampling was 10 minutes. At the other stations the interval between collecting samples was always greater than this and often up to 45 minutes. Chemical samples were collected in this way in order to reduce the possibility of a small batch of unusual water producing a misleading analysis result. pH was measured with a Lovibond Comparator. Phenol red, thymol blue and diphenol purple, which together cover a pH range of 6.8 to 9.6,were the indicators used. Temperature was measured with a mercury thermometer.

Laboratory methods

Initially 10, but later 5, biological samples were drawn at random from the samples collected at each sampling point, and the animals in these samples were identified as far as possible and counted, using a binocular dissecting microscope. Contrary to the sample counting procedure adopted in the recent past in South African river surveys (Allanson 1961, Chutter 1963, and the studies on the Vaal Dam Catchment later in this thesis) all the animals were counted in every sample.

The surface area of each stone was then calculated from the dimensions measured in the field and the numbers of animals collected from the stone were converted by direct proportion to the numbers which would have been collected had the stone had a surface area of 1000 sq cms. On one occasion (Station 54, January 1964) the measuring tape was mislaid and only the volumes of the stones were known. For this series of samples the surface area was estimated from a curve fitted by eye to a graphical plot of all the known surface area/volume relationships for stones collected from the same sampling point.

Water samples were analysed within two weeks of being brought back to the laboratory. Analysis methods were those adopted by the

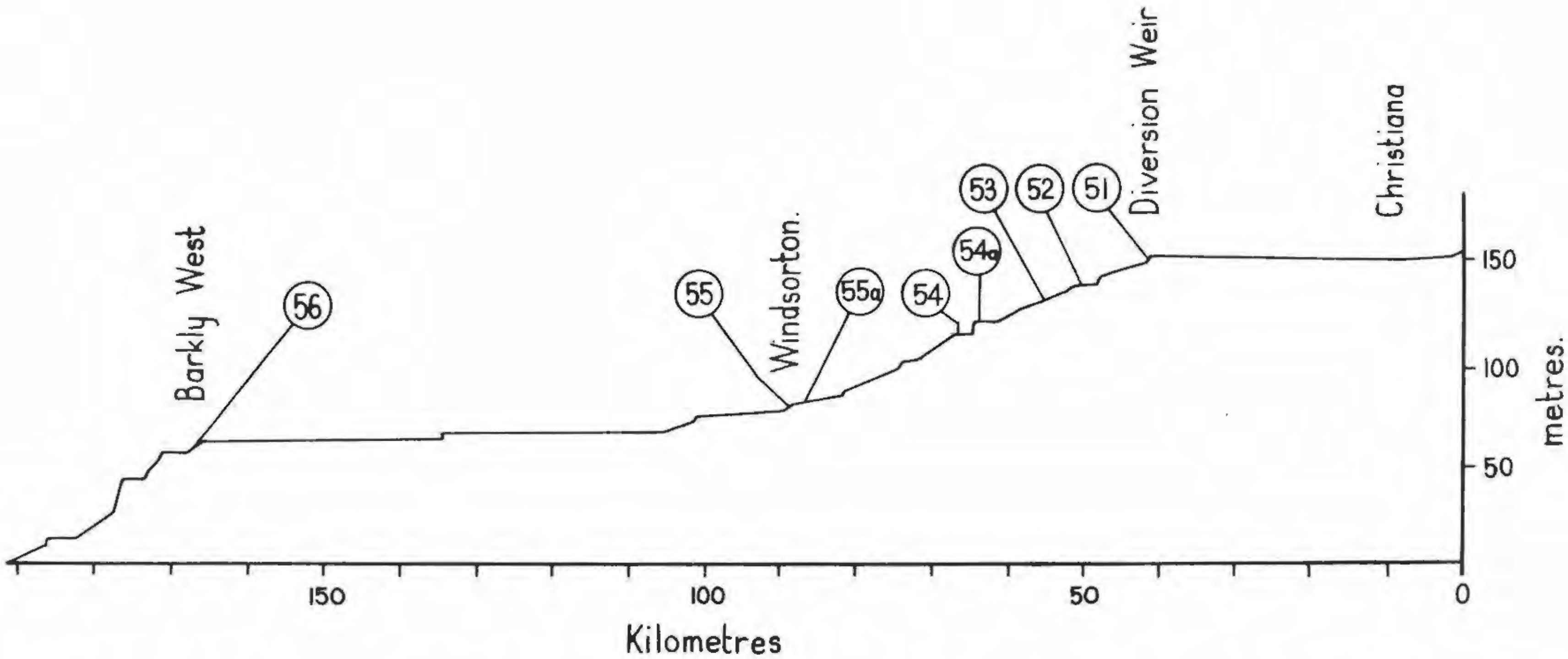


Figure 2. Profile of the Vaal River in the Warrenton area, showing sampling points. The base line is 1036 m. above sea level.

National Institute for Water Research, a recent description of which is given by Hellwig and Noble (1965).

A general description of the Vaal River in the Warrenton area

A few miles above the village of Warrenton a major part of the flow of the Vaal River is diverted, by means of a weir and a canal system, into a large irrigation scheme in the valley of the adjacent Hartz River (Fig. 1). Above the Vaal Hartz Diversion Weir the countryside and rate of fall of the river are extremely flat with the result that the relatively low wall of the weir holds the water of the Vaal River back some 35 km (Fig. 2). From the Weir to Windsorton the river bed is mainly stony and the river falls rapidly, cutting through an escarpment. From Windsorton to Barkly West the countryside is again flat and the bed of the river is mainly sandy. At Barkly West its rate of fall again increases as the river cuts through another escarpment. The steeper falls below the Weir and below Barkly West are analogous to the Rejuvenation Zone in the Tugela River (Oliff, 1960a).

Alluvial diamonds are found in this part of the Vaal River, with the result that the river bed has in the past been considerably disturbed by diamond digging. Rocks and boulders have been lifted from holes in the river and left in huge heaps wherever convenient, that is most often in the bed of the river where they form artificial islands. During the period of study disturbance of the river bed on a large scale took place only at Windsorton, where a coffer dam was built through a stony run which had been a sampling point.

The sampling programme and sampling points

An exploratory visit to the area was carried out in May, 1963. On the basis of results obtained during this visit and of the objectives of this study the following sampling points where chosen and visited in October, 1964, and January, April and August, 1965:-

Station 51. Immediately below the Vaal Hartz Diversion Weir. The bed of the river was composed of very large boulders here, and there was no stony run from which faunal samples might be drawn. Only water samples for chemical analysis were therefore collected at this point.

Station 52. (Plate I). At the Maria Prinsloo Bridge into Warrenton. The bed of the river was stony at this point and the river was divided by a number of small stony islands. The river is of the order of 300 m wide, the bridge (Plate I) about 400 m long. Water samples and the stony run fauna were collected at this point.

Station 53. (Plate II). On a farm about 5 km below Warrenton where there was a bone-meal factory about 400 m from the river. At this station the river was wide and slow-flowing but still mainly with a stony bottom. When the sampling point was visited the effluent from the bone-meal factory did not reach the river, though it was clear that the effluent does very occasionally do so. The biotope formed by a fringing growth of vegetation dominated by _Cyperus_ sp. and including some _Scirpus_ sp. was sampled for animals, and water samples for chemical analysis were collected here.

Station 54. On the farm Stonehill about 15 km below Warrenton. At this sampling point the river was divided by a large stony island. The biotope sampled was a stony run and water samples for chemical analysis were collected here. The channel containing the stony run from which the fauna was collected was dry on the third and fourth sampling visits and this point was abandoned in favour of Station 54a.

Station 54a (Plate III). On the farm Witrand about 13 km below Warrenton. Here the main body of water (to the right of Plate III) was flowing very fast and cascading in places, and the river was about 40 m wide across the rapids. Sampling of the fauna was undertaken in the stony run in the centre of the plate, where the water was flowing fast but not cascading. In addition to faunal samples from the stony run biotope, water samples for chemical analysis were collected. This sampling point was visited in April and August, 1964, when Station 54 was dry.

Station 55 (Plate IV). At Windsorton. Here pools in the river were long and the river was about 80 m wide. Faunal samples from a stony run and water samples for chemical analysis were collected. When the final field trip was undertaken a coffer dam had been built across the biotope previously sampled. The August, 1964, samples were therefore collected at the next stony run upstream. This was about 2.5 km above Station 55 and was called Station 55a.

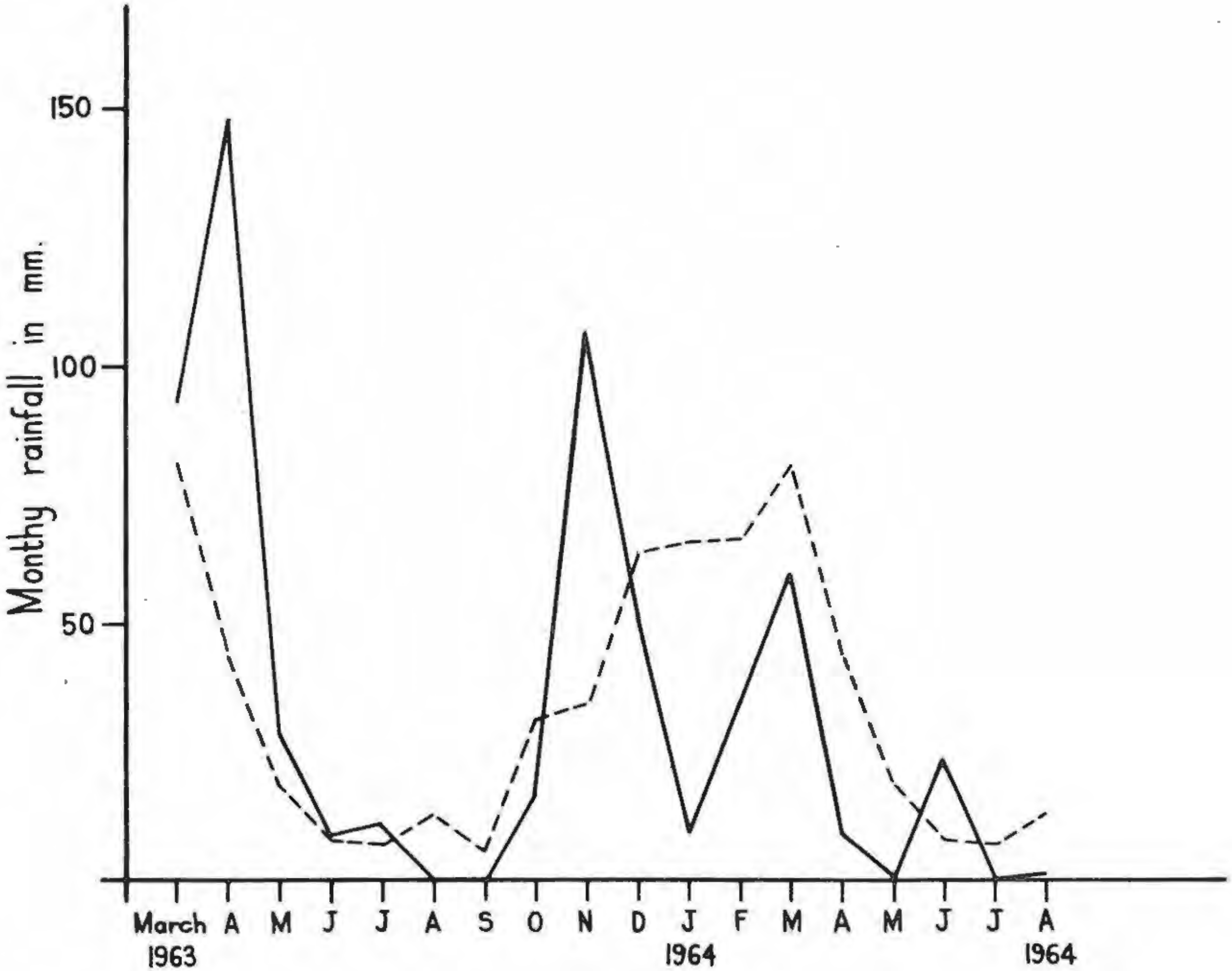


Figure 3. The rainfall in the Vaal Hartz Irrigation Scheme, May 1963 to August 1964. Actual rainfall ——; normal rainfall - - - -.

Station 56. (Plate V). At Barkly West. The bed of the river was stony here and where sampled it was about 100 m wide. Water samples and faunal samples from the stony run biotope were collected.

Environmental measurements, May 1963 to August 1964

Air and water temperatures

All readings of water temperature were made in obviously moving water above stony runs, except at Station 53 where readings were made about a yard from the bank of a large pool. The water temperatures are summarised in Table 1. The maximum recorded temperatures are probably closer to the actual maxima than are the minima, as many records were made in the afternoon, the period when temperatures would be at their highest, but none were made in the very early morning. The comparable results show that in October and January there may have been little difference in temperatures along this stretch of the river. In April there was a greater difference between the temperatures at the Vaal Hartz Diversion Weir (Station 51) and at Barkly West (Station 56). However comparable records are so few that they do not justify the drawing of conclusions about temperature changes along this stretch of the river.

The South African Weather Bureau maintains weather stations at Kimberley and in the Vaal Hartz irrigation area. Station 56 (Barkly West) is about 30 km west of Kimberley, and the Vaal Hartz weather station is about 20 km north of Warrenton. Comparison of air temperature data from these two weather stations showed that:-

a) the mean normal monthly temperature was about 0.5°C higher at Kimberley than at Vaal Hartz,

b) the minimum average daily temperature per month and the lowest temperatures recorded each month were about 2°C lower at Vaal Hartz than at Kimberley, and,

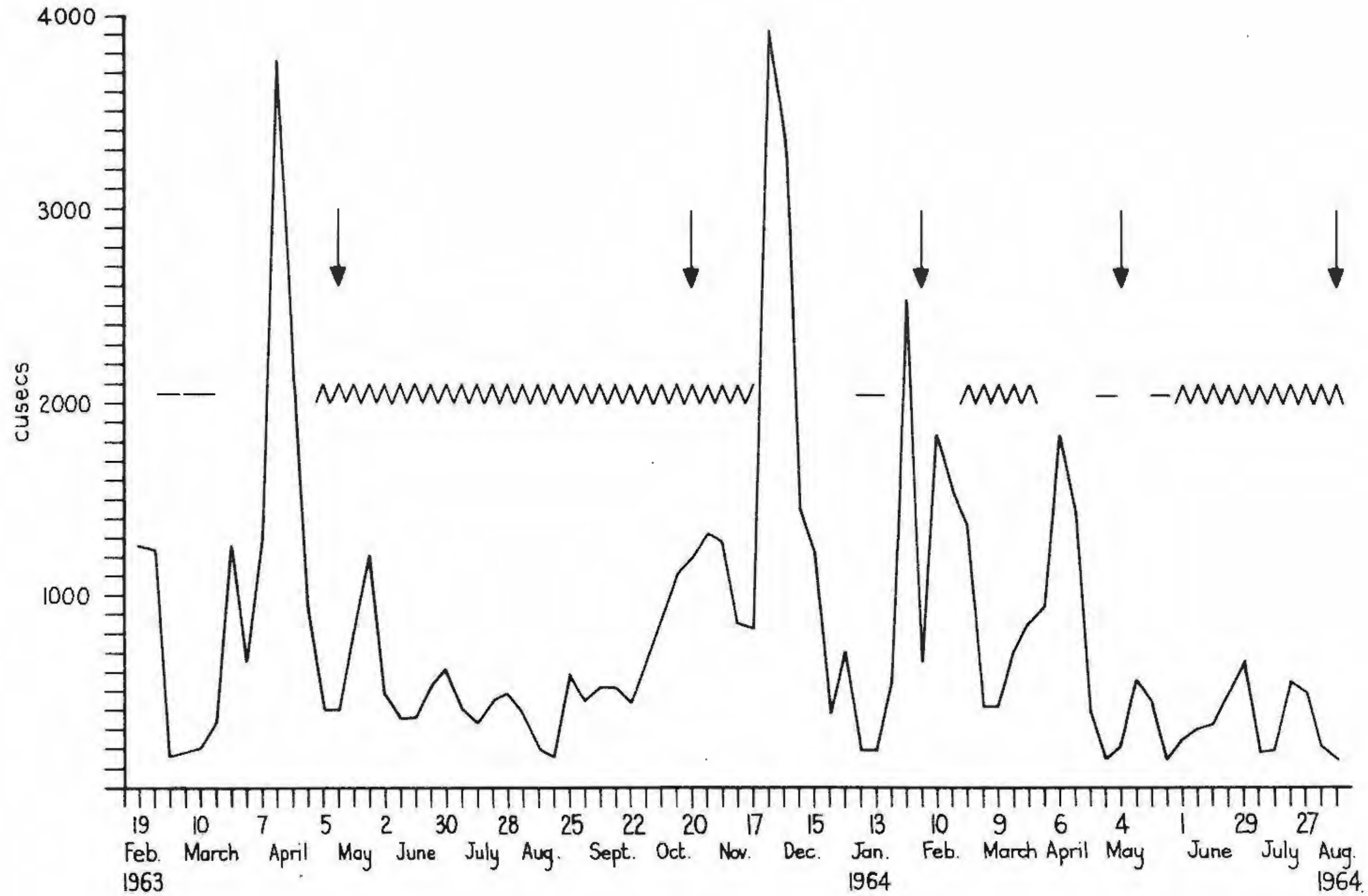


Figure 4. The average daily rate of flow, week by week, of the Vaal River at the Vaal Hartz Diversion Weir, based on daily readings at 8 am. Periods with a peak week-end flow ʌʌʌʌ, periods of steady flow ——.

↓ Field trips

c) there was little difference in the maximum average daily temperatures per month or the highest temperatures recorded each month.

This means that air temperatures probably did not fall quite as low at Station 56 as they did at Station 51 and the other stations close to Warrenton. However maximum air temperatures were probably about the same along the whole of this stretch of the river. This small difference in air temperatures indicates that water temperature differences, if they are present, are unlikely to be large.

Rainfall

The seasonal distribution of the rainfall at the Kimberley and Vaal Hartz weather stations is the same, though the Kimberley normal annual rainfall is about 20 mm less than the Vaal Hartz. The area is one of summer rainfall (Fig. 3) and during the study period there were heavy rains in April and November 1963 and in March 1964.

The rainfall data and also the air temperature data which have been presented here were obtained from the 'Monthly Weather Reports' issued by the South African Department of Transport.

Flow

The flow of the river (Fig. 4) followed the rainfall cycle, the greatest flows being recorded in the summer. However local rainfall is not responsible for the major flow fluctuations in this part of the river. They are largely governed by the rate at which water is released from Vaal Dam, about 580 kilometres upstream. There is however an important local influence on the rate of flow of the river. The Vaal Hartz irrigation farmers do not use water on Sundays, and the unwanted water is allowed to flow down the Vaal instead of being diverted to the irrigation scheme. The water takes about a day to

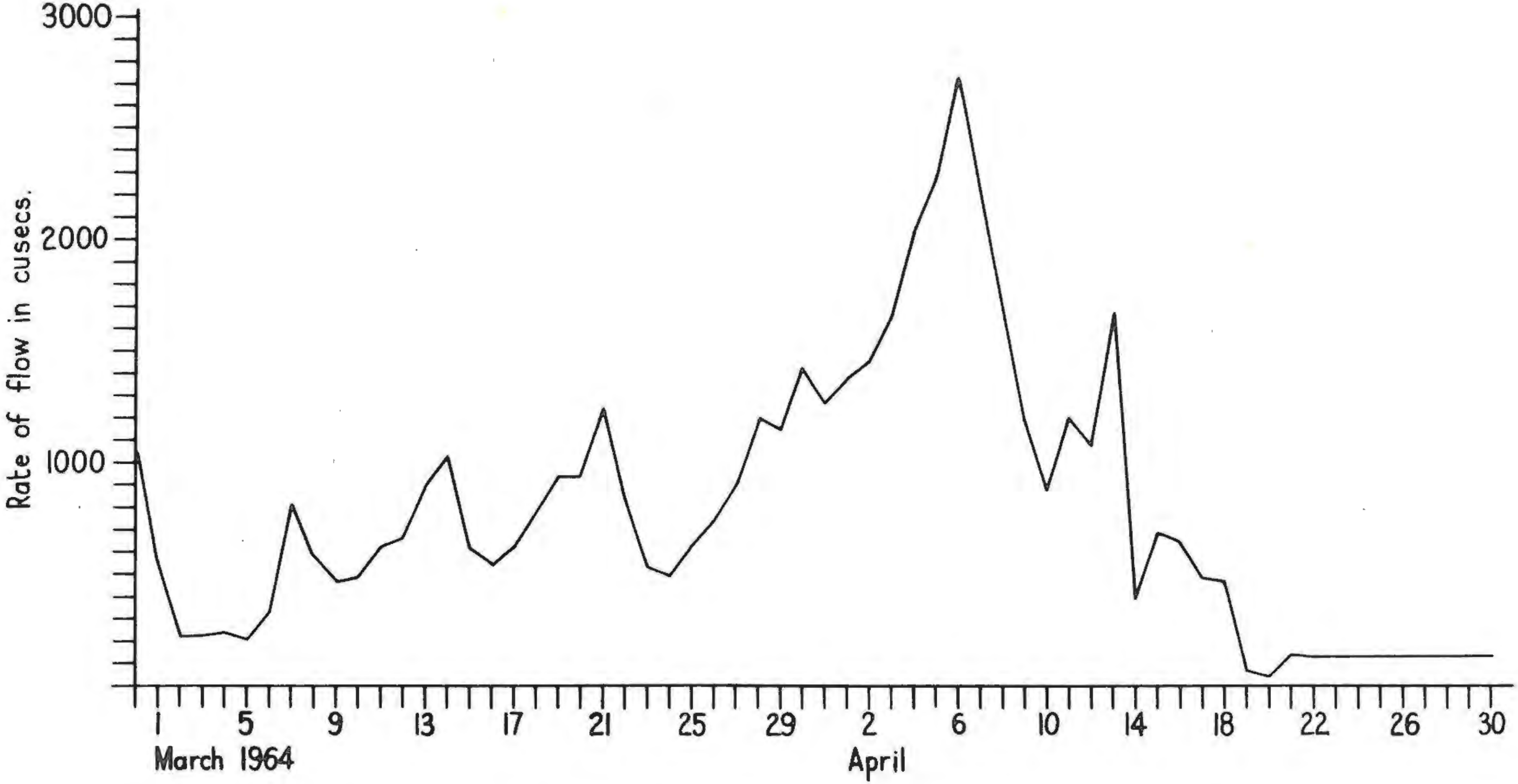


Figure 5. The flow of the Vaal River at the Vaal Hartz Diversion Weir at 8 a.m. in March and April 1964.

reach the irrigation farmers so that there are peak flows in the Vaal on Saturdays (Fig. 5) followed by a sudden drop in the flow on Sundays as water is diverted to meet the Monday irrigation demand. This weekly pattern of daily flow was masked by high flows and it was not apparent when irrigation water was not being used at all (Fig. 4). It was, however, apparent for the greater part of the time that the river was being studied. This is unusual in South African summer rainfall area rivers, as the flow of these is relatively stable in the dry season (Fig. 6).

Water chemistry

Sampling points used during the preliminary survey (May 1963) did not all coincide with those used later, and replicate water samples were not taken. However certain results are of interest and are shown in Table 2. By comparison with the Great Berg River (Harrison & Elsworth 1958) and with the Tugela (Oliff, 1960a) nitrate and Kjeldahl nitrogen figures were unnaturally high. However it is obvious from the analyses that the source of this large amount of nitrogenous compounds was above the Vaal Hartz Diversion Weir. There was no systematic tendency for total nitrogen to increase or decrease down the river in spite of there being samples above and below the village of Warrenton. Free and saline ammonia increased in concentration from Station 51 to Station 54 and organic nitrogen decreased sharply but less evenly. However these changes were not substantiated in later sample series and they were therefore probably the chance outcome of snap sampling.

The concentrations of forms of nitrogen found during the main study (Table 3) were far lower than those recorded during the preliminary survey (Table 2). Apart from one instance when the replicate nitrate analysis figures were 0.11, 0.04, 0.06 and 1.47 ppm, there was very little variation in the results obtained from the four separate water

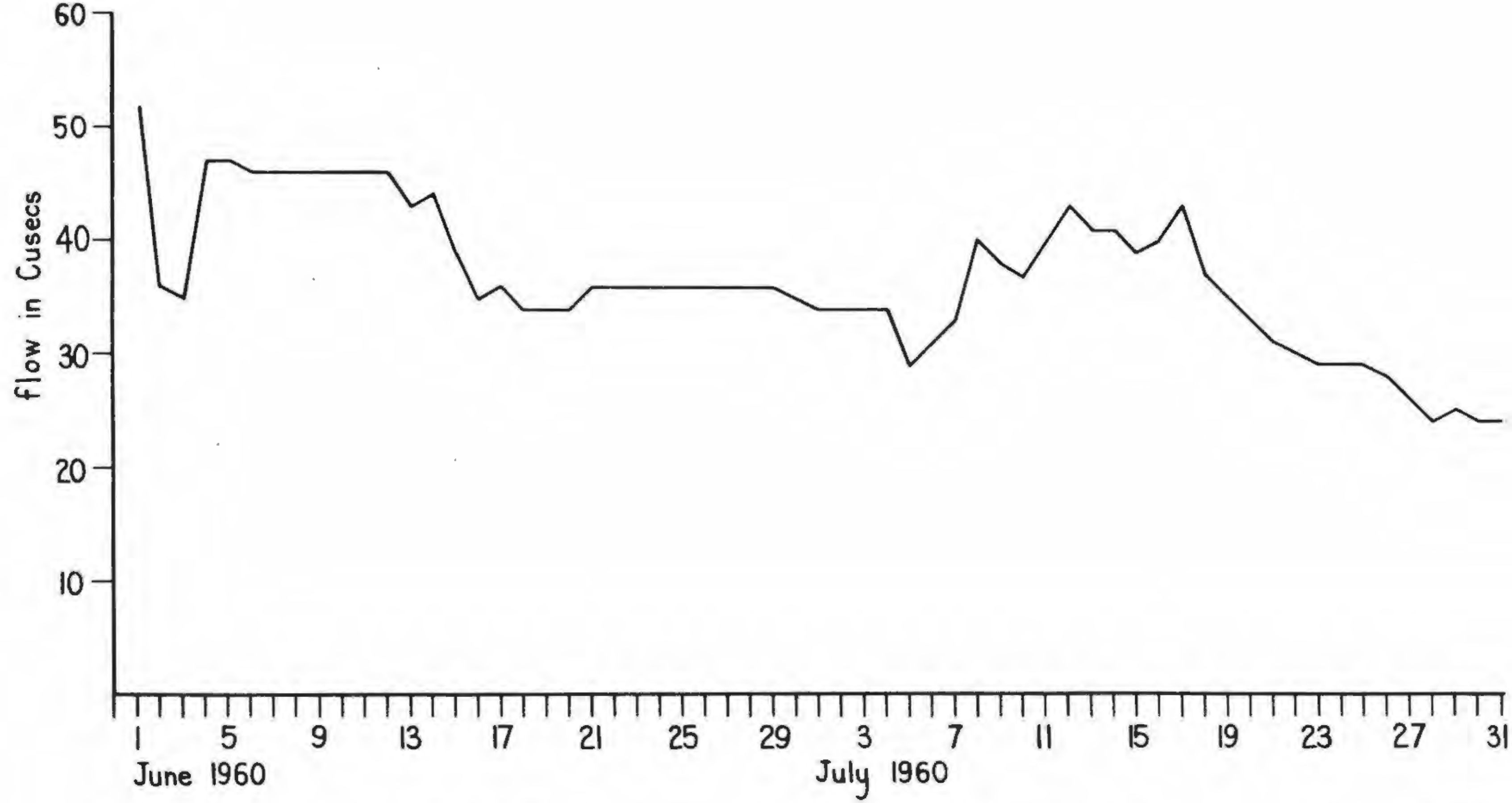


Figure 6. The daily flow of the Vaal River at Standerton in winter 1960, where the flow is not artificially regulated.

samples taken on each visit to each sampling point. Comparison of analysis results from individual sampling points revealed that they were rather variable. Mean values have therefore been given in Table 3 and they show that in January the concentration of all forms of nitrogen was lower than at other times. Except for free and saline ammonia, for which results were variable, the concentration of all forms of nitrogen was lower at Station 56 than it was at Station 51, but the analyses for individual sampling points were so variable that it was not possible to establish where the reduction in concentrations took place.

The pH of the water was rather high (Table 4) and varied little, indicating with the high total alkalinity (Table 3) that the water was well buffered. Turbidities were high in October, January and April, but at all times the turbidity of the water decreased between Station 51 and Station 56 (Table 3). This decrease was sufficient to be noticed in the field without directly comparing water samples. Sulphates and chlorides were higher in January 1964 than in April and August. It is not unlikely that the high sulphate concentrations recorded in January originated in the gold mining areas of the Southern Transvaal and were carried down by the high flows of the river in January (Fig. 4). High sulphate waters are known from the gold-mining areas (Chutter 1963, Table 1). Sampling was too infrequent to arrive at more detailed conclusions and the main purpose of Table 3 is to give an idea of the type of water in this part of the Vaal River.

Environmental measurements, stones in current biotopes

The environmental variables which have been discussed thus far have been the type of variables which would affect the fauna of any biotope. However variables such as the current speed and the epiphytes growing on stones would be important only to the animals living in the stones in current biotopes. These are described here.

Current speeds

The mean current speed (Table 5) at most sampling points followed the flow of the river (Fig. 4), higher mean speeds being recorded when the flow was higher. Thus the flow was highest in October, lower in January, and lowest in April, and at all sampling points except Station 56 the highest mean current speed was recorded in October and the lowest in April. To judge by the August flows (Fig. 4) current speeds would have been even lower then than they were in April.

In October and April the highest mean current speeds were recorded at Station 55 and the lowest at Station 56. In January Station 55 still had the highest speed, but now the speed at Station 56 was higher than that at Stations 52 and 54. Speeds at Stations 52, 54 and 54a were of the same order.

Epiphytes on the stones

Dr. B.J. Cholnoky was kind enough to examine the epiphytic algae and plants which occurred on the stones and to name them for the author.

Epiphytic algae were not seen on the two sampling visits paid to Station 54. At the other stony run sampling stations short dense growths of epiphytes were present on top of at least some of the stones in October, 1963, January and April, 1964. These growths consisted mainly of Cladophora, Stigeoclonium and an alga belonging to the Oedogoniales. In August, 1964, there were thick brown mat-like growths of algae on top of all the stones at Stations 52 and 54a; at Station 55a the stones were covered with a very thin layer of extremely slimy growth, presumably diatoms, and at Station 56 the mat-like growths were again found. Trailing or conspicuous green algae were not observed at Stations 52 and 55a, but they were present at Station 54a and were abundant at Station 56. The brown mat-like growths at Stations 52, 54a and 56 were made up largely of the diatoms Cymbella and Synhedra, while Stigeoclonium sp. was also found at all three stations. At Station 56 there was a lot of Cladophora and some Spirogyra. Cocconeis pediculus, a diatom seldom recorded in South Africa, was abundant at Station 56 where it was growing epiphytically on the Cladophora. Cyanophyta, mainly Oscillatoria sp., were present at all three sampling points but were not abundant. Cholnoky's comment on the algal flora was that it indicated an unpolluted water with a high pH, which agrees well with the chemical data reported above.

The fauna of the stones in current

General remarks

At the beginning of the study the fauna of ten stones at each sampling point was counted. However when the January samples came to be analysed it became apparent that there was not time to count the animals on so many stones. In that month and thereafter the fauna of only five stones from each sampling point was analysed. However because the surface area of the stones collected at Station 54 in January was unknown and had to be estimated from the volume/surface area relationships of the stones collected in October (see above) the animals from ten stones were counted in January at this station, as having more counts for this sample series would help to cancel out the effect of having to estimate surface areas. (The term 'sample series' has been used here to describe the faunal samples collected during any one of the field trips from any one of the sampling points and subsequently analysed. It is used with the same meaning on several occasions in the pages which follow.)

The mean numbers of individuals per 1000 sq cms stone surface, together with the numbers of stones on which they were found, for the commonest stones in current animals are shown in Table 6. The densities of animals in sample series were often highly variable and there was then a considerable overlapping of single sample densities in different sample series, whose mean densities differed by fairly large amounts. In view of this it was necessary to use a statistical comparison of density data in pairs of sample series to test whether they came from populations likely to be of the same or of differing sizes. However the numbers of animals recorded in single sample series could not be fitted to a theoretical distribution and this had two important statistical consequences. Firstly it meant that non-parametric statistics had to be used instead of parametric statistics. Secondly it meant that the reliability of sample means could not be calculated and expressed in the usual forms such as the standard error or the standard deviation.

The Mann-Whitney U Test (Siegel 1956 for theory, Owen 1962 for significance tables) was used to compare sample series. The probability of the samples being drawn from populations with the same density had to be 0.05 or less before it was accepted that the sample means represented populations of different sizes. The Spearman Rank Correlation Coefficient was calculated when correlations were investigated. Correlations were regarded as significant only if their probability was 0.95 or greater. There are of course two kinds of correlations. The first kind is positive, meaning that higher and lower numbers of the quantities being investigated are found together. The second kind is negative, meaning that higher numbers of one quantity are found where lower numbers of the other are found and vice versa.

General description of the stones in current fauna

The commonest stones in current animals were the mayflies Baetis glaucus and Neurocaenis sp., the caddisflies Amphipsyche scottae and Cheumatopsyche thomasseti, Simulium chutteri and Chironomidae of the subfamily Orthocladiinae (Table 6). These and the majority of other common stones in current animals were recorded from all the stations where the biotope was sampled. However, the density of the different animals varied considerably from sampling point to sampling point and also from season to season. For example the greatest numbers of Simuliidae were found at Stations 54 and 54a and Simulium densities were rather low in January. Neurocaenis and C. thomasseti densities were highest at Station 56. In the sections which follow, the variation in the fauna is related to the variation in environmental and biotic factors.

The rarer stones in current animals, together with the rarer marginal vegetation animals, are shown in Table 7.

Seasonal variation due to life-history

In the aquatic insects with aerial stages it frequently happens that the developmental stages are present in rivers only at certain times of the year. The life histories of very few African aquatic insects are known, but there were certain insects in the lower Vaal River whose seasonal changes in abundance were probably primarily related to life history phenomena. Neurocaenis sp. was not found at all in the samples collected in August (Table 6) and this was probably due to life history, as it also vanished from the Berg River (Harrison & Elsworth 1958, Table 16, as Tricorythus) and from the Tugela River (Oliff 1960a, Figure 8a) in the winter. Centroptilum medium was found mainly in January and not at all in October and August. This pattern of occurrence was also found in the Vaal River below the Vaal

Barrage (Chutter, 1963, Tables 12, 14) and in the streams and rivers of the Vaal Dam Catchment (Part 2 below) and is therefore probably due to life history.

The scarcity of Hydropsychid juveniles in August (Table 6) suggests that the Hydropsychidae encountered in this part of the river do not have winter hatching eggs. In January very large numbers of adult Hydropsychidae were found. This taken with the rather low numbers of A. scottae, C. thomasseti and Hydropsychid juveniles occurring then suggests that the greater part of the population was in the adult stage at this time. Porifera had numerous gemmules in October, were very scarce in January, not recorded in April, and were found at three of the four sampling points in August, when a few gemmules were found in only one colony. It would therefore appear that the scarcity of Porifera in January and absence in April was due to a life-cycle in which the summer and autumn are spent in the resting (gemmule) stage. As would be expected ? Sisyra sp. (Neuroptera, Sisyridae) larvae were found only where Porifera were found. The Cladoceran Moina sp. were not recorded anywhere in August, 1964, and this is typical of the seasonal occurrence of this animal in South Africa, where it has previously been recorded mainly in the summer (Chutter, 1963). It is perhaps surprising to find this Cladoceran in a stony run fauna and its presence was almost certainly due to its being swept through the stony runs, rather than to its living there permanently.

Faunal variation with size of stone sampled

The variation in surface area of the stones whose fauna is described in this study is shown in Table 8. The smallest stone had a surface area of 280 sq cms and the largest a surface area of 1698 sq cms, while the greatest range in stone size for a series of samples from one sampling point was 682 to 1698 sq cms (Station 56, October).

Correlations between stone-size and density/1000 sq cms of the species found on half or more of the stones in any sample series were estimated using the Spearman rank correlation test. All the results could not be lumped together for the test as seasonal changes in density and changes in density due to sampling point could not be eliminated. Because Station 54 was in a semi-permanent stony run and had a peculiar fauna (see below), data from this sampling point were not used in correlation tests. There was therefore a maximum of fourteen correlations (four each for Stations 52 and 56, two for Station 54a, three for Station 55 and one for Station 55a) for each species.

The species whose densities were significantly correlated with surface area of stones in any of the correlation tests are shown in Table 9. In this table significant ($P > 0.95$) positive correlations would mean that the density of the animal was higher on larger stones and significant negative correlations would mean that the density of the animal was higher on smaller stones. In all the animals shown in Table 9 the proportion of correlation tests with significant results was low and it was concluded that, in the range of surface areas of the sampled stones, the density of all species varied independently of the surface area of stones.

Such is the nature of the available data and test used that had any species density shown a constant significant correlation with stone surface area, then surface area would have been an unusually important factor in the species' choice of habitat. It would have meant that surface area was more important than, for instance, current speed, shape of stone and the way the stone was resting on the river bed. However, there are animals in South African rivers such as the large mayflies Centroptiloides bifasciatum and the Oligoneuriidae which are found mainly under stones too large to lift from the water single-handed.

Water chemistry and the fauna

A large part of the total nitrogen in the water was in the form of organic nitrogen (Table 3) indicating that there may have been rather large amounts of microplankton in the water. The impoundment behind the Vaal Hartz Diversion Weir would provide suitable sheltered conditions for this to develop.

Harrison (1958b) found that mild pollution lead to the development of large Simulium populations some way downstream from the source of the polluting material and this he ascribed to the development of large quantities of microplankton on which the Simulium were feeding. It is therefore distinctly possible that the large Simulium populations from Stations 52 to 55 (Table 6) developed because there was an ample food supply for them. At Station 56 where the amount of organic nitrogen in the water was lowest Simulium populations tended to be smallest. However, the availability of microplankton food was obviously not the only factor governing the abundance of the Simuliidae for the sampling point nearest to the Diversion Weir (Station 52) did not have the largest Simulium populations.

Total nitrogen concentrations were lowest in January possibly due to the floods of the previous fortnight (Fig. 4). There were no really large Simulium larval densities in January and it could be that suitable food was less abundant then than at other times.

No clear relationships between the other chemical features and the fauna were found. However, the low turbidity of the water in August, a physical characteristic shown with the chemical features in Table 3, was very important as the greater transparency of the water then helps to account for the large growths of epiphytic algae, which did affect the fauna.

Current speed and the stones in current fauna

Mean current speeds at Stations 52 and 54 and at Stations 52 and 54a differed by so little in each of the months they were measured (Table 5) that current speed does not seem likely to account for the faunal differences between these stations. The fauna of Station 54 was unusual because of the semi-permanent nature of the biotope and is therefore left out of consideration in the rest of this section.

In October and January current speeds at Station 55 were higher than elsewhere. Hydropsyche sp. density at this station appeared to be related to current speed. In October and January this animal was most abundant at Station 55, less abundant at Station 52 and not recorded at Station 56. In October this density change followed current speed changes between the three sampling points, but even in January the correlation began to break down as the current speed at Station 56 was of the same order as that at Station 52, but Hydropsyche was present at Station 52 and not recorded at Station 56. However, as will be discussed later, the density of this species followed that of S. chutteri and there was no evidence that S. chutteri numbers were highest where current speeds were highest.

Current speeds were variable at Station 56, but in October they were a lot, and in April a little, slower than elsewhere (Table 5). The mean densities of Amphipsyche scottae, Cheumatopsyche thomasseti and Neurocaenis sp. were higher at Station 56 than elsewhere. However, counts of these animals often varied considerably from stone to stone. At Station 56 in October the mean number of C. thomasseti/1000 sq cms was 210 (Table 6), but this was largely due to one stone with 1329 individuals/1000 sq cms. Without this stone the mean density of C. thomasseti in this sample series was 77/1000 sq cms. The Mann-Whitney U Test consequently showed that there was no significant difference between the size of the populations at Stations 52 and 56. In A. scottae the density in October was highest at Station 56, but then higher at Station 55 than at Station 52, so that density was not inversely related to current speed. It is therefore unlikely that current speed was the most important factor bringing about the high densities of these animals at Station 56.

As was pointed out from a consideration of the relation between current speed and flow (p. 16 above) it seems likely that the current speeds were lowest in August because the flows were lowest then. This may have played a part in the appearance of the epiphytic growths in such profusion in August. Although the numbers of several types of animals increased, this was in nearly every case a result of the increase in the epiphytes (see p. 31). However, the August increase in the numbers of Mermithidae and Simulium larvae parasitized by Mermithidae was not directly related to the increase in the epiphytes, for the numbers of these animals increased at Station 55a where there was no large increase in the epiphytes. It is therefore possible that the large numbers of Mermithidae then were due to lower current speeds, though it must be admitted that it is equally possible that this seasonal change in abundance was related to the Mermithid life-cycle.

Animals associated with particular stone characteristics

At times of the year other than August there were always some stones with short tufty growths of filamentous algae on top of them (p. 16 above). Catoxyethira and Chironomid larvae were abundant in the algae on these stones. As a result of this preference for algae covered stones there was a significant positive correlation between the densities of Catoxyethira and Chironomini from series of samples analysed at single sampling points on the same day. However, the Orthocladiinae, even though their density increased sharply in August when thick mats of diatoms and algae appeared, were equally abundant on the stones with and without algae at other times of the year.

In the field Caenodes, Choroterpes (Euthraulus) sp. and Gomphocythere appeared on those stones with a cavity under the side away from the direction of flow. The observation that these three species occurred together was confirmed by the data for Station 52, which showed that the correlation between the three groups was positive and significant. At other sampling points one or other of these three animals was usually rare but correlations between pairs from the three groups were always significant and positive. Choroterpes (Euthraulus) is very similar in body form to the European Habroleptoides modesta (Hagen) which Ruttner (1963, p. 239) illustrates as an example of a cavity dweller. In the Vaal Dam Catchment Choroterpes was often extremely abundant in the stones out of the current.

The correlations between the species associated with algae, and those between the species associated with cavities, were the only correlations which were found in a large number of the sample series from the various sampling points. Other pairs of animal groups or species were occasionally significantly correlated with one another, but there were so many sample series in which the correlations were not significant that the significant correlations must be regarded as spurious.

Water level fluctuations exclusive of flooding and the stones in current fauna

The river was widest at Station 52, narrowest at Station 54a and of intermediate width at Stations 55, 55a and 56 (descriptions of sampling points, p. 11). Changes in water level due to the weekly fluctuation in daily flows (Fig. 4) would be greatest where the river was narrowest (Station 54a) and least where the river was widest (Station 52).

The main differences between the fauna of Stations 52 and 54a were that S. chutteri and Hydropsyche sp. were more abundant at Station 54a and S. adersi, S. damnosum, S. mcmahoni and Macronema capense were more abundant at Station 52. A. scottae was found in low numbers at Station 52, but was not recorded at Station 54a. Cheumatopsyche thomasseti and Neurocaenis densities were very variable from stone to stone with the result that the differences between the mean numbers of these animals at the two sampling points were not substantiated as probable population density differences by the Mann-Whitney U Test.

These groups of animals whose densities differed significantly at Stations 52 and 54a all belonged to groups which strain their food from the water, the Hydropsychid caddis and the Simuliidae. However, the current speeds at the two sampling points differed by so little that the faunal differences may not be attributed to current speed differences.

The densities of the animals at the sampling points further downstream than Station 54a, where the fluctuation in water levels would be expected to be intermediate between those at Stations 52 and 54a, were not intermediate between those recorded at these two stations. Possibly these sampling points were sufficiently far away from Stations 52 and 54a for other factors, such as distance from the Diversion Weir (which might be inversely proportional to the amount of microplankton in the water), temperature and turbidity (which would affect algal growth and hence the food resources of the biotope) to have an appreciable effect on the fauna.

However, a special and interesting case of extreme water level fluctuation was found at Station 54, where the biotope sampled was part of a side channel of the river which dried up when flows were low. There was a strong flow of water at this sampling point in October, 1963, and January, 1964, but it was dry in April and August, 1964. From a consideration of the flow pattern of the river prior to these field trips (Fig. 4) it was estimated that in October, 1963, water could have been permanently flowing over the stones for a maximum of two months, while in January, 1964, it could have been permanently flowing for only two weeks. During these two weeks there was a minor flood.

The fauna recorded at Station 54 in both October and January (Table 6) was unusual and its composition reflected the semi-permanent flow there. In October S. chutteri, Baetis glaucus and Chironomidae were the only abundant animals and many animals which were widespread or abundant elsewhere, such as the other Ephemeroptera, the caddis flies and the Mollusca, were rare or not recorded. The community therefore resembled that recorded during the early stages of recolonisation of an intermittently flowing stream in the Western Cape, where Simuliidae, Baetis spp. and Chironomidae were the important early re-invaders (Harrison 1958a, Table 40). Among the rarer animals the leech ?Salifa perspicax and the parasitic Nematoda (?Mermithidae) were early re-invaders. However, ?S. perspicax was found to be predaceous on Simuliidae and the ?Mermithidae were Simulium parasites, so their presence was mainly related to the very large numbers of Simulium larvae.

In January the fauna was similar to the October fauna in that *Baetis glaucus* and Simuliidae were the only really abundant animals, but *S. chutteri* was very much less abundant than in October. The lower numbers in January could have been due either to the short period that the water had been flowing in the run, to the flood that occurred during that short period or possibly to a reduction in the amount of food available which is discussed above (p. 22).

The most important point shown by the fauna at Station 54 is that rapids in semi-permanently flowing parts of the river bed are important sites of massive *Simulium chutteri* larval development.

Floods and the stones in current fauna

The effect of floods on the stony run fauna has often been described in South Africa (Allanson 1961, Oliff 1960a, 1960b, 1963, Oliff & King 1964) and elsewhere (Allen 1951, Jones 1951). The conclusion, based on field observations made with various sampling techniques, of these workers was that floods drastically reduce the faunas of stones in flowing water biotopes. Macan (1963, pp. 122, 130-131) found it hard to believe that floods would wash animals out of stable stony runs, since he would expect them to crawl into places suitably protected from the increased velocity of flood waters. In the Vaal at Warrenton high flows occurred in the latter part of November, 1963, and in the week before sampling in January, 1964 (Fig. 4). Significant decreases in density of several species or groups of animals were found after the floods (Table 6) but species showing a decrease at one sampling point often showed either no significant change or sometimes a significant increase in density at other sampling points. The only species and groups which had a January density significantly smaller than the October density at all sampling points were *Simulium damnosum*, Chironomini, and Hydropsychid juveniles. Several other species had significantly smaller populations in January than in October only at the sampling points where they were most abundant. Species in this category were Neurocaenis sp. (Station 56), Amphipsyche scottae (Stations 55 and 56) Cheumatopsyche thomasseti (Stations 52 and 56), Hydropsyche sp. (Station 55, Catoxyethira sp. (Station 52) and Simulium mcmahoni (Station 56). Because of the three month interval between samples, it is impossible to ascribe any of these significant changes in density solely to the floods, since the life-cycle of the species might in any case result in a mid-summer larval population smaller than the spring population. Indeed this would appear to be the case in Cheumatopsyche thomasseti, thousands of adults of which were present at Station 56 in January. Such numbers of adult C. thomasseti were not seen on other sampling visits.

Floods could not be shown to have had any effect on the density of S. chutteri populations. At Station 52 the January density was significantly larger than the October population, in spite of the minor flood during the fortnight before the January field trip (Fig. 4), but at Station 55 the January S. chutteri density was significantly smaller than the October density. Densities at Station 54 were markedly influenced by the semi-permanent nature of the biotope (see above) and therefore contribute nothing to the effect of floods on the S. chutteri densities. According to local information the numbers of adult S. chutteri were high from before the October sampling trip until the end of November, when there was a period of cooler, rainy weather lasting nearly a fortnight. In January the numbers of adult flies were not high, and this could have been due to the effect of adverse weather conditions on the adult stages.

Mermithidae and Simulium chutteri

Most of the Mermithidae recorded during this study probably

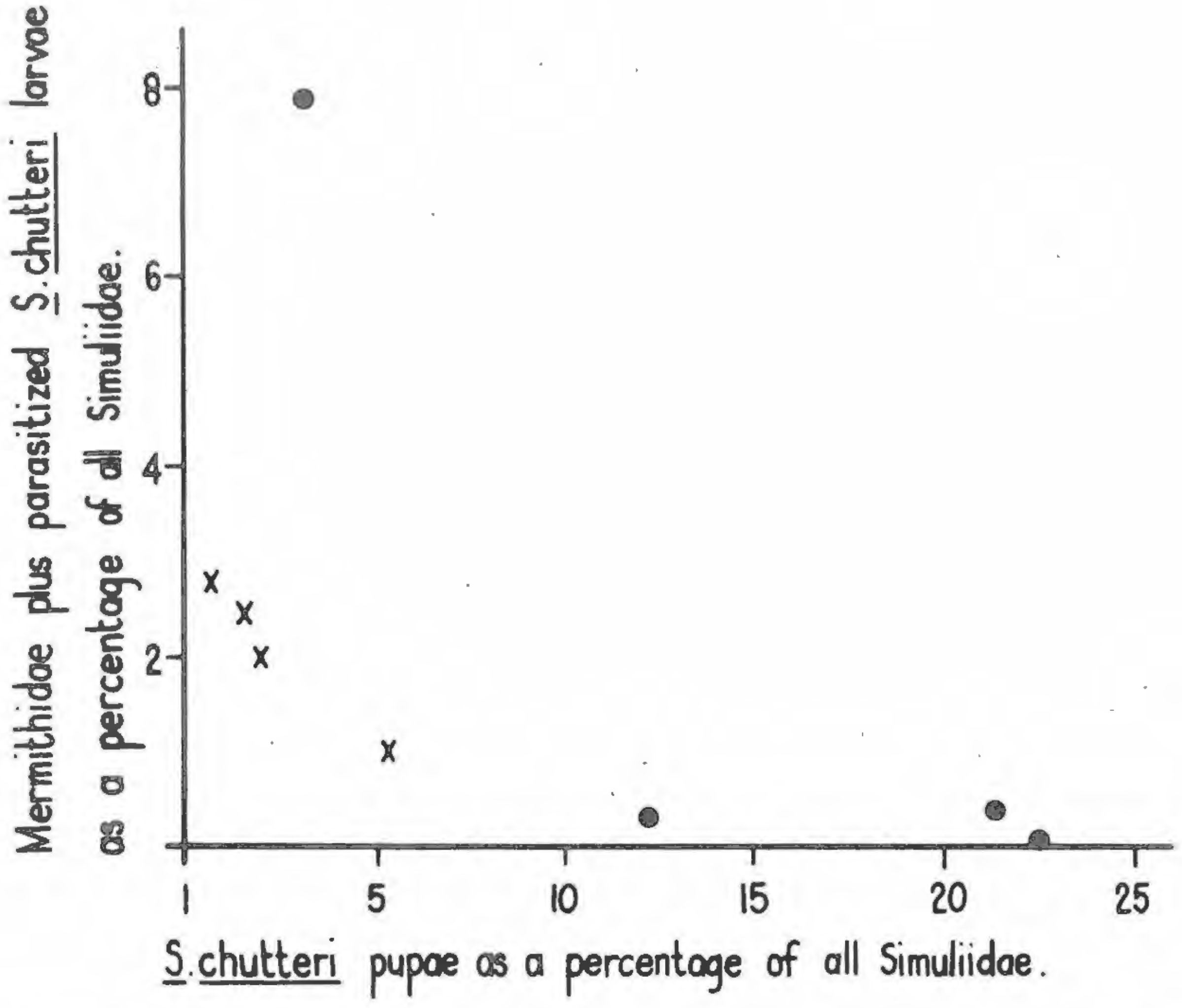


Figure 7. Simulium chutteri pupae and Mermithidae at stations 52 (x) and 54/54a (•), based on data given in Table 6.

left their Simulium hosts only in the sample bottle, for free-living specimens were not seen in the field and the pickled material included many Simulium larvae with the parasite breaking out of their bodies. Large Mermithidae may easily be seen inside Simulium larvae and parasitized larvae were counted separately from the normal larvae (Table 6). Larvae were not dissected to look for Mermithidae and the numbers of parasitized larvae given in Table 6 represent the numbers of large Simulium larvae with large Nematoda inside them. Mermithidae were not found in S. adersi, S. damnosum or S. mcmahoni larvae, all the parasitized larvae belonging to S. chutteri.

No parasitized larvae had developed pupal respiratory histoblasts, which is in keeping with the observations of Anderson & De Foliart (1962) and Anderson & Dicke (1960) that Mermithidae prevent the pupation of most parasitized larvae. At Stations 52 and 54/54a the proportion of S. chutteri pupae to the total numbers of Simuliidae fell as the proportion of Mermithidae rose (Fig. 7), suggesting that the Mermithidae were preventing the pupation of S. chutteri larvae. Mermithidae and parasitized larvae were most abundant in August. In April at Station 54a there were 1.38 S. chutteri pupae present for every S. chutteri larva. Had the ratio between larvae and pupae been the same in August at this sampling point then 120 pupae would have been recorded and not 43 (Table 6). It may be concluded that in August the Mermithidae were considerably influencing the size of the S. chutteri population. There are some instances of Nematoda eliminating Simuliidae on record in the literature. Phelps and De Foliart (1964) found that on two occasions there was a virtual elimination of Simulium larvae due to Nematode parasites and Rubtsov (1963) reported that high infections of the parasites were sometimes followed by an almost complete disappearance of the Simuliidae for several years.

Epiphytes and the stones in current fauna

The most conspicuous change in the stony run biotopes during the year in which they were visited was the appearance of the algal and diatom mats on the top of the stones at Stations 52, 54a and 56 in August. Animals found on and in the epiphytic growths were Nais sp., Chaetogaster sp., Catoxyethira sp., Chironomini and Orthocladiinae and the numbers of these animals were consequently higher at Stations 52, 54a and 56 in August than they were at other times of the year (Table 6). It was obvious that in August the growth of the epiphytes had far outstripped the grazing capacity of the herbivores. The epiphytes bloomed in August because the turbidity of the water was lowest then (Table 3) allowing light penetration to greater depths. Other factors may have been the low flow then which would mean that the current speed was probably low and also that the stones were not submerged far and therefore well lighted. Although there were increases in the numbers of some herbivores (Catoxyethira, Chironomini and Orthocladiinae) it was obvious that there was a vast unexploited food supply. This may be because it developed at the end of winter, which may be a time when most animals are in advanced juvenile stages, but few are in the reproductive stage. If this is true, late winter would be a time of little recruitment to larval populations and the herbivores would consequently not be in a position to increase rapidly in response to the increased food supply.

The massive epiphytic growths had disappeared by October probably due to increasing turbidity (Table 3) and flows (Fig. 4). There was no obvious reason why the epiphytes were not as abundant at Station 55a as they were at the other sampling points.

Simulium larvae and pupae were not found attached to the epiphytic growths, which means that in August the area available for Simulium attachment was lower than at other times. It seems likely

Species	12	11	10	9	8	7	6	5	4	3	2
1 *Amphipsyche scottae*	–	–	–	0	0	0	0	0	–	+	+
2 *Cheumatopsyche thomasseti*	–	–	0	0	0	0	+	0	0	0	
3 *Baetis glaucus*	0	0	0	0	0	0	–	0	–		
4 *Burnupia* sp.	0	0	0	0	0	0	0	0			
5 *Choroterpes* sp.	0	0	0	+	0	0	+				
6 ? *Caenodes* sp.	0	0	0	0	0	+					
7 *Gomphocythere* sp.	0	0	0	0	0						
8 *Catoxyethira* sp.	0	0	+	+							
9 Chironomini	+	0	+								
10 Orthocladiinae	+	0									
11 *Hydropsyche* sp.	+										
12 All Simuliidae											
Neurocaenis sp.	0	–	0	0	0	0	0	0	0	0	0

Figure 8 A trellis diagram of the significant correlations, based on arithmetic means from Table 6 , between important species recorded from the stony run biotopes of the lower Vaal River. The species are numbered on the vertical axis and only the numbers are shown along the horizontal axis. Data from station 54 were omitted when calculating correlations and only data for October, January and April were used for calculating the correlations between *Neurocaenis* sp. and the other species.

Key to symbols : + positive significant correlation

– negative significant correlation

0 correlation not significant

that Simulium larval populations would have been even larger in August had there been no epiphytic growths.

Biotope preferenda of the stones in current fauna

In this section correlations between the mean densities of pairs of the more abundant species or groups of animals are described (Fig. 8). Here the topic in question is not whether certain species preferred the same stones or different stones, but it is whether there were particular biotopes preferred by pairs of species or preferred by one species and not by another.

The correlations were made using the Spearman Rank Correlation Test on the mean densities given in Table 6. In testing these correlations densities of each kind of animal were ranked irrespective of month or sampling point, but data from Station 54 were not taken into account because the fauna there was unusual due to the intermittant flow. Where correlations were significant they therefore meant that the densities of the animals were correlated irrespective of season or sampling point.

The reasons for some of the significant correlations (Fig. 8) are readily apparent. Caenodes was significantly correlated with Gomphocythere and Choroterpes (Euthraulus) because these animals preferred the stones with cavities behind them (p. 25, above), and this preference was so strong that it masked density differences from sampling point to sampling point or from season to season. However density differences due to season or sampling point did result in there being no significant correlation between Choroterpes and Gomphocythere, although these were both cavity dwellers. Catoxyethira and Chironomini were significantly correlated because they preferred the stones with algae on top of them, but both these species were significantly correlated with Orthocladiinae, in spite of the fact that

Orthocladiinae were not associated with stones having algae on top of them in single sample series (p. 25 above).

The density of all the Simuliidae taken together was highest at the sampling points where the density of S. chutteri was highest, and was lowest where the density of the other Simulium species was highest (Table 6). Significant correlations between 'All Simuliidae' and other animals were therefore really correlations between S. chutteri and the other animals. On the other hand any animal which was correlated with 'All Simuliidae' would also be correlated with the Simulium species other than S. chutteri, but the kind of correlation would be the opposite to that with S. chutteri. For instance Amphipsyche scottae was negatively correlated with 'All Simuliidae' (Fig. 8), which means that its densities were lower where S. chutteri densities were higher. This negative correlation also means that A. scottae occurred in larger numbers at the same sampling points as did the Simuliidae other than S. chutteri (as may be seen from Table 6).

The filter feeding component of the fauna clearly falls into two groups of animals whose densities were correlated with one another. The first group was S. chutteri and Hydropsyche which occurred together and the second group was the other Simulium species, A. scottae and C. thomasseti. The members of each group were negatively correlated with the members of the other group, showing that the fauna either included large numbers of one group or of the other, but that large numbers of both groups were not found simultaneously at a sampling point. The original data given in Table 6 clearly illustrates these correlations. When the faunas of Stations 52 and 54a were compared in relation to the fluctuations in water level (see above, p. 26) the same sort of difference between the filter-feeding component was found, but taking the data from all sampling points into account makes the contrast more marked as it brings in C. thomasseti too. The data for Station 54, which was left out of consideration in calculating the correlations shown in Figure 8, also showed that where S. chutteri densities were high other Simulium species were not abundant (Table 6). However owing to the intermittent flow at this sampling point the Hydropsychidae did not become established in large numbers.

There are probably many factors having a bearing on this division of the filter-feeders and they are discussed later, when the diet of the Hydropsychidae, which has an important bearing on the problem, has been described. So little is known about the habitats and feeding habits of the other animals shown in Figure 8 that it is not possible to understand completely the meaning of the other significant correlations. What can be said about them is that they were not due to the animals showing preferences for the same, or for different stones in single sample series.

The diet of the Hydropsychidae found in the lower Vaal River

The following observations on the diet of the Hydropsychidae were made on preserved material, in order to establish whether any of the large larvae were likely to eat Simulium larvae or the food likely to be eaten by the Simulium larvae themselves.

Macronema capense has a strongly toothed gizzard and the gut of the specimens examined contained large amounts of insect exoskeleton. It was concluded that large larvae of this species are mainly carnivorous and would probably readily eat Simulium larvae. The gizzard of Amphipsyche scottae was moderately strongly toothed. Its gut contained mainly exoskeletal fragments, but there were some algae present too. The gut contents of Hydropsyche sp. were similar to those of A. scottae but its gizzard was more weakly toothed. These two animals were omnivores, possibly eating more animal food than plant food. Cheumatopsyche thomasseti had a weakly toothed gizzard and its gut contents were mainly algal filaments and diatoms. There were however also fragments of Orthoclad head capsules, ? Entomostraca and ? Baetid cerci. C. thomasseti was therefore also an omnivore, probably eating more plant food than animal food.

It was therefore concluded that, given the opportunity, the large larvae of all these Hydropsychidae would eat Simulium larvae. This is confirmed by more detailed studies of the feeding habits of Hydropsychidae carried out in other parts of the world. Slack (1936) and Scott (1958) showed that net building Hydropsychidae are omnivorous. Kaiser (1965) found that the younger Hydropsyche larvae are plankton feeders, and that the older are predators with a preference for larger prey. From Kaiser's description of the feeding habit of the young larvae it is obvious that their diet is microplankton. Both the Cheumatopsyche and the Hydropsyche larvae recorded by Hynes and Williams (1962) in Uganda had eaten Simulium larvae. Peterson and Davies (1960) observed Hydropsyche and Cheumatopsyche larvae actively preying on Simulium larvae and concluded that the larvae of Hydropsyche were the most important predators of Simulium larvae in Algonquin Park, Canada. Ussova (1964, p. 247) found that there were few Simulium larvae where there was a large number of Trichoptera.

It is perhaps at first difficult to understand how an animal which builds a net and then passively waits for food material to be swept into the net, can be put forward as a predator of Simulium larvae which, when seen in the field, are usually firmly attached to stones or other substrata. However, Simulium larvae do move about a lot in the stones in current, one of the most frequently employed methods being to attach a thread onto the substratum and then to drift downstream on the end of the thread. Such drifting larvae would easily be carried into a Hydropsychid net. The extent to which Simuliid larvae move about may be seen from the success with which various Simulium traps, all of which depend on larvae attaching themselves to an artificial substratum, have been developed (Wolfe & Peterson 1958, Williams & Obeng 1962).

The fauna of the marginal vegetation at Station 53

The marginal vegetation biotope

The marginal vegetation at Station 53 was mainly Cyperus sp. with a little Scirpus sp. The leaves of these plants die off at the end of summer. In the spring (October) the biotope consisted of the new spring growth amongst which there was still a lot of decaying leaves and stalks from the previous summer's growth. This decaying matter had disappeared in January, possibly through having been washed away by the November floods. In August the cycle was completed and the vegetation was dead, but not yet obviously decaying (Plate II).

In October and January small amounts of epiphytic and free floating filamentous algae were present, but in April none was seen. However, in August masses of a brown growth, some free floating and some entangled in the vegetation had appeared. These were predominately diatoms of the genera Cymbella and Synhedra (which were abundant in the stones in current in August) and some Achnanthes.

The water level varied with the flow of the river and was highest in October and lowest in April and August, with the January level intermediate. This resulted in variation of the width of the fringe of vegetation standing in the water. The fringe was about 1.3 m wide in October, about 1 m wide in January and about 0.6 m wide in April and August.

The marginal vegetation fauna

General remarks

The variation of the numbers of animals found in each sample series from the marginal vegetation was not as great as it was in the stones in current sample series, with the result that changes in mean numbers were usually a more reliable guide to changes in abundance than they were in the stones in current. This may be because the sampled vegetation biotope was more uniform than the stones in current biotopes. Moreover the marginal vegetation samples were taken in such a way that if there are microhabitats in the marginal vegetation due to distance from the bank or from the outer fringe of the vegetation they were sampled by each sweep. This was certainly not the case in the two microhabitats recognised in the stones in current, the cavities and the tufty algal growths.

The mean numbers of the animals found at all regularly in the marginal vegetation are shown in Table 10, the rarer animals are listed in Table 7 with the rarer stones in current animals. The commonest animals in the marginal vegetation were Simocephalus vetulus, Cyclops spp., Caridina nilotica, Baetis bellus, Centroptilum excisum and the Orthocladiinae. Insofar as identifications at the species level were possible, the species recorded at Station 53 were all, except for Camptocercus sp. (Table 7) found in the Vaal River in the Vereeniging area (Chutter 1963).

Environmental factors and the marginal vegetation fauna

The fauna collected in both January and April showed the effect of the high summer flows. Numbers of the Cladocera, Ostracoda, C. excisum and the Chironomidae were low as in the catchment of Vaal Dam (Part 2, Tables 39 & 40). Of these animals only S. vetulus and the Orthocladiinae occurred in large numbers in both October and August when the dead and decaying vegetation was found in large quantities. However, the overall changes in abundance of these animals were more probably due to the changes in the flow of the river than to the changes in the amount of dead vegetation.

Numbers of Prostoma sp., Nais sp., Chaetogaster sp. and Chironomini were highest in August and these animals appeared to be closely associated with the diatom clumps, for they were found mainly inside them in the samples. Other animals whose numbers may have been influenced by the growths of diatoms in August were Mesocyclops sp. and Cyclops spp., for they were unusually abundant in August (Table 10).

The numbers of Caridina nilotica were highest in January because this animal breeds in mid-summer and the population included large numbers of juveniles. Young Barbus were present in the vegetation in January and they may have preyed rather heavily on some invertebrates. In particular the Barbus may have accounted for the unusually low numbers of Baetis bellus found then. In the catchment of Vaal Dam (Part 2, Table 40) Baetis bellus numbers were clearly highest in the summer, but at Station 53 B. bellus was far more abundant in October and April than it was in January. If B. bellus were being affected by Barbus predation it would be the very small B. bellus which would be the most likely to be eaten and numbers of Baetid juveniles were certainly unusually low in January. However, this is really one of several hypotheses which could be put forward to explain the low numbers of B. bellus in January. It is possible that mid-summer temperatures in the Warrenton area were too high for the species. The minimum temperature at Warrenton (Table 1) in January was higher than the mean summer temperature in the catchment of Vaal Dam (Part 2, Table 12).

Although there were many changes in the abundance of animals in the marginal vegetation which were not explicable, the fauna as a whole was typical of a marginal vegetation fauna in an unenriched or unpolluted river. An interesting point is that Simulium larvae were present in October, January and April, even though there was no visible flow of water past the fringe of vegetation and the nearest rapids upstream were several hundred metres away. These larvae must have migrated downstream and show how widely Simulium larvae may be dispersed throughout this part of the river.

Discussion

The underlying factor which permitted the large numbers of S. chutteri to develop in the Warrenton area is that there was sufficient food for the larval stages in the water. It seems likely that this was primarily microplankton which developed in the waters held back by the Vaal Hartz Diversion Weir. There was no large and regular enrichment of the water below the Diversion Weir, to which the large amounts of food material for the Simulium larvae might be ascribed, in the way in which Harrison (1958b) was able to ascribe the Simulium outbreak in the Great Berg River at Wellington to microplankton increases due to organic enrichment further upstream.

The biotope most successfully exploited by S. chutteri larvae was a semi-permanent one (Station 54). The alteration of the natural river bed during alluvial diamond mining has probably resulted in an increase in the number of semi-permanent stones in current biotopes. This is further supported by the fact that where fluctuations in water level, due to the weekly cycle of daily flows, were greatest, the numbers of S. chutteri larvae were high. However, the numbers of several Hydropsychid Trichoptera were low where the flows fluctuated most. The large larvae of these animals would eat Simulium larvae if they drifted into their nets. From what is known of the feeding habits of the very small larvae it seems that they would be in competition with the large Simulium larvae for food. The lower numbers of Hydropsychidae where the water level fluctuation was greatest therefore seems unlikely to be due to a shortage of suitable food, stone size (p. 20), or current speed (p. 23) but seemed to be due to the weekly fluctuation in water level. It is likely that where the water level frequently fluctuates the area within a stones in current biotope that can be utilised by animals which build a fixed refuge and a fixed net (the Hydropsychidae) is restricted. However, this did not apply to all Hydropsychidae for Hydropsyche was found where S. chutteri was abundant. The Simuliidae would be at an advantage in such places because they are free to move up and down with the water level.

One possible reason for the large numbers of S. chutteri where the fluctuation in water level was greatest is therefore that they were freed from the competition for food and predation when drifting by the majority of Hydropsychidae. This might also explain why such large numbers of S. chutteri occurred in the semi-permanent stones in current biotopes for Hydropsychidae were rare in them. Other animals which did not occur in large numbers where the fluctuation in water level was greatest, or in the semi-permanent biotopes, were the other Simulium species. In such places S. chutteri either competed highly successfully with these species or else did not have to compete with them at all. Insofar as S. damnosum is concerned it is interesting that its distribution in October, April and August and its complete absence in January is in accord with Crisp's (1956) and Wanson and Henrard's (1945) observations that fluctuating flows and water level are unfavourable to this species.

As in an earlier study on the Vaal River (Chutter, 1963) the numbers of Cheumatopsyche thomasseti and Amphipsyche scottae were highest where there were drifting Entomostraca in the river, that is at Station 56 where Moina was far more abundant than anywhere else (Table 6). However, it was obvious from the data contained in Table 6 that large populations, particularly of C. thomasseti could occur in the absence of Moina in large numbers (Stations 52, 55a). An interesting point is that at Station 52 the numbers of Simuliidae increased in January and April when numbers of C. thomasseti were low, further confirming the inverse relationship between the numbers of these two animals.

However, to move on from the more specific - the factors which influence the numbers of S. chutteri larvae in the river - to the more general, a most important facet of the Warrenton study is that it begins to reveal the nature of some particularly biotic relationships which govern the composition of the river fauna.

Reduction in the size of S. chutteri populations is certainly assisted by parasitism of the larvae by Mermithid Nematodes. The competition for a food source between Simulidae and juvenile Hydropsychidae is highly probable and the outcome of this competition appears to be dependent on changes in the physical environment. The predation effects of large Hydropsychid larvae have been suggested above. These conclusions are drawn from a field study not primarily designed to investigate these relationships, but they do nevertheless indicate the very great advances that will be made in our understanding of river ecology when a detailed approach is adopted. Likewise the algae-browser relationship has only been glanced at, but it is clear that the close correlation between Catoxyethira and Chironomini is due to both of them utilizing the epiphytic habitat. Catoxyethira makes its case from algae and probably eats them too (Nielsen, 1948) and the Chironomini are effective browsers of this rich "aufwuchs". In winter when the epiphytic growth is most luxurious other groups, particularly Nais, Chaetogaster and Orthocladiinae take advantage of the increased food supply and microhabitats now available. A similar situation was found in the marginal vegetation where epiphytic growths provided food and shelter for the same groups.

The sampling method employed in the stones in current at Warrenton was unusual and yielded highly variable estimates of the faunal density. The reasons for this variability must lie in the very great variability of stony runs as habitats. They are a multiplicity of habitats, some, such as the cavities occupied by Gomphocythere, Caenodes and Choroterpes (Euthraulus) or the algal "aufwuchs", readily recognised by the human observer. Others, dependent perhaps on factors such as the thickness of the boundary layer (Ambuhl 1959),are impossible to recognise in the turbid waters so frequently encountered in the field. Even where it was possible to recognise habitats such as the cavities, the size of these habitats was not closely related to the surface area of the stones as the range of stone sizes was restricted. These physical factors contribute to the very great variability of the fauna from stone to stone and doubtless biotic relationships do so too. However, in spite of this variability of densities from stone to stone, and the consequence that it was not possible to compare data from different sample series by means of the precise methods available in parametric statistics, the sampling method has been justified by the considerable contribution the data it yielded have made to our understanding of the ways in which the fauna in South African rivers is related to environmental and biotic factors.

Among the animals recorded in the stones in current at Warrenton, Baetis glaucus stood out as the species whose numbers were least variable from stone to stone in single sample series. It was the animal whose numbers varied least in Chutter and Noble's (1966) Surber sampler study. It is an early re-invader of semi-permanent biotopes. Waters (1965) found that a large part of the invertebrate 'drift' in American streams was made up of a Baetis species. It is therefore not at all unlikely that B. glaucus 'drifts' on a large scale in South African streams. An animal which readily 'drifts' might be expected to be comparatively evenly distributed in biotopes in the current, and also to rapidly colonise newly covered parts of the river bed. Of course the occurrence of Simulium larvae in the marginal vegetation also suggests that its powers of rapid re-invasion of semi-permanent parts of the river bed may also be partly due to drift.

This discussion of the broader aspects of the Warrenton study has dealt with aspects of river biology which have been rather neglected in the study of the fauna of South African rivers, and the reasons for this are fairly straightforward. There is very rarely sufficient knowledge of the basic biology, such as the duration of the various stages of the life cycle, the habitat (as defined by Macan 1963) and the food and feeding habits of even the commonest animals, to permit the interpretation of observed faunal changes in terms of the biological environment. In addition many South African river studies have been specifically aimed at relating faunal change to variation in the chemical composition of river waters, and while this is particularly striking as between certain areas, for example the acid waters of the Western Cape (Harrison & Agnew 1962) and the well buffered, alkaline waters of the remainder of the Republic, studies within these alkaline waters themselves have not been altogether fruitful. For this reason the subsequent sections of this thesis attempt to interpretate the physical, chemical and biological data against a background of current, biotope position and the eroding or sedimenting nature of the river, since they have been considered by the author to be immediately relevant, although admittedly we are still poorly equipped as regards the detailed biology of most of the species with which this study is concerned.

PART 2

STUDIES ON THE STREAMS AND RIVERS OF THE CATCHMENT OF VAAL DAM

The background to the studies

Vaal Dam is a large storage reservoir which has been built across the Vaal River to ensure that, in spite of the seasonal nature of the rainfall and the consequent highly variable flow of water in the Vaal River, there is always an adequate supply of water for the large areas of the country which use the Vaal River as a source of supply. These include the Witwatersrand complex, that is Johannesburg, Pretoria and the mining towns of the southern Transvaal, Kimberley and the Vaal Hartz irrigation area. The studies which are presented here were part of a comprehensive study of the quality of the waters, and of the factors which affect the quality, in the streams and rivers which flow into Vaal Dam. These studies included not only the chemistry of the water but also the flora and fauna of the rivers. The investigations into the purely chemical aspects of the water quality have been published (Malan, 1960); Mr. R.E.M. Archibald is at present making a study of the diatoms and the results of the zoological studies are presented here. In order to be able to relate changes in the fauna to changes in the quality of the water it is necessary, except where there is gross organic pollution or poisoning of the water, to have a background knowledge of the major factors, in addition to water quality, which may bring about changes in the fauna. This study is therefore an attempt to relate changes in the fauna to changes in the environment, one of the many facets of which is the chemical quality of the water.

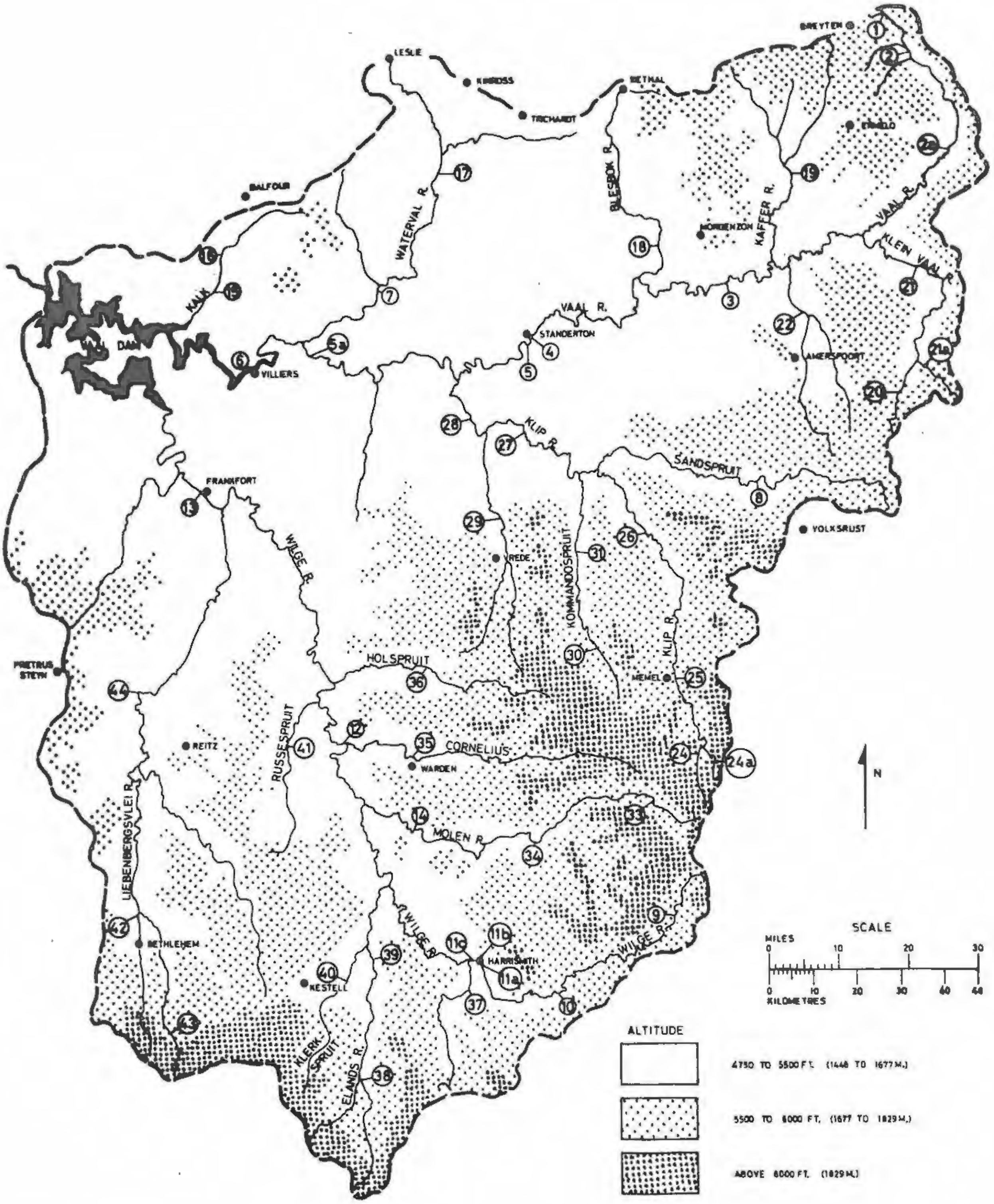


Figure 9. Water courses, topography, sampling points (numbered) and towns in the Vaal Dam Catchment.

Methods and apparatus

Field methods

Sampling points were established on the streams and rivers of the area, taking the results of Malan's chemical studies into account. At some of these the fauna and environment were studied at monthly intervals, while at others sampling visits were less frequent (see p. 58 below). Wherever possible the fauna of the stones in current, marginal vegetation, stones out of current or stony backwaters and sediment biotopes was sampled.

A one square foot Surber sampler (Surber 1936) was used to sample the fauna of stones in current biotopes, but where the water was deep enough to cover the upright frame of the Surber sampler, a hand net of 25 cm (10 ins) diameter was used. Stony backwater and marginal vegetation biotopes were sampled with the hand net. In the marginal vegetation the hand net was swept vigorously back and forth so that each area of vegetation sampled was covered twice, once in each direction. Rough estimates of the length of the fringe of vegetation sampled were made by eye. Bottom sediment samples were collected with a hand operated Ekman grab (mud) or with the scoop used by Allanson (1961) (sand and gravel samples). The subsequent treatment of samples was the same as that described by Harrison et al (1963). The netting used on all biological field sampling apparatus was the same as that used at Warrenton, that is bolting silk with 23 meshes/cm and an average opening of 0.29 mm.

Water samples, taken to supplement Malan's chemical study, were collected in dark screw cap bottles following standard procedure and stored in an insulated ice box until arrival at the laboratory where they were immediately placed in a cold room. These precautions were taken in order to suppress changes in the water due to biological

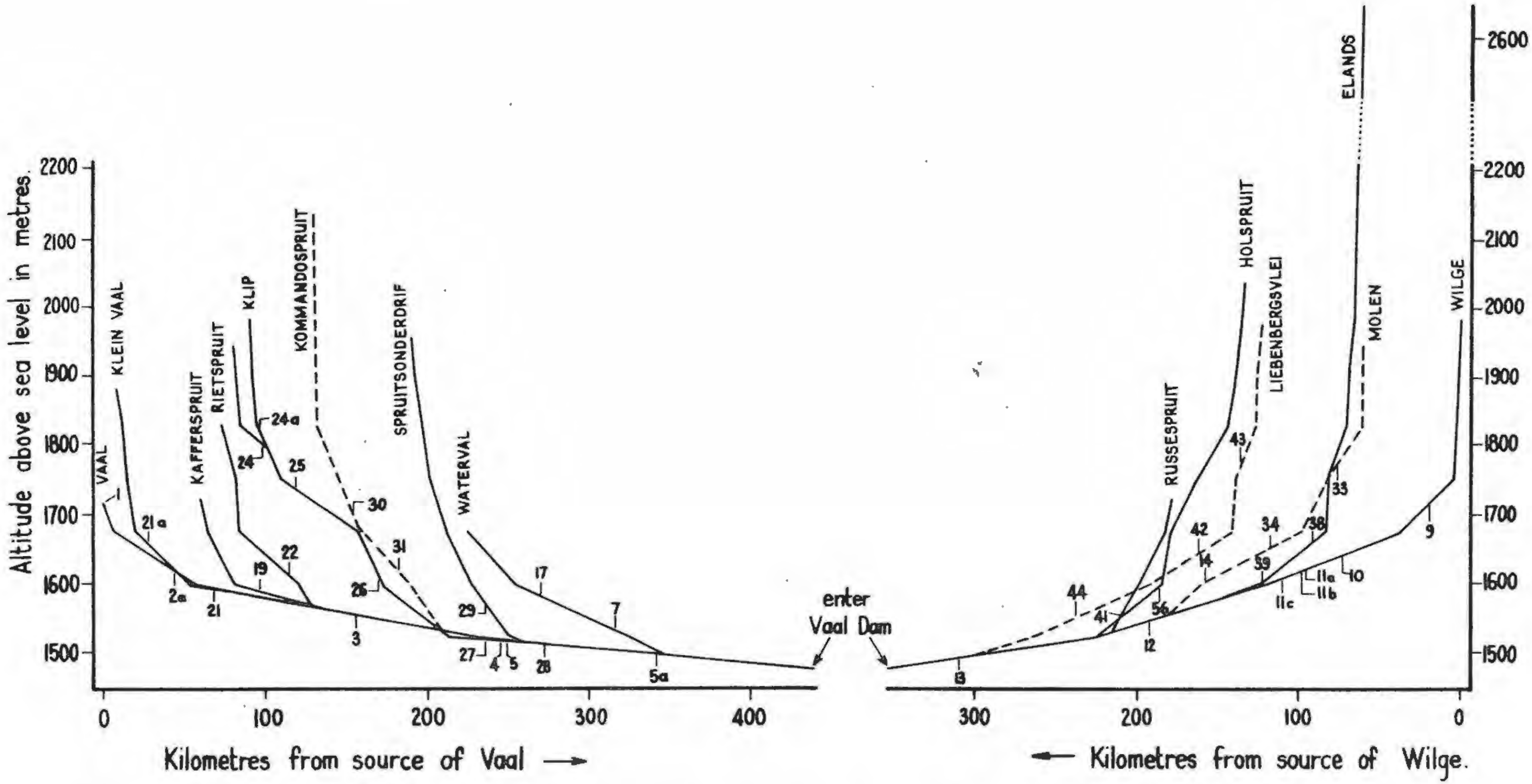


Figure 10. Profiles of Vaal Dam Catchment streams and rivers, showing the position of sampling points.

- - - - - is sometimes used to avoid confusing one river with another.

activity. Field trips lasted four days and the mercuric chloride method for the preservation of water samples for chemical analysis (Hellwig 1964) was at that time unknown.

Temperatures were measured in the field with a mercury thermometer in flowing water where possible, but at sampling points where there was no perceptible flow the bulb of the thermometer was held about 5 cms below the water surface. Current speeds were measured with an Ott Laboratory Minor propellor driven current meter. pH was measured in the field with a portable glass electrode meter to begin with, but as this proved to be unreliable a Lovibond comparator was subsequently used with chloro-phenol red, bromo-thymol blue, phenol red and thymol blue indicators covering the pH range 4.8 to 9.6.

Laboratory methods

Methods used in the analysis of water samples were the same as those used by Allanson (1961) with the following additions and exceptions:-

Nitrate nitrogen was determined by the method of Müller and Widemann (1955),

Sulphates were determined by the method of Vosloo & Sampson (1958),

Oxygen absorbed from $KMnO_4$ was determined by the method of the South African Bureau of Standards (1951),

Kjeldahl nitrogen was determined by the methods given in "Standard methods for the examination of water, sewage & industrial wastes", American Public Health Association, New York. 10th edition 1955.

Methods used for analysis of biological samples were based on a sub-sampling technique described by Allanson and Kerrich (1961)

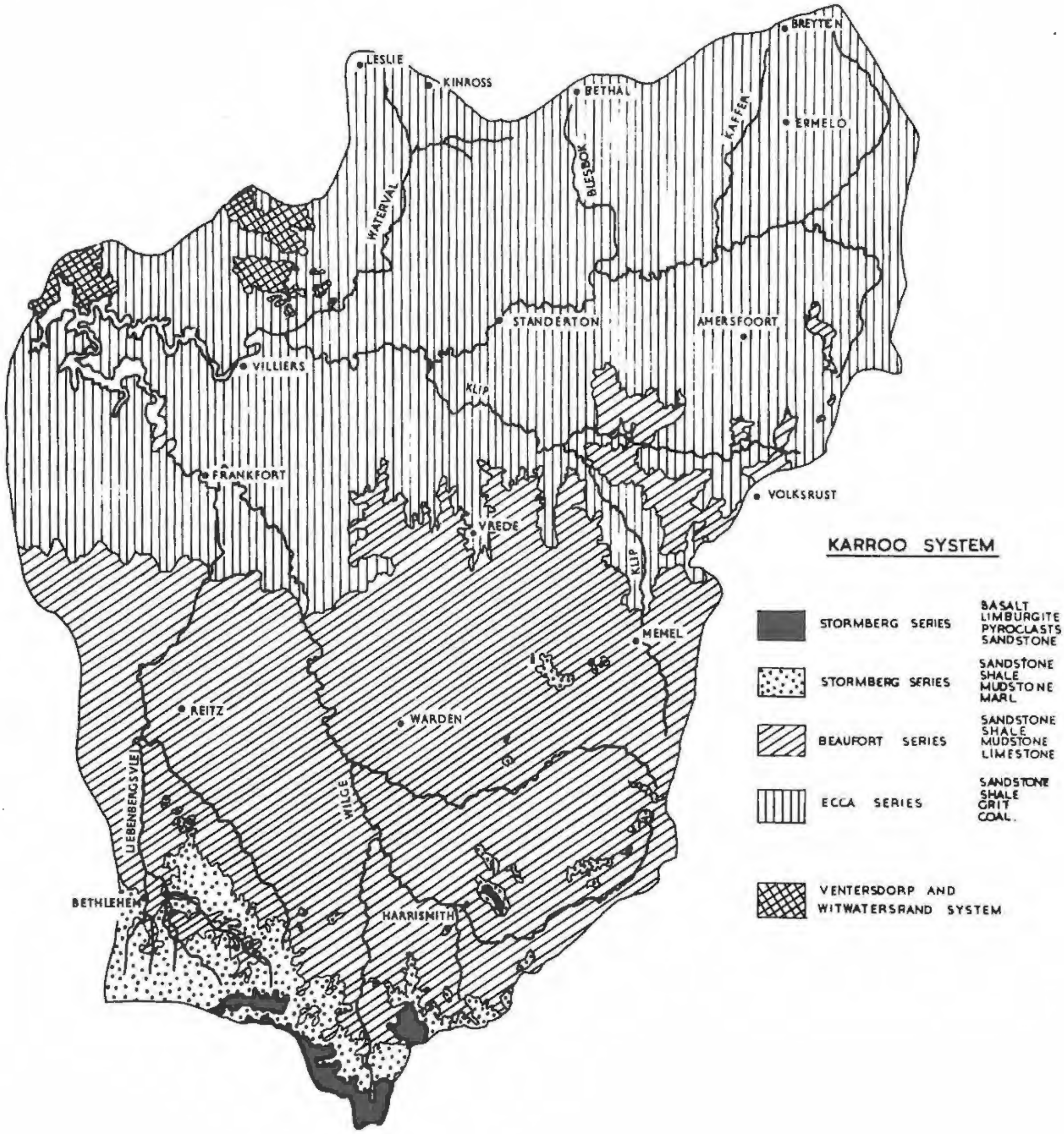


Figure 11. Geology of the Vaal Dam Catchment (From a 1:1,000,000 geological map of South Africa published by the Government Printer, Pretoria. 1955 geological survey.)

and were the same as those used in an earlier study (Chutter, 1963).

Methods used in the physical and chemical analysis of bottom sediments are given where the sediments are described.

A general description of the catchment of Vaal Dam

The catchment of Vaal Dam covers about 38,000 sq km of the southern Transvaal and north-eastern Orange Free State. The greater part of the area is gently-rolling country lying between 1,450 m (4,750 feet) and 1,753 m (5,750 feet) above sea level (Fig. 9). The high lying ground of the catchment is in the south-east and south, where a tributary of the Wilge River rises on the northern slopes of Mont-aux-Sources, whose eastern slopes carry the headwater streams of the Tugela River. The western, northern and north-eastern boundaries of the catchment are however not mountainous, so that the rivers which rise in these parts do not fall steeply from their sources (Fig. 10, Vaal, Kaffersspruit and Waterval Rivers).

Geological formations of the Karroo System, namely the Ecca, Beaufort and Stormberg Series, underlie nearly the whole of the catchment (Du Toit, 1954). The distribution of these series (Fig. 11) is closely related to the topography of the area (cf Figs. 9 and 11), the highest lying ground belonging to the Stormberg Series. A characteristic feature of the Karroo System is the occurrence of numerous intrusive dykes and sills of igneous rock known as Karroo Dolerite. This dolerite is less easily eroded than the sedimentary rocks of the Karroo System with the result that nearly all the runs, stickles and cascades (Allen 1951) in the streams and rivers of the Vaal Dam Catchment are found where the water courses cut through dolerite dykes or where sills are exposed in the bed.

On the foothills of the mountains along the south-eastern

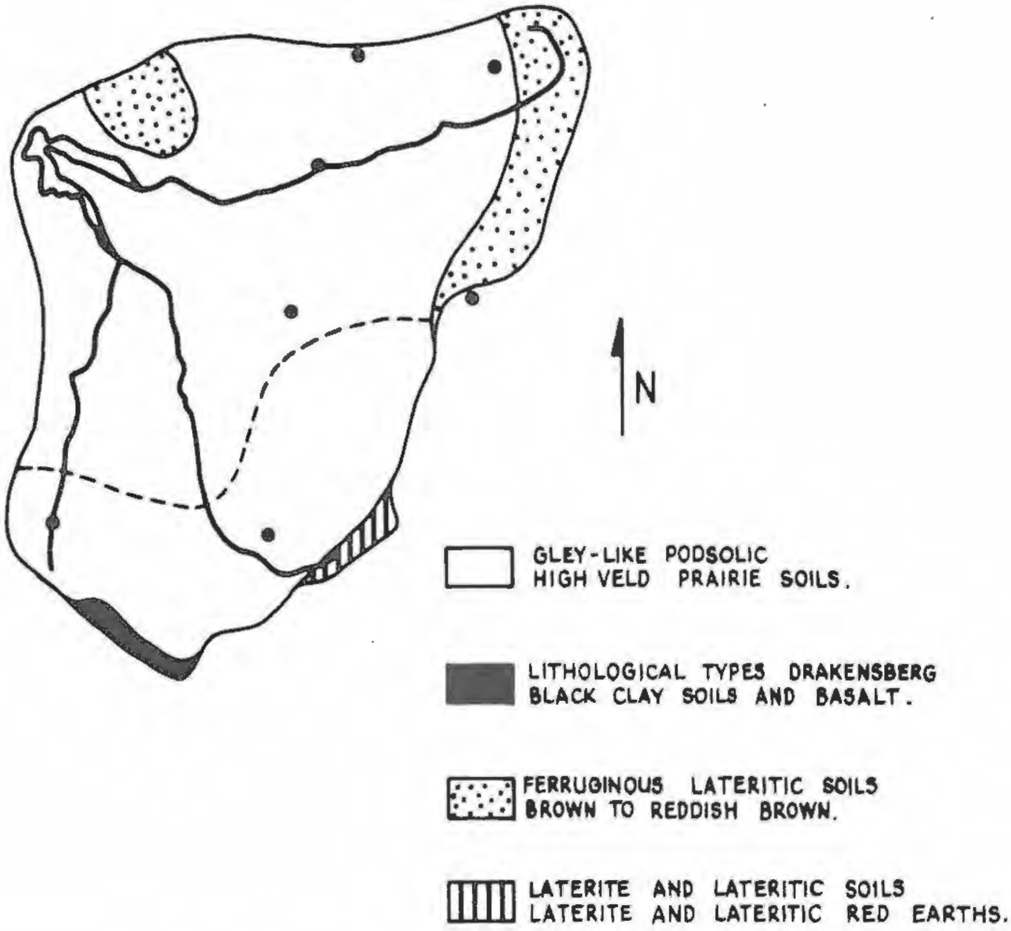


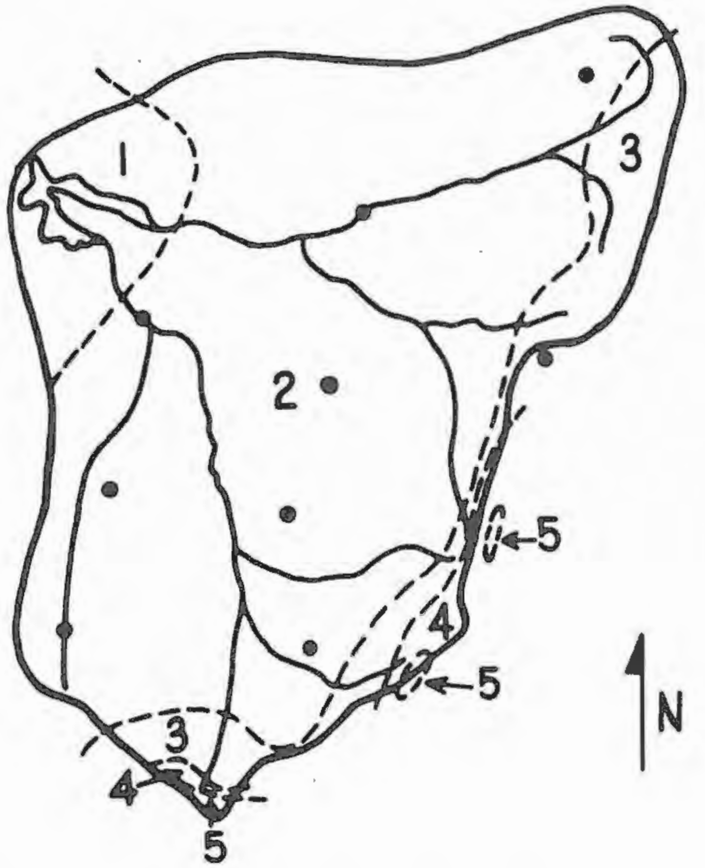
Figure 12. Soil types in the Vaal Dam Catchment
(From van der Merwe, 1941.)
----See text p. 48.

border of the Vaal Dam Catchment the High Veld Prairie soils are more sandy and the horizons thicker than in the northern part of the area (van der Merwe, 1941). The broken line in Figure 12 indicates the approximate limit between the more and less sandy soils. These differences in soil characteristics have an important bearing on the type of sediments found in water courses.

The catchment lies in a summer rainfall area and 80 to 85 per cent of the annual precipitation occurs between October and March (Weather Bureau 1954). Most rain falls on the high-lying south-eastern area and the western parts of the catchment are the driest (Fig. 13). The reliability of the rainfall is high by South African standards, the annual rainfall varying from 60 per cent to about 160 per cent of the normal rainfall. Over 90 per cent of the summer rain falls from thunderstorms which often yield heavy downpours of short duration. In most winters there are falls of snow on the mountains to the south and south-east of the catchment.

During the summer, flows of the streams and rivers fluctuate widely and rapidly, due to the thunderstorm origin of the rain (Fig. 14). After the summer, flows are far less variable and show a gradual decrease from the end of the rainy season through the dry winter until the rains commence again (Figs. 15 & 6).

The two main water-courses in the Catchment of Vaal Dam are the Wilge River, which rises in the south and flows northwards, and the Vaal, which rises in the east and flows westwards (Fig. 9). These two rivers are about the same size when they enter Vaal Dam. The main north-bank tributaries of the Vaal are, from west to east, the Waterval River, the Blesbokspruit and the Kafferspruit; the larger south-bank tributaries are the Klein Vaal River and the Klip River which are each about the same size as the Vaal River where



AREA 1. 601 - 700 mm. (24" - 28").
2. 701 - 800 mm. (28" - 32").
3. 801 - 1000 mm. (32" - 40").
4. 1001 - 1250 mm. (40" - 50").
5. 1251 - 1500 mm. (50" - 60").

Figure 13. Vaal Dam Catchment.
Normal Annual Rainfall.

they join it. The Holspruit and the Cornelius and Molen Rivers join the Wilge River from the east and the Elands and Liebenbergsvlei Rivers join it from the west. The Liebenbergsvlei River is long, but it lies mainly in the drier part of the Catchment and its own catchment is narrow, so that its flow is small. On the other hand the Elands River headwaters are in a high rainfall area and the river is large in relation to its catchment area.

Over the greater part of the Vaal Dam Catchment human activities are mainly directly concerned with, or dependent on, agriculture. Extensive areas in the Vaal valley and in the lower Wilge valley are devoted to cultivation, the main crops being maize and sunflowers. In the more hilly country from Ermelo round to Bethlehem mainly stock farming is carried out. The larger towns in the area, Bethlehem, Harrismith, Ermelo and Standerton, have all attracted secondary industries, such as milk processing, dependent on agriculture. In addition there are textile factories at Standerton and Harrismith. There are gold mines in the area between Leslie and Kinross and coal mines in the Ermelo district and at Grootvlei near the Vaal Dam.

The zonation of the streams and rivers of the Vaal Dam catchment

The Vaal and the Klein Vaal Rivers were the only Vaal Dam Catchment Rivers whose sources were visited. The source of both rivers was a sponge from which water drained into a muddy bottomed pool. In the summer the pool at the head of the Vaal was succeeded by a grassy furrow through which the water flowed into another pool, and so on until the stream was out of sight. In the winter (dry) season these pools of water persisted but were no longer connected by a surface flow of water. Sponges are probably the usual sources of streams and rivers in the Vaal Dam Catchment. The sponge and

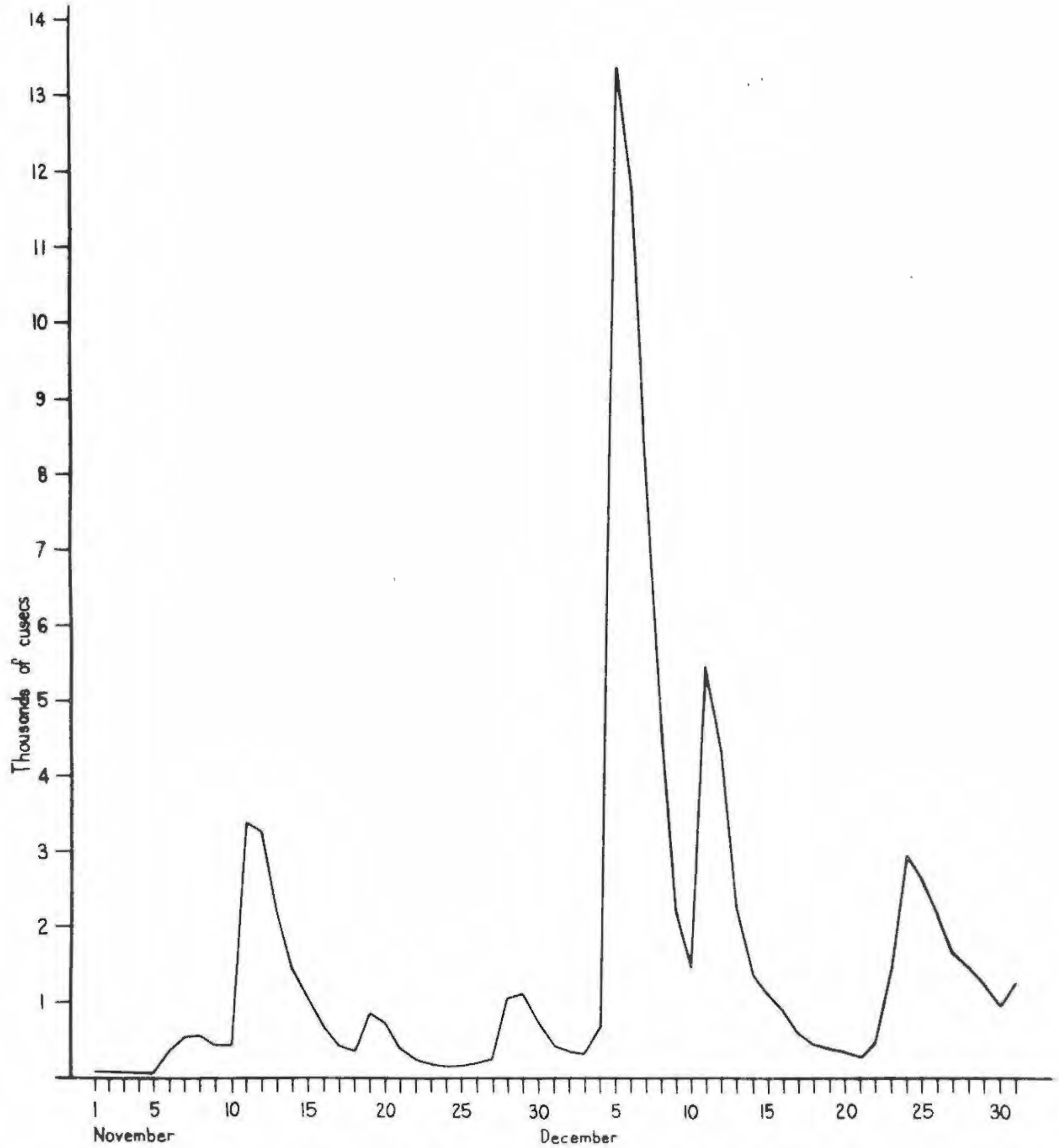


Figure 14. The daily rate of flow of the Vaal River at Standerton in November and December 1958.

pools at the headwaters of the Vaal River constitute its Source Zone.

Moon (1939) suggested that rivers could be divided into three major regions on the basis of the amount of silt deposited in their beds. The upper reaches of a river, where the profile is steeper, forms the erosion zone. Here the stream bed is stony and deposition of silt and sand is at a minimum. This is followed by an intermediate zone in which the profile is less steep and areas of erosion and deposition alternate. Finally there is the deposition zone where the profile of the river is nearly flat and where silt is deposited.

Up to a point this way of looking at the changes taking place in rivers can also be applied to the rivers in the Vaal Dam Catchment. The main differences between the type of river that Moon described and the Vaal Dam Catchment rivers arise out of the seasonal nature of the rainfall, which results not only in great fluctuation in flow but also, by comparison with European conditions, severe soil erosion and high rainy season turbidities, and the fact that sand, in addition to silt, occurs in large quantities in the lower reaches of the rivers. Moreover soil erosion has resulted in deposition zones in streams where eroding zones might otherwise be expected.

The course of the Klein Vaal/Vaal River illustrates the changes taking place down a river in the Vaal Dam Catchment. At Station 21a, the uppermost sampling point, the stream was eroding (Plate VII). There were no growths of semi-aquatic or fully aquatic macrophytes because the bed was stony, and there were no banks of silt or sand on which such vegetation might take root. Pools were deep and the stream bed was filled by the winter (dry season) flow.

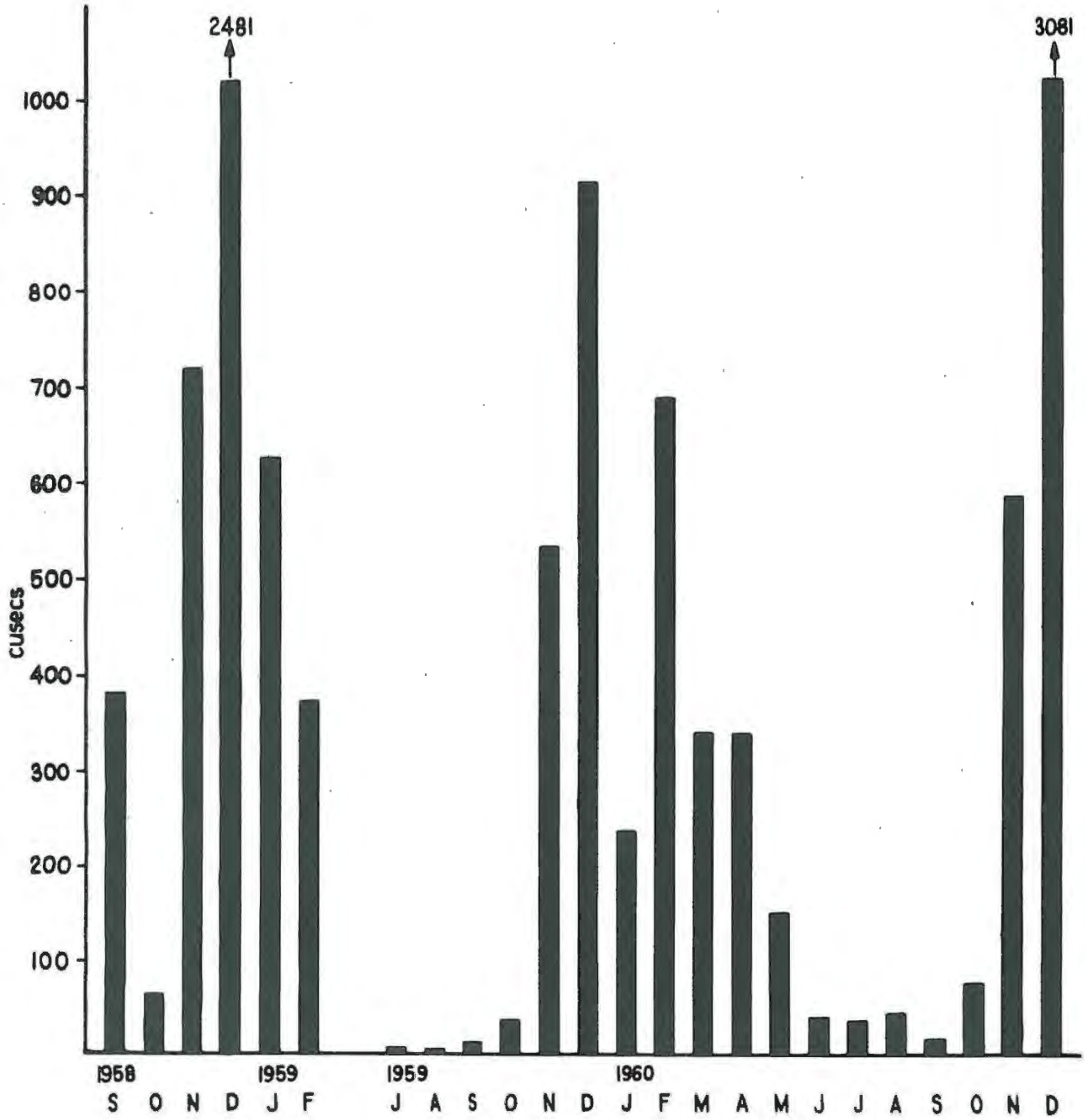


Figure 15. The monthly rate of flow of the Vaal River at Standerton, for the periods when samples were collected.

At the next sampling point downstream, Station 21, deposition had started to take place and there were now growths of semi-aquatic plants, predominately Cyperus fastigiatus Rottb. on the banks of the stream (Plate VIII). Where mud or gravel occurred in the stream bed there was Potamogeton thunbergii Cham. & Schlechndl. in the flowing water, and Nitella, Crassula natans Thunb. and Lagarosiphon in the quieter parts. A moss, Fissodens capensis (C.M.) Broth., grew on many stones in the current. There were still stony bottomed pools, but the stones on the bottom of the pools were covered by a thin layer of fine silt. As at Station 21a the dry season flow at Station 21 was sufficient to fill the river bed. Between Stations 21 and 3 the river changed considerably and from Station 3 downstream large sand and mud banks, devoid of higher plants, were present. Fringing truly semi-aquatic plants were very few and limited mainly to Scirpus, a tough plant which was most often found growing on stony islands (Plate IX). The dry season flow was not sufficient to fill the river bed and sand banks were exposed, while there was usually a fringe of mud at the water's edge. Plate X illustrates dry season conditions in the lower reaches of Vaal Dam Catchment rivers rather more clearly than Plate IX, as it shows the exposed fringe of mud.

Stones in current occurred all the way down the Vaal River to Vaal Dam, though they were far more widely separated in the lower reaches of the river than in the upper. Strictly speaking the river from Station 21 downstream therefore falls into Moon's zone where erosion and deposition alternate. However, deposition predominated to so great an extent in this area that it will be called the depositing zone.

The depositing zone in the Klein Vaal/Vaal River was then divided into two distinct parts, an upper zone where plant growth was a marked feature and a lower zone characterised by a lack of plants and naked sand and mud banks. The difference between this upper and lower zone is probably a result of the interaction of several factors which arise out of the seasonal nature of the rainfall and soil erosion. The seasonal rainfall causes a seasonal fluctuation in flow. When once soil erosion begins not only is the amount of silt and sand washed into the river bed increased, but also the rapidity with which rain water reaches the river increases. Floods become sharper and this contributes to instability in the bed of the river. At the same time the river bed becomes more and more choked with sand and silt washed into it. The turbidity of the flood water rises. The high rate of run off means that less rain water is absorbed by the land to be slowly released into the rivers from sponges and springs. The difference between the dry and wet season flow is accentuated by this and the river no longer fills its bed in the dry season. The lack of aquatic vegetation in the lower depositing zone of the Vaal River may therefore be ascribed to heavy floods, sand abrasion, instability of deposited material, very great fluctuations in water level and high turbidity. The upper depositing zone is called the Stable Depositing Zone and the lower depositing zone, the Unstable Depositing Zone.

The distribution of these zones in the streams and rivers of the Vaal Dam Catchment was fairly closely related to the profiles of the rivers. Thus the Vaal River downstream from between Stations 2a and 3, the Klip River downstream from between Stations 26 and 27 and the Wilge River downstream from between Stations 10 and 11a were all Unstable Depositing Zone rivers, and their profiles were gently falling (Fig. 10).

The Eroding Zone extended a long way down the Klip River, that is to beyond Station 26. This was undoubtedly related to the longer distance over which the profile (Fig. 10) of this river fell comparatively steeply. However, in the southern part of the Catchment, where soils are more sandy (Fig. 12), there were a number of streams of comparatively steep profile with beds typical of the Unstable Depositing Zone. These were the Kommandospruit at Stations 30 (Plate XI) and 31, the Molen River at Stations 34 and 14 (Plate XII), the Klerkspruit at Station 40 and the Elands River at Station 39 (Plate XIII). Plate XIII clearly shows the particularly severe silting up of the Elands river, whose bed has reached the stage where pools are completely obliterated. Further upstream at Station 38 the bed of the river consisted of small rounded pebbles between which there was sand and silt. Pools were being gradually filled with these pebbles and there was marked bank erosion. In the catchment of these streams there was probably unusually heavy soil erosion.

Another effect of unusually heavy soil erosion was found at Station 19, in the north-eastern part of the catchment, where the soils are less sandy. At this sampling point the profile of the Kafferspruit falls gently (Fig. 10) and there was an unusually large deposition of very fine silt. The tops of stones out of the current were covered by a layer of silt up to a centimetre thick and the Ekman grab would sink into the muddy bottom until it disappeared. There were no fully submerged aquatic plants, such as Potamogeton and Lagarosiphon, but there was a more or less continuous fringe of semi-aquatic plants on the banks of the stream. This sampling point was intermediate between the Stable Depositing Zone and the Unstable Depositing Zone in that submerged aquatic plants had disappeared but there was still a fringe of semi-aquatics. Its marginal vegetation suggests that sand may be essential to bring about a change from typical Stable Depositing Zone conditions (Plate VIII) to typical Unstable Depositing Zone conditions (Plate X).

These Unstable Depositing Zones which occurred where stream profiles indicated that Eroding or Stable Depositing Zones should have been expected have been called the <u>high-lying</u> <u>Unstable</u> <u>Depositing</u> <u>Zones</u> to distinguish them from the other <u>Unstable</u> <u>Depositing</u> <u>Zones</u>, which have been simply called by this name or have been called the <u>normal</u> or the <u>low-lying</u> <u>Unstable</u> <u>Depositing</u> <u>Zones</u>.

Stable Depositing Zones with plant growths as profuse and varied as those at Station 21 were found nowhere else in the streams and rivers of the Vaal Dam Catchment. However, Station 2a (on the Vaal River) and Station 10 (on the Wilge River) can be considered as belonging to the zone. At both these points there was rather more deposition than at Station 21, but there was fringing semi-aquatic vegetation and some fully aquatic plants.

Within the Unstable Depositing Zone, dams, weirs and in some instances dolerite sills resulted in some stability in the river beds and above such obstructions the banks of the rivers supported a growth of fringing semi-aquatic plants. The change brought about by a weir was particularly marked in the Wilge River at Harrismith. At Station 11a the river was canal-like, fringed with willow (<u>Salix</u> <u>babelonica</u>) trees, <u>Phragmites</u> and <u>Cyperus</u>. This canal-like stretch was the result of a weir about 300 metres above Station 11b. Immediately below the weir the river bed became a steep-banked, sandy channel about 5 metres below the level of the surrounding country. There were a few willows immediately below the weir but then none to where the river passed out of sight.

There is an anomaly in the succession of zones down the Klein Vaal/Vaal River. There is first of all an Eroding Zone of comparatively steep profile, then a Stable Depositing Zone of less steep profile and finally an Unstable Depositing Zone where the profile is least steep. It might be expected that the stability of the river bottom would increase as the profile became flatter. The Stable Depositing Zone should on the basis of river profile therefore be found below, and not above, the Unstable Depositing Zone. However, the stability of river beds in the Vaal Dam Catchment is intimately bound to soil types, agricultural practice and the extent of soil erosion. The more hilly areas in the southern and south eastern part of the Catchment, from the Klein Vaal River to the As River (Fig. 9) are primarily stock raising areas, while the remainder of the Catchment is mostly given over to arable farming, particularly in the river valleys. The soils are sandy in the southern part of the catchment (Fig. 12), and from the occurrence of Unstable Depositing Zones in this part of the Catchment (see above) it is obvious that these soils erode easily no matter what type of farming is carried out on them. The sediments found at Station 3 show that considerable soil erosion takes place above this station, which is above the confluence of any major tributary of the Vaal River from the area of sandy soils. This suggests that arable farming in the area of the less sandy soils also leads to large scale sediment deposition in the river beds. However, the combination of agriculture and soil type in the Klein Vaal River catchment is unique - predominately stock farming on less sandy soils. Soil erosion is less severe than elsewhere with the result that as soon as the river bed flattens out profuse growths of semi-aquatic and fully aquatic plants appear. It might well be that, were the amount of soil erosion in the remainder of the Vaal Dam Catchment similar to that taking place in the Klein Vaal River catchment, then there would be no division of the Depositing

Zone into stable and unstable sections.

Seasons in the Vaal Dam Catchment

As was the case in the Vaal Barrage study (Chutter 1963) inspection of the sample data has revealed that the greatest changes in the composition of the fauna occurred with the first summer spates in the streams and rivers. Spring and autumn pass very quickly in the Vaal Dam Catchment. For purposes of describing seasonal changes in the fauna as a whole, the year has therefore been divided into three seasons, as follows:-

1. Winter - from late April to August. This is a period during which spates very seldom occur and flows gradually fall off. The water becomes clear and algal and diatom growths appear.
2. Dry early summer - from September until widespread and heavy summer rains. In 1958 and 1960 the summer rains came after the October field trip, but in 1959 they were later, coming after the November field trip. Water temperatures rise during this period, the water is clear to slightly cloudy, flows are low and steady and growths of algae and diatoms are usually profuse.
3. Summer - from the first heavy summer rains to March. Flows fluctuate widely and rapidly, the water never loses its turbidity in the lower reaches of the rivers, and algae and diatoms are virtually absent.

The sampling programme and sampling points

Sampling stations were established on all the major streams and rivers in the Catchment (Fig. 9) and during a preliminary study of the area all sampling points were visited, and the fauna sampled. This preliminary study lasted from September 1958 to February 1959 and during this period monthly samples were collected from Stations 1 to 14, the remaining sampling points being visited as opportunity arose. As a result of this study it was decided that attention should be directed towards a detailed study of the Vaal, Klein Vaal and Waterval Rivers and the Kafferspruit, and from July 1959 to October 1960 sampling of these streams was carried out at more or less monthly intervals. Finally in August 1961 samples were collected from most of the other sampling points in the catchment, so that conditions at these sampling points were investigated at least once in the summer and once in the winter.

Sampling points are shown in Figure 9, and they are easier to follow if the system adopted in numbering them is given. This was as follows:-

1. from the headwaters of the Vaal River down to Vaal Dam (Stations 1 to 6),
2. tributaries of the Vaal River which seemed important from Malan's (1960) chemical study (Station 7 on the Waterval River and Station 8 on the Sandspruit),
3. from the headwaters of the Wilge River down to Vaal Dam (Stations 9 to 13),
4. tributaries of the Wilge River which seemed important from Malan's (1960) chemical study (Station 14 on the Molen River),
5. starting from the north west corner round the Catchment wherever the large streams were crossed by major roads (Stations 15 to 44).

As a result of findings of the preliminary study some additional sampling points were deemed necessary and these were given an alphabetical suffix (e.g. Station 2a) while others were omitted from the more detailed studies. The position of each sampling point is described in Table 11.

Water temperatures

Nowhere in the Vaal Dam Catchment were water temperatures under continuous observation, and readings made on field trips are the only data available. Since these were not made simultaneously they can only be used to show the broader trends of temperature change in the streams and rivers of the area. It should, however, be borne in mind that far more visits were made to sampling points on the Vaal River and its north bank tributaries and to the Klein Vaal River than to other parts of the catchment, so that means (Table 12) are weighted in favour of conditions in these parts. Mean temperatures tended to be lowest in the Source Zone and, as would be expected, highest in the Unstable Depositing Zone. In winter and summer the difference between the mean temperatures in these two zones was 2°C (Table 12). Eroding Zone mean temperatures were of the same order as Unstable Depositing Zone temperatures except in the winter. In the dry early summer and the summer mean temperatures in the Stable Depositing Zone were lower than those in the zones above and below it, possibly because this was a zone where pools were comparatively deep and also because there was some shading of the rivers by trees at Stations 21 and 10, two of the three sampling points in this zone. Shading was not often met with in other zones and it is known (Edington 1965) that shading can appreciably lower the temperature of streams. In the high-lying Unstable Depositing Zone mean winter and dry early summer temperatures were rather low, possibly because the water in these streams was shallower than elsewhere and would cool rapidly. The mean summer temperature was however no higher than in other zones, though the highest maximum summer temperature (30.5°c) was recorded in this zone. Mean dry early summer temperatures were much closer to mean summer temperatures than to mean winter temperatures showing that this is a time when the water is comparatively warm.

The highest maximum winter temperature (20.5°C) was recorded in the Source Zone, probably due to the fact that the flow ceased there in this season. In the other zones the winter maxima increased the further downstream the zone. In other seasons maximum temperatures were very similar in the Eroding and Unstable Depositing Zones, the Stable Depositing Zone maxima were rather low. In all seasons minimum temperatures were low in the Stable Depositing Zone. Generally speaking the differences between the maximum and minimum temperatures in the Eroding and Unstable Depositing Zone were not large. The low summer temperature after a hailstorm shows the rapid and extreme temperature fluctuations to which the river fauna is exposed. If temperature is an important factor governing the distribution of aquatic animals it therefore does not seem likely that animals are restricted to the upper or lower parts of the river by their tolerances to high or low temperatures. The influence of temperature is far more likely to act through the speed with which the life cycle can be completed at a given mean temperature.

On two occasions water temperatures were measured at hourly intervals for twenty-four hours, and these records indicate the daily range of temperature variation. At Station 4 in mid-April the temperature ranged from 15.0°C to 21.6°C and at Station 17 in early September it ranged from 13.5°C to 18.2°C.

Water chemistry

Malan's (1960) work on the chemistry of the surface waters of the Vaal Dam Catchment showed that they were well-buffered and alkaline with a large part of the dissolved solids made up of the bicarbonates of calcium and magnesium. Sodium, chlorides and sulphates usually occurred in small concentrations. A representative cross-section of Malan's data is shown in Table 13 where it may be seen how the concentrations of dissolved ions increased down the course of the Vaal and Wilge Rivers. The maximum concentrations of sodium, chlorides and sulphates were high in the Waterval River, in the headwater catchment of which gold mines were being developed when Malan's work was done. The mineral quality of this stream underwent further deterioration during the course of the biological studies, as will be shown later.

Malan was unable to show that there were differences in the nature of the water due to the geological formations over which it had flowed. On the other hand he found that the relationship between volume of flow and the concentration of dissolved materials at single sampling points was variable. In the Vaal River at Station 2 (near its source) and at Standerton and in the Wilge River at Harrismith there was no variation in the total dissolved solids concentration with the volume of the flow. However in the Wilge River at Frankfort, in the Klip, Liebenbergsvlei and Molen Rivers and in the Holspruit the concentrations of the bicarbonates of calcium and magnesium rose steadily during prolonged periods of low flow (the winter) and declined markedly in the rainy season.

Malan measured the 5-day Biochemical Oxygen Demand in water samples he collected at monthly intervals. However in view of the way in which he treated his samples (storing them in an ice box for up to two days before starting the analysis) and analysed them (by dilution and inoculation) differences of the magnitude found by Malan (his mean BOD values ranged from 0.7 to 2.9 ppm O_2) may have little meaning. His results would certainly not be comparable with those of workers such as Harrison and Elsworth (1958) who started their analyses in the field. However Malan was justified in drawing the conclusion that at none of his sampling points was there very heavy organic pollution, because this would have resulted in far higher BOD figures than he found.

Malan's study did not include several biologically important aspects of the chemistry of the water and the biological sampling points did not always coincide with the sampling points used by Malan. Further chemical studies were therefore undertaken during the biological studies. The analyses of the water at most sampling points did not differ meaningfully from the general type of analysis reported by Malan, and they are therefore not presented in detail. However at Station 1 the concentrations of dissolved solids were low (mean 36 ppm), and although the most important ions were still calcium, magnesium and bicarbonate, the pH of the water was variable (Table 15) showing that they were not present in sufficient quantities to adequately buffer the water.

Station 17 was the only sampling point where there was a major change in the quality of the water from 1957/58 (Malan 1960) to 1959/60. At this sampling point mean total dissolved solids, chlorides, sulphates and sodium (Table 14) were higher in 1959/60 than in 1957/58. The trend towards deterioration in water quality was continued in a series of daily water samples collected from 1960 to 1961 by the National Institute for Water Research, the results of which have not been published. In this study chlorides and sodium were frequently above 300 ppm, sulphates were frequently above 100 ppm and the total dissolved solids were often between 900 and 1000 ppm. Maximum values for these ions and also for the total dissolved solids were high also (Table 14).

Analysis results for some of the ions and characteristics which Malan did not record are shown in Tables 15 and 16. pH values usually lay in the range 7.0 to 8.5 and at most of the regularly sampled stations (Table 15) concentrations of ammonia, nitrites, nitrates and Kjeldahl nitrogen and the amount of oxygen absorbed from $KMnO_4$ were low.

At all sampling points there was a tendency for the pH to be higher in the winter and the dry early summer than in the summer and this may be related to the amount of algae and microplankton in the rivers. There was no systematic trend of seasonal variation in the concentrations of ammonia or nitrites, but the highest nitrate concentrations were recorded in the winter and the lowest in the dry early summer. The highest 4-hour oxygen absorbed figures were usually recorded in the summer when the turbidity of the water was higher than at other times. Oliff (1960), Harrison & Elsworth (1958) and Chutter (1963) all found that, in the unpolluted parts of the rivers they studied, the 4-hour oxygen absorbed reached a peak in silt-laden waters.

Chemical conditions at certain sampling points require more detailed comment. At Station 1 the high mean Oxygen Absorbed in 4 hours (Table 15) and the high Kjeldahl nitrogen suggest that the water contained larger than usual amounts of organic matter. In the dry season, when the flow had ceased, Station 1 was used as a drinking trough by sheep and cattle and this would account for the enrichment of the water there. Station 4 was situated just below where a milk processing factory effluent, said to be can washing water, was piped into the river. As may be seen in Table 15 this had no obvious effect on the chemical quality of the water, a conclusion which was substantiated by a simultaneous 24 hour study of the dissolved oxygen in the water just above and just below the effluent pipe. At both points the percentage saturation of the dissolved oxygen rose to 110% in the late afternoon and fell to 82% at dawn. However below the effluent pipe there was often a wind-blown scum at the water's edge and there were particularly distinct changes in the flora and fauna of the river, which could only have been due to an alteration of the environment by the effluent.

At Station 5 treated sewage was irrigated on fields sloping down towards the river. However, no direct surface run-off into the river was ever observed, though there may have been underground seepage of this water into the river. The mean values for nitrites, nitrates and Kjeldahl nitrogen at Station 5 (Table 15) were higher than at sampling points upstream (Stations 2a, 3, 4) and had returned to normal levels at the next sampling point downstream (Station 5a).

The Waterval River was obviously enriched with nitrites and nitrates (Station 17, Table 15). Kjeldahl nitrogen was low at the sampling point but was not analysed in the two samples which contained the highest concentrations of nitrates. The mean 4-hour Oxygen Absorbed at Station 17 was higher than at any other sampling point except Station 1.

The turbidity of the water at these regularly visited sampling points was not measured regularly. The rather limited number of measurements made showed that turbidities were low in the winter and the dry early summer, and were usually of the order of 15 ppm on the SiO_2 scale. This contrasted strongly with the summer, when turbidities higher than 100 ppm were recorded. Notes on the turbidity made during field trips suggested that during summer the turbidity could be high anywhere, but that the high turbidities in the Source and Stable Depositing Zones were limited to times when the rivers were flowing strongly. At the other sampling points visited regularly, that is Station 19 in the high-lying Unstable Depositing Zone of the

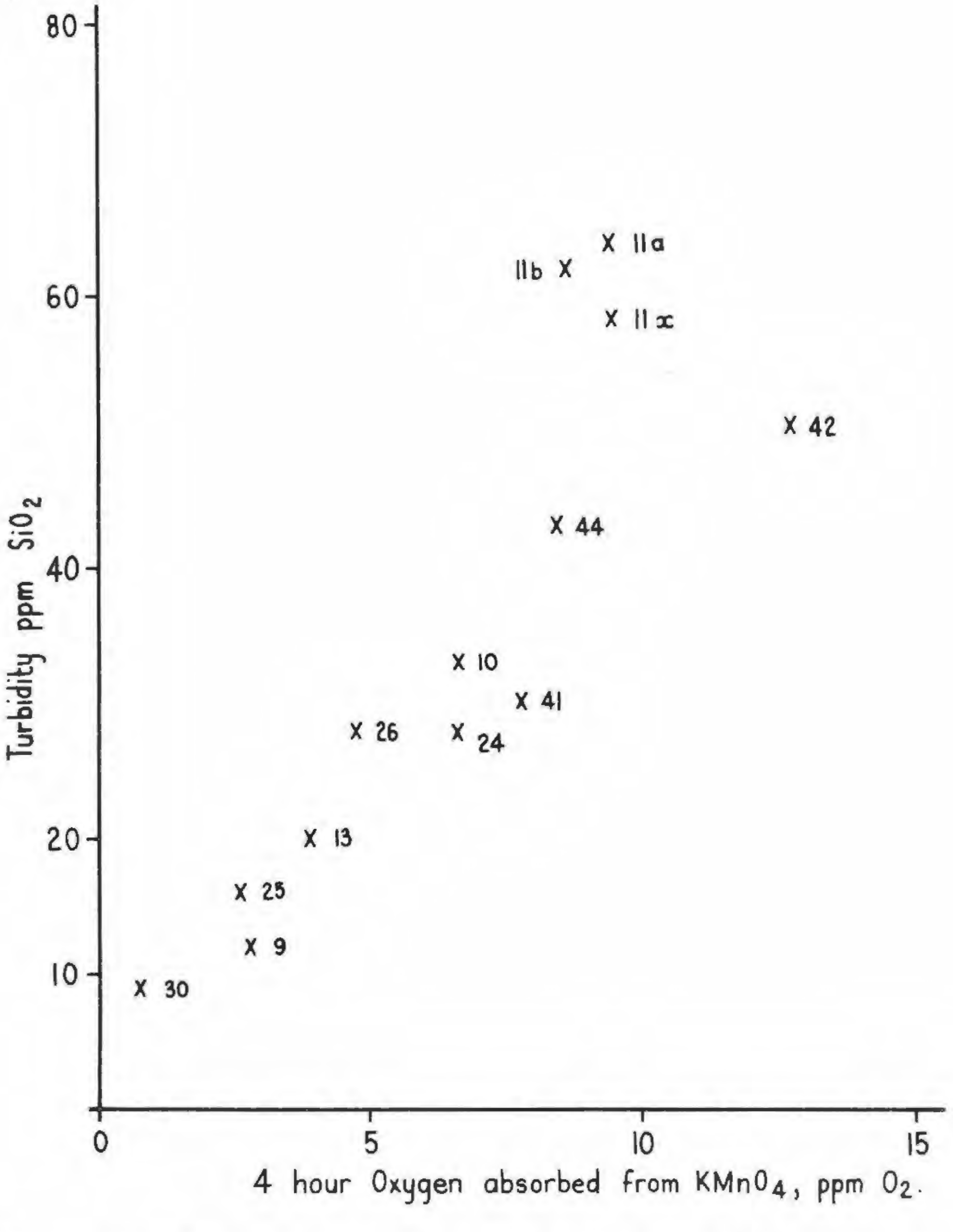


Figure 16. The relationship between turbidity and 4 hour Oxygen Absorbed in a series of water samples drawn from the southern part of the Vaal Dam Catchment, August 1961. Based on data in Table 16 and showing Station numbers.

Kafferspruit and Stations 3 to 5a and 17 in the normal Unstable Depositing Zone, the turbidity remained high right through the summer.

In parts of the catchment area other than those where sampling was undertaken regularly, there was only one opportunity to undertake water analyses to extend Malan's work. This was in August 1961 and the results are shown in Table 16. Weather conditions were unusual in that it rained for nearly the whole four days of the field trip and turbidities were consequently often high for the winter (Table 16). When the turbidity analyses shown in Table 16 are plotted against the 4 hour Oxygen Absorbed values (Fig. 16) it is immediately obvious that they tended to rise together.

Several of the sampling points shown in Table 16 were below potential sources of stream contamination. At Harrismith Station 11a was below some ponds next to the river in which a milk processing factory effluent was treated, while Stations 11b and 11x were below ponds in which textile factory effluents were treated. Analysis results from these three sampling points suggest that there was seepage of waters rich in nitrogenous compounds and chlorides into the river, most notably at Stations 11b and 11x. The fauna at these sampling points strongly suggested that the chemical quality of the water was not normal. During the preliminary biological survey when no water samples were collected for chemical analysis the textile effluent drained straight into the river above Station 11b.

Bethlehem straddles the upper Liebenbergsvlei River and all waters leaving the municipal area drain down into a large shallow dam about 3 km below the town. Station 42 was below this dam, and the chloride, sulphate, sodium and total dissolved solids concentrations of the water there were rather high. However this was another sampling point where the stream fauna indicated that there was a change in the chemical quality of the water.

Station 41 was on a small stream whose course was relatively low-lying and well away from the mountainous southern fringe of the Catchment (Figs. 9, 10). Compared with other streams its calcium and magnesium hardness were low, but its content of chlorides and particularly sodium were very high for a stream far from any town or village.

A feature of the water at the other sampling points shown in Table 16 is that the total nitrogen ranged from 2.2 to 3.5 ppm which is high by comparison with the regularly sampled stations (Table 15) and also by comparison with other uncontaminated rivers in South Africa (Oliff 1960a, Harrison & Elsworth 1958). The chloride concentrations shown in Table 16 were high by comparison with Malan's (1960) data, but other analysis values were of the same order as Malan's.

The sampling points where there was chemical, biological or circumstantial evidence that the chemical quality of the water was altered by effluents were therefore Stations 4 and 5 on the Vaal River at Standerton, Stations 11a, 11b, and 11c on the Wilge River at Harrismith, Station 17 on the Waterval River and Station 42 on the Liebenbergsvlei River below Bethlehem. In describing the fauna found in the streams and rivers it has been found convenient to separate off this group of sampling points and for this purpose they have been called the sampling points where the chemical quality of the water was not normal or abnormal.

THE FAUNA

General remarks

A considerable problem in the presentation of the biological data arising out of river surveys is to decide which data have biological meaning in terms of the aims and objectives of the study and which data may be ignored. Harrison and Elsworth (1958, p. 170) laid down criteria for the selection of species, the aim of which was "to select species from the biotopes which really belonged there and to eliminate casual migrants from the discussion". On the other hand Allanson (1961) considered species which were likely to be collected in a repetition of the sampling to be important and his basis for selecting species was therefore aimed at discarding species unlikely to be collected in repeated sampling.

The aims and objectives of this study were to increase our knowledge of the factors governing the major faunal changes taking place along the course of the rivers, and also through the seasons of the year, in the commonest biotopes. It is desirable therefore to take as many kinds of animals into account as possible to achieve these aims, but at the same time it is not desirable to base interpretations on data which includes species so rare that there is not a high probability of encountering them again. The author's reasons for selecting species are therefore the same as Allanson's. However the basis on which Allanson recognised such species included an assumption of the way in which the proportion of a single species would vary in a set of replicate samples. In the paragraphs which follow the criteria used by Harrison and Elsworth and by Allanson to recognise the species they selected are re-examined.

Harrison and Elsworth called their selected species "significant". Their significant species were those animals which

1. constituted more than 5 per cent of the total fauna in one or more samples in a season, or,
2. occurred in lower percentages in two or more of the

samples in a season (there were three samples per season).

Criteria very similar to those are arrived at here to recognise the species likely to be collected in a repetition of sampling.

Allanson called the species he selected 'common'. Basing his analysis on an assumed binomial distribution of the proportion, p, that a species would constitute of the fauna collected in a single sample in a set of replicate samples, he showed that as the size of samples increases the confidence limits of estimates of p become narrower. In samples containing more than 587 individuals, species constituting 1 per cent or more of the fauna could reasonably be expected to be found 19 times out of 20 in replicate sampling. Since his samples were always larger than this he defined common species as those species whose percentage in individual samples was 1 or >1 for at least three consecutive months in a season. The stipulation of at least three consecutive months was made especially to omit those species "which bloom rapidly and die down equally rapidly". Since Harrison and Elsworth used a net of wider mesh than Allanson, their samples usually contained less than 578 individuals. For these smaller samples Allanson was able to suggest that animals constituting 5 or more per cent of the fauna were those likely, in 19 cases out of 20, to be collected in replicate sampling. This then apparently added a further meaning to Harrison and Elsworth's choice of 5 per cent in their definition of significant animals.

It is unfortunate that Allanson did not have a set of suitable sized replicate samples with which to test the validity of his findings. Chutter and Noble (1966) took ten separate square foot samples from a stony run in the Vaal River at Standerton in order to test the reliability of their sampling method. Since the sampling method and apparatus was the same as that used by Allanson in this type of biotope and since the numbers of animals in the individual samples varied between 778 and 2831 (mean 1633), then following Allanson's criterea for the recognition of "common" species it should be expected that:-

1. Species not found in all samples should very rarely exceed 1 per cent of the numbers of individuals in separate samples.
2. Species found in all ten samples should exceed 1 per cent of the animals in each separate sample always or very nearly always (in 19 samples out of 20).

The analysis of Chutter and Noble's data in Table 17 has been made to show how these expectations fit the results of replicate sampling. Only 3 of the 43 species not found in every sample exceeded 1 per cent of the fauna of individual samples. Owing to the fact that one of these 3 species exceeded 1 per cent twice there were four occasions on which percentages of species not found in every sample exceeded 1. The actual percentages were 3.2, 2.5, 1.6 and 1.2. Thus the first of the two expectations based on Allanson's criteria is borne out by the replicate sampling. Approaching the problem solely from the point of view of the first expectation it would be reasonable therefore to assume for practical purposes that no species not found in all of a series of replicate samples would ever exceed a percentage somewhat above 3.2, say 5 per cent, of the fauna of any single sample.

As there were 10 and not 20 replicate samples in Chutter and Noble's data, species found in all 10 samples should exceed 1 per cent of the fauna of individual samples 10, 9 or perhaps 8 times in order to confirm the second expectation arising out of Allanson's findings. However, only 13 of the 26 species found in all of Chutter and Noble's samples exceeded 1 per cent 8 or more times (Table 17). In 8 species 1 per cent was exceeded 3 or less times and one species never exceeded 1 per cent. These data therefore show that the second expectation arising from Allanson's criteria is not correct, because there were too many instances of species found in all the replicate samples not exceeding 1 per cent of the animals in individual samples.

It was concluded earlier that species making up more than 5 per cent of the fauna in an individual sample were almost certain to be present in a replicate sample. The problem, of recognising the many species which make up a very low percentage of the fauna in single samples, but which at the same time are likely to be found in replicate samples remains to be considered. The only way in which data, based on single samples drawn at monthly intervals, may be used to reveal these species is to take account of the number of samples in which the animals were found. In this study the following criteria have therefore been used to recognise the species likely to be found in a repetition of sampling:-

1. Animals found in more than half the samples collected in a season, irrespective of their percentage in individual samples.
2. Animals making up more than 5 per cent of the fauna in single samples, irrespective of the number of samples in which they are found.

These criteria differ from Harrison and Elsworth's only in that species present in more than half the samples in a season are included, the year being divided into three seasons of unequal duration, whereas Harrison and Elsworth's year was divided into four equal seasons and they included species found in two of the three samples in a season.

The author intends to follow Harrison and Elsworth in naming his selected species "significant", because Allanson's "common" species were selected on rather a different basis, and also because it is useful to be able to use the adjective "common", when describing the relative abundance of the different kinds of animals.

Many of the sampling points in the present study were visited only once or twice in a season. In these cases species have been considered significant if they:

1. constituted more than 5 per cent of the fauna in a sample, or,
2. occurred in both samples where two samples were collected, or,
3. occurred in only one sample but were significant at another comparable sampling point where there was more intensive sampling.

Presentation of results

While it is always satisfactory to deal with quantitative data, that is data in which the numbers of animals are directly comparable because they are given as numbers found per unit area or per unit collecting time, it is not always possible to achieve this. In the stones in current biotopes a hand net, which does not yield numbers of animals per unit area, had to be used when the water was too deep for the Surber sampler, and it was always used in the stones out of the current. Sampling for a specified time is not suitable when general collections of the fauna are being made, for either the clinging animals have to be ignored, or removing them from the stones upsets the comparability of the data, as they are not equally abundant at all sampling points or on all sampling occasions. Even where there are quantitative data available it usually has to be used with considerable caution, as it is, as far as is known, not very reliable (Needham & Usinger 1956, Chutter & Noble 1966).

For these reasons many workers (for example Hynes 1961, Harrison & Elsworth 1958, Allanson 1961) have found it convenient to transform their raw data of numbers of animals in samples into percentages of the total numbers of animals in samples. This transformation has been used here and the quantitative data, where they are available, have been considered in order to minimise artificial effects due to the percentage transformation. In the Vaal Dam Catchment data a marked artificial effect was due to the Cladocera and the Copepoda, which occurred in large numbers in the winter and dry early summer and in small numbers in the summer. This resulted in the percentages of all other groups being very low in the winter and dry early summer and then suddenly rising in the summer with the disappearance of the Cladocera and Copepoda. To eliminate this effect the Cladocera and Copepoda have been considered separately, and percentages of the remainder of the fauna calculated omitting these two groups. However, in order to consider these two groups as part of the whole community their percentages have been calculated including all the animals found in samples.

In order to reduce the amount of data to be presented and to make it possible to recognise the principal faunal changes taking place, percentage data for each month have not been given except where faunal change is clearer through giving the detailed figures. Instead the mean seasonal percentage has been used. This is the mean of the percentages of a species in all the samples collected at a single sampling point in any season. It should be noted that the mean seasonal percentage is not arrived at by pooling the untransformed data and then working out the percentages of the various species. This should not be done because, as Allanson (1961) pointed out, the numbers of single species vary too widely from month to month and because the size of samples also varies. The mean seasonal percentage composition of the fauna is shown in tabular form, but only significant species whose mean seasonal percentage exceeded 5 per cent in the particular biotope at one or other of the sampling points concerned are shown. This means that data about significant species whose mean seasonal percentage was never as high as 5 per cent are not tabulated. These species are, however, brought into consideration, when the fauna is described.

Current speed and the stones in current fauna

Current speeds varied both from sampling point to sampling point and also from season to season (Table 18). They were not however closely related to the zones of the rivers. Current speeds were usually lowest in the winter and highest in the summer with the dry early summer speeds intermediate. Mean summer speeds in the Unstable Depositing Zone are probably higher than those shown in Table 18, for in this zone there were many occasions in the summer when the water was flowing too strongly and also too deeply to sample the fauna and to measure the current speed. Some sampling points stand out for the very high or very low current speeds found at them. Sampling points where the current speed was high were Stations 26, 10, 38 and 17, and where it was low were Stations 24a, 24, 2a, 12 and 19.

However before faunal differences are attributed to current speed it is necessary to examine whether, under field conditions there are correlations between the numbers of animals found and the current speed, measured as it was in this study.

Detailed field and laboratory studies of the effect of current speed on the micro-distribution of the aquatic fauna (Ambühl 1959, Scott 1958) have suggested that current speed is extremely important. Ambühl's field investigations showed that, where samples were drawn within a few metres of each other, the current speed profoundly influenced the quantitative composition of the fauna, but that the qualitative composition was very much less influenced by the current. Macan (1963, p. 120), in discussing these field observations, suggested that Ambühl's attribution of the quantitative faunal change to current speed alone may have been an oversimplification, because Ambühl made no allowance for possible biotic effects and because he (Macan) had never seen such clearcut differences in nature. On the other hand Zimmerman (1961) found that there were considerable differences in the fauna and particularly in the flora, which developed in three experimental furrows, which were initially similar in all respects other than current speed.

There are at present no studies of the effects of current speed on the stones in current fauna in South African rivers. Both Harrison and Elsworth (1958) and Oliff (1960a) measured current speeds in the rivers they studied, but did not attempt to relate faunal differences to current speed differences, except in the broadest terms. In their study of data obtained with a Surber sampler Chutter and Noble (1966) measured the current speed in each square foot. They did not attempt to correlate the numbers of animals found with the current speed, but this has been done here for two reasons. Firstly to see whether Ambühl's field data can be substantiated or whether Macan's scepticism is justified. Secondly, if any species were significantly correlated with current speed, to recognise those species whose occurrence in the Vaal Dam Catchment samples would be likely to be related to current speed.

Chutter and Noble's samples were drawn from a transect across the Vaal River at Station 5. The samples were numbered from 1 to 10 across the river and the depth of the water increased gradually from about 10 cms (sample 1) to about 23 cms (sample 10). The mean current speeds at each sampling site, which were based on only 3 readings, ranged from 35 to 62 cm/sec. Since the Surber sampler is not a precise sampler, and since 3 readings is a very small number on which to base a mean current speed, a nonparametric correlation coefficient, the Spearman rank correlation coefficient (Siegel 1956) rather than a parametric coefficient, was calculated for five sets of data, which were as follows:-

a) numbers of individuals per sq ft of a species or group of animals and current speed,

b) numbers of individuals per sq ft of a species or group of animals and depth (assuming that depth could be ranked in the same order as the numbering of the samples),

c) numbers of individuals per sq ft of a species or group of animals expressed as a percentage of the total number of individuals in a sample and current speed,

d) numbers of individuals per sq ft of a species or group of animals expressed as a percentage of the total number of individuals in a sample and depth, and

e) current speed and depth.

The correlation coefficient between depth and current speed was 0.682 ($0.05 > P > 0.01$), faster speeds being recorded in deeper water. This significant correlation means that there is a possibility that significant correlations between the fauna and current speed could be spurious, being really correlations between fauna and depth. Correlation coefficients between fauna and both speed and depth were therefore calculated.

Correlations c. and d. were investigated because much of the stones in current data is presented in the form of percentages and conclusions are based on changes in the percentages of species or groups. If there were significant correlations between the numbers of species or groups of animals and the current speed it was therefore important to know whether these would also be apparent in the data transformed to percentages.

The significant ($P < 0.05$) correlation coefficients between species or groups of animals on the one hand and depth and current speed on the other, are shown in Table 19. Considering first of all the correlations between numbers/sq ft and depth and current speed (columns a and b on Table 19), Aethaloptera maxima, Cheumatopsyche thomasseti and Simulium larvae were significantly correlated with current speed, larger numbers being recorded with higher current speeds, but not with depth. Amphipsyche scottae was significantly correlated with both depth and current speed, though the correlation with depth was closer than with current speed. These animals, together with Macronema capense, were very seldom found in stones out of the current or stony backwater biotopes in the Vaal Dam Catchment (Tables 29, 30). Moreover they belong to groups, the Hydropsychid caddis and the Simuliidae, whose percentages were higher in faster currents in Ambühl's field studies.

Choroterpes (Euthraulus) sp. numbers were very significantly correlated with both depth and current speed. However, it would appear that in this case the correlation between numbers and current speed was spurious. Choroterpes (Euthraulus) nymphs were particularly abundant under stones out of the current, the percentages of this species recorded from stones out of current biotopes being higher than the percentages from stones in current biotopes (cf. Tables 20 and 29). The animals occur under stones and at Warrenton (Part 1) were found to be cavity dwellers. It is possible that at Standerton the larger stones (and therefore the larger cavities behind them) were in the deeper, faster water.

In Hydra sp. and Centroptilum excisum there were significant negative correlation coefficients between numbers and depth and current speed, indicating that as current speed and depth increased numbers declined. For both these species the correlation between numbers and depth was closer than the correlation between numbers and current speed. However, as in the case of other animals, data from stones out of current biotopes provides support for the current speed correlation and suggests that it is not a spurious depth effect (cf. Hydra and C. excisum percentages in Tables 20 and 29). Moreover Harrison & Elsworth's (1958) study showed that while C. excisum was found in a wide variety of biotopes in the Great Berg River, its percentages were lowest in the stones in current.

Nais spp., Orthotrichia sp., Stenelmis spp. and Burnupia spp. numbers were all significantly correlated with depth, but not with current speed. It is impossible, from our present knowledge of the occurrence of these animals to know whether this correlation is meaningful or not. However, Burnupia (an Ancylid) and Orthotrichia are probably algal feeders, while Nais was abundant in stony runs only when there were pronounced growths of algae. The reason for the significant correlation between the numbers of these animals and depth could therefore be that their numbers were related to the abundance of algae, provided that there were more algae in the shallower water. This is not at all unlikely in a river, where light reduction due to turbidity increases rapidly with depth, reducing the light essential for algal growth.

Turning now to the significant correlations between percentages and current speed and depth (columns c and d, Table 19) all the species whose numbers were significantly correlated with current speed, with the single exception of A. scottae, had percentages which were also significantly correlated with current speed. Likewise all the species whose numbers were significantly correlated with depth, with the single exception of Nais spp., had percentages which were significantly correlated with depth. Most of the significant correlations were therefore still apparent in the transformed data, though there were a comparatively large number of other significant correlations between percentages and current speed (Orthotrichia, Pentaneura, Burnupia) and between percentage and depth (A. maxima, C. thomasseti, M. capense, Simulium larvae) which were not found between numbers and depth and current speed and which must be regarded as spurious and due to the transformation.

Examination of Chutter & Noble's data for species other than those discussed above failed to reveal any species whose peak densities appeared to be in the middle of the range of speeds recorded from the 10 samples. Among the species found in only a few of the 10 samples the Glossiphoniidae, Ecnomus sp. and Simulium nigritarsis pupae were found mainly in the shallower, slower flowing water, while a large number of Elmid larvae "type 7" (which are probably Stenelmis larvae) were in the sample where the current speed was greatest (see Chutter & Noble's Table 1).

The range of current speeds in Chutter & Noble's data was rather narrower than that in Ambühl's field studies. However this

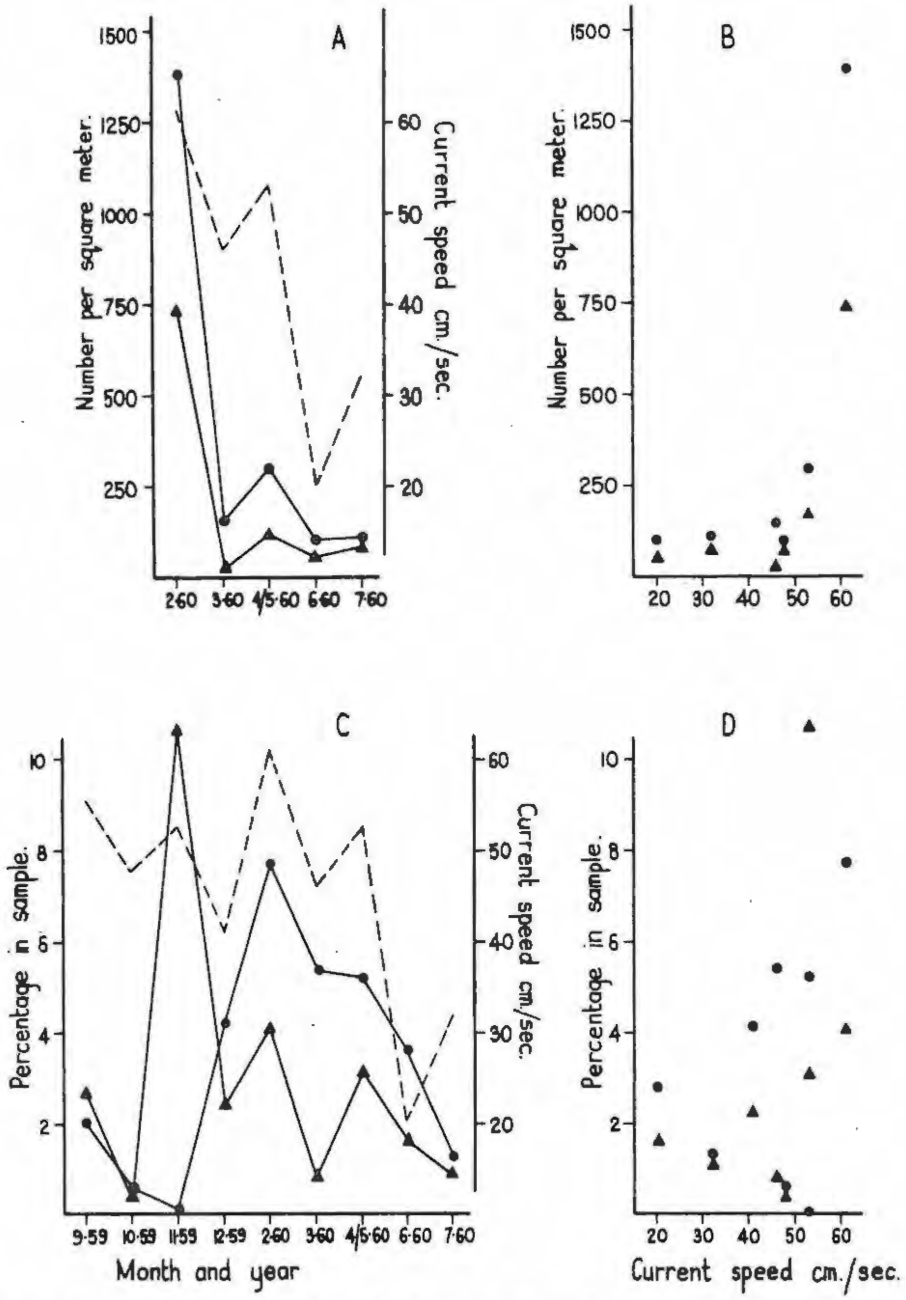


Figure 17. <u>Cheumatopsyche</u> <u>afra</u>, <u>C</u>. <u>thomasseti</u> and current speeds from the stones in current at station 21.

A. Monthly variation in current speed and numbers of individuals per square meter.

B. The relationship between numbers per square meter and current speed.

C. Monthly variation in current speed and numbers of individuals expressed as a percentage of the total number of animals in the samples.

D. The relationship between percentages and current speed.

Symbols: ---- current speed, ▲ <u>C</u>. <u>afra</u>, ● <u>C</u>. <u>thomassetti</u>.

The sample dated 4/5.60 was taken midway between the March and June samples.

analysis of the 10 Surber sample data does lend support to Ambühl's finding that, even in field samples, the numbers of at least some species can be shown to be related to current speed. This finding had two consequences. Firstly, it became necessary to examine the density of the fauna from month to month at single sampling points to see whether there were species present whose density changes followed current speed changes. Secondly it was necessary to examine the density of the fauna and the current speed from station to station in order to see whether current speed alone was likely to bring about station to station differences in the density of species or groups of animals.

Only at Stations 2a and 21 was there a suitable number of successive monthly quantitative samples and current speed measurements to investigate whether the density of species or groups of animals was related to the current speed from month to month. At Station 21 C. excisum and A. scottae were too rare in the quantitative samples to compare their densities and percentages with current speed. Of the common animals found at this sampling point (Table 20) the numbers of only C. thomasseti and the closely related C. afra followed current speed fluctuations (Fig. 17a). Taking all quantitative data for these species at this sampling point, and not only the successive monthly data shown in Figure 17a, into consideration (Fig. 17b) shows that in both species there was little increase in the numbers of individuals as the current rose from 20 to 50 cm/sec, but that the density increased sharply at speeds above 50 cm/sec. In C. afra, percentage peaks followed current speed peaks fairly closely, but in C. thomasseti they did not do so (Fig. 17c). In both species the highest percentages were found at the highest current speeds (Fig. 17d). In none of the other common significant animals at Station 21 was there any obvious

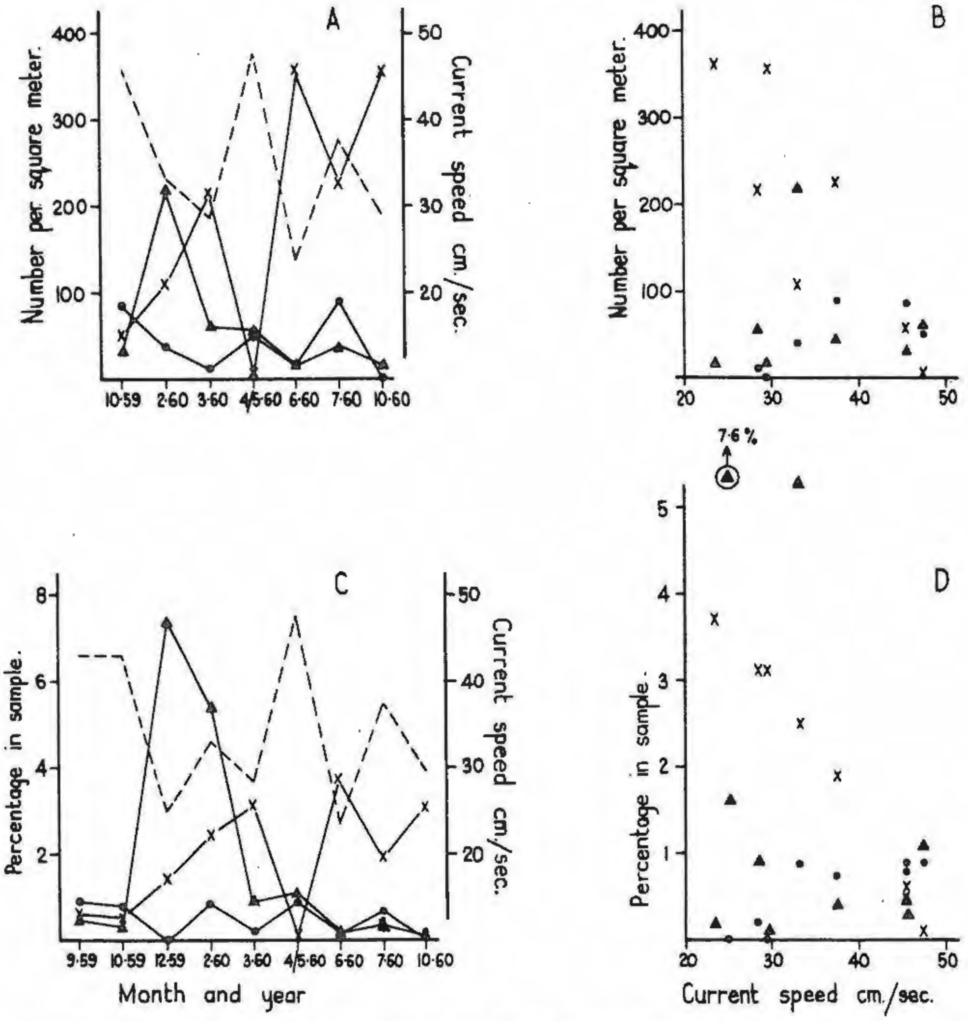


Figure 18. Centroptilum excisum, Cheumatopsyche afra, C. thomasseti and current speed from the stones in current at station 2a.

A. Monthly variation in current speed and numbers of individuals per square metre.

B. The relationship between numbers per square metre and current speed.

C. Monthly variation in current speed and numbers of individuals expressed as a percentage of the total number of animals in the sample.

D. The relationship between percentages and current speed.

Symbols: ---- current speed, x C. excisum, ▲ C. afra, • C. thomasseti.

The sample dated 4/5.60 was taken midway between the March and June samples.

relation between density and current speed.

At Station 2a the species whose numbers and percentages followed current speed changes were C. excisum and C. thomasseti (Fig. 18). C. afra numbers and percentages were not nearly as closely related to current speed as were those of the other two species (Fig. 18b, d). The correlation between C. excisum percentages and current speed was remarkably close.

What this analysis has so far shown is that an animal which was far more common in stones in the current than in stones out of the current (C. thomasseti) was found in larger numbers at higher current speeds in a series of samples taken in one day at one sampling point and also in a series of samples taken at monthly intervals at two other sampling points. Another animal (Centroptilum excisum) which was commoner in stones out of the current biotopes than in stones in current biotopes, was found in larger numbers at slower current speeds in a series of samples taken from one sampling station on one day, and was found in larger numbers at slower current speeds in a series of samples taken at monthly intervals from one sampling point. For both these animals there is therefore very comprehensive evidence that the numbers of individuals found is so strongly influenced by the speed of the current in the place where the sample was collected, that the multitude of other factors which would also influence the number of individuals of a species found in any place are not apparent. Other animals were found in larger numbers at higher current speeds in the series of 10 samples collected on the same day (Aethaloptera maxima, Amphipsyche scottae) but were so scarce at Stations 2a and 21 that their variation with current speed from month to month could not be investigated. Finally the Simuliidae occurred in larger numbers where the current was faster in the samples taken on the same day, but did not do so in the samples taken at monthly intervals. Several factors could account for this and important amongst them would be that the Simulium larvae almost certainly belonged to more than one species (possibly with different current speed preferenda). The correlations between numbers and current speeds in Centroptilum excisum and Cheumatopsyche thomasseti were such that even when the numbers were transformed into percentages, there were correlations between the percentages of these animals and current speed.

When the numbers and percentages of these animals found at different sampling points at various current speeds were compared it was found that numbers were no longer correlated with current speed. This was found to be true even when possible seasonal effects were ruled out by comparing data collected at several sampling points in the same month. It is therefore obvious that while current speed may be an important factor regulating the density of certain animals in single biotopes, its influence from biotope to biotope is small. This would be because the numbers at sampling points are the outcome of so many variables. For instance for the filter feeding Hydropsychidae the amount of filterable food would obviously be very important. This is likely to vary from sampling point to sampling point and it is easy to conceive that where food is abundant Hydropsychidae will be abundant whatever the current speed, provided of course that there is at least some current. Thus, due to food resources, the numbers of Hydropsychidae found at the same current speeds at two sampling points could differ widely.

Many of the sharpest changes in occurrence of the species which Ambühl found to be correlated in the field with current speed took place in the current speed range 0 to 10 cms/sec (Ambühl, Figs. 23, 24, 25). Mean current speeds as low as this were not recorded in the stones in current biotopes sampled in the catchment of Vaal Dam (Table 18). In view of this, and because not even in those species whose density was related to current speed at single sampling points was there a sampling point to sampling point variation in density following the current speed variation, current speed may be regarded as one of the less important factors likely to bring about station to station variations in the stones in current fauna.

The zonation and seasonal variation of the stones in current fauna

There are two ways in which the broad trends of the zonation and seasonal variation of the fauna may be viewed. Firstly there is the zonation and seasonal variation in the presence or absence of animals, and secondly there is variation in the abundance of kinds of animals from zone to zone or from season to season. Both these types of variation have been investigated in the stones in current fauna, and also in the fauna of the other biotopes.

In this section the procedure adopted in describing the seasonal changes and zonation of the fauna has been first of all to describe the changes taking place in the fauna of the Klein Vaal/Vaal River, because this river includes all zones, except the high-lying Unstable Depositing Zone, and also because these sampling points in this river were all studied intensively. The changes are then discussed and at this point data from other, mostly less intensively studied, stations in other rivers is brought into consideration in order to see how representative the type of change found in the Klein Vaal/Vaal River is of the streams and rivers in the area as a whole.

In the subsequent section the fauna of the high-lying Unstable Depositing Zone is compared with that of the other zones and then changes in the fauna brought about by the addition of effluents to the rivers are considered.

Finally the rather incomplete quantitative data on the stones in current fauna are presented to show that the faunal changes described on a basis of mean seasonal percentages are not artifacts of the percentage transformation.

The fauna of the Klein Vaal/Vaal River and a comparison of it with the fauna of other Vaal Dam Catchment Rivers.

The sampling points along the course of the Klein Vaal/Vaal River, whose fauna is the basis of this section, are Stations 21a, 21, 3 and 5a (Fig. 9). The following descriptions of conditions at the sampling points include aspects likely to have an important bearing on the fauna collected. Notes on the algae, diatoms and turbidities are based on the author's field observations. Insofar as possible Allen's (1951, p. 17) definitions of biotopes have been followed.

Station 21a : (Plate VII) Eroding Zone. At this sampling point the Klein Vaal River flowed across a dolerite sill. The biotope sampled was a shallow stickle (about 5 cms deep) made up of rounded stones lying at the downstream edge of the sill. Nowhere were there banks of mud or sand in the stream bed, which was not cut deeply below the level of the surrounding fields, even below the sill. Pools were deep. There was therefore no evidence of scouring sand or silt-laden floods at this sampling point. Chlorophyta and diatom growths were prominent only at the end of the dry early summer. In summer turbidities of high flows were not as high as at sampling points downstream and the water was only very slightly turbid in summer periods of low flow.

Station 21 : (Plate VIII) Stable Depositing Zone. This was the only sampling point in the whole catchment where the stream bed was largely made up of a hard slate-like shale. The stones in the sampled stickle were consequently predominantly flat pieces of shale, submerged about 10 cms below the water surface. Another peculiarity of this sampling point was that many stones supported growths of a closely adhering moss, Fissedens capensis (C.M.) Broth. In the current a patch of Potamogeton thunbergii Cham. & Schlechndl. was growing. Although the river bed was in places up to 3 metres below the level of the

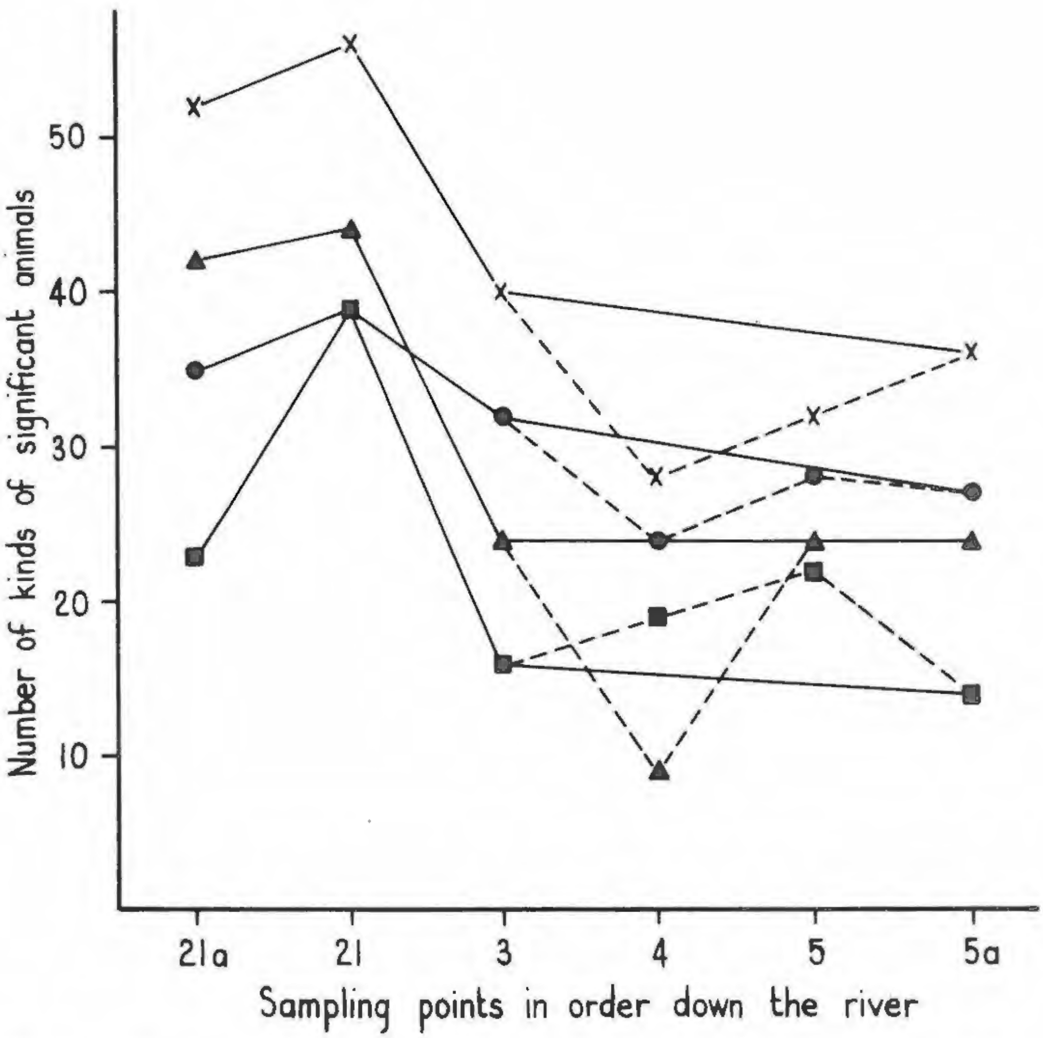


Figure 19. Stones in current communities of the Klein Vaal/ Vaal River. The numbers of kinds of significant animals, other than Cladocera and Copepoda, recorded at each sampling point, combining all seasons (x) and by season (● winter, ▲ dry early summer, ■ summer). Data for stations 4 and 5 are joined by broken lines.

surrounding fields the stream was not subject to scouring floods or excessive amounts of silt and sand, since in addition to the moss and Potamogeton growing in the stream bed, the banks supported a vigorous growth of emergent aquatic vegetation. The bed itself was mainly stony though stones in quieter parts of the bed were usually covered with a thin layer of silt. Prominent algal growths were not found. Diatom growths were however very obvious in winter and dry early summer. Maximum turbidities were probably higher than at Station 21a, but not as high as further downstream. As at Station 21a the water cleared in summer periods of low flow.

Station 3 : Unstable Depositing Zone. At this sampling point the bed of the river was some 10 to 12 metres below the level of the surrounding countryside. The biotope sampled consisted of stones amongst which sand was in places obvious. The biotope was intermediate between a stickle and a run, and the water was about 15 cms deep at normal flows. There were extensive areas of sand, gravel and mud in the river bed. On occasions there was a deposit up to 2 cms deep of silt over all the parts of the river bed out of strong currents. Fluctuations in water level were considerable and aquatic vegetation was absent. Station 3 was therefore subject to large floods heavily laden with silt and in this respect it differs from Station 21a and 21. Algal and diatom growth were never heavy. Summer turbidities were very high, except in January, 1960, when there was a period of about three weeks with very little rainfall.

Station 5a : (Plate IX). Unstable Depositing Zone. At this sampling point there was again an extensive dolerite sill, the downstream side of which terminated in a cascade about a metre high. Stickles below the cascade, about 15 cm deep, were sampled. At periods of low flow an extensive sand bank, some way below the cascades, was exposed. Masses of Cladophora were found in the current in late winter and dry early summer. Diatoms were also abundant at these times. Turbidities were low in winter, sufficient to cause a cloudiness in the dry early summer and high in summer.

The numbers of kinds of significant animals recorded from stones in current biotopes in the Klein Vaal/Vaal River are shown in Figure 19. The most varied fauna was found at Station 21, that is in the Stable Depositing Zone, and the least varied fauna (omitting Stations 4 and 5 from consideration) was found at Stations 3 and 5a, that is in the Unstable Depositing Zone. It was only in the summer that there was a large difference in the numbers of significant animals found in the Stable Depositing Zone and in the Eroding Zone (Station 21a). At Station 21 the moss on the stones provided an ample food supply and shelter not available to the same extent at other sampling points and several animals, such as the aquatic caterpillar Argyractis periopis, were found there and nowhere else. This helps to explain why the diversity of the fauna was greatest at Station 21. It does not, however, help to explain why the fauna of the Eroding and Stable Depositing Zones should have been so much more diverse than the fauna of the Unstable Depositing Zone. This must be due to there being fewer microhabitats in the stones in current biotopes of the Unstable Depositing Zone or to the Unstable Depositing Zone being too silty and sandy for many kinds of animals, since the major difference between the Eroding and Stable Depositing Zones on the one hand and the Unstable Depositing Zone on the other was in the amount of silt and sand in the river bed (p. 51 above). Silt and sand could of course adversely affect an animal directly by smothering or abrading it or its eggs or indirectly by altering the food resources of the biotope, again by smothering or abrasion or also by reducing the amount of light available for algal growth.

In the Eroding and the Stable Depositing Zones the diversity of the fauna was greatest in the dry early summer, in the Unstable Depositing Zone it was greatest in the winter (Fig. 19). The reasons for this are not clear, but there is a good reason why the diversity of the fauna should be lowest in the summer in the Eroding and Unstable Depositing Zones. In these zones the fluctuating summer flows resulted in such unstable conditions that sediments were not deposited in the Eroding Zone and macrophytes could not become established in the Unstable Depositing Zone. The Stable Depositing Zone was however much more sheltered and groups of animals which disappeared in the

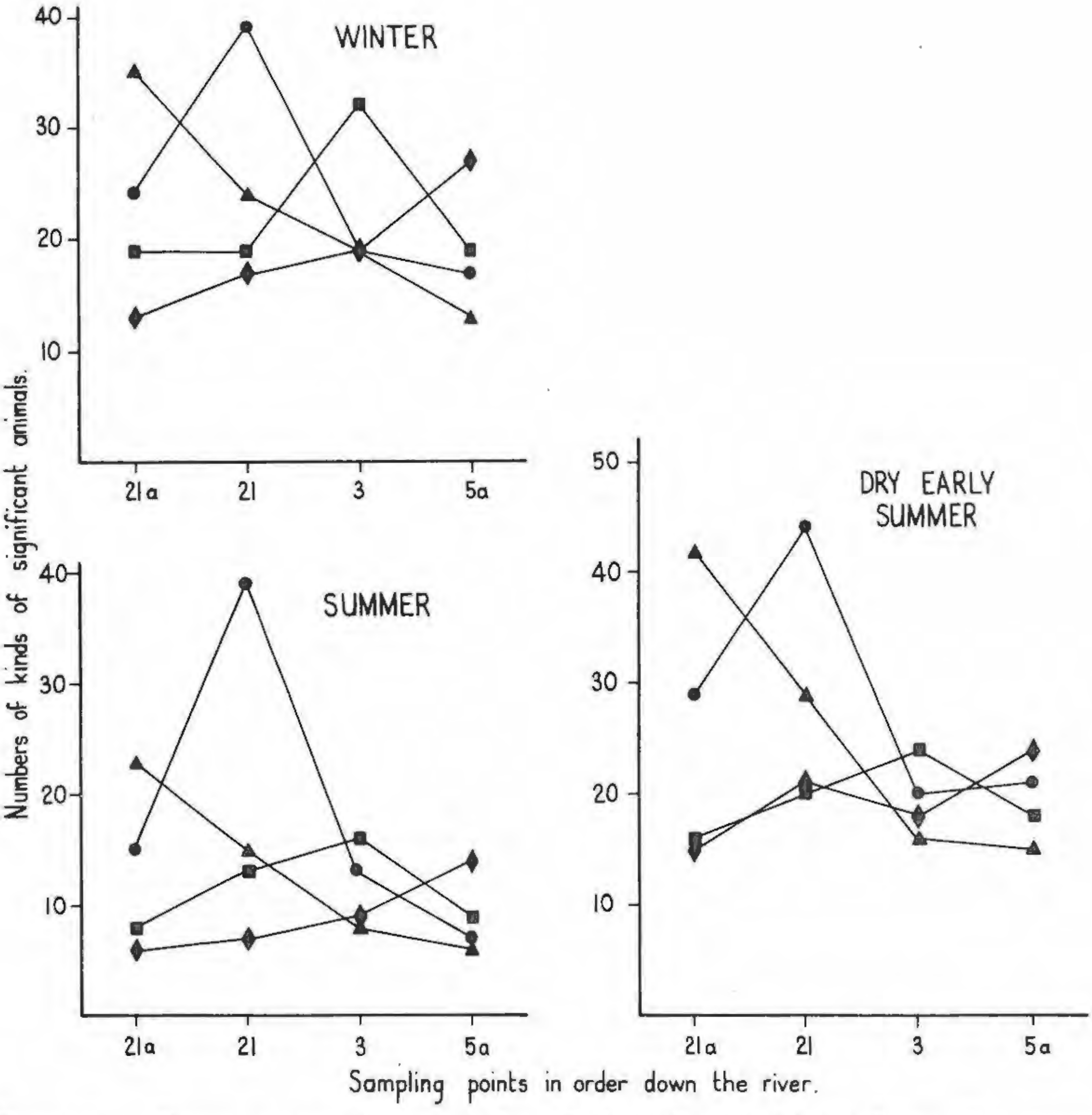


Figure 20. Stones in current communities of the Klein Vaal/Vaal River. The numbers of kinds of animals significant at each sampling point, omitting Cladocera and Copepoda, and the number of them which were significant at the other sampling points season by season.

▲ species significant at station 21a

■ species significant at station 3

● ——— " ——— 21

♦ ——— " ——— 5a

summer in other zones (Table 20, Nais, Cypridopsis, Chironomini) were still found in this zone.

The commoner animals found at these sampling points are shown in Table 20, which shows some of the species or groups which were responsible for the changes in the faunal diversity along the course of the river. Important among these were the Baetidae, in which Baetis glaucus was an Unstable Depositing Zone species and Centroptilum sp. nov. I and C. sudafricanum were upper river species, and the Trichoptera in which there were more significant Hydropsychid species in the Unstable Depositing Zone than in the other two zones. In the Elmidae, Hydraenidae and Simuliidae, the species of which have been grouped in Table 20, there were large changes in diversity down the river. There were 5 significant Elmid species in the Eroding Zone, 9 in the Stable Depositing Zone and 2 in the Unstable Depositing Zone. Three groups of Hydraenidae were significant in the Eroding Zone and only one of these was significant in the other zones. Of the 8 Simulium species found S. nigritarsis was recorded in all zones, S. bequaerti, S. medusaeforme and S. wellmanni in the Eroding Zone, S. adersi and S. damnosum in the Stable Depositing and Unstable Depositing Zones and S. chutteri and S. griseicolle in the Unstable Depositing Zone only.

In Figure 20 the fauna is further analysed to show how many of the species or groups of animals significant at each station were also significant at other stations, season by season. In all seasons species or groups significant in the Eroding Zone (Station 21a) fell off down the course of the river. Likewise species or groups characteristic of the Unstable Depositing Zone (Stations 3 and 5a) disappeared in the Stable Depositing and Eroding Zones. In the dry early summer the fauna of the Eroding Zone (Station 21a) and of the

Stable Depositing Zone (Station 21) included many species or groups which were not significant at other sampling points. On the other hand most of the species or groups found in the Unstable Depositing Zone (Stations 3 and 5a) were found in the other zones. The faunas of Stations 3 and 5a were similar to one another, suggesting that the fauna of the Unstable Depositing Zone is reasonably homogeneous. The form of the graphs for the summer fauna is similar to the form of those for the dry early summer. However in the summer the diversity of the fauna in the Eroding and Unstable Depositing Zones was, as already mentioned, much lower than in other seasons, so that the diversity of the Stable Depositing Zone fauna contrasted strongly with that of the other two zones. However the winter fauna of the river does not appear from Figure 20 to follow the type of change from zone to zone that was apparent in the dry early summer and the summer. At each sampling point the curves show a pronounced peak, suggesting that the fauna of each is distinctive and in particular that there was no longer a great similarity between the fauna of the two sampling points in the Unstable Depositing Zone. The animals which were significant at each station in the winter, but not at any other station were:-

Station 21a

Limnodrilus sp.
Centroptilum sudafricanum
Pseudocloeon maculosum*
Hydroptila cruciata
Hydraenid 'type C'*
Simulium bequaerti*
Simulium medusaeforme*
Corynoneura spp.*

Station 21

Prostoma sp.*
Gomphocythere sp.*
Argyractis periopis (Nymphulidae)*
Microdinodes transvaalicus (Elmidae)*
Microdinodes pilistriatus (Elmidae)*
Pachyelmis rufomarginata (Elmidae)*
Helminthopsis ciliata (Elmidae)*
Elmid larvae 'type 8'
Bezzia type larvae
Atherix sp. (Rhagionidae)*
Corbicula africana*

Station 3	Station 5a
Tubifex sp. *	Tubificid incert sed.*
Chaetogaster sp.	Afronurus sp.
Ilyocypris sp.	Stenelmis gades (Elmidae)*
Isocypris sp.	Simulium chutteri
Oribatoides sp.*	? Limnophora sp. (Muscidae)*
Orectogyrus sp.*	
Stenelmis thusa	

The species or groups marked with an asterisk are those which were not significant at any other station in any season. At Stations 21a and 21 there was a large number of these exclusive species or groups, but at Stations 3 and 5a there were few. This shows that the changes in diversity down the course of the river in winter were, in spite of the form of the winter graphs in Figure 20, really similar to those in the other two seasons. These marked changes in the diversity of the fauna down the river were associated with the amount of silt and sand present in the river bed, the stability of the river bed and also with the amount of vegetation present in it. As will be shown in the following paragraphs the Eroding Zone fauna included species which do not tolerate silty conditions, the Stable Depositing Zone fauna included species which tolerate slightly silty conditions and others which were probably present on account of the aquatic vegetation and detritus and the Unstable Depositing Zone fauna included species which were only found where there was silt.

The distinctive feature of the fauna at Station 21a was that the typically Unstable Depositing Zone species or groups such as Baetis glaucus, Aethaloptera maxima, Amphipsyche scottae, Macronema capense, Simulium adersi, S. damnosum, S. chutteri and S. griseicolle were either not recorded or were very seldom recorded. Most of the animals found at Station 21a were also found in the Stable Depositing Zone, though their percentages were often higher in the Eroding Zone than in the Stable Depositing Zone (Table 20). These animals were

Baetis harrisoni, Centroptilum sudafricanum, Adenophlebia, Cheumatopsyche afra and three Hydroptilids and five Elmids which are listed when the fauna of Station 21 is described. Animals which were significant only at Station 21a were Cyprilla, Centroptilum sp. nov. I, Pseudocloeon maculosum, Aeschna rileyi, Hydraenids 'types A and C', Simulium bequaerti, S. medusaeforme and S. wellmanni. Generally speaking the fauna of the other Eroding Zone sampling points (Table 22) was similar to that found at Station 21a, though at Station 26 which was a long way from the source of the Klip River (Fig. 9) certain species such as B. glaucus, A. scottae and M. capense which were characteristic of the Stable and Unstable Depositing Zones appeared, and C. sudafricanum was not recorded. Although the sampling intensity at these other sampling points was low, three of four Elmid species were recorded from all of them except Stations 43 and 33. The variety of Simuliidae recorded from these stations was greater than at Station 21a, but this is to be expected where so many more sampling points are involved. The species recorded were S. bequaerti, S. dentulosum, S. ?bovis, S. medusaeforme, S. nigritarsis and S. unicornutum f. rotundum, a list which includes two of the species recorded only from Station 21a in the Klein Vaal/Vaal River and none of the species recorded from other zones, except for S. nigritarsis, a ubiquitous species.

The significant animals at Station 21 could be divided into four main groups, depending on their distribution in other parts of the river. The first of these was a ubiquitous group, which consisted mainly of animals in which taxonomy is not far advanced in South Africa. This suggests perhaps that, were the taxonomy of these animals better known, the ubiquitous group would have been smaller and the differences between the animals found in the different zones greater. The second group consisted of animals which were significant only at

Stations 21a and 21 and the third group consisted of animals which were significant at Stations 21, 3 and 5a. Finally there was a group of animals which was significant only at Station 21. The four groups were as follows:-

Ubiquitous	Only at Stations 21a and 21
Tricladida	Centroptilum sudafricanum
Nematoda	Adenophlebia sp.
Nais spp.	Cheumatopsyche afra
Cypridopsis sp.	Hydroptila cruciata
Ilyocypris sp.	Pachyelmis convexa
Centroptilum excisum	Pachyelmis rufomarginata
Choroterpes (Euthraulus) sp.	Lobelmis harrisoni
Neurocaenis spp.	Helminthopsis bifida
Caenidae	Helminthocharis cristula
Cheumatopsyche thomasseti	Oxyethira sp.
Orthotrichia sp.	Hydroptilid - sand case
Aulonogyrus spp. larvae	
Hydraenid type B	
Simulium nigritarsis	
Chironomidae	
Bezzia type Ceratopogonidae	
Burnupia spp.	

Only at Stations 21, 3 and 5a	Only at Station 21
Isocypris spp.	Prostoma sp.
Centroptilum medium	Gomphocythere sp.
Prosopistoma sp.	Centroptilum parvum
Amphipsyche scottae	Argyractis periopis
Stenelmis thusa	Microdinodes transvaalicus
Simulium adersi	Microdinodes pilistriatus
Simulium damnosum	Helminthopsis ciliata
Pisidium spp.	? Atherix sp.
	Corbicula africana

No species were significant only at Stations 21 and 3, one species (Macronema capense) was significant only at Stations 21 and 5a, and only one species (Baetis harrisoni) was significant at Stations 21a, 21 and 3 but not at Station 5a. Only four species (Baetis glaucus, Aethaloptera maxima, Simulium chutteri and S. griseicolle) were found at Stations 3 and 5a and not at the other sampling points. The greatest discontinuity in the downstream distribution of the upper river fauna therefore took place between Stations 21 and 3, but the greatest discontinuity in the upstream distribution of the lower river fauna took place between Stations 21a and 21. This helps to account for the very great diversity of the fauna at Station 21, but it does not mean that the fauna found there was simply a mixture of the fauna of the zones above and below it, because there were the above 9 species or groups of animals which were found in the stones in current only at this sampling point and, as will be shown later, the structure of the community differed from that in the zones above and below it. The upper river fauna was not found below Station 21 because of the large amounts of silt and sand and the instability of summer conditions in the Unstable Depositing Zone. However now that the animals from the various zones have been listed it is possible to begin to understand how the presence of the silt and sand may affect the fauna. Some groups, such as the Elmidae and the Hydroptilidae, which are feeders on vegetation, algal aufwuchs or debris, disappear in the Unstable Depositing Zone probably because these food resources are scarce there. In other groups, such as Centroptilum sp. nov. I, C. sudafricanum, C. parvum and Adenophlebia, it seems that there is an intolerance of silty conditions. On the other hand it seems that the habitat requirements of the Unstable Depositing Zone animals are only fulfilled in parts of the river where there is some sedimentation. This does not mean however that it is the sedimentation itself which is necessarily important. While the sedimenting material doubtless contains food materials which some animals are able to exploit, the very great increase in the variety of the Hydropsychid caddis and the change in the *Simulium* species which took place between the Eroding and the two Depositing Zones suggests that there were changes in the type of filterable food material available, and that these followed the change in the river bed from being eroding to sedimenting. In the Eroding Zone the filterable food material probably consists mainly of fine detritus and fine pieces of aufwuchs dislodged from the stream bottom. However in the sedimenting zones there is probably less aufwuchs, on account of the smothering by silt of surfaces on which the aufwuchs might grow and also in the summer on account of the poorer penetration of light due to the high turbidities. At the same time the percentages of the Cladocera and Copepoda recorded in the stones in current samples (Table 20) were very much higher in the sedimenting zones than in the Eroding Zone, indicating not only greater amounts of Cladocera and Copepoda available to be filtered from the water, but also greater amounts of the small organic particles on which the Cladocera and Copepoda would themselves have been feeding.

The commonest significant animals from other Stable Depositing Zone sampling points (Stations 2a and 10) are shown in Table 22. The fauna of both these sampling points was similar to that of Station 21, in that typically Unstable Depositing Zone animals such as the Hydropsychid caddis other than the *Cheumatopsyche* species were found with typically Eroding Zone animals such as *Adenophlebia*, and the Elmidae, which were represented by 7 species at Station 2a and 5 species at Station 10.

The fauna of the Unstable Depositing Zones of rivers other than the Vaal (Table 23) was similar to that of Stations 3 and 5a. Animals typical of the Eroding and Stable Depositing Zone, such as *Centroptilum sudafricanum* and *Adenophlebia* were not recorded, and animals typical of the zone such as *Baetis glaucus*, *Amphipsyche* scottae and Macronema capense were recorded. The only Elmidae recorded from these sampling points were Stenelmis gades and S. thusa, which were the only Elmids recorded from the Unstable Depositing Zone in the Klein Vaal/Vaal River. The Simuliidae found were S. adersi, S. chutteri, S. damnosum, S. mcmahoni and S. nigritarsis and were therefore comparable with the Klein Vaal/Vaal River Simuliidae. However Stations 29, 36 and 41 (Table 23) were situated on rather small streams and this may account for some of the rather atypical aspects of their faunas. For instance Neoperla spio was not found in these streams and the variety of the Hydropsychid Trichoptera was limited. Elmids were not found in two of them and Burnupia was not found in any of them. These faunal peculiarities are unlikely to be due to the streams drying up occasionally, for the Spruitsonderdrif and the Holspruit are not known to do so. It may be that the environment in small streams is such that the food available to aquatic animals is different to that in larger rivers, or that these animals may be restricted to larger rivers by biotic factors, such as, in the insects, choice of egg laying site by the adult.

This description of the stones in current fauna has so far shown that the distribution of the significant animals follows the zonation of the rivers closely, and that this faunal zonation applies not only to the Klein Vaal/Vaal River but also to the other rivers in the catchment of Vaal Dam. The fauna obviously responds to the changes in the eroding or sedimenting nature of the rivers on which the description of the zonation of the rivers was originally based.

However thus far we have been entirely concerned with the presence or absence of significant species, and no account has been taken of their relative abundance in the various zones. In Figure 21 the percentage of the species contributing more than 5 per cent to the

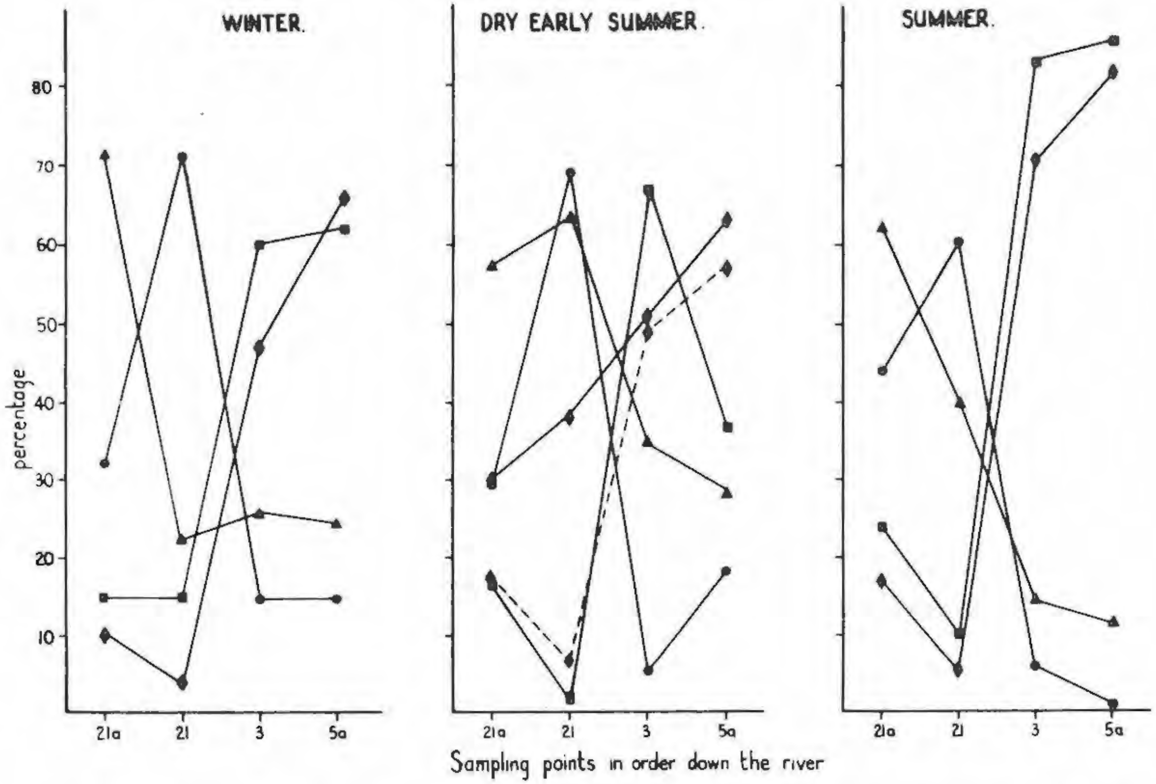


Figure 21. Stones in current communities of the Klein Vaal / Vaal River. The percentage of the total fauna (omitting Cladocera and Copepoda) at each sampling point contributed by species whose mean seasonal percentage was > 5, and the percentage contributed by these species to communities at other sampling points, season by season. For further details on the construction of this figure see p. 94. Broken lines are for data omitting Nais.

▲ species over 5% at station 21a
● ———— ,, ———— 21
■ species over 5% at station 3
♦ ———— ,, ———— 5a

total number of individuals collected at each sampling point are added and then compared with the percentages of these same animals at each other sampling point. For instance in the winter at Station 21a the species or groups of animals contributing more than 5 per cent to the total numbers of individuals collected were, as inspection of Table 20 will show, B. harrisoni, C. sudafricanum, Choroterpes (Euthraulus) sp., Caenidae and Simuliidae. The following table shows the percentages of these species in the winter at Station 21a and at Stations 21, 3 and 5a, all percentages being taken directly from Table 20:-

Station	21a	21	3	5a
B. harrisoni	31.3	1.6	0.5	P
C. sudafricanum	8.6	0.2	-	-
Choroterpes (Euthraulus) sp.	10.5	0.8	23.3	21.0
Caenidae	8.2	8.7	0.7	P
Simuliidae	12.7	11.2	1.5	3.6
Totals	71.3	22.5	26.0	24.6

The curve for species exceeding 5 per cent at station 21a in the winter in Figure 21 was plotted from the totals shown above, and all the curves shown in Figure 21 were constructed in this way. However, many species exceeded 5 per cent of the fauna at more than one sampling point (Table 20). It follows therefore that at any sampling point the sum of the percentages for the four curves exceeds 100 per cent and that this method of analysis does not divide the communities at each sampling point into non-overlapping parts typical of themselves and of other communities.

Figure 21 therefore shows the changes in the relative abundance of the commonest animals along the course of the Klein Vaal/Vaal River. The most striking feature of this figure is the way in which the curves for the winter and the summer follow the zonation of the river. The curves for the Eroding Zone (Station 21a), the Stable Depositing Zone (Station 21) and the Unstable Depositing

Zone (Stations 3 and 5a) are distinctive and the close similarity between the curves for Stations 3 and 5a is particularly striking. In the dry early summer there were large numbers of Nais at all sampling points except Station 3. This lack of Nais at Station 3 was associated with a lack of algae there and obscured the fact that there was a reasonably close similarity between the commonest animals at Stations 3 and 5a. This becomes more apparent when Nais is omitted from consideration.

Figure 21 summarises a lot of data, but in order to begin to understand why the fauna of the different zones differed so much it is best to examine the actual species concerned. The commonest animals in each zone were as follows:-

Eroding	Stable Depositing	Unstable Depositing
Tricladida	Tricladida	Nais*
Nais*	Nematoda*	Ilyocypris*
Cypridopsis*	Nais*	Baetis glaucus*
Baetis harrisoni*	Hydrachnellae	Centroptilum excisum*
Centroptilum sudafricanum*	Caenidae*	Choroterpes (Euthraulus)*
Choroterpes (Euthraulus)*	Elmidae*	Neurocaenis*
Caenidae*	Simuliidae	Amphipsyche scottae
Hydroptila cruciata*	Tanytarsini	Cheumatopsyche thomasseti
Elmidae*	Orthocladiinae*	Simuliidae
Simuliidae		Tanytarsini
		Chironomini*

Species or groups which are aufwuchs or detritus feeders, as opposed to predators or filter feeders, are marked with an asterisk. These changed considerably down the course of the river due to the changes in this type of food material and also due to the increasing siltiness of conditions, as has already been described in relation to the presence or absence of groups of animals. The second major change in the commonest animals down the river was in the filter-feeding animals. In the Eroding Zone the filter feeders were Simuliidae, in the Stable Depositing Zone they were Simuliidae and Tanytarsini and in the Unstable Depositing Zone they were Simuliidae, Tanytarsini, Cheumatopsyche thomasseti and Amphipsyche scottae. However there was only one Simulium species, S. nigritarsis, common to all zones. The percentages of the filter-feeders therefore indicate, as did the changes in the significant species, that the amount and nature of the filterable food changes down the course of the river. However these trends of change in the food resources of the river should not be allowed to obscure the fact that other factors also play important roles in governing the abundance of the fauna. For instance at Station 21 the stones were peculiar (see above, p. 83) in that they were slate-like and this might account for the low percentages of Choroterpes (Euthraulus) at this sampling point, because these animals appear to be cavity dwellers (Part 1, p. 25) and there are very few cavities amongst slate-like stones. Other changes might be due to animals being unable to tolerate silty or sandy conditions and the animals in which this is an important factor become clearer from a consideration of the fauna of the high-lying Unstable Depositing Zone (see below). However the available records (Tables 12 and 18) suggest that current speed and temperature are not likely to be important factors bringing about these changes. Current speeds differed little from sampling point to sampling point down the course of the Klein Vaal/Vaal River. Temperatures did vary, but the only season in which they increased down the river was the winter. In other seasons the Eroding Zone mean temperature was as high as the Unstable Depositing Zone mean temperature. In the high-lying Unstable Depositing Zone B. glaucus appeared in the summer, but was not recorded in the winter, probably because temperatures were too low for it then (Tables 12 and 24). To judge by temperature alone it may therefore be concluded that B. glaucus should have been present in large numbers in the Eroding Zone in the summer, but the fact that it was very rare there (Table 20) shows that it was not temperature alone which made the Eroding Zone unsuitable for it. Competition with B. harrisoni may have been important, and the outcome of it may have depended on the type of food available.

Generally speaking the commonest animals in other rivers in the area studied were similar to those in the Klein Vaal/Vaal River. Thus in the Eroding Zone of other rivers (Table 22) percentages of Tricladida, Baetis harrisoni, Centroptilum sudafricanum, Choroterpes (Euthraulus), Caenidae and Simuliidae were high. However the percentages of several groups or species which were not high at Station 21a were sometimes high in other Eroding Zone rivers. These animals were Baetis glaucus, Neurocaenis, Cheumatopsyche afra, C. thomasseti, Hydraenidae, Tanytarsini and Orthocladiinae. In some instances the reasons for the high percentages of these animals were fairly straightforward. Thus Cheumatopsyche percentages were high in the Klip River right down from Station 24 and suitable filterable food must have been unusually abundant there. The percentage of B. glaucus was high in the summer at Station 26 where the Klip River was larger than any of the other rivers in the Eroding Zone. Stream size may be important for the occurrence of this species, or on the other hand Station 26 being at a lower altitude than the other Eroding Zone sampling points (Fig. 10) it was presumably warmer than them, and this may have been the factor to which B. glaucus responded. Hydraenidae, which were unusually abundant at Station 43, were living amongst, and also probably feeding on, very profuse growths of Nostoc. There was no apparent reason why Nostoc should have been so abundant at Station 43, and it was seldom encountered at other sampling points.

The commonest animals at Station 2a in the Stable Depositing Zone (Table 22) were similar to those at Station 21. However at Station 2a the stones were rounded with cavities and Choroterpes (Euthraulus) made up a large part of the fauna than it did at Station 21 where the stones were flat and slate-like without cavities. On the other hand the commonest animals at Station 10, which was also in the Stable Depositing Zone included several whose percentages were high only in the Unstable Depositing Zone in the Klein Vaal/Vaal River. These were Baetis glaucus, Neurocaenis and Macronema capense. Typically Stable Depositing Zone features of the fauna at Station 10 were the high Caenid and Elmid percentages. The fauna at Station 10 was more similar to the Unstable Depositing Zone fauna than that at Stations 2a and 21 probably because the river was rather more muddy there than was usual for the Stable Depositing Zone. The commonest animals in the Unstable Depositing Zone in rivers other than the Klein Vaal/Vaal (Table 23) were very similar to those found in that river. The fauna was mainly made up of Baetis glaucus, Choroterpes (Euthraulus) sp., Neurocaenis, Amphipsyche scottae, Cheumatopsyche thomasseti, Chironomini and Orthocladiinae.

Thus the composition of the fauna, based on the percentages of the commonest animals, varied from zone to zone, and the most important factors bringing about this variation were related to the eroding and sedimenting nature of the river beds. The Unstable Depositing Zone fauna was particularly homogeneous, but the commonest animals in the other zones were more variable.

Most of the Cladocera and Copepoda found in samples drawn from stones in current biotopes were undoubtedly being swept downstream by the current when collected. The numbers of these collected are therefore influenced by the current speed and the time the net was in the water as each sample was collected. However, the percentages of these animals (Table 20) do show consistent trends related to changes in ecological conditions, suggesting that the lack of standardisation in the method by which they were collected was not of overriding importance. Identifications down to the specific level were carried out only in Simocephalus where they are comparatively easy. In other Cladoceran genera it may be that the species are those found in the Vaal River by Harding (1961), but Harding's Vaal River material was collected in an artificial canal-like stretch of the Vaal (Chutter 1963) and it is therefore possible that in the river environment the species are different. Cladocera and Copepoda from the Vaal River were preserved and await identification.

Broadly speaking the percentages of the Chydorinae - Alona, Leydigia, Pleuroxus and Chydorus - declined down the course of the river, while the percentages of Moina, Bosmina, Diaptomus and Cyclops increased down the river. However the zonal differences found among the other macroinvertebrates were not apparent in the Cladocera and Copepoda.

At all sampling points the percentages of all the Cladocera and Copepoda taken together were clearly highest in the dry early summer, when a greater variety of genera was found than in other seasons. The percentages of Daphnia, Ceriodaphnia, Macrothrix, the Chydorinae and frequently Diaptomus and Cyclops were highest in this season. In the dry early summer there were no floods to wash away these animals, the water was warm and there were more algae and diatoms than in other seasons. All these factors would play a part in bringing about the large populations of Cladocera and Copepoda.

A feature of the occurrence of the Cladocera and Copepoda in samples drawn from the stones in current biotope was the very great changes in the percentages of these animals from month to month. Some examples of these changes, showing the rapidity with which these animals built up to, or declined from, a high percentage of fauna, are given in Table 21. It was only seldom that these changes could be readily associated with a change in the environment. In the year for which results are shown in Table 30, the first heavy floods came between the November and December field trips, and as may be seen from the table several species disappeared after November and were not found again until the middle of the winter of 1960. Moina is essentially a summer animal in the southern Transvaal (Chutter 1963, Fig. 4 and Table 10). In January, 1960, the flow of the Vaal River was very low and peak percentages of Moina were found then. Cyclops tended to be recorded rather more regularly than the other genera. The percentages given for this genus for Station 3 represent the greatest fluctuations found in this animal. The percentages for Station 5 are given as a more typical example of the occurrence of Cyclops.

The Cladocera and Copepoda recorded from the sampling points in the Eroding, Stable Depositing and Unstable Depositing Zones of other rivers (Tables 22 and 23) showed the same trends of seasonal change and zonation as did those in the Klein Vaal/Vaal River. The fauna of Eroding Zone was very sparse, but this was not unusual for at most stations there were no dry early summer samples, which were the only samples in which Cladocera and Copepoda were abundant in the Eroding Zone of the Klein Vaal/Vaal River (Table 20).

The fauna of the high-lying Unstable Depositing Zone

The sampling points whose fauna is discussed in this section are:-

Station 19 - The biotope sampled was a stickle in which the stones were rather widely spaced, lying on top of muddy gravel. A lot of fine silt was deposited in the quieter parts of this river (see Zonation above).

Station 30 - When this station was visited in January, 1959, there was no stones in current biotope. In winter, 1961, a stickle formed where stones had been placed in the stream bed to make a ford (centre Plate XI) was sampled. The bed was otherwise sandy and the banks nearly devoid of emergent fringing vegetation.

Station 31 - A stickle was sampled. The river was less sandy than upstream at Station 30.

Station 34 - The biotope sampled was a stony run. The river bed was sandy, and there was no emergent fringing vegetation.

Station 14 - Biotope sampled - a run. The river bed was sandy gravel and there was no emergent fringing vegetation. (Plate XII).

Station 38 - Biotope sampled - a run. River bed choked with sandy gravel and pebbles up to about 15 cms in diameter. No fringing vegetation.

Station 39 - There were a number of stones lying on top of the sand in the current at this sampling point. Animals were collected off these but the biotope was not really either a run or a stickle. River bed otherwise completely choked with clean sand and devoid of fringing emergent vegetation. (Plate XIII).

Within this group of sampling points there are really two types of Unstable Depositing Zones, conditions at Station 19 being very silty whereas at the other sampling points they were sandy. However, all the stations whose fauna is described here were at altitudes or in places where the stream profile was such as to suggest that Eroding Zones or Stable Depositing Zone conditions should have been found.

Were it not for the large amounts of silt at Station 19 it would probably have been similar to Station 21, in that it would have been in a Stable Depositing Zone and not in the Eroding Zone. In a number of ways the fauna recorded at Station 19 (Table 24) was similar to the fauna recorded at Station 21 in the Stable Depositing Zone. Thus a large part of the community consisted of Caenidae and the percentages of the Hydrachnellae were higher than they usually were in the Unstable Depositing Zone. As in the Stable Depositing Zone Baetis glaucus was not a significant animal. It may therefore be concluded that the factor which brought about the decline in the importance of the Caenidae and Hydrachnellae from Stable Depositing Zone to the Unstable Depositing Zone in the Klein Vaal/Vaal River was not the siltiness of the Unstable Depositing Zone, for had this been the case Caenidae and Hydrachnellae would not have made up such a large part of the fauna at Station 19. On the other hand Caenidae made up only a very small part of the fauna in the summer at the other, sandy, high-lying Unstable Depositing Zone sampling points (Table 24), which does suggest that the Caenidae were affected by some factor connected with the presence of large amounts of sand. This could be either a lack of suitable food, if they feed on fine organic detritus in silt, or more direct effects such as smothering of microhabitats or abrasion by sand.

However the community at Station 19 showed many resemblances to the normal Unstable Depositing Zone communities. Thus Adenophlebia, Centroptilum sp. nov. I and C. sudafricanum were not recorded, only one Elmid species was found, Orthocladiinae were not recorded in the summer, Triclads made up only a small part of the fauna, and Tubificidae, Centroptilum excisum and Chironomidae made up a large part of the fauna. The Hydropsychidae were similar to those of the Unstable Depositing Zone because Cheumatopsyche thomasseti was more abundant than C. afra and Aethaloptera maxima was recorded. Amphipsyche scottae and Macronema capense were not recorded, but it is impossible to tell whether this was due to direct effects of silt on them or on their usual food. The absence of Adenophlebia, C. sudafricanum and C. sp. nov. I and the lack of variety in the Elmidae were because these animals do not like silty conditions, possibly because the nature of the food available is no longer suitable for them. The increase in the Tubificidae would be due to the silt and gravel amongst the stones in the current which would provide a suitable biotope for them. Pisidium spp., Corbicula africana and Unio caffra were also found at Station 19, occupying the same microhabitat as the Tubificidae.

In yet other ways the fauna at Station 19 was unlike that found anywhere else. Neurocaenis was not recorded, the Simuliidae (S. nigritarsis) were only a small part of the community, but the Tanytarsini were a very large part. These may be due to the siltiness of the biotope, but yet the fact that it was so silty does suggest that the current speed may have been lower than in less silty stones in current biotopes. However the current speed readings at this station (Table 18), while lower than at many sampling points, were not as low as at some where Simuliidae were abundant and Tanytarsini rather scarce (Station 12, Table 23). This suggests that the siltiness of the environment, and not current speed, was of major importance in bringing about these changes. Afronurus was not found at Station 19, neither was it found at the other high-lying Unstable Depositing Zone sampling points and this must have been due to the greater instability of conditions in this zone, for it was found in all other zones.

At the sandy high-lying Unstable Depositing Zone sampling points the fauna was somewhat variable, though there were ways in which it resembled the fauna of sampling points in the normal Unstable Depositing Zone. These were the very high summer percentages of Neurocaenis spp., and the low percentages of Tricladida, Elmidae, Tanytarsini and, except at Station 39, of Caenidae and the low percentages of Hydrachnellae at many sampling points. Similarities to the normal Unstable Depositing Zone fauna were greatest in the summer, when not only were Neurocaenis percentages high, but also Baetis glaucus appeared. It is to be expected that the high-lying Unstable Depositing Zone fauna should resemble the normal Unstable Depositing Zone fauna most in the summer, for this is the season when the extremely important factors of bed instability, siltation and sand abrasion would be similar in both zones. In other seasons the zones differed in some important ways, for instance in their temperatures (Table 12). In the winter typically Eroding Zone animals such as Baetis harrisoni, Centroptilum sudafricanum and Adenophlebia were found and this may be because conditions in these high-lying Unstable Depositing Zone sampling points were sandy rather than silty.

Ways in which the sandy high-lying Unstable Depositing Zone stones in current communities were unlike those of other zones were that Burnupia was not recorded at any of them, neither were the Pelecypoda Pisidium spp. and Corbicula africana. In other zones Ostracoda were recorded mainly in the dry early summer (Tables 20, 22, 23) so their absence from the summer and winter samples in the high-lying Unstable Depositing Zone is not really remarkable. However they were not recorded in the dry early summer samples from this zone, nor in samples from other biotopes which are described in the sections which follow. Afronurus was also entirely absent from the high-lying Unstable Depositing Zone. All these animals were widespread in the other zones and their absence from this zone is due to an aspect of the environment found only in the sandy high-lying Unstable Depositing Zone. This is likely to be the high degree of bed instability and the consequent massive movement of sand in the summer, which smothers microhabitats and might also directly injure the animals.

Large numbers of a variety of Cladocera and Copepoda were found in the dry early summer at Station 19 showing that there was a plentiful food supply for them. Even in the dry early summer the variety of Cladocera and Copepoda recorded in the sandy high-lying Unstable Depositing Zone was limited and so too were the numbers, except at Station 39, of these animals indicating that there was less food for them than in other zones.

The fauna at sampling points where the chemical quality of the water was not normal

All the sampling points where the chemical quality of the water was not normal, with the exception of Station 42 where conditions were stable, were in the Unstable Depositing Zone. The stones in current fauna was sampled at the following points:-

Station 4 : Above Station 4 the Vaal River entered an extensive dolerite area which extended to below Station 5. Pools were deep, with a muddy bottom, and the bed of the river was about 5 to 10 m below the level of surrounding country. The biotope was a run about 30 cms deep. Some 200 m above the run a milk processing factory effluent entered the river. Thiocheate chutteri Welsh, a blue-green alga superficially resembling sewage fungus, blanketed the tops of the stones in dry early summer. In winter the stones were covered with a dark slimy layer up to 1 cm thick, largely made up of Phormidium. The area of slimy growths and of T. chutteri was less in the summer. In summer turbidities remained high even during the low flow period in January, 1960, but the water was clear in winter.

Station 5 : Here the bed of the Vaal River contained extensive sheets of dolerite and the biotope sampled consisted of a stickle about 15 cms deep. The river was generally speaking shallow; sand and mud banks were absent. Ground along one bank of the river at this sampling point was used for the irrigation of the Standerton sewage works effluent, but direct flows of irrigated water into the river were not observed. Diatoms were particularly abundant in winter and dry early summer, though other algal growths were sparse. Summer turbidities were high but the water was clear in winter.

Station 17 : The Waterval River at Roodebank, which is about 20 km below where water pumped out of gold mines and a sewage works effluent enters the river. The biotope sampled was a stickle below a dolerite sill, above which there was a very long quiet pool. Profuse algal growths were present in the biotope in the winter and dry early summer.

Station 7 : Waterval River below Station 17. The biotope sampled was a stickle. Profuse algal growths were present in the biotope in the dry early summer. Sampling at this point was undertaken only during the preliminary survey, after which it was abandoned in favour of Station 17.

Station 11b: Wilge River just below Harrismith. Just below where a textile factory effluent entered the river. The biotope sampled was a stickle with a lot of rubbish such as broken bottles, old tin cans and pieces of brick in it. Stones always covered with slimy growths. In the winter blue-green algae and either Thiochaete or Sphaerotilus were present. The river bed was very sandy.

Station 11x: Wilge River about 300 metres below Station 11b, at a point where there was seepage of water, probably from nearby effluent treatment ponds, into the river. The biotope sampled was a bed of small pebbles (up to about 4 cm in diameter) and sand in the current. There were abundant growths of either Thiochaete or Sphaerotilus and some Stigeoclonium in the biotope.

Station 11c: Wilge River further downstream from Harrismith (Fig. 9). The biotope sampled was a stickle in which there were diatom growths in the dry early summer. River bed sandy.

Station 42 : Liebenbergsvlei River below Bethlehem. The biotope sampled was a stickle tending towards a cascade in which there was a lot of green and Phormidium like blue-green algae. The sampling point was situated immediately below a large shallow dam, and conditions in the stream were stable although there was no fully submerged aquatic vegetation present.

At Stations 4 and 5 a smaller variety of animals was found than in the other Unstable Depositing Zone sampling points in the Vaal River (Fig. 19). At Station 4 this was largely due to a decline in the variety of the fauna in the winter and the dry early summer, but the number of significant animals at Station 4 in the summer was greater than at Stations 3 and 5a. Most of the animals whose presence or absence brought about these changes in the variety of the fauna at Station 4 are shown in Table 20. The low number of significant animals in the dry early summer was due mainly to the absence of the Ostracoda, and to the fact that animals which were usually significant in the Unstable Depositing Zone, such as Centroptilum excisum, Caenids, Amphipsyche scottae, Cheumatopsyche thomasseti, Orthotrichia, Simuliidae, Tanytarsini and Pentaneura were not significant. On the other hand the large number of significant animals at Station 4 in the summer was not due to a group of species not encountered elsewhere, but to the species usually found in this zone, of which a larger number than usual were significant in the summer. Examples of these are Baetis harrisoni, Centroptilum excisum and the Chironomini (Table 20). The only significant animals recorded at Station 4 which were not also significant at other sampling points were the worms Pristina and Dero (Dero) and the leech Salifa perspicax.

In the winter and the dry early summer the fauna at Station 4 was very largely made up of Nematoda, Nais and Orthocladiinae, and the animals which were usually abundant in these seasons in the Unstable Depositing Zone, that is Baetis glaucus, Choroterpes (Euthraulus) and Cheumatopsyche thomasseti were scarce and not always found (Table 20). The fauna changed considerably in the summer and was dominated by Nematoda, Baetis glaucus, Choroterpes (Euthraulus) and Burnupia, a group of dominants nearer to the normal in the Unstable Depositing Zone than was the case in the winter and dry early summer. However

Neurocaenis and Cheumatopsyche thomasseti percentages were very low.

An important aspect of these pronounced changes in the fauna at Station 4 was that they were due to an effluent which caused no detectable change in the river water (see above, p. 63). A feature of the fauna was that representatives of groups of animals highly sensitive to oxygen depletion, such as the Ephemeroptera, Trichoptera and Simuliidae were always present in the biotope, confirming the finding from the 24 hour study of the dissolved oxygen content of the river, namely that the effluent did not cause discernable oxygen depletion. The effluent did stimulate the growth of blue-green algae, which could affect the fauna by providing food and shelter for some animals (Nematoda, Nais, Orthocladiinae, Burnupia) and by smothering the habitat of others (the Ephemeroptera and Trichoptera). With the increased summer flows and the reduction in the amount of epiphytes on the stones a more normal fauna developed. The effluent consisted of cooling water (though the temperature of the river was not found to be abnormal) and water used for washing milk cans in a milk processing factory. Traces of milk obviously reached the river, since there were sometimes small amounts of floating scum around the margin of the pool into which the effluent flowed. Some algae are known to assimilate organic nitrogen (Fogg 1953; Syrett 1962; Cholnoky (personal communication)) and it may be that traces of organic nitrogen in the effluent brought into being conditions ideal for the growth of Thiochaete chutteri. If this was the case then the organic nitrogen was not detected by the methods of chemical analysis used in this study. In the Bristol Avon in England milk wastes resulted in the growth of large amounts of sewage fungus without much deoxygenation (Hynes 1960, p. 92).

Whatever the nature of the contaminants causing the pronounced growths of blue-green algae at Station 4, they disappeared rapidly from the river. At Station 5, only 3 kilometres below Station 4, blue-green algae were no longer apparent. Moreover the fauna at Station 5 (Table 20) was more normal with percentages of Nematoda, Ostracoda, C. excisum, Choroterpes (Euthraulus) sp., Cheumatopsyche thomasseti and Tanytarsini more in keeping with those recorded at Stations 3 and 5a. However the percentages of Tricladida, Amphipsyche scottae (in the summer), Orthocladiinae (in the winter and dry early summer) and Burnupia spp. were high and those of B. glaucus and Neurocaenis spp. were low, and these changes were probably due to the slight enrichment of the water at this point (see above, p. 64). The larger diatom growths observed at this station would have been brought about by the enrichment and the Orthocladiinae and Burnupia were probably feeding on this aufwuchs. At the same time the Cladocera and Copepoda were rather abundant at this station (see below) and they, or the particles they were feeding on, would account for the increase in the percentage of Amphipsyche scottae.

At Station 17 (Table 25) the fauna was dominated by Nais, Amphipsyche scottae, Cheumatopsyche thomasseti, Simuliidae and Orthocladiinae. The Ephemeroptera were an unusually small part of the fauna but the percentages of Tricladida and Elmidae (Stenelmis thusa only) were somewhat higher than was usual for the Unstable Depositing Zone. This distinctive community developed in response to some clearly defined environmental changes. There were such large numbers of the Hydropsychid caddis that the stones were usually bound together and almost entirely covered by their cases. At all seasons there was an abundant drift of Cladocera and Copepoda over the stones and the numbers of Hydropsychidae were abnormally high because they were feeding either directly on these animals or on the food which the Cladocera and Copepoda would themselves have been feeding. The large numbers of Cladocera and Copepoda were almost undoubtedly due to an unusually abundant microplankton food supply which developed as a result of the enrichment of water in the long pool above the stones in current. The Simuliidae, which were S. adersi, S. damnosum, S. medusaeforme and S. nigritarsis, would have also been feeding on this type of food as it was washed down the river. Nais, Stenelmis thusa and the Orthocladiinae were probably feeding on the algae. The very low numbers of Ephemeroptera were probably due to their being crowded out by the Hydropsychidae, though it is also possible that the current speed may have been too high for them (Table 18). While it should not be forgotten that there were large increases in the total dissolved solids in the Waterval River water, the changes in the fauna seem to be more likely to be due to changes in the food resources of the environment due to organic enrichment than to changes in the dissolved solids. Oliff (1963) found that where streams were polluted with certain amounts of sulphates and mineral nutrient ions (nitrates and phosphates) the Ephemeroptera tended to disappear and the Trichoptera tended to occur in larger numbers. However from the large amounts of algae Oliff found it would seem that in his rivers too, the major faunal changes were due to changes in the food resources of the environment and that the non-nutrient ions had no discernable effect on the fauna except where the polluted waters were acid.

At Station 7 (Table 25) the fauna was more normal than at Station 17 as the percentages of the Ephemeroptera were higher, though Neurocaenis and Choroterpes (Euthraulus) still formed a smaller part of the community than they did in the normal Unstable Depositing Zone fauna. Nais, Amphipsyche scottae, Elmidae, Simuliidae and

Orthocladiinae percentages were at a more normal level too. These changes, together with the reduction in the density of the fauna (see below), show that the stream was less enriched with nutrients at Station 7 than Station 17. However percentages of Tricladida were still high but the high summer percentage of Limnodrilus is shown by the quantitative data (see below) to be rather misleading as the density of this group was not high.

At Stations 11b and 11x, where a textile mill effluent entered the Wilge River, either directly (Station 11b) or by seepage (Station 11x), the fauna was considerably altered (Table 25). Important groups such as the Tricladida, Hydrachnellae, Baetidae, Choroterpes (Euthraulus) and Neurocaenis were not recorded while others such as the Trichoptera, Simuliidae and Burnupia were represented by a very few individuals. The fauna was mostly Tubificidae, Nais and Chironomidae (amongst which there were a few Chironomus larvae). The density of the fauna was however not unusually high (Table 27) and this suggests that the changes which were found at these stations were not primarily due to oxygen depletion associated with an organically rich effluent. It does seem rather more likely that there were toxic substances in the effluent and that these caused so many groups to disappear. Some recovery of the fauna had taken place at Station 11c, where most of the Ephemeroptera were again found, though many groups were still not recorded.

At Station 42 the fauna was very largely made up of Nematoda, Nais, Chaetogaster, Simuliidae (S. adersi, S. damnosum, S. medusaeforme and S. nigritarsis) and Orthocladiinae (Table 25). The Ephemeroptera and Trichoptera were very poorly represented and no Tubificidae, Hydracarina or Coleoptera were found (Table 25). Since the sampling point was below a large dam the absence of large numbers of Hydropsychid

Trichoptera was notable, for they are known (Chutter 1963) to occur in large numbers in such places, particularly when there are large numbers of Cladocera and Copepoda in the water leaving the dam. It is not very likely that the absence of these animals and of the Ephemeroptera was due to oxygen depletion as the water flowed over a spillway and was cascading in places before the sampling point. It seems that the reason for the absence of the Ephemeroptera and the low percentage of the Trichoptera was the large amounts of encrusting slimy blue-green algae in the biotope which must have smothered the microhabitats of many animals.

At all these sampling points the percentages of the Cladocera and Copepoda (Tables 20 & 25) were higher than at sampling points where there were no effluents, and at all of them they were probably feeding on bacteria, protozoa and similar small organisms which developed as a result of the enrichment of the water by the effluents. However at Station 11b this enrichment probably took place higher up the river at Station 11a. The main groups to benefit from the enrichment were Daphnia, Moina, Bosmina, Diaptomus and Cyclops. Moina and Daphnia are genera which thrive in enriched conditions in sewage purification ponds (Loedolff 1965). Where there were no effluents entering the streams and rivers few Cladocera and Copepoda were found in the winter and summer, but at points where effluents rich in organic matter entered the rivers Cladocera and Copepoda were present in large numbers in all seasons.

Quantitative data on the stones in current fauna

The sampling points where quantitative (Surber sampler) data were obtained and the numbers of occasions on which it was possible to obtain such data are shown in Table 26. Wherever possible three square feet were sampled on each sampling visit. Comparison of Table 26 with Tables 20 and 22 to 25 shows that the amount of quantitative data was limited by comparison with the amount of data available when non-quantitative data was brought into consideration by using the percentage transformation. The percentage data on which the description of the stones in current fauna was based in the previous section is in certain cases preferable to untransformed quantitative data. For instance when describing how the dominants changed down the course of the river the reduction of all data to a common scale (the percentage scale) greatly facilitated the comparison. However density changes are often highly informative and while percentage changes often coincide with density changes this is not always so. Therefore, provided that it is remembered that samplers such as the Surber sampler yield estimates of population densities and not exact figures, quantitative data about the fauna helps considerably in the recognition of the important factors governing the distribution and abundance of the fauna.

The quantitative data have been condensed for presentation here by treating the fauna by major groups. Thus the Ostracoda, Baetidae, Hydropsychidae and Chironomidae have been treated as single groups, but where it is necessary to know the species making up these groups they may be found by reference to Tables 20 and 22 to 25.

The quantitative data (Table 27) shows some of the variations in the abundance of groups of animals from zone to zone, which were suggested by the percentage data, particularly clearly. For instance there was a decline in the density of the Baetidae and Simuliidae and an increase in the density of the Chironomidae as the rivers changed from the Eroding Zone to the Stable Depositing Zone, reflecting the increased siltiness of the river. The density of *Choroterpes*

(Euthraulus) was low at Station 21, because, as previously explained, of the type of stone making up the biotope. On the other hand the density of Neurocaenis was clearly lowest in the Stable Depositing Zone. The probable reason for this requires a digression into the seasonal occurrence and taxonomy of the genus. As may be seen the density of Neurocaenis tended to be highest in the summer in the Unstable Depositing Zone and lowest in the winter, but at Station 21a the density in the summer was lowest and there was little difference between the densities found in the winter and dry early summer. There is strong circumstantial evidence that two species of Neurocaenis were involved in this. The first was an Unstable Depositing Zone species, whose nymphs were never found in the months of July, August and September. This was probably the species found at Warrenton which was not recorded in the August samples there (Table 6). The second was an Eroding Zone species whose nymphs were found in July, August and September and at other times at Station 21a, the only Eroding Zone sampling point to be visited on a monthly basis. This would be the Neurocaenis which was found at Stations 24a, 24, 25 and 26 in the single winter samples which were collected in August. Unfortunately it was not possible to confirm, by rearing adult material, that there were two species of Neurocaenis involved. More than one species of Neurocaenis has been described from South Africa, but the nymphs differ in difficult characters and it is impossible to be certain which species is present without confirmation of nymphal identifications with adult material. The Stable Depositing Zone may be the zone where the two species meet and where neither occurs in large numbers. The Eroding Zone type was present at Stations 21, 2a and 10 for Neurocaenis nymphs were found at all three stations in July, August or September. However for purposes of constructing

Figures 19 to 21 the Neurocaenis nymphs were treated as a single group and not divided into an Eroding Zone group and an Unstable Depositing Zone group.

The comparatively sheltered summer conditions in the Stable Depositing Zone, particularly at Station 21, are reflected in the densities of several groups which did not decline as much in the summer in this zone as they did in other zones. These groups were Nais, Ostracoda, Caenidae, Elmidae, Chironomidae and Burnupia. The density of Baetidae (mainly B. glaucus and C. excisum), Neurocaenis and the Hydropsychidae increased from the Stable to the Unstable Depositing Zone, while the densities of Tricladida, Hydrachnellae, Caenidae, Elmidae, Chironomidae and Burnupia declined. The reasons for these changes have been discussed in the section where percentage composition of the stones in current fauna was presented.

There were no quantitative data from the 'muddy' high-lying Unstable Depositing Zone (Station 19), but the data from the 'sandy' high-lying Unstable Depositing Zone show how very similar this zone was to the normal Unstable Depositing Zone. Densities of many groups and species (Tricladida, Nais, Hydrachnellae, Baetidae, Neurocaenis, Caenidae, Elmidae) were similar in the two zones. Hydropsychid densities were low by comparison with the normal Unstable Depositing Zone, and this was probably due to a shortage of food in this zone. Certainly the Cladocera and Copepoda were not as abundant as they were in the normal Unstable Depositing Zone (see above, p. 105).

Many large changes in the density of the stones in current fauna took place where effluents reached the rivers (Table 27) and large densities of some animals which were usually scarce were also recorded. These are shown in Table 28. The main point shown by the quantitative data for these sampling points is that, except at Stations

11b and 11c, percentage increases (Tables 20 and 25) were indicative of large density increases, showing that enrichment of the water was associated not only with an alteration in the composition of the fauna but also with an increase in the density. This is of course the normal type of change brought about by organic enrichment in the absence of toxic substances. However the large increases in the numbers of Hydropsychidae at Station 17 were unusual and represent a type of recovery stage of the fauna which is not often encountered in rivers. However where rivers are dammed and a rich plankton develops faunal changes similar to those at Station 17 are sometimes found, as was the case in the Vaal River below the Vaal Barrage (Chutter, 1963). At Station 11b the density of the fauna as a whole was not high, and although the fauna was practically limited to Nais, Chaetogaster, Tubificidae and Chironomidae (which included a few Chironomus larvae), the density of none of these animals was particularly high (Tables 27, 28). This suggests that the changes in the fauna were not due to the appearance of large amounts of organic matter which would have brought about large increases in the densities of these animals. The quantitative data indicates that the complete absence of so many groups from the fauna was due to toxic substances. At both Stations 11b and 11c the density of the fauna in the summer was very low, largely due to the greatly reduced densities of Nais, a species which was unable to withstand summer conditions in the normal Unstable Depositing Zone.

The zonation and seasonal variation of the stony backwater fauna

The biotopes whose fauna is to be described in this section were all stony and most of them were out of the current for most of the year. Certainly none of them was ever subject to the direct effects of strong currents such as are found in the stones in current biotopes. However there were sampling points where there were no true stony backwaters. At some of these there were stones in a very slow current or stones on the bottom of pools from which samples were drawn, but at many others there was no biotope of this type. During floods in the summer rainy season it is to be expected that currents would appear in the stony backwaters.

Sampling of stony backwaters was not undertaken until the summer of 1960. By this time field work was concentrated on the Vaal River, its north bank tributaries and the Klein Vaal River. Monthly field trips to this area ceased in July 1960, but an opportunity arose during October 1960 to sample this type of biotope during the dry early summer season. In the other streams and rivers of the Vaal Dam catchment the only available data are from samples collected during the field trip of the winter in 1961.

The procedure adopted in the description of the stony backwater fauna is the same as that used for the description of the stones in current fauna. The fauna of the Klein Vaal/Vaal River is first described and compared to the fauna of other rivers, then the fauna of high-lying Unstable Depositing Zone, and finally the fauna at sampling points where the rivers were affected by effluents.

The fauna of the Klein Vaal/Vaal River and a comparison of it with the fauna of other Vaal Dam Catchment rivers

The main features of the biotopes sampled at the sampling points along the course of the Klein Vaal/Vaal River were as follows:-

Station 21a. The biotope consisted of widely separated stones lying submerged in water up to 50 cm deep, on top of a sheet of dolerite. It could perhaps be better described as stones on the bottom of a shallow pool, rather than as a stony backwater.

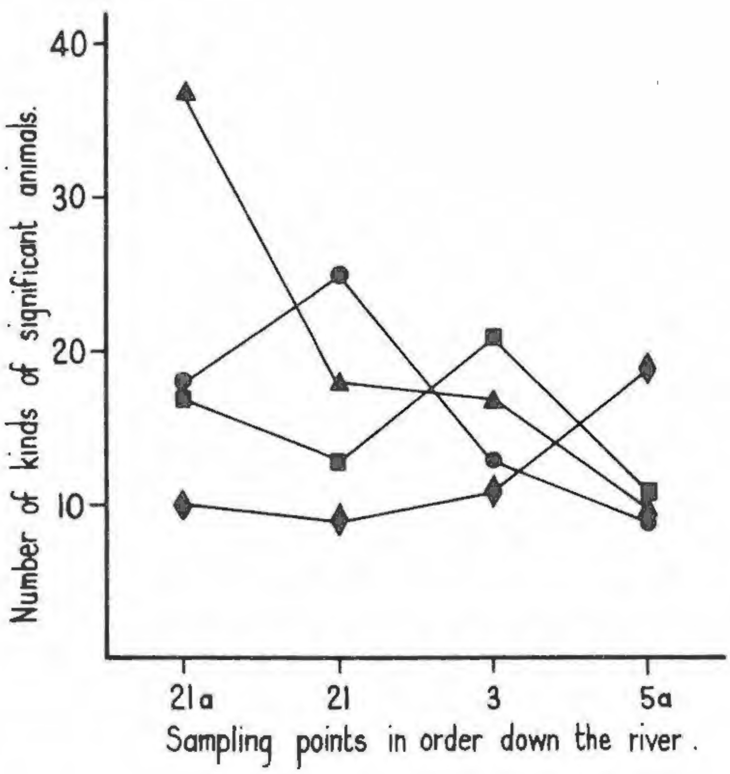


Figure 22. Stony backwater communities of the Klein Vaal / Vaal River. The numbers of kinds of animals significant at each sampling point in the winter, omitting Cladocera and Copepoda, and the number of them which were significant at the other sampling points.

▲ species significant at station 21a ■ species significant at station 3
● ———— " ———— 21 ♦ ———— " ———— 5a

Station 21. Here the biotope consisted of a stony bottom out of the current and, as in the stones in current biotope, the stones were flat. The water was rather shallow, about 25 cm deep. Silt was deposited in moderate amounts in this backwater and in winter and dry early summer there were large growths of diatoms.

Station 3. Here there was a true stony backwater out of the current. The water was about 50 cms deep and there were often thick deposits of muddy silt on top of the stones in the summer.

Station 5a. There was no true stony backwater here and the stones sampled were exposed to a slow current.

There was only one sample taken from the stony backwaters at Station 21a in the dry early summer and summer, and at the remaining stations in the dry early summer (Table 29). At stations where there was only one sample taken in a season it is, of course, impossible to know which species would be significant through having been found in more than half the samples in a season. However, an analysis of the zonation of the fauna, such as was made in Figures 19 and 20 for the stones in current biotopes, depends on the recognition of significant species. Because winter was the only season in which more than one sample was taken at each sampling point in the stony backwaters, it is the only season in which the significant species from all the sampling points may be compared. Figure 22 shows that in this season there were many more species or groups of animals significant at Station 21a, in the Eroding Zone, than at the other sampling points. About half these animals were significant at Station 21 and then fewer were found further downstream. The fauna at each of the other sampling points appeared to be fairly distinctive, but this was somewhat misleading for at Station 3 there was only one kind of animal, Chaetogaster sp., which was not significant at one or other of the remaining sampling points. As in the case of the stones in current fauna the kinds of animals which were significant at each sampling point but not at any other sampling point help to reveal the important factors bringing about changes in the fauna. In the winter these animals were:-

Station 21a

Prostoma sp.
Limnodrilus sp.
Nais sp.
Ilyocypris sp.
Cyprilla sp.
Baetis harrisoni
Centroptilum sudafricanum
Centroptilum sp. I
Centroptilum sp. II
Pseudocloeon vinosum
Athripsodes sp.
Hydroptilid sand case
Elmid larvae 'type 3'
Hydraenid larvae

Station 21

Gomphocythere sp.
Pionocypris sp.
Helminthopsis bifida
Helminthocharis cristula
Elmid larva 'type 6'

Station 3

Chaetogaster sp.

Station 5a

Baetis glaucus
Centroptilum medium
Prosopistoma sp.
Pseudagrion vaalense
Cheumatopsychie thomasseti
Elmid larvae 'type 7' (?Stenelmis)
Hydraenid 'type B'

The species or groups found at Station 21a include several, such as the three Centroptilum species, P. vinosum and Hydroptilid "sand case", which prefer silt-free conditions. Many of the others belonged to widespread groups. The three Elmids which were significant only at Station 21 would have been associated with the abundant vegetation there. The marginal vegetation data (see below) suggest that Pionocypris, another animal significant only at Station 21, is found only in biotopes well sheltered from the current. At Station 5a the presence of B. glaucus, Prosopistoma, C. thomasseti and Elmid larva 'type 7' was due to the current, for these are all stones in current animals.

The kinds of animals significant at more than one sampling point are less informative than those significant at single sampling points. They were as follows:-

Stations 21a, 21

Adenophlebia sp.
Ecnomus sp.
Hydroptila cruciata
Elmid larva 'type 2'
Simulium larvae
Bezzia type larvae

Stations 21, 3, 5a

Austrocloeon africanum

Stations 21, 3

Pisidium

Stations 21, 5a

Burnupia

Stations 21a, 21, 3

Isocypris sp.
Hydrachnellae
Micronecta spp.
Tanytarsini

Stations 21a, 3, 5a

Afronurus sp.
Orthotrichia sp.
Chironomini

Stations 21a, 3

Tubifex sp.
Cypridopsis sp.
Centroptilum pulchrum

Ubiquitous - Tricladida, Nematoda, *Centroptilum excisum*, *Choroterpes* (*Euthraulus*) sp., Caenidae, *Pentaneura*, Orthocladiinae.

Some of these distributions are explicable in terms of what is known about the biotopes at the various sampling points in relation to the habitat of the animals. For instance it is not surprising that the Corixids *Micronecta* spp. should not have been significant at Station 5a where there was a current through the biotope. However in general terms the most important point about the kinds of animals significant at groups of sampling points was that no animals were exclusively significant at Stations 3 and 5a, the Unstable Depositing Zone sampling points. Except where stones in current species were found because the stones were not in true backwaters, the winter fauna of the Unstable Depositing Zone was therefore made up of species found in other zones and was not distinctive because of the presence of species or groups exclusive to it.

In the summer more than one sample was analysed from Stations 21, 3 and 5a (Table 29) and it is therefore possible to recognise the significant species or groups of animals. There were 32 of these at

Station 21, 13 at Station 3 and only 9 at Station 5a. However the single sample collected from Station 21a contained 36 kinds of animals, showing that the fauna in the Eroding Zone was the most varied in this season as well as in the winter. This was also the case in the dry early summer when the numbers of animals recognised in single samples from each of the four stations was as follows:-

Station 21a (Eroding Zone)	38
Station 21 (Stable Depositing Zone)	31
Station 3 (Unstable Depositing Zone)	29
Station 5a (Unstable Depositing Zone)	22

In the summer there was one significant species (Cloeon sp. nov., Table 29) exclusive to the Unstable Depositing Zone.

As in the stones in current, some animals, which were significant at all or nearly all sampling points in the winter or dry early summer, were significant only at Station 21 in the Stable Depositing Zone in the summer. These were Nais, Tanytarsini and Orthocladiinae (Table 29) and their presence in the summer at this station shows that it was more sheltered from the scouring effects of summer floods than were the other sampling points.

The only stony backwaters sampled in the Eroding Zone of other rivers were in the Klip River (Table 30). The fauna at these sampling points was more like that at Station 21a than that at the other Vaal River sampling points in that Baetis harrisoni, Centroptilum sp. nov. II, Adenophlebia and Eubrianax were recorded. In addition to these species which are shown in Table 30, Centroptilum sp. nov. I, another typically Eroding Zone species was recorded from Stations 25 and 26. No Ostracoda were recorded but it is impossible to know whether this was a seasonal effect or whether these animals were permanently absent from this river. The Stable Depositing Zone

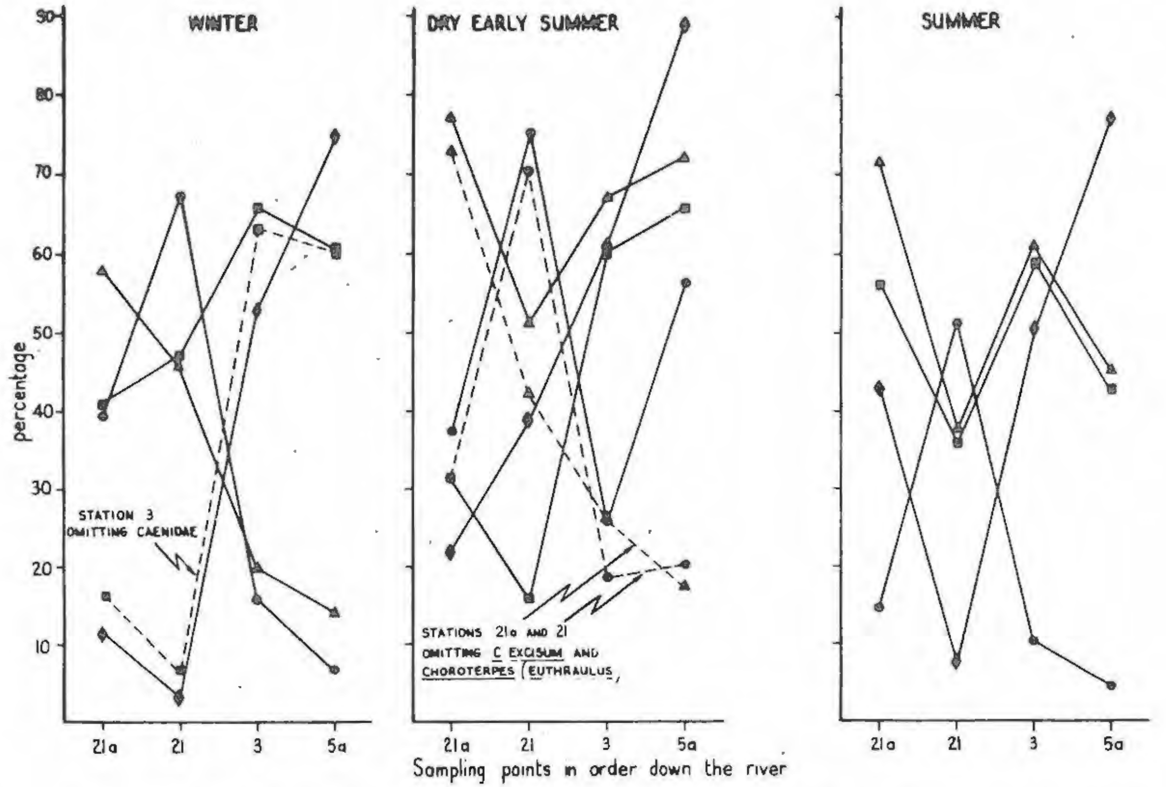


Figure 23. Stony backwater communities of the Klein Vaal / Vaal River. The percentage of the total fauna (omitting Cladocera and Copepoda) at each sampling point contributed by species whose mean seasonal percentage was > 5, and the percentage contributed by these species to the communities at other sampling points, season by season. Broken lines are for data omitting the animals indicated.

▲ species over 5% at station 21a
● ——— ,, ——— 21
■ species over 5% at station 3
♦ ——— ,, ——— 5a

fauna in other rivers (Table 30, Stations 2a and 10) was similar to the fauna at Station 21, except that there were fewer kinds of Elmids at Stations 2a and 10. The fauna of Station 12 and 13 in the Unstable Depositing Zone of the Wilge River was similar to that found at Station 3. (Station 19, also shown in Table 30, was in the high-lying Unstable Depositing Zone as is described in the next section).

In Figure 23 the percentages of the commonest animals found in the stony backwaters are compared in the same way as the stones in current animals were compared in Figure 21. Comparison of Figures 21 and 23 shows that whereas in the stones in current there were marked changes in the percentages of the commonest animals from zone to zone, the changes in the stony backwater fauna were not straightforward. In winter and summer the fauna at Station 21 was distinctive and the commonest animals at this sampling point made up only a small part of the fauna in the other two zones. In the winter the Eroding Zone fauna was distinctive and so too was the fauna at Station 5a, because the curves for the data from these stations showed sharp peaks. The percentages of the animals significant at Station 5a were very low at Stations 21a and 21. On the other hand, because the Caenidae just exceeded 5 percent of the fauna at Station 3 and because they made up very large percentages of the fauna at Stations 21a and 21 (Table 29) the curve for Station 3 did not fall away sharply to Stations 21 and 21a. In the summer the curves for Stations 21a and 3 followed each other closely, which was unusual for they were in different zones. From Table 29 it may be seen that the dominant animals or species or groups making up more than 5 percent of the fauna in any season at each sampling point were as follows:-

Station 21a	Station 21
Cyprilla sp.	Tricladida
Centroptilum excisum	Nais spp.
Centroptilum medium	Cypridopsis sp.
Centroptilum sudafricanum	Hydrachnellae
Centroptilum sp. nov. II	Centroptilum excisum
Choroterpes (Euthraulus) sp.	Caenidae
Caenidae	Micronecta spp.
	Tanytarsini
	Pentaneura sp.
	Orthocladiinae

Station 3	Station 5a
Cyprilla sp.	Ilyocypris sp.
Centroptilum excisum	Baetis glaucus
Centroptilum medium	Centroptilum excisum
Austrocloeon africanum	Centroptilum medium
Choroterpes (Euthraulus) sp.	Choroterpes (Euthraulus) sp.
Caenidae	Burnupia

The distinctiveness of the Station 21 fauna is immediately apparent from this list, and species or groups which were dominants at this sampling point, but not at others, were mainly animals which would prefer quiet, sheltered conditions, with silt and detritus. At Station 21a the dominants included two species, Centroptilum sp. nov. II and C. sudafricanum, which prefer silt-free conditions. The other Station 21a dominants were also dominants at Station 3 and several of them (C. excisum, C. medium and Choroterpes (Euthraulus) were dominants at Station 5a too. Part of the reason why the dominant stony backwater animals did not change with the zonation of the river was therefore that the Eroding and Unstable Depositing Zones had too many dominant animals in common. These animals are not affected by the amount of silt in the river, but two of them (C. medium and Choroterpes (Euthraulus)) showed a preference for the backwaters where there were not large amounts of organic detritus and very sheltered conditions. They were not found in large numbers at Station 21. The differences in the dominants at Station 5a and 3 which led to the large differences in the curves for these two stations in the winter and summer (Fig. 23) were due mainly to Baetis glaucus. The percentages of this current loving form were high at Station 5a in these two seasons (Table 29).

The percentages of certain ubiquitous dominant animals (Centroptilum excisum, Choroterpes (Euthraulus), Caenidae) tended to change in a regular manner along the course of the river (Table 29). Caenid percentages were not particularly high in the Unstable Depositing Zone (Table 29), but the percentages of the other two species were higher in this zone than in the Eroding or Stable Depositing Zone. As may be seen from the dotted lines in Figure 23, when the data are recalculated omitting certain of these species the type of zonation found in the stones in current (Fig. 21) appears, and the distinctiveness of the Eroding, Stable Depositing and Unstable Depositing Zone fauna is clear. This means that the percentages of C. excisum, Choroterpes (Euthraulus) and Caenidae masked the fact that the relative abundance of the other animals in the backwater fauna followed the zonation of the river.

At other sampling points in the Eroding Zone of other rivers (Table 30) the percentages of Hydrachnellae and Choroterpes (Euthraulus) were similar to those at Station 21a. However, Afronurus, Centroptilum excisum and Orthoclads made up a larger part of the Klip River Eroding Zone fauna than of the Klein Vaal Eroding Zone fauna. Animals whose percentages were higher in the Klein Vaal were Centroptilum sp. nov. II, C. sudafricanum and Caenidae. However, as the data for the Klip River and also that for the Wilge River (Table 30) is based on only one series of samples and is compared with data based on several samples, differences in the percentage composition of the fauna are to be expected and they should not be regarded as being too important.

The fauna of the Stable Depositing Zone of other rivers was similar to that of the Stable Depositing Zone in the Klein Vaal River. Thus at Stations 21 (Table 29), 2a and 10 (Table 30) the percentages of the Ostracoda, Choroterpes (Euthraulus), Caenidae, Micronecta spp. and Chironomidae were similar. There were however some differences between the fauna of the three sampling points. At Station 2a the percentages of Centroptilum excisum and of C. pulchrum were high, at Station 10 the percentage of Afronurus was high and at both these sampling points the percentages of Hydrachnellae and Elmidae were lower than at Station 21. The backwaters at both Stations 2a and 10 did not contain as much detritus as that at Station 21 and in addition there were often large growths of Spirogyra in the backwater at Station 2a. Factors such as these may help to account for the differences between the fauna of these three sampling points.

The Unstable Depositing Zone fauna in the Vaal and the Wilge River was very homogeneous, when allowance is made for the effect of current at Station 5a. The dominant winter animals, Centroptilum excisum, Choroterpes (Euthraulus) and Caenidae, were similar in the two rivers.

The Cladocera and Copepoda were most numerous in the Klein Vaal/Vaal River stony backwaters at Stations 21 and 3 in the dry early summer (Table 29), when temperatures were fairly high and flow conditions were stable. Percentages of Ilyocryptus, Macrothrix and Diaptomus were higher in the Unstable Depositing Zone, while percentages of Alona and Chydorus were higher in the Eroding and Stable Depositing Zones. As in the stones in current Moina was mainly a summer animal.

Very few Cladocera and Copepoda were found in the Eroding Zone backwaters of the Klip River (Table 30) but there were no samples collected in the dry early summer, when they would be expected to be most abundant. The Chydorinae, Cyclops and at Station 10, Paracyclops, were abundant in the Stable Depositing Zone of the Vaal and Wilge Rivers (Table 30, Stations 2a and 10), reflecting stable conditions and large amounts of detritus and algae in this zone. The Cladocera and Copepoda of the Unstable Depositing Zone in the Wilge River were similar to those of this zone in the Vaal River, bearing in mind that they were collected in winter.

The fauna of the high-lying Unstable Depositing Zone

Station 19, where conditions were excessively silty, was the only high-lying Unstable Depositing Zone sampling point where a stony backwater biotope was sampled. The stones were usually covered with a thick layer of fine muddy silt. The variety of animals found at Station 19 was similar to that of the Unstable Depositing Zone or the Stable Depositing Zone. Centroptilum sp. nov. I, Centroptilum sp. nov. II and C. sudafricanum, which are not found in silty conditions, were not recorded. However the percentage composition of the fauna at Station 19 (Table 30) was more similar to the Unstable Depositing Zone than to the Stable Depositing Zone because the percentages of Centroptilum excisum and Choroterpes (Euthraulus) were high and of Caenidae were low. The environment at Station 19 was more similar to the Unstable Depositing Zone than to the Stable Depositing Zone where there was a lot of plant detritus. However there were some animals whose percentages at Station 19 were unlike those recorded elsewhere in any zone. The Ostracoda, Tanytarsini and Orthocladiinae were particularly abundant. This was because conditions were so sheltered and because the large amounts of fine sediments would have contained an ample supply of detritus for them to feed on. Conditions were too silty for Afronurus which was not recorded. It was absent from the stones in current too. Most of the Cladocera were Chydoridae and these were more abundant in the Eroding and Stable Depositing Zones of the Klein Vaal/Vaal River than in the Unstable Depositing Zone. At Station 19 the percentage of Paracyclops was higher than at most other sampling points.

The fauna at sampling points where the chemical quality of the water was not normal

The stony backwater fauna was studied at only two of the sampling points where the chemical quality of the water was not normal, Stations 4 and 5 (Table 29). At other sampling points belonging to this group there were no stony backwaters. The biotopes at Stations 4 and 5 were as follows:-

Station 4. The stones sampled here were not completely out of the current and were very close to the edge of the river. They were covered on top with slippery brownish-grey growths.

Station 5. A stony backwater with very large growths of diatoms in the winter and dry early summer. The water was normally about 30 cms deep. Silt and mud were deposited on the stones in summer.

The fauna at Station 4 was considerably affected by the changed conditions and in the winter was dominated by Nematoda, Nais, Chaetogaster and Orthocladiinae (Table 29) and in the summer by Nematoda, Limnodrilus, Nais, Chaetogaster, Salifa perspicax, Choroterpes (Euthraulus) and Caenidae. Although the Ostracoda, Tricladida, Hydrachnellae and the two Baetis species (Table 29) were not recorded it does not seem likely that the peculiarities of the fauna at this sampling point were due to deoxygenation, because animals likely to be affected by deoxygenation were always present, sometimes in large numbers (Caenidae in winter, Choroterpes (Euthraulus) in summer). The more likely explanation for the change in the fauna was that the large growths of unusual slimy epiphytes smothered the microhabitats of some animals and provided a large food resource for others, such as the Oligochaeta, which could exploit it.

At Station 5 the fauna was more normal than at Station 4 and the percentages of most animals were not strikingly changed. However in the winter Nais, Chaetogaster and Orthocladiinae, and in the dry early summer Nais and Cypridopsis percentages were higher than they usually were in the Unstable Depositing Zone. This may be associated with the unusually abundant diatom growths present at this sampling point in these seasons. However there is no explanation for the absence of the usually very abundant Choroterpes (Euthraulus) from this station in the dry early summer.

Few Cladocera and Copepoda were found at Station 4, because this biotope was at the edge of the river next to a stony run. At Station 5 the Cladocera and Copepoda were similar, both in variety and abundance, to those at Station 3, except for Moina and Diaptomus. These animals were a larger part of the Station 5 fauna, and this was due to the mild enrichment of the water there.

The zonation and seasonal variation of the marginal vegetation fauna

In this section the fauna of the fringing vegetation is described in relation to the zonation of the river and the seasons of the year. As was done with the stones in current data, the fauna of the Klein Vaal/Vaal River is described first from a point of view of the kinds of significant animals found at each sampling point, and this is followed by a description of the changes in the percentage composition of the fauna from sampling point to sampling point. At the same time the fauna of sampling points in the same zones as those found in the Klein Vaal/Vaal River is brought into consideration to show whether changes taking place in the Klein Vaal/Vaal River are representative of the whole area. In the next two sections the fauna of the high-lying Unstable Depositing Zone and of the sampling points where the chemical quality of the water was not normal are described, again from the aspects of the variety of the fauna and its percentage composition. Finally the quantitative data on the important groups of animals is given to show that the percentage changes usually represent density changes.

Neither stones in current nor stony backwater biotopes were found in the Source Zone and the marginal vegetation fauna is therefore the fauna of the first biotope to be described from this zone. The Source Zone was sampled only at Station 1 on the Vaal River. In order to bring this zone in with the Eroding, Stable Depositing and Unstable Depositing Zones Station 1 has been included in the sampling points described as belonging to the Klein Vaal/Vaal River. In this section these are therefore Stations 1, 21a, 21, 3 and 5a.

The fauna of the Klein Vaal/Vaal River and a comparison of it with the fauna of other Vaal Dam Catchment rivers

The sampling points whose fauna form the basis of this section are Station 1 on the Vaal River, Stations 21a and 21 on the Klein Vaal and Stations 3 and 5a on the Vaal (Fig. 9). The following descriptions of the biotopes include features which are likely to influence the composition of the fauna:-

Station 1. The Source Zone. An open pool near the sponge at the source of the Vaal River. The banks of the pool were firm and the biotopes sampled consisted

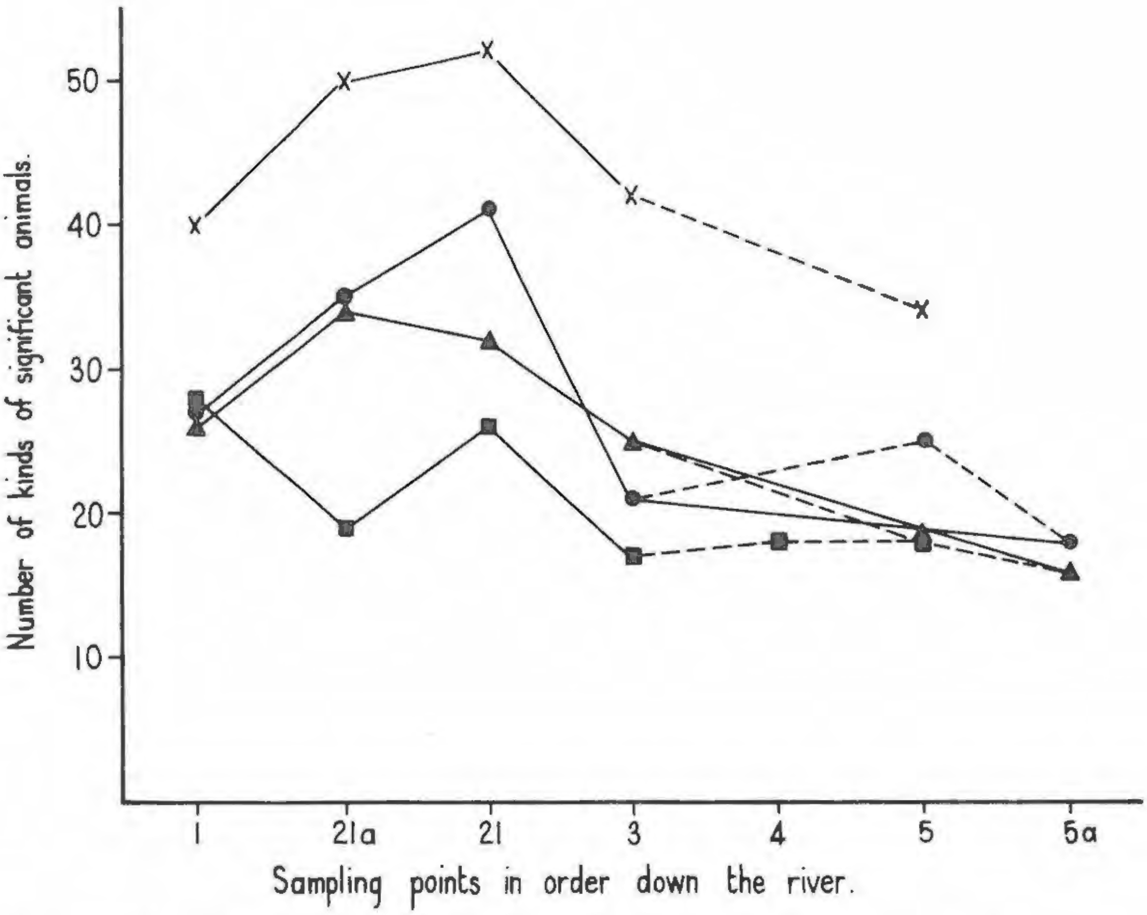


Figure 24. Marginal vegetation communities of the Klein Vaal / Vaal River. The number of kinds of significant animals, other than Cladocera and Copepoda, recorded at each sampling point combining all seasons (x) and by season (● winter, ▲ dry early summer, ■ summer). Data for stations 4 and 5 are joined by broken lines.

of the leaves of bank grasses which trailed in the water. In summer the stream flowed along a grassy furrow to the next pool, but in winter the water level fell so that pools were no longer connected by a surface flow. Sheep and cattle frequently drank from the pool. The water was invariably turbid.

Station 21a. The Eroding Zone. The biotope sampled consisted mainly of the leaves of non-aquatic grasses trailing in the water. There was a gentle current through these trailing leaves.

Station 21. Stable Depositing Zone. The biotope sampled consisted of Cyperus fastigiatus Rottb. This plant dies off in the winter. Decay takes place in this season and in the dry early summer too. The new season's growth starts in the spring and by summer the remains of the previous year's growth have disappeared and been completely replaced.

Station 3. Unstable Depositing Zone. The vegetation was a sparse fringe of Scirpus and grasses, growing on a steep bank. There was some current through the vegetation, particularly in the summer.

Station 5a. Unstable Depositing Zone. A fringe of Scirpus round a small island in the rapids (Plate IX) was sampled. There was some current through the Scirpus. In the summer the river rose and it was no longer possible to reach the island to take samples.

At all these sampling points there were large amounts of filamentous algae in the marginal vegetation in the dry early summer. These algal growths were not found in the summer and first appeared during the later part of the winter.

The numbers of significant animals recorded at these sampling points are shown in Figure 24, which shows that the greatest variety of animals over the whole year was found in the Stable Depositing Zone (Station 21). Data for Station 5a were not complete because the marginal vegetation there was not sampled in the summer (see above). In the Source Zone there was no seasonal variation in the diversity of the fauna, and this was due to the sheltered nature of Station 1, which was below a marsh and therefore not subject to scouring summer floods. In the other zones the summer fauna was

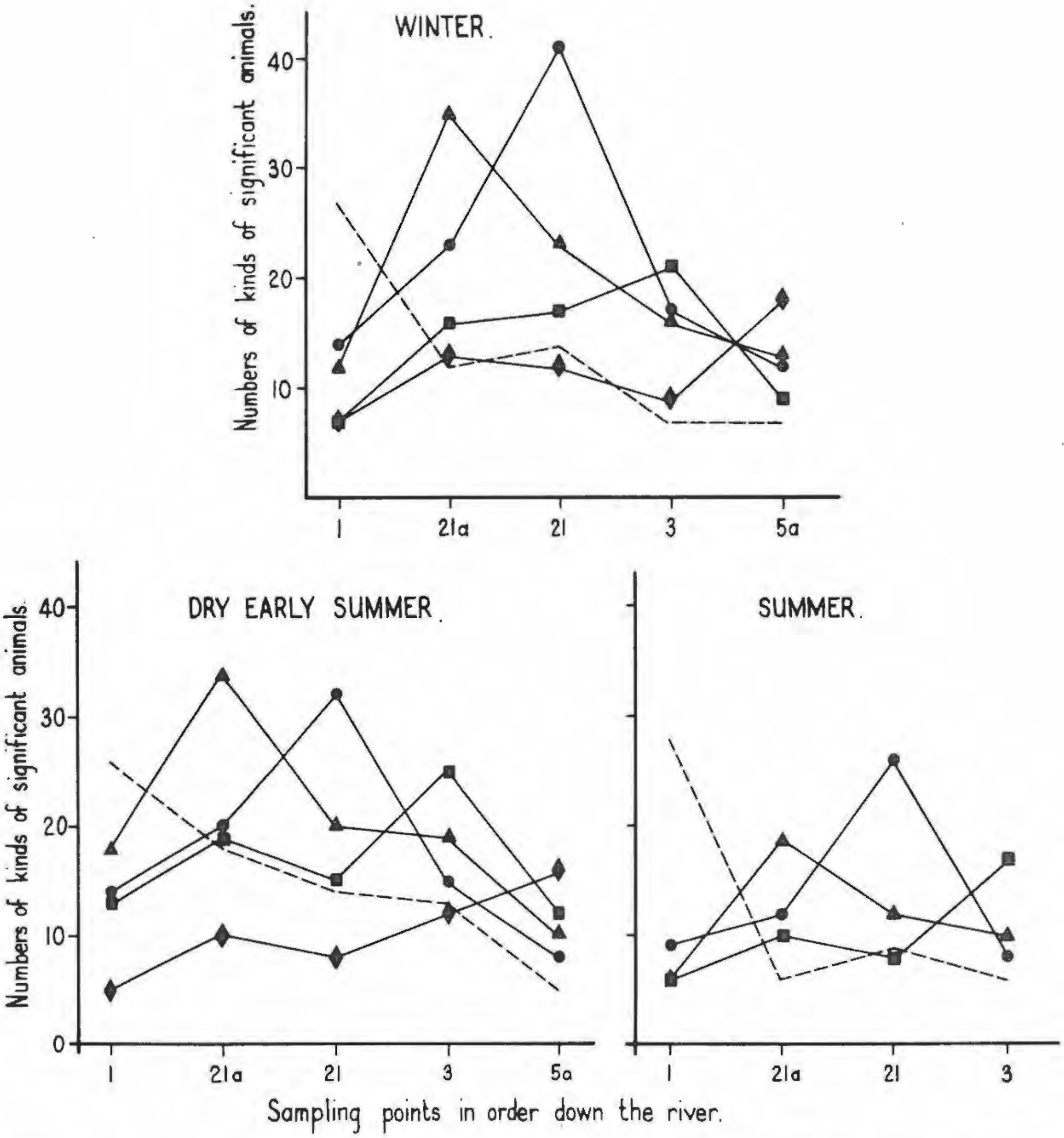


Figure 25. Marginal vegetation communities of the Klein Vaal / Vaal River. The numbers of kinds of animals significant at each sampling point, omitting the Cladocera and Copepoda, and the number of them which were significant at the other sampling points; season by season.

▲ Species significant at station 21a. ■ Species significant at station 3.

● ———— ,, ———— 21. ♦ ———— ,, ———— 5a.

– – – – Species significant at station 1.

less diverse than in other seasons and this was probably due to summer flooding, but it is interesting that the summer diversity at Station 21 was greater than at the other riverine sampling points, emphasizing once again the sheltered nature of the Stable Depositing Zone. In this zone rather more significant species or groups of animals were recorded in the winter than in the dry early summer, but in the Eroding (Station 21a) and Unstable Depositing (Stations 3, 5a) Zones there was very little difference between the diversity of the winter and the dry early summer fauna.

The distribution of the significant animals is analysed in further detail in Figure 25. As the biotope at Station 5a was in a strong current and that at Station 3 was not, it should be expected that the kinds of significant animals found at these two sampling points would differ, although they were in the same zone. The difference between them is shown in Figure 25, which also shows that the variety of animals found at each sampling point was distinctive, as would be expected because they were all, apart from Stations 3 and 5a, in different zones. Flow conditions at Station 1 were always stable. Seasonal changes in the shape of the curves for Station 1 species or groups are interesting for they reflect the seasonal changes in the stability of the river environment. In the summer when conditions in the river were most unstable due to floods, few of the significant animals at Station 1 were significant in the river and the curve for the Station 1 species or groups fell away sharply to Station 21a. In the dry early summer, when conditions were most stable in the river, most of the Station 1 species or groups were significant in the river too and the curve for Station 1 animals fell away gradually to Station 3, but then sharply to Station 5a where there was always a current through the biotope. Because the beginning of winter is a period when conditions in the river settle down after the summer floods and the fauna gradually recovers, the shape of the curve for the animals significant at Station 1 was intermediate in this season.

Many of the significant marginal vegetation animals always made up too small a part of the fauna to be included in Table 31 and the table therefore gives a very incomplete picture of which species were significant at the various sampling points in the different seasons. However in order to show that it was still water forms from Station 1 which made up a large part of the dry early summer significant animals at the river sampling points, the species or groups of animals significant at Stations 21a and 1 and at Stations 3 and 1 are given below season by season:-

Species or groups significant at Stations 21a and 1

Winter	Dry early summer	Summer
Nematoda	Nematoda	Nematoda
Nais spp.	*Nais* spp.	*Nais* spp.
Stenocypris spp.	*Cypridopsis* spp.	*Isocypris* spp.
Isocypris spp.	*Stenocypris* spp.	Hydrachnellae
Hydrachnellae	Hydrachnellae	Chironomini
Hydraenid 'type A'	*Austrocloeon* spp.	*Pentaneura* spp.
Culex spp.	Caenidae	
Chironomini	*Oxyethira* sp.	
Tanytarsini	*Plea pullula*	
Pentaneura spp.	*Plea piccanina*	
Orthocladiinae	Dytiscid larvae	
Bezzia type larvae	Chironomini	
	Tanytarsini	
	Pentaneura spp.	
	Corynoneura spp.	
	Orthocladiinae	
	Bezzia type larvae	
	Pisidium spp.	

Species or groups significant at Stations 3 and 1

Winter	Dry early summer	Summer
Chaetogaster spp.	Nematoda	Nematoda
Isocypris spp.	*Nais* spp.	*Stenocypris* spp.
Chironomini	*Cypridopsis* spp.	*Plea pullula*
Tanytarsini	Hydrachnellae	Dytiscid larvae
Pentaneura spp.	*Oribatoides* spp.	*Simulium* larvae
Orthocladiinae	Caenidae	Chironomini
Bezzia type larvae	*Plea pullula*	*Pentaneura* spp.
	Hydraenid 'type A'	
	Chironomini	
	Pentaneura spp.	
	Corynoneura spp.	
	Orthocladiinae	
	Bezzia type larvae	

The important points about these lists are that very few of the animals could be identified to species and had this been possible these lists might have been shorter. A second point is that the only one of these groups to be a specifically flowing water type was the *Simulium* recorded from Stations 3 and 1 in the summer, and many of the animals included in them are definitely standing water types, such as the two *Plea* species, *Austrocloeon* spp., Dytiscid larvae and *Culex* spp. These lists therefore show that at Stations 21a and 3 there were more stable condition species and groups in the dry early summer than in the other seasons. Data for Stations 21 and 5a are not given as the types of animals significant at these stations and at Station 1 were very much the same as those listed above.

However, the seasonal change of the fauna in response to changing conditions of stability is by no means the only relationship between the diversity of the fauna and the environment shown by the marginal vegetation fauna. Other relationships were mostly not as directly related to seasonal changes, and the significant animals found at the various sampling points in the three seasons have therefore been combined to make the following lists of species significant at the various sampling points, but as Station 5a was not sampled in the summer it has been omitted:

Significant at Station 1 only

Hydra sp.
Dero (*Dero*) sp.
Eucypris sp.
Enallagma sp.
Sphaerodema capensis
Hydraenid 'type G'
Procladius sp.

Significant at Station 21 only

Austrocloeon africanum
Anax sp.
Ranatra parvipes
? *Nyctiophylax* sp.
Laccophilus pellucidus
Leptelmis fragilis
Orectogyrus spp.
Hydraenid 'type D'
Hydrophilid 'type N'

Significant at Stations 1, 21a and 21 only

Austrocloeon spp.
Pisidium spp.
Tadpoles

Significant at Station 21a only

Baetis harrisoni
Centroptilum sudafricanum
Athripsodes harrisoni
Uvarus peringueyi
Hydrophilid 'type A'
Anopheles spp.

Significant at Station 3 only

Caridina nilotica
Neurocaenis sp.
Aulonogyrus sp.
Hydraenid 'type H'

Significant at Stations 1, 21a and 3 only

Limnodrilus spp.
Stenocypris spp.
Plea piccanina
Plea pullula
Dytiscid larvae

Significant at Stations 1 and 21 only

Rhabdocoelida
Pionocypris sp.
Haliplidae
Hydraenid 'type C'
Hydrophilid larvae

Significant at Stations 21a and 21 only

Prostoma sp.
Laccocoris limigenus
Tropocorixa pectoralis
Orthotrichia sp.
Helminthopsis bifida
Gyraulus lamyi
Burnupia spp.

Significant at Stations 1, 21a, 21 and 3

Nematoda
Nais spp.
Cypridopsis spp.
Isocypris spp.
Hydrachnellae
Oribatoides spp.
Caenidae
Hydraenid 'type A'
Chironomini
Tanytarsini
Pentaneura spp.
Corynoneura spp.
Orthocladiinae
? *Bezzia* spp.

Significant at Stations 1 and 3 only

Chaetogaster sp.
Hydrophilid 'type G'
Simulium larvae

Significant at Stations 21a, 21 and 3 only

Cyprilla sp.
Baetis bellus
Centroptilum excisum
Centroptilum pulchrum
Pseudocloeon vinosum
Pseudagrion spp.
Nychia marshalli
Anisops sp.
Micronecta dimidiata
Hydraenid 'type B'
Hydraenid larvae

Significant at Stations 1 and 21a only

Oxyethira sp.
Hydraenid 'type E'

Significant at Stations 21 and 3 only

Tricladida
Gomphocythere sp.
Baetis latus

Significant at Stations 21a and 3 only

Ilyocypris sp.

The important points shown by these lists of animals are firstly that many animals were found everywhere except in the Source Zone (animals significant at Stations 21a, 21 and 3), which is not at all exceptional since the Source Zone was pond-like. All the species and groups significant only at Station 1 were still water forms. The animals significant only at Station 21a included Centroptilum sudafricanum which is not found where there are large amounts of silt. Many of the species and groups of animals significant only at Station 21 were still water forms confirming that this biotope was more sheltered than the other river biotopes. This is also shown by the rather long list of kinds of animals significant only at Stations 1 and 21, all of which were still water forms. However there was also a large group of animals which was significant only at Stations 21 and 21a. The fauna at Station 3 included only four species or groups which were not significant at some other station and of these Neurocaenis is really a stones in current animal and Aulonogyrus spp. adults were found in all zones except the Source Zone. However only at Station 3 did they regularly occur in the marginal vegetation. It is interesting that there is not a single specific identification among the animals significant at all four sampling points, as this suggests that many of these groups may have been ubiquitous simply because it was not possible to identify them further. The important points about the significant animals at Station 5a, which is not included in above lists, may be seen in Table 31. The fauna included typically current dwelling animals such as Baetis glaucus and Simulium, but at the same time large numbers of Ostracoda were also found. Baetis glaucus was the only animal significant at Station 5a which was not significant at one or other of the sampling points further upstream. The occurrence of Pseudocloeon vinosum (Table 31) is interesting because it was significant throughout the year in the Eroding Zone, but was not significant in the lower zones in the summer. Its distribution and seasonal occurrence in the Vaal River and the Great Berg River

(Harrison & Elsworth 1958, p. 221) were therefore similar.

Station 1 was the only Source Zone sampling point and there are therefore no other sampling points with which its fauna may be compared to see how typical the fauna there was of the Source Zone in general. The commonest animals occurring in the marginal vegetation biotopes of the Eroding Zone of rivers other than the Klein Vaal are shown in Table 33. At Stations 22 and 26 the vegetation was a thin fringe of Scirpus in the current, at Station 9a it was Polygonum rather sheltered from the current, but at all the other stations the biotope sampled was the leaves of bank grasses trailing in the current. Of the animals found only in the Eroding Zone of the Klein Vaal/Vaal River only Baetis harrisoni and Centroptilum sudafricanum were recorded from some, but not all, of these sampling points (Table 33). Generally speaking the variety of animals recorded from these sampling points was not as great as it was at Station 21a, and a likely reason for this was the greater currents through these biotopes, which are shown by the large numbers of Simuliidae collected at some stations. The Ostracoda were poorly represented at these sampling points, except for Station 22.

The commonest animals at Stations 2a and 10, the other Stable Depositing Zone sampling points, are shown in Table 33. At both these sampling points the vegetation was sheltered from the current and at both Cyperus was the dominant plant in the vegetation sampled. In these respects they were therefore similar to Station 21. The fauna recorded from Station 2a was very similar to that found at Station 21 and of the animals significant only at Station 21 in the list shown on page 154, Austrocloeon africanum, Ranatra parvipes, Laccophilus pellucidus and Orectogyrus spp. were also significant at Station 2a. So too were Pionocypris sp., Haliplidae and Hydraenid larvae which are three of the five groups significant only at Stations 1 and 21, where conditions were more sheltered in the Klein Vaal/Vaal River. There were, however, differences between the two faunas. Caridina nilotica, an Unstable Depositing Zone animal in the Klein Vaal/Vaal River, and Eucypris which was significant only in the Source Zone were both significant at Station 2a. The fauna at Station 10 was not as intensively studied as that at Stations 2a and 21, and this may be the reason why many of the animals significant at these two stations were not significant at Station 10. However both the percentage and the density, which are described below, of Baetis bellus at this station in the summer suggest that the biotope was less sheltered from the current than it was at Stations 21 and 2a and this may have been why the diversity of the fauna from the three sampling points was not more uniform.

The commonest animals found at sampling points in the Unstable Depositing Zones of rivers other than the Vaal are shown in Table 34. The vegetation at these sampling points was Scirpus, except at Station 41, where it was the leaves of bank grasses hanging into the water. Station 41 was on a small tributary of the middle reaches of the Wilge River (Fig. 9) and the vegetation was hanging into a pool which was really more like a pond than a pool in a stream, so small was the flow. In addition to the animals shown in Table 34 a variety of Hemiptera and beetles of the families Dytiscidae, Hydraenidae and Hydrophilidae were found at Station 41. The Baetidae there, which in summer were solely Austrocloeon spp., were similar to those of the Source Zone, but on the other hand, although the presence of large percentages of Ostracoda was also a Source Zone characteristic, the genera at Station 41 were either widespread (Cypridopsis, Stenocypris) or riverine (Ilyocypris, Cyprilla). This might suggest that Ostracoda occur in sheltered biotopes in the summer, but that some of them are affected by other factors, which could include whether the biotope is in a stream or a pond or the chemical nature of the water. At Station 44 the Scirpus was in a strong current, but at the remaining stations the current was more gentle. The variety of animals recorded at these sampling points was not great and there were few more than those shown in Table 34. Conditions were not sufficiently sheltered for Caridina nilotica to be found at several of these sampling points. Ostracoda were found in large numbers in the only dry early summer sample from Station 12 and this was probably a seasonal effect.

This description of the diversity of the marginal vegetation fauna of the various zones has shown that current is an important factor bringing about faunal changes from zone to zone. In the Source Zone where there is virtually no current the fauna is really a pond fauna. In the Eroding Zone the fringing vegetation biotopes are almost all exposed to the current. Here few still water species are found and the fauna includes species, such as Centroptilum sudafricanum and Pseudocloeon vinosum, which are not found in silty conditions. Generally the marginal vegetation in the Stable Depositing Zone is sheltered from the current and many species not found in the other zones are present. No matter how little the current in the river the fauna was not the same as that found in the pond-like Source Zone of the Vaal River. Marginal vegetation biotopes sheltered from the current are not often encountered in the Unstable Depositing Zone. The variety of the animals is not great and only few are found in this zone but not in others. The effects of current and the zonation of the fauna are clear too from the relative abundance of the commonest animals which is examined in the following paragraphs.

Figure 26 shows the way in which the percentages of the dominant animals (i.e. those whose mean seasonal percentage was > 5)

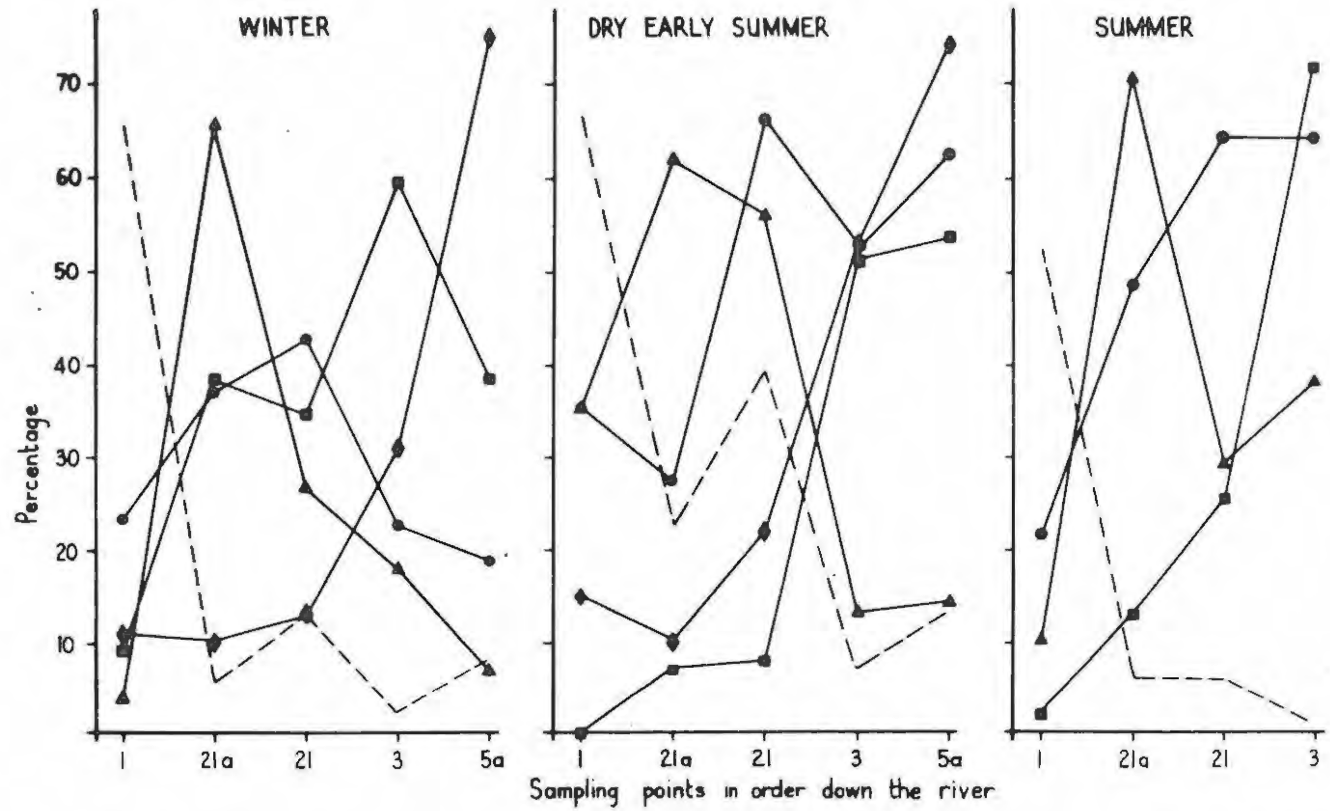


Figure 26. Marginal vegetation communities of the Klein Vaal / Vaal River. The percentage of the total fauna (omitting Cladocera and Copepoda) at each sampling point contributed by species whose mean seasonal percentage was > 5 and the percentages contributed by these species to the communities at other sampling points, season by season.

---- species over 5% at station 1
▲ ——— " ——— 21a
● ——— " ——— 21
■ species over 5% at station 3
♦ ——— " ——— 5a

at each sampling point changed along the course of the river. In all seasons the percentages of the Source Zone dominants declined sharply to the Eroding Zone, but then rose, slightly in the winter, but more sharply in the dry early summer to Station 21 in the Stable Depositing Zone, reflecting once more that conditions were more sheltered in the Stable Depositing Zone than in the Eroding Zone. However the percentage data for the Station 1 dominants are interesting in another way, for just as the diversity data (Figure 25) showed that the fauna of the Source Zone and the other zones was most similar in the dry early summer and least similar in the summer, so do the percentage data (Fig. 26). This is because conditions are most stable in the river in the dry early summer. In the winter and the dry early summer the curves for the Station 1 dominants rose from Station 3 to Station 5a. This was anomalous, but Table 31 shows that this was due to <u>Cypridopsis</u> spp., which was a dominant at Station 1 and more abundant at Station 5a than at Station 3. However so different were ecological conditions at Stations 1 and 5a that it is likely that two species of <u>Cypridopsis</u> were involved.

The dominants at Station 21a were distinctive, for the curves for this sampling point showed clear cut peaks. In the dry early summer and in the summer the curves for the Stable Depositing Zone (Station 21) did not fall away in the Unstable Depositing Zone. In the winter the percentages of the dominants at Stations 3 and 5a differed markedly from each other and also from the dominants at other sampling points, in the dry early summer they were similar to each other and very different from the dominants in other zones, and in the summer the dominants at Station 3 formed a small part of the fauna at other stations.

These are the broad trends of differences or similarities between the dominant animals at the various sampling points. The percentages of the species or groups bringing about these faunal differences are shown in Table 31. A consideration of the animals concerned in more detail helps to show which factors were responsible for these faunal differences between stations. In the winter the species or groups making up more than 5 per cent of the fauna at the various sampling points were as follows:-

Station 1	Station 21a	Station 21
Nematoda	Pseudocloeon vinosum	Nematoda
Nais	Caenidae	Pionocypris
Cypridopsis	Orthocladiinae	Caenidae
Hydrachnellae		Hydraenidae
Austrocloeon spp.		Orthocladiinae

Station 3	Station 5a
Isocypris	Cypridopsis
Gomphocythere	Isocypris
Baetis bellus	Baetis glaucus
Centroptilum excisum	Centroptilum excisum
Caenidae	Hydraenidae
Chironomini	Simuliidae
Orthocladiinae	

The groups at Station 1 were ubiquitous (Nematoda, Nais, Cypridopsis) still water forms (Austrocloeon spp.) or forms found mainly in the Source, Eroding and Stable Depositing Zone (Hydrachnellae). At Station 21a the dominants included two riverine groups (Caenidae, Pseudocloeon vinosum) of which P. vinosum was found by Harrison & Elsworth (1958) to be a species preferring vegetation with a little current but without silt. These animals therefore reflect the current and the lack of silt in the vegetation at Station 21a. The dominants in the Stable Depositing Zone (Station 21) included Pionocypris which was essentially a quiet water form, Caenidae, which were riverine and reached very high percentages in all biotopes in the Eroding and

Stable Depositing Zones (Tables 20, 29, 31), and other groups which were widespread. At Station 3 the Caenidae were still among the dominants, but the percentage of them was not as high as at Stations 21a and 21. Two species very characteristic of marginal vegetation bathed in gentle currents, Baetis bellus and Centroptilum excisum made up a large part of the fauna. The high percentages of Baetis glaucus and Simuliidae in the marginal vegetation at Station 5a were due to the strong current there.

In the quiet stable flow conditions of the dry early summer the dominant animals changed at some sampling points. In this season they were:-

Station 1	Station 21a	Station 21
Nematoda	Nais	Nais
Nais	Cypridopsis	Cypridopsis
Cypridopsis	Cyprilla	Centroptilum excisum
Stenocypris	Pseudocloeon vinosum	Caenidae
Hydrachnellae	Caenidae	Corynoneura
Chironomini	Tropocorixa	

Station 3	Station 5a
Centroptilum excisum	Cypridopsis
Baetid juveniles	Ilyocypris
	Centroptilum excisum
	Simuliidae

The main changes in the dominant animals from the winter to the dry early summer were that several animals which live in more sheltered conditions appeared in the Eroding Zone, even though the current-loving Pseudocloeon vinosum was still present. In the Unstable Depositing Zone the only dominant Baetid was Centroptilum excisum and the low percentages of Baetis bellus and B. glaucus suggest that currents were not as strong as they were in the winter. At Station 5a there was still a stronger current than at most sampling points for the percentage of Simuliidae were higher than elsewhere.

In the summer there was a sharp change in the environment as flows increased and currents appeared more strongly in the marginal vegetation biotopes of the river. The dominants in this season were:-

Station 1	Station 21a
Nematoda	Nais
Nais	Cyprilla
Eucypris	Baetis bellus
Austrocloeon spp.	Pseudocloeon vinosum
Oxyethira sp.	Caenidae
Orthocladiinae	

Station 21	Station 3
Nematoda	Baetis bellus
Pionocypris	Centroptilum excisum
Baetis bellus	Baetid juveniles
Caenidae	
Micronecta spp.	

The dominants in the Source Zone were still quiet water groups, but in the Eroding Zone the dominants, with the exception of Nais, were animals which are found only in rivers and not in the Source Zone. B. bellus and P. vinosum prefer vegetation through which there is a current, while Caenidae and Cyprilla are tolerant of a wide range of current conditions. B. bellus percentages increased down the course of the river in this season, and P. vinosum was not a dominant in any other zone because it is unable to tolerate silty conditions. The sheltered environment at Station 21 is shown by the presence of Pionocypris and Micronecta among the dominants, while the dominants at Station 3 were typical of marginal vegetation biotopes exposed to gentle currents in the Unstable Depositing Zone.

The percentage composition of the Eroding Zone fauna in streams and rivers other than Klein Vaal/Vaal River (Table 33) was in some ways rather different to that found at Station 21a. At Station 24a the high percentages of Baetis harrisoni, Centroptilum sudafricanum and Simuliidae were related to the strong current through the biotope and the fact that the stream was not silty. At Station 26, another sampling point where the biotope was in a strong current the winter dominants were B. harrisoni, C. excisum, P. vinosum, Caenidae and Simulium and the difference between the dominants at Stations 24a and 26 may have been due to temperature, since Station 26 was at a far lower altitude (Fig. 10) than Station 24a and was therefore probably warmer. However the dominants at both these sampling points include species which do not tolerate silty conditions (C. sudafricanum and P. vinosum). In the summer at Station 26 the dominants were B. bellus, Baetid juveniles (probably mostly B. bellus) and Orthocladiinae. Large numbers of B. bellus were also recorded in the summer at Stations 24, 9, 33 and 43. At these stations the current was not as strong as it was at Stations 24a and 26 so that in the winter the percentages of C. sudafricanum, P. vinosum and B. harrisoni were not high. However at many of these sampling points the Caenidae made up a large part of the fauna and this was typical of the Eroding and Stable Depositing Zones in the Klein Vaal/Vaal River. Percentages of the Chironomid groups were often high at these sampling points, and at Station 24 percentages of Micronecta spp. and Burnupia increased in summer showing that conditions were sheltered there. Large numbers of Pristina sp. were found at Station 43, but there was no obvious reason for this.

At Station 2a (Table 33) in the Stable Depositing Zone of the Vaal River, the dominant animals were in some respects similar to those at Station 21. Caenidae percentages were high in all seasons and the percentage of B. bellus was high only in the summer. The percentages of no other Baetidae were high at either sampling point. Cypridopsis percentages were high at both sampling points, but whereas Pionocypris (a sheltered biotope Ostracod) was a dominant at Station 21, another sheltered biotope Ostracod, Eucypris, was a dominant at Station 2a. The reason for this difference is unknown, so too is the reason why Caridina nilotica should have been a dominant at Station 2a and very seldom recorded at Station 21. However the main point of similarity between Stations 21 and 2a is that the fauna at both sampling points reflected that conditions were sheltered from strong currents. At Station 10 in the summer the percentage of B. bellus was very high and the percentages of the Ostracoda were not as high as at Stations 2a and 21, showing that the biotope at Station 10 was less sheltered in this season than those at Stations 2a and 21. Moreover the high proportion of Nematoda in the winter and dry early summer and the rather low proportion of Caenidae in all seasons were probably due to there being more silt at Station 10 than there was at the other two stations. The comparison of the diversity of the fauna at these three sampling points (p. 138) also showed that Station 10 was not quite like Stations 2a and 21. However there are aspects of the fauna found at Station 10, such as the proportion of Ostracoda in the summer, which show that conditions there were more sheltered than in the normal Unstable Depositing Zone.

The fauna of the Unstable Depositing Zone sampling points other than those in the Klein Vaal/Vaal River is shown in Table 34. As was the case when the variety of animals found was described, the fauna at Station 41 stands out as being very different from that found at the other sampling points in this zone. The dominant animals in the summer included groups which do not usually stand summer conditions (Ostracoda, Nais) and Austrocloeon spp. and Culex spp. which are typically standing water animals. As explained earlier this sampling point was located on a small stream which had not flooded for some time prior to the collection of the summer sample, and this accounts for the type of dominant animals. It also suggests that the disappearance of the Ostracoda from the Unstable Depositing Zone in the summer is not due to life-cycle or temperature effects, but happens because the biotopes in this zone are not suitable for them in the summer. In the winter the dominants were more typical of the Unstable Depositing Zone and included Nais, C. excisum and the Orthocladiinae. At Stations 27, 29, 12 and 36 the fauna was very similar to that found at Station 3, with high summer percentages of B. bellus and, in other seasons, high percentages of C. excisum. Animals which do not tolerate silty conditions, such as B. harrisoni, C. sudafricanum and P. vinosum were not recorded or were present as only a very small percentage of the fauna. Caenid percentages were not high and this is another way in which the fauna of these sampling points resembled that at Station 3 and differed from that in the other riverine zones. At Station 44, where there was a strong current through the vegetation, large numbers of Simuliidae were collected in both seasons, and the summer percentage of B. bellus was not high, possibly because the current was too fast for it. Mayflies which appeared there in the summer were Neurocaenis and the Caenidae. (It should be noted that nomenclature is confusing here. Neurocaenis is a Tricorythid and not a Caenid). The high summer percentage of the Caenidae was exceptional as this was the only sampling point where large numbers of this group were recorded in the Unstable Depositing Zone. It is impossible to say whether this was typical of vegetation fringes in fast current in this zone, as no others were sampled in the summer. However it was not exceptional to find Caenidae where there was a fast current, for they were often found in stones in current biotopes (Table 20, Stations 21a and 21).

As was the case in the other biotopes the Cladocera of the marginal vegetation (Table 31) changed down the course of the river. In the Source, Eroding and Stable Depositing Zones the dominant genera were the Chydoridae, Alona and Chydorus, and these were not found in large percentages in the Unstable Depositing Zone. Another Chydorid, Acroperus, was found only in the Eroding and Stable Depositing Zone, but Pleuroxus was recorded in large percentages in all zones. Percentages of the Daphniidae (Daphnia, Simocephalus, Ceriodaphnia) tended to be higher in the Unstable Depositing Zone than in the other zones, but Moina which also belongs to the Daphniidae was widespread. Of the Copepoda, the Harpacticidae were found mainly in the Source, Eroding and Stable Depositing Zones, Mesocyclops was found most often in the Source Zone, Diaptomus was found mainly in the Unstable Depositing Zone and the other genera were widespread. So strong was the water current at Station 5a that the Cladocera and Copepoda found there were probably being swept through the biotope by the current, rather than actually living there.

The seasonal changes in the Cladocera and Copepoda followed the amount of shelter from the current in the biotopes. In all zones the percentages of these animals and also the variety of them was greatest in the dry early summer, which is the season when conditions are most stable. Then, as in other South African rivers (Oliff, 1960b, Allanson 1961, Chutter 1963), the summer floods washed away most members of these groups and during the winter, populations built up to their dry early summer levels. However, at Stations 1 and 21, where conditions were most stable the Cladocera and Copepoda were, as would be expected, not as adversely affected during the summer as they were at other sampling points. Moina sp. was, as in the other biotopes, the only member of these groups to be found in large numbers in the summer. The sudden large changes in the percentages of the Cladocera and Copepoda which were found in the stones in current (Table 21) were also found in the marginal vegetation. An interesting point about these is that while many sudden decreases in percentages took place with the first floods and are therefore readily understood, some populations built up very rapidly. The reasons for the rapid increase in the numbers of animals found were never obvious but they may sometimes have been due to rising temperatures during the dry early summer (Table 21, Bosmina, Pleuroxus and Diaptomus percentages in September and October).

The Cladocera and Copepoda found in the other streams and rivers followed the patterns of seasonal occurrence and variation from zone to zone found in the Klein Vaal/Vaal River, confirming that the changes taking place in the Klein Vaal/Vaal River were characteristic of the various seasons and zones. These were the declining importance of the Chydoridae, Alona and Chydorus, down the course of the river and the increasing importance of Daphnia, Simocephalus and Ceriodaphnia down the river. As in the Klein Vaal/Vaal River Harpacticidae and Acroperus (Chydoridae) were not found in the Unstable Depositing Zone. The Cladocera and Copepoda found at Station 41 in the summer (Table 34) were a good example of how many of these animals could be found in this season provided the biotope was not subjected to floods.

The fauna of an artificially stable sampling point and of the high-lying Unstable Depositing Zone

The sampling points whose fauna is described in this section are:-

Station 8. Cyperus and Potamogeton were sampled. At this sampling point the Sandspruit was dammed up and this resulted in artificially stable conditions in which there were luxuriant growths of fringing macrophytes and also some fully aquatic plants.

Station 19. The marginal vegetation sampled was mostly Cyperus amongst which there was some Gomphostigma virgatum (Linn. f.) Baill. and Polygonum. The biotope was not in the current, but neither was it particularly well sheltered.

Station 30. The summer sample was collected from non-aquatic grasses hanging from the bank into the stream. The winter sample was collected from the roots of a bank of Phragmites which was being undermined by the stream. These biotopes were exposed to gentle currents.

Station 31. The sample was collected from a variety of non-aquatic plants hanging over the bank into the stream where there was no obvious current.

Station 34. As for Station 31 except that the vegetation was grass leaves.

Station 14. Leersia hexandra Sw., a grass which floats out on the water from the bank, was sampled. Some was in the current.

Stations 38 and 39. At both these sampling points roots of shrubs on the stream bank which had been eroded by the current were sampled. Both biotopes were in the current.

Station 40. Leaves of bank grasses trailing in the current were sampled.

The damming of the Sandspruit at Station 8 led to the appearance of a standing water fauna. Animals such as Rhabdocoelida, Enallagma, Sphaerodema capensis and Procladius which occurred at Station 1 in the Klein Vaal/Vaal River were significant at Station 8. However Nymphula circealis and Bulinus sp., which were associated with the large growths of aquatic vegetation as well as with the sheltered conditions, were significant at Station 8 but not at Station 1. The other Mollusca recorded at Station 8 were Gyraulus lamyi, Burnupia sp. and Pisidium sp., but these were not often encountered at Station 1, possibly on account of the poorly buffered water there.

The commonest animals at Station 8 were Nematoda, Limnodrilus, Nais, Cypridopsis, Pionocypris, Stenocypris, Oribatoides, Nychia marshalli, Micronecta spp., Chironomini and Orthocladiinae (Table 35).

Limnodrilus was almost certainly collected when the hand net hit the muddy bottom, which it was difficult to avoid doing at the dry early summer water level. Comparatively high percentages of some of these animals (Nematoda, Pionocypris) were also recorded at Stations 1 and 21 and they were associated with sheltered marginal vegetation communities. On the other hand the truly standing water characteristics of the Station 8 community showed up mainly in the high percentage of Stenocypris and also in the Baetid Ephemeroptera which were like those recorded at Station 1 but very different from those found at Station 21. As at Station 1 Austrocloeon spp. were the only significant Baetids and only stray individuals of Baetis bellus and Centroptilum excisum, which were such prominent components of the riverine sampling point communities, were recorded. Caridina nilotica is not found in truly standing waters and this is probably why it was not found at Station 8. The very low Caenid percentages at Station 8 were nearest to those at Station 1 and in this respect the fauna of Station 8 differed from the Stable Depositing Zone fauna. The high percentages of Oribatoides, Nychia marshalli and Micronecta spp. were due to the sheltered conditions but they cannot be associated with any particular zone. The main feature of the Cladocera and Copepoda at Station 8 which may be associated with the sheltered conditions was that many genera were significant in the summer. Chydorus percentages were high in the dry early summer which was also the case at other sampling points where conditions were sheltered (Stations 1, 21, 2a and 10). Tropocyclops percentages were highest at Station 8. The Ilyocryptus recorded in the dry early summer were from the bottom mud.

The fauna at Station 19, where conditions were very silty, included many significant animals not shown in Table 35. A comparison of the fauna of this station with that found at sampling points in the Vaal River (p. 134) showed that the following animals significant at the indicated stations (or groups of stations) were also significant at Station 19:-

Groups significant only at Station 21a

none

Groups significant only at Station 21

Austrocloeon africanum
Laccophilus pellucidus

Groups significant only at Station 3

Caridina nilotica

Groups significant only at Stations 21a, 21

Orthotrichia sp.
Helminthopsis bifida
Gyraulus lamyi
Burnupia sp.
(i.e. all except 3 groups)

Groups significant only at Stations 21a, 21, 3

All significant at Station 19, except for P. vinosum

Groups significant at Stations 1, 21a, 21, 3

All significant at Station 19, except for Oribatoides sp.

It is interesting that P. vinosum was not significant at Station 19, for this confirms that this animal does not tolerate silty river conditions, which was found in the other zones and also by Harrison and Elsworth (1958). The main point shown by the above lists is, however, that there was not a large reduction in the variety of the fauna at Station 19 due to the silt. Indeed two animals, Micronecta scutellaris and Laccophilus cyclopis were significant at Station 19 but not at the sampling points in the Klein Vaal/Vaal River.

The dominant animals recorded at Station 19 (Table 35) were not typical of any particular zone, nor were they typical of the communities recorded in sheltered marginal vegetation biotopes. Of the most common animals at this sampling point, Chaetogaster, Caenidae, Chironomini and Orthocladiinae occurred in percentages which could not be said to be typical of any zone. The dry early summer percentage of Nais was high but this may also not be associated with any single zone. However the low winter and summer percentages of Nais are more typical of sampling points exposed to the current than of sheltered sampling points. The same may be said of the fact that only one Ostracod genus was significant in the summer. However, the Baetid Ephemeroptera were fairly typical of the Stable Depositing Zone communities at Stations 21 and 2a. The proportion of B. bellus in the summer was only moderately high, that of C. excisum was low and the proportion of Austrocloeon spp. was higher than in the biotopes exposed to the current. Other features of the Station 19 community indicative of some shelter were the high Micronecta and C. nilotica percentages. The remaining animals which made up a large part of the Station 19 fauna were Ilyocypris (mainly an Unstable Depositing Zone animal), Hydraenidae (percentages highest in the Unstable Depositing Zone), Corynoneura (percentages highest in the Eroding Zone) and Burnupia (percentages higher in the Eroding and Stable Depositing Zones than in the Source and Unstable Depositing Zones). The most important Cladocera at Station 19 were Simocephalus vetulus and representatives of the genera Pleuroxus and Chydorus, with Pleuroxus spp. forming a larger part of the community than Chydorus spp. In these respects the Cladocera and Copepoda at Station 19 were like those recorded from the Eroding and Stable Depositing Zones of the Klein Vaal/Vaal River. However Acroperus and the Harpacticidae, groups which were not recorded from the Unstable Depositing Zone of the Klein Vaal/Vaal River, were not recorded at Station 19, which indicates that highly silty conditions may not suit them.

The marginal vegetation fauna at Station 19 as a whole was not as affected by the large amounts of silt in the river as was the stones in current fauna.

Beyond those shown in Table 35 very few kinds of animals were recorded from the sampling points in the high-lying Unstable Depositing Zone where conditions were sandy, that is at Stations 30, 31, 34, 14, 38, 39 and 40. The animals recorded but not shown in Table 35 are:-

Animal	Where found
Centroptilum sp. nov. I	Station 38
Cloeon sp. nov.	Station 34, 14 (summer)
Plea pullula	Stations 30, 34, 14 (summer)
Triaenodes sp.	Stations 31, 14 (summer)
Hydroptilid - sand case	Stations 38, 39 (winter)
Orthotrichia sp.	Stations 14, 38, 39
Hydrophilidae	Stations 30 (winter and summer), 14 (dry early summer), 39, 40

This is a very short list, considering that there were 7 sampling points involved. However as may be seen from Table 35, the diversity not only of the rarer animals but also of the commoner animals was low and many groups which were frequently encountered in other zones were either not recorded or infrequently recorded as very small percentages of the total fauna. The sampling points were probably too high up the rivers for Caridina nilotica and Austrocloeon africanum to be found, even had they been able to tolerate conditions in the sandy high-lying Unstable Depositing Zone. However, Tricladida, Ostracoda, Austrocloeon spp., Micronecta spp. and the genera Bezzia, Burnupia and Pisidium were very seldom recorded, even at Stations 31, 34 and 14 where some of the biotopes sampled were sheltered from the current.

In some ways, the percentage composition of communities at these sampling points approached the normal Unstable Depositing Zone communities. Thus Hydrachnellae percentages were low, summer

B. bellus percentages were usually very high, C. excisum percentages were sometimes high (even at Station 30 which was the highest of these sampling points) and most Caenid percentages were low and in the Unstable Depositing Zone range (cf Tables 31 and 35). On the other hand the presence of B. harrisoni, C. sudafricanum and P. vinosum at several of these sampling points is interesting as they are typically Eroding Zone species. However none of them were recorded in the summer samples, suggesting that they were unable to withstand the highly unstable conditions in this zone then.

At many of the sandy high-lying Unstable Depositing Zone sampling points there were no Cladocera or Copepoda, though this was partly because the samples were collected in the winter or the summer. However at Stations 14 and 39, where dry early summer samples were collected, the variety and percentages of these groups were low, suggesting that these groups were also severely affected by conditions in the sandy high-lying Unstable Depositing Zone rivers.

The fauna at sampling points where the chemical quality of the water was not normal

The biotopes sampled at these stations were as follows:-

Station 4. The marginal vegetation here was a sparse growth of Scirpus sheltered from the current. In winter and dry early summer the Scirpus was usually above the water level.

Station 5. The marginal vegetation here consisted mainly of Polygonum lapathifolium var. glabrum Burtt Davy with some Paspalum sp. amongst it. The biotope was in a gentle current.

Station 17. A large dolerite sill resulted in very still conditions in the river above the sill. The marginal vegetation sampled consisted mainly of Cyperus marginatus Thunb. and C. fastigiatus Rottb. with some Leersia hexandra Sw. amongst it.

Station 7. A growth of Scirpus which was more in the current in the summer than in the dry early summer was sampled.

Station 11a. Conditions at Station 11a were artificially stable due to a weir just above Station 11b. However the stream banks at Station 11a were steep and there was a limited amount of fringing vegetation, mainly Cyperus, growing between willow (Salix babelonica) trees. The Cyperus was sampled.

Station 11b. The leaves of bank grasses hanging in the water were sampled. They were on the margin of the water only when the water level rose with higher summer flows.

Station 42. The vegetation sampled consisted of Cyperus and was out of the current.

Filamentous algae were found at Stations 17 and 42 in large quantities towards the end of the winter, and also in the dry early summer at Stations 17, 7 and 11a (Stations 11b and 42 not being sampled in this season).

The fauna found in the dry early summer at Station 4 (Table 31) was peculiar because the river had only recently risen from its lowest level to flood the vegetation, so that the animals found were mainly types which readily live on top of the bottom of the river, or free in the water. These are Centroptilum excisum, Nychia marshalli, Micronecta spp. and tadpoles. In the summer only one more animal, Sphaerodema capensis, in addition to those shown in Table 31 was significant. A more diverse fauna was found in this season than in the dry early summer but it differed from the normal Unstable Depositing Zone fauna in only minor ways. The percentages of Nais, Caridina nilotica, N. marshalli and Chironomini were a little higher than was usual in this season in this zone, and the percentage of B. bellus was low.

At Station 5 there were four significant genera or species in addition to those shown in Table 31. These were ? Prostoma, Aulonogyrus spp., Hydraenid 'type B' and Gyraulus lamyi, but they do not reveal anything further about the biotope. The only ways in which the percentage composition of the fauna at Station 5 was unusual were that Nais and Ilyocypris percentages were high in the winter and that Caridina nilotica percentages were a very little higher and Baetis bellus percentages lower than usual in the summer. These small changes might have been due to enriched seepage waters reaching the river.

There were ten more species significant at Station 17 than those shown in Table 36, and most of them belonged to groups found mainly in sheltered marginal vegetation. They were Hydra, Enallagma and Sphaerodema capensis which were significant only in the Source Zone of the Klein Vaal/Vaal River, Rhabdocoelida and Laccophilus pellucidus which were found at Station 21 and Batracobdella nilotica (Hirudinea), Anisops spp., Micronecta scutellaris, Ecnomus and Orthotrichia. The percentage composition of the fauna was typical of a biotope sheltered from the current. Important groups or species which showed this were Nais (percentages high in all seasons), the Ostracoda (several genera significant in the summer), Ilyocypris (percentages always low), Pionocypris, C. nilotica and Micronecta (percentages always high) and the Ephemeroptera, in which group percentages of B. bellus, C. excisum and Caenidae were very low and percentages of A. africanum and Austrocloeon spp. were comparatively high. Most of the other animals making up a large part of the community (Cypridopsis, Chironomini, Orthocladiinae) could not be associated with any particular conditions. Chaetogaster made up an unusually large part of the community but this was also the case at several other sampling points (Stations 11a, 11b, 27, 30, 38).

There were no changes in the fauna at Station 7 which could be ascribed to changes in the chemical quality of the water, bearing in mind that the marginal vegetation biotope there was exposed to the current. At Station 11a, as at Station 17, the most important influence on the fauna was that the biotope was sheltered from the direct effects of the current. There were many significant animals, in addition to those shown in Table 36, present and they were mostly still water Hemiptera and Coleoptera. The percentage composition of the fauna was also of the type found in still waters. Nematoda, Nais and Austrocloeon spp. percentages tended to be high and B. bellus, C. excisum and Caenid percentages were low. However rather atypically for this type of biotope, Ostracods were not recorded in the summer, Chironomid percentages were low in the summer and the percentage of Pionocypris was never high. The absence of C. nilotica and A. africanum from Station 11a was probably due to factors associated with the zonation of the fauna, because these species were also not recorded from Station 10, the next sampling point upstream. They were mainly found in the Unstable Depositing Zone and less often in the Stable Depositing Zone. The percentage of Chaetogaster was high in seasons other than the summer. The summer fauna was dominated by Nematodes, Austrocloeon spp. and Micronecta, whose percentages were highest in sheltered biotopes, and also by Pseudagrion and Hydrachnellae which were not as markedly influenced by the current conditions in the biotopes.

The fauna at Station 11b (Table 36) consisted of rather a few species or groups of animals, and only two groups (? Prostoma and Chironomus) in addition to those shown in Table 36 significant. No Ostracoda were found but this may have been a seasonal effect. The percentage composition of the fauna was peculiar as it consisted mainly of Nais, Dero, Chaetogaster and Chironomidae. This was the sampling point where the stones in current fauna was very impoverished and it was suggested that there might have been toxic substances in the textile mill effluent which entered the river here. The marginal vegetation fauna was more varied than the stones in current fauna but it is possible that this was due to reinvasion from upstream. This would not have been possible for the stones in current animals because there was not a biotope from which they might re-invade for about 3 kilometres upstream. Furthermore the quantitative marginal vegetation data (see below) shows that the density of the fauna at Station 11b was not high.

The marginal vegetation fauna at Station 42 was sampled only once, but the fauna contained within this single sample was fairly normal for a sampling point sheltered from the current. Baetidae were very scarce and the fauna was very largely made up of Tricladida, Nematoda, Nais, Chaetogaster, Cypridopsis, Isocypris and Caenidae.

The percentages of the Cladocera and the Copepoda taken together were usually higher at the sampling points where the chemical quality of the water was not normal than at other sampling points (Tables 31 and 36). Groups whose percentages were higher than at normal sampling points were Daphnia and Ceriodaphnia and, in the summer, Moina. The percentage of Pleuroxus also was often high at these sampling points. At Stations 17 and 11a the sheltered conditions resulted in the percentages and variety of the Cladocera being greater in the summer than at the other sampling points. Paracyclops, which has been found in other studies (Allanson 1961, Harrison 1958b) to be closely associated with organic pollution, was found in large numbers only at Station 11a. The Moina spp. found at Station 11b probably originated in the waters above the weir between Stations 11a and 11b and were carried by the current down to Station 11b.

At most of these sampling points where the chemical quality of the water was not normal the largest changes in the percentage composition of the marginal vegetation fauna were found in the Cladocera and Copepoda. The composition of the dry early summer fauna at Station 4 and the reason why certain species made up a large percentage of the fauna there, that is the recent covering of the biotope by an increase in the amount of the water in the river, are interesting. It would have been easy to conclude that the water was deoxygenated since nearly two-thirds of the animals recorded were air breathing Hemiptera (Table 31). However the large proportion of the mayfly Centroptilum excisum clearly shows that this was not the case.

Quantitative data on the stones in current fauna

A note on sampling

Rough estimates of the amount of vegetation sampled were made in the field and have been used to estimate the numbers of animals per 0.3 m (1 foot) of the vegetation. No great accuracy is claimed for these estimates.

As has already been described in the section on sampling methods (p. 45 above) the hand net was swept backwards and forwards through the vegetation in sampling. This sampling method differed from that used by Oliff (1960a,b) who made single sustained undirectional sweeps through the vegetation (Oliff 1960a, p. 295). A simple investigation of the effect of sweeping the net twice through the vegetation in opposite directions was made during the course of the work on the Klein Vaal/Vaal River. Two individuals, each with a hand net, stood side by side in the river facing the vegetation to be sampled. The first worker swept his net through the vegetation for about two feet, lifted it out of the water, and the second worker immediately swept his net in the opposite direction through the same vegetation. The process was repeated until 8 or 10 feet had been sampled. Analysis of the samples collected in this way showed that the second sweep tended to collect more animals than the first (Table 37). The proportion of the catch from both sweeps, yielded by the first sweep, for the most important groups of animals varied greatly

(Table 38, range). However the mean proportions (Table 38) showed that the first sweep usually collected fewer individuals than the second, though for the Chironomidae there was little difference between the numbers caught by the two sweeps. It could be that the current set up by the first sweep carries animals into the area it has sampled and that, as the second sweep travels against this current, more water passes through the net on the second sweep than on the first sweep. Also attached animals might be dislodged by the disturbance caused by the first sweep and collected by the second sweep. The most important point about the second sweep is, however, that it does collect large numbers of animals. The numbers of individuals per 0.3 m of the vegetation sampled in both directions which are presented in the following sections are comparable only with data collected using a hand net of the same opening, fitted with the same type of bolting silk and used in the same way as was done in this study.

The numbers of animals found

The purpose of this section is to add to the information obtained from the percentage data. However the quantitative data is not as complete as the percentage data as there were many samples for which there was no record of the length of the fringe sampled.

The numbers of Cladocera and Copepoda and of animals other than these two groups are shown in Table 39. At those sampling points where quantitative data for all three seasons may be compared the largest numbers of Cladocera and Copepoda were collected in the dry early summer. The most important environmental factors allowing for the development of these large dry early summer populations were the stable flow conditions, the low turbidities (which allowed for greater algal growths) and the warmer temperatures. This is shown by the way in which densities of these animals declined sharply in the summer, except where the vegetation was sheltered from floods, that is at Stations 1 and 41. Moreover the highest summer densities of these animals after those recorded at Stations 1 and 41 were recorded from the sampling points where there was some shelter from the current, that is Stations 2a, 21, 11a and 17. The summer density of these groups at Station 10 is misleading as it is based on a single sample taken shortly after a flood. There were other summer samples from this station which did include fairly large numbers of Cladocera and Copepoda (Table 35). Very large numbers of Cladocera and Copepoda were found at some of the sampling points (Stations 17, 11a, 42) where the chemical quality of the water was not normal.

Many of the changes taking place in the numbers of the animals other than Cladocera and Copepoda (Table 39) were similar to those described in the previous paragraph. Thus where there were samples from all three seasons the density was usually highest in the dry early summer and densities were usually very low in the summer, except where there was some shelter from the current or from floods. The density of these animals was very high at Station 30 in the winter. However the increase in the density of the other fauna at Stations 17, 11a and 42 was not as great as it was in the Cladocera and Copepoda.

The densities of the most important species and groups are shown in Tables 40 and 41. Several of the most clear-cut responses to changes in the environment were recognised in the Baetid Ephemeroptera. For the most part percentage changes (Tables 31, 33 to 36) in these animals followed density changes. For example the density of _B. bellus_ (Table 40) was highest in the summer at sampling points where there was some current through the vegetation. In the summer its density could not be said to be higher or lower in any particular zone. Here the density data do lead to an interpretation different from that arrived at from the percentage data, which showed that B. bellus percentages were very high at Stations 12, 29, 36 and 31 (Tables 33, 34). Few B. bellus were found at Station 5, where the vegetation looked as though it should be suitable for this species. It may be that it was adversely affected by the very mild enrichment of the water there (Table 15). Centroptilum excisum numbers were highest in the Unstable Depositing Zone in the winter and the dry early summer. Its density was always low at sampling points in still water (Stations 1, 8, 11a, 17 and 41 in the summer). Densities of this animal were often fairly high in the sandy high-lying Unstable Depositing Zone. It was not adversely affected by conditions at Station 5. The density of Austrocloeon spp. was usually not particularly high and they were still water animals. The densities of the other Baetidae is shown in less detail in Table 41, but the density data, for all species other than P. vinosum, follow the percentage data and nothing further need be said about them. The density of P. vinosum in the summer shown in Table 41 is misleading as very large numbers of this animal were found in another, non-quantitative sample. The densities of Baetid juveniles (Table 40) were variable and they could not be said to be most abundant at any particular season. This was probably because they consisted of so many species.

Caenid densities were always low in the Unstable Depositing Zone. In the high-lying Unstable Depositing Zone few Caenids were collected in the summer, the season when this zone would most resemble the normal Unstable Depositing Zone, but otherwise densities of Caenids were higher there than in the normal Unstable Depositing Zone. Caenids were numerous in the Stable Depositing Zone, particularly in the dry early summer but the density of them was rather variable in the Eroding Zone. They were never found in large numbers at the sampling points (Stations 1, 8, 41, 17, 11a) where conditions were most pond-like. The largest density of these animals was found at Station 42, but otherwise the densities of this group were not unusual where the chemical quality of the water was not normal.

The densities of <u>Nais</u> (Table 40) did not show any definite zonational differences. In the winter and the dry early summer there were no marked differences between the densities of <u>Nais</u> recorded from the vegetation sheltered from or exposed to the current, but in the summer higher densities tended to be recorded where the vegetation was sheltered from the current (Stations 1, 41, 17). In the dry early summer the highest <u>Nais</u> density was found at Station 11a, but the winter densities of this genus at Stations 41 and 30 were far higher.

At most sampling points in the Eroding Zone, in the Unstable Depositing Zone and in the high-lying Unstable Depositing Zone Ostracoda were rare or not recorded (Table 40). They were not, however, restricted to sampling points sheltered from the current as is shown by the numbers of them collected at Station 21a, 3 and 5a. At most sampling points the highest densities were recorded in the dry early summer, but at some (Station 3, 5a) the highest density was in the winter. Summer densities were high only at Stations 21, 2a and 17. A very high density of Ostracoda was recorded from Station 42, but otherwise there was no marked change in the density of Ostracoda at the sampling points where the chemical quality of the water was unusual.

The numbers of Chironomidae (Table 40) varied greatly within each group of sampling points and there was no pronounced tendency for higher or lower densities to be recorded in any zone.

Summer densities were usually very much lower than those found in the other seasons. All the really high Chironomid densities were recorded in the winter, but at some sampling points (1, 21, 2a, 17, 11a) the dry early summer densities were the highest. Breaking the data down into more precise taxonomic units showed that Tanytarsini numbers were high only at Stations 24a, 24 and 9a which are all in the upper reaches of the Eroding Zone. The numbers of Chironomini, Pentaneura and Orthocladiinae varied considerably in all groups of sampling points.

The densities of some other animals are shown in Table 41. Triclad numbers were high only at Station 42. Nematode numbers were also highest at this station, but these animals were also fairly abundant at several other sampling points, all of them with marginal vegetation sheltered from the current. Chaetogaster numbers were never high in the summer. High numbers of this animal were found at Stations 17, 11a and 42, which were all on streams where the chemical quality of the water was unusual, but the greatest density of this animal was recorded elsewhere (Station 30). The highest numbers of Caridina nilotica were recorded at Stations 2a and 17, which shows its preference for sheltered, but not pond-like, conditions. Densities were highest in the summer when there are large numbers of juveniles. At Stations 41 and 34 unusually large numbers of Pseudagrion larvae were found in the summer and most of these were very juvenile. The samples from these two points were collected in February, which is a month in which Chutter (1961) found a large number of P. salisburyense juvenile nymphs. This being a common and widespread species in the Vaal Dam Catchment, there would appear to be no more significance in the fact that these high Pseudagrion densities were found at Stations 41 and 34 than that at these points collection of the samples coincided with a recent Pseudagrion hatch. The next highest Pseudagrion densities were recorded at Station 17 and were far lower than at Stations 41 and 34. Nychia marshalli numbers were highest at Station 4. This and the high number at Station 7 was largely due to juveniles. Micronecta spp. numbers were higher in the dry early summer and the summer, the seasons when juveniles may be collected, than in the winter. The highest densities of this genus were all at sampling points sheltered from the current. Hydraenids were most abundant in winter, when the larvae were found. Large numbers were found at sampling points both sheltered from the current (Stations 43, 19) and exposed to the current (Stations 5a, 39). The greatest densities of Simuliidae were recorded in the winter at sampling points where there was a strong current through the vegetation. Summer numbers were never high. Burnupia was never an abundant animal.

The quantitative data show, as did the percentage data, that in the marginal vegetation biotopes the most important factor to which faunal changes are related is the amount of shelter from the current where the sampled vegetation grows. The Ephemeroptera, in which Austrocloeon spp. and A. africanum were sheltered condition species and in which the remaining Baetid genera were found mainly in more exposed conditions, illustrated the importance of current particularly clearly. In other important groups such as the Ostracoda and the Chironomidae current could not as clearly be shown to be important, but this is quite probably due mainly to the poor state of the taxonomy of these groups. Zonal changes in the fauna were very closely related to the amount of shelter from the current in the marginal vegetation of the different zones. Thus the fauna of the Source and Stable Depositing Zones was distinctive mainly because the vegetation was sheltered from the current in these zones and usually exposed to the current in the other zones. There was, however, a zonation of some animals in the fauna. Thus Caridina nilotica was a sheltered vegetation animal, but was not recorded in the Source or Eroding Zone. Pseudocloeon vinosum, Baetis harrisoni and Centroptilum sudafricanum were exposed vegetation animals and were found mainly in the Eroding Zone, because conditions were less silty there than elsewhere. As might be predicted from its distribution in stones in current biotopes, B. glaucus was found mainly in the marginal vegetation exposed to strong currents in the Unstable Depositing Zone. The sandy high-lying Unstable Depositing Zone fauna was similar to that of the Eroding Zone fauna in the winter and dry early summer as large numbers of Caenids and typically Eroding Zone Baetidae, such as Centroptilum sudafricanum and Pseudocloeon vinosum were found. However densities of C. excisum were often higher at these sampling points than they were in the Eroding Zone. Caenid densities were low in the summer. Baetis glaucus was found at Station 39. In these ways the sandy high-lying Unstable Depositing Zone fauna was similar to the normal Unstable Depositing Zone fauna. However at Station 19, the silty high-lying Unstable Depositing Zone sampling point, the silty conditions would not be shown to be affecting the fauna, which was normal for a biotope moderately sheltered from the current.

The numbers of most animals were higher in the winter and dry early summer than in the summer. However the numbers of B. bellus, Pseudagrion, Micronecta and Caridina nilotica were highest in the summer. At sampling points (Stations 4, 5, 17, 11b, 42) where there were marked changes in the composition of stones in current communities due to organic enrichment, changes were very much less obvious in the marginal vegetation communities. Changes in the diversity and percentage composition of the fauna were often minor. So too were changes in the density of the animals, except for the Cladocera and Copepoda, the density of which rose sharply. This shows that the effect of the changes in the chemical quality of the water on the environment was to increase the amount of fine, suspended, food particles. The most unusual communities were recorded from Station 4, where the temporary nature of the marginal vegetation was the most important factor, at Station 11b, where mainly Oligochaetes and Chironomidae were found and where there was evidence of toxic effects and at Station 42, where the numbers of Triclads, Nematodes, Chaetogaster, Ostracods and Caenidae were unusually high.

The fauna of sediments

General remarks

The fauna of the sediments of the Vaal River was sampled at all sampling points where there was a sediment. The work was not planned to give a detailed picture of the relationship between fauna and sediment type but rather to show the broader trends of faunal change from sediment to sediment in the various seasons. Single sediment samples were therefore taken on each visit to each sampling point. At the same time a sample was taken for particle size and sulphide analysis. Faunal counts and the physical and sulphide analysis results varied considerably from month to month and the tentative relationships between fauna and environment, which are described in this section have had to be arrived at by considering mean values.

Morgans' (1956) method of particle size analysis was followed, and sulphides were determined by the method given by Harrison et al (1963).

Insofar as our knowledge of the biology of the animals concerned permits, the fauna presented here has been limited to burrowing and interstitial forms or to forms which live more or less permanently on top of the sediments. These have been taken as Nemertine worms, Nematoda, Tardigrada, Oligochaeta, Hirudinea, Ilyocryptus (Cladocera), Paracyclops, Tropocyclops and Harpacticidae (Copepoda), all Ostracoda, Ephoron (Ephemeroptera), Gomphidae (Odonata), Dipseudopsis (Trichoptera), Tipulidae, Chironomidae, Ceratopogonidae and Pelecypoda.

The fauna of sediments (Tables 42 to 46) was dominated by the Nematoda, Oligochaeta, Ostracoda, Chironomidae and Pisidium. The variety of animals recognised in the fauna was, however, very much smaller than in the other biotopes. This is in part a reflection of the poor state of knowledge of the taxonomy of these groups, particularly when the samples were analysed. Of the animals shown in Tables 42 to 46, it was possible to identify only one, Branchiura sowerbyi, down to the species level. Recently Brinkhurst (in press) has reported on the Oligochaeta from Vaal Dam catchment sediments. He found that the animals recorded here as Limnodrilus spp. are actually a mixture of up to three species (L. hoffmeisteri Claparede, L. udekemianus Claparede and L. claparedeanus Ratzel), which indicates how very much greater the species diversity of the sediment fauna really is.

The sediments

Physical characteristics

Morgans (1956) suggested that the median Phi value, the silt content, the Phi quartile deviation and the Phi quartile skewness are the most important measurements which may be used to define the physical characteristics of sediments. The median Phi value is the particle diameter, expressed as a logarithm, corresponding to that particle size where half the sediment is composed of larger particles and half is composed of smaller particles. Morgans gives a chart for converting Phi values into the corresponding particle diameters in millimetres, and it has often been convenient to do this and then to describe sediments in terms of the Wentworth Scale nomenclature.

Most of the sediments in the streams and rivers of the Vaal Dam catchment were Coarse to Fine Sands (Table 47). In the Source Zone the small median particle diameter reflects the quiet flow conditions in which small particles could settle out. The median particle size of Eroding Zone sediments was higher due to the stronger currents there. Indeed at Stations 21a and 24a there was no expanse of sediment large enough to be sampled by the methods used in this study. Stable Depositing Zone sediments were sometimes finer than Eroding Zone sediments. In the normal (as opposed to the high-lying) Unstable Depositing Zone, sediments were very variable, not only from sampling point to sampling point (Table 47) but also at each sampling point. At Stations 3 and 5a two types of sediment were sampled, but more usually only one type of sediment was studied at each station. The division of the high-lying Unstable Depositing Zone streams and rivers into sandy and silty, which was made in connection with the fauna of other biotopes, is clear in the sediment, where the sediment at Station 19 on the Kaffersspruit was very much finer than the other sediments (Table 47).

The silt and clay content or subsieve fraction of the sediments (Table 48) followed the median particle size very closely, the finer sediments containing the larger amounts of silt and clay. There was, with the exception of Station 19, very little silt and clay in Eroding and high-lying Unstable Depositing Zone sediments.

The Phi quartile deviation of a sediment is a measure of the spread of the particle size distribution about the median Phi value. The smaller the spread of the distribution about the median the lower the Phi quartile deviation. Morgans termed sediments with a low Phi quartile deviation "well sorted". In the streams and rivers of the Vaal Dam catchment many of the sediments were well sorted (Table 49). The poorly sorted sediments were found mainly among the very fine, high subsieve fraction sediments, the coarser sediments being more uniform. Well sorted sediments are those which are exposed to stronger currents for at least part of the year.

The Phi quartile skewness of a sediment is a measure of the skewness of the particles size distribution about the median. In most sediments it lay between -0.10 and 0.10 which means that the particles larger and smaller than the median size were nearly equally well sorted. The Phi quartile skewness of the sediments was not obviously related to any of their other measured physical characteristics. It could not, as was shown by Allanson (1961) be shown to vary seasonally (see below) neither could the occurrence of any animals be shown to be related to this parameter.

The sulphide and detritus content of the sediments

In most sediments the concentration of sulphides was less than 5 ppm (Table 50). In general, high sulphide concentrations were found only in fine sediments with a high subsieve fraction (cf Table 50 with Tables 47 and 48), but not all the fine sediments had high sulphide concentrations. The amount of detritus in sediments was assessed as large or small when the fauna in sediment samples was counted. Apart from the sediment at Station 35 on the Cornelius River, all the fine sediments contained large amounts of detritus. The correlation between the sulphide concentration and detritus was close, all the sediments with more than 5 ppm sulphides containing a lot of detritus.

The Vaal River at Standerton (Stations 4, 5) and the Wilge River at Harrismith (Stations 11b, 11c) were contaminated by effluents rich in organic matter and the sulphide content of the sediments (Table 50) was high, although there was no obvious detritus in them. These high sulphides could have been due either to large amounts of soluble organic matter or to detritus so fine that it was washed away with the fine particles and therefore not noticed when samples were sorted.

In the Stable Depositing Zone all sediments had large amounts of detritus, even though the sediments at Stations 21 and 2a were not particularly fine. This was due to the more stable conditions and greater amounts of aquatic and semi-aquatic vegetation in this zone.

Seasonal changes in the sediments

Monthly analyses of particle size distributions in sediments failed to show that the physical nature of the sediments changed in any regular way with season. Some sediments were coarser in the summer rainy season than in the dry seasons (Stations 1, 5a), but others (Stations 4, 5) were finer in the wet season than in the dry. The median Phi values of most sediments varied haphazardly and not in any systematic way, though in most the range of variation was less than two Phi values. There was also no regular seasonal variation in the subsieve fractions, the Phi quartile deviations and the Phi quartile skewness of the sediments. Nothing is known about the variability of the particles size distributions in a series of sediment samples taken from one sediment at the same time. If this variability is high it could account for the observed haphazard month to month variability shown by single monthly analyses.

It was, however, clear that at many sampling points there was considerable deposition and erosion of sediments in the rainy season and little in the dry seasons. An idea of the amount of sediment that could be moved in the wet season is given in Plate X11. Sandy sediments were often covered with a layer of fine silt which would rapidly disappear. Such layering of sediments was not apparent in the winter or the dry early summer.

In the Jukskei River summer sediments were coarser than winter sediments (Allanson, 1961). The Jukskei River is a rapidly falling stream with sediments usually coarse and containing little subsieve material. Possibly due to the extensive urban areas in its headwaters floods in the Jukskei were unusually sharp and of a short duration, and this is probably why the summer sediments were coarser than the winter.

The seasonal variation in the sulphide concentration of the regularly sampled stations is shown in Table 51. Generally there was little seasonal variation in the concentration of sulphides in sediments. However, where the chemical quality of the water was affected by effluents the concentration in the summer was very much lower than in the other two seasons (Table 51, Stations 4, 5 (Vaal River, Standerton) and 17 (Waterval River)).

The relationship between particle size distribution, sulphide concentration and amount of detritus and the fauna

Density of all animals and sediment type

The total numbers of animals recorded per 0.1 sq. m. of sediment are shown at the foot of Tables 42 to 46. The density of the fauna is analysed seasonally in relation to sediment type in Table 52, but because seasonal changes in density at sampling points where the chemical quality of the water was affected by effluents, were unusual, data from such sampling points were omitted from the analysis. In the summer the difference between the physical analysis and sulphide content of sediments where the faunal density was high ($>$ 1000 individuals/0.1 sq. m.) or low ($<$ 1000 individuals/0.1 sq. m.) was negligible (Table 52), and nearly as many sediments with a lot of detritus had low numbers of individuals as had high. In the winter and more markedly in the dry early summer high faunal densities were recorded in the less well sorted, fine sediments with a high subsieve fraction, sulphide content and a lot of detritus. During these two seasons the flows are stable and these sediments are found in sheltered positions and support large populations of animals. In the summer the density of the fauna was not related to sediment type, showing that sediment type no longer reflected how sheltered were the conditions. Some of the sediments would be heavily eroded and on some there would be excessive deposition of silt. Both these events would be detrimental to the fauna and they would depend not on the type of sediment but on variable patterns of flow and silt load in the rivers.

The fauna at Station 25 in the Klip River (Table 43) provides a good example of the effect of stable conditions on the faunal density. When this coarse, well sorted sediment with a low subsieve fraction, sulphide content and amount of detritus was sampled in the summer there was a lot of algae and diatoms in the river bed, indicating that flow conditions had been stable for some time. This was very unusual in the summer. So too was the density of the fauna which was more than three times as great as the density in the summer at any other sampling point (where the chemical quality of the water was not affected by effluents).

However as is implicit in the names given to the various zones, sediment stability and instability is closely related to zonation. The density of the fauna also tended to follow this zonation (Tables 53 and 54), and the zones where conditions were most stable (the Source and the Stable Depositing) had the greatest faunal density in summer when conditions are generally most unstable. Table 54 is somewhat misleading here for it shows that the Eroding Zone had a mean summer faunal density nearly as great as the Source and Stable Depositing Zones. However this was very largely due to the exceptionally dense fauna found at Station 25, as described in the previous paragraph. The high-lying Unstable Depositing Zone had the highest proportion of low density faunas in all seasons (Table 53), as would be expected in this very unstable zone where most sediments were coarse, well-sorted and had small amounts of sulphides and detritus. In all zones the highest densities were usually recorded in the dry early summer and the lowest in the summer, reflecting the seasonal change in the stability of the rivers.

Density of different kinds of animals and sediment type

The physical state, sulphide content and detritus of sediments where the density of the most numerous kinds of animals was high are compared with the sediments where their densities were low in Tables 55 and 56. For each species or group of animal the boundary between what should be regarded as a high or low density was arbitrarily chosen from an inspection of the mean seasonal density data for the animal concerned. The data on the physical characteristics and sulphides and detritus of the sediments were taken from Tables 47 to 50. For each variant the mid-value of the tabulated range was taken as the value for a sampling point. This analysis therefore shows the relationships between sediment and fauna in general terms. It masks the fact that large or small numbers of individuals were sometimes found in sediments other than the type in which large or small numbers were most often found. However the analysis does facilitate the recognition of such unusual numbers and the factors which may play an important role in bringing them about.

Nematoda, Limnodrilus, Branchiura sowerbyi, Ilyocryptus, Chironomus, Procladius, Tanypus, Bezzia and Pisidium were found in larger numbers in the less well sorted, finer sediments with higher subsieve fractions, sulphide concentrations and quantities of detritus (Tables 55 and 56). This group of animals includes burrowing forms (Limnodrilus, B. sowerbyi, Chironomus, Pisidium), interstitial forms (Nematoda) and an animal which lives mainly on the surface of the sediments (Ilyocryptus). Bezzia, Procladius and Tanypus are predators, Chironomus and Pisidium are filter feeders, relying on food suspended in the water above the sediment, and the rest are probably detritus feeders obtaining their food from within the sediment or possibly from on top of it (Ilyocryptus). The important features of the sediments where these animals occurred in large numbers were that they were sheltered from the current, stable and contained large amounts of organic food material. These three characteristics are of course closely interdependent. In most cases the relationship between organic food material and high density was even closer than is apparent from Tables 55 and 56. Nematoda, Limnodrilus, B. sowerbyi, Ilyocryptus, Chironomus, Procladius and Tanypus also occurred in large numbers in the absence of large amounts of detritus (Table 56) at Stations 4, 5, 11b and 11c, at which points the chemical quality of the water was affected by organic effluents and consequently sulphides were found in the absence of detritus (Table 50). The reasons why these animals were not found in all the sediments with a lot of detritus were sometimes readily apparent. For instance B. sowerbyi was found in certain zones only and Limnodrilus was not found in very soft sediments. Such factors are discussed in a later section.

Ostracoda of several genera were recorded from sediments but they were usually all found together (Tables 42 to 46), which is why they have been treated in Tables 55 and 56 as a single group rather than genus by genus. Moreover examination of the data for single genera failed to show that their occurrence was different from that of the whole group. Even at sampling points where they were comparatively abundant the Ostracoda showed a marked seasonal variation of occurrence, and were usually rare or absent in the summer. Results from sediments sampled only in the summer have therefore been omitted from consideration for purposes of determining Ostracod sediment preferences (Tables 55 and 56). The Ostracoda belonged to the group of animals occurring at higher densities in the finer sediments with high subsieve fractions and sulphide concentrations and large amounts of detritus. There are, however, other factors with which Ostracod numbers appeared to be related (see below, p.182).

The comparison of sediments where Paracyclops was found in large or small numbers is particularly interesting because it confirms other workers' (Harrison 1958b, Oliff 1960b, Allanson 1961) conclusion that it is abundant where there is organic enrichment. Paracyclops numbers varied independently of median Phi value, subsieve fraction and Phi quartile deviation (Table 55) and also of the amount of detritus. Large numbers of Paracyclops were found mainly in sediments with a high sulphide concentration, though there were two sediments (at Stations 1 and 8) with high sulphide concentrations and low Paracyclops densities. The sediments with high Paracyclops densities and low sulphide concentrations are discussed below (p.181).

Tables 55 and 56 show that larger numbers of Tanytarsini and Orthocladiinae were associated with coarser sediments, lower subsieve fractions and mainly with sediments with a little detritus. Generally, coarse sediments tended to be well sorted, but the coarse sediments where Tanytarsini and Orthocladiinae numbers were higher were not well sorted (Table 55), suggesting that they were showing a preference for coarse sediments sheltered from the current. Many Tanytarsini and Orthocladiinae live in small tubes built on suitable surfaces on top of the substratum and their numbers were higher in coarser sediments because such sediments would provide solid surfaces suitable for tube attachment. The effect of unusually stable conditions on the summer fauna at Station 25 has already been mentioned. The group whose numbers were spectacularly high were Tanytarsini. Hynes' (1960, p. 89) reference to a smothering and lethal effect of large quantities of inert solids on all but the burrowing animals provides another possible biological explanation for the lower numbers of Tanytarsini and Orthocladiinae in the finer sediments. Since the tubes of these animals are attached to the sediment surface they would mostly be horizontal and thus rapidly smothered where the rate of silt deposition is high. They may be compared with Chironomus larvae which live in tubes in fine sediments, but here the tube is vertical, and is therefore presumably easily extended to the sediment surface should this become necessary.

There was very little difference between the sediments where Chironomini (other than Chironomus) and Pentaneura were found in larger or smaller numbers. This means either that factors other than sediment type governed their density, or that they were mixtures of species with definite sediment preferences. Nais numbers were higher where the subsieve fraction and Phi quartile deviation of the sediments were lower and on only a few sediments with a lot of detritus. The mean median Phi values do not show the important fact that Nais was not found in large numbers in sediments finer than Fine Sands. Nais was therefore clearly not a fine sediment animal. This is perhaps somewhat surprising as it has frequently been found in stones in current and marginal vegetation biotopes when there are algal or 'slimy' growths (Harrison 1958b, Chutter 1963 and p. 31 above). Such growths usually contain a lot of silt. Oliff (1960b), Allanson (1961), and Harrison (1958a) all recorded large numbers of Nais in sediment samples but the sediments concerned were either coarse or where the rivers were polluted. However Nais was not among the commoner animals found by Harrison et al in the fine sediments of the Vaal Barrage.

Among the animals which were found either in very low numbers or at a very few sampling points there were some whose occurrence was clearly related to sediment type. Paragomphus cognatus was found only in Fine Sand or coarser sediments confirming Keetch & Moran's (1966) finding that this species avoids fine sediments. However the other Gomphid found in the Vaal Dam catchment, Ceratogomphus pictus, was recorded only from Fine Sand or finer sediments. The two species were never recorded from the same sediments.

The respiratory siphon of both of them is about the same length so they presumably burrow to about the same depth in the sediments. The flattened abdomen of C. pictus may help it to maintain its depth in soft, fine sediments. The abdomen of P. cognatus is more rounded. This is, however, certainly but one of many differences between these two species, habitat selection being unlikely to be based on this single difference alone. Tubifex (possibly T. templetoni according to Dr. Brinkhurst) were found in large numbers only at Station 3 in the granule, which was a type of sediment not often sampled (Table 47). Harpacticidae were recorded in sediments finer than Coarse Sand, but they were not found where the subsieve fraction of the sediment was less than 15 per cent, or in well sorted sediments. Dipseudopsis, a burrowing caddis with legs adapted for digging and a highly modified labium, occurred only in Fine Sand and finer sediments. It makes a tube in the sediment and it is quite possible that it is a filter feeder like the South American Macronema described by Sattler (1963). The occurrence of Corbicula africana (Pelecypoda) was not related to sediment type.

Percentage composition of the fauna and sediment type

The relationship between the proportion of species or groups of animals expressed as percentages of the total numbers of all kinds of animals in samples (Tables 42 to 46) and sediment type (Table 57) were usually similar to those between density and sediment type (Table 55). In other words the percentages of animals were usually higher in the sediment type where the densities were higher. Except in the case of Paracyclops, animals whose percentages were higher where sulphides were high also had higher percentages where there was a lot of detritus. A tabulation of the amount of detritus in sediments in relation to percentages has therefore not been presented.

The densities of all animals tended to be lower in the coarse well-sorted sediments, but as might be expected, the densities of some animals were not reduced as much as those of others. High percentages (Table 57) of Pentaneura, Tanytarsini, Orthocladiinae, Bezzia and Pisidium were found in coarser, better sorted sediments with a higher subsieve fraction and sulphide concentration than were high densities (Table 55), showing that the densities of these animals were not reduced as much as those of other animals. They were either predators (Pentaneura, Bezzia) or forms probably obtaining their food from on top of the sediments (Tanytarsini, Orthocladiinae, Pisidium) rather than from within them. Forms which feed on detritus within the sediment are notably absent from this group of animals, which correlates well with the low subsieve fraction, sulphide content and amount of detritus in the coarser sediments.

The sediment fauna and factors other than the physical nature, sulphide concentration and amount of detritus in the sediments

The sediment preferences of the important sediment animals having been described, it is to some extent possible to recognise variation in the fauna due to other environmental factors. These factors were mainly season, zone and the abnormal chemical quality of the water at sampling points where effluents reached the rivers, and the fauna is discussed in relation to each of these factors in turn. However, changes in the type and stability of sediments followed season and zone so closely that it has not been possible to entirely eliminate a consideration of sediment preferences from this section. Finally the fauna is discussed in relation to special conditions at certain sampling points.

Zonation

Very few animals showed a preference for certain zones irrespective of sediment type. Branchiura sowerbyi was not recorded in large numbers or percentages in the Source, Eroding or high-lying Unstable Depositing Zones, and was found only at Station 2a in the Stable Depositing Zone (Tables 42 to 46). Most of the sediments in these zones were coarse and well sorted and therefore unlikely to be suitable for B. sowerbyi, but it was also not recorded from Stations 1, 10, 8 and 19 where the sediments were finer, contained a lot of detritus and appeared to be suitable. B. sowerbyi is a tropical species and has been reported from England (which has a cooler climate than the southern Transvaal) mainly from artificially warm waters (Mann, 1958). It seems likely, therefore, that its absence from these apparently suitable sediments in the upper reaches of Vaal Dam catchment streams and rivers was due to low temperatures.

There were several sampling points in the high-lying Unstable Depositing Zone (Table 44, Stations 30, 14, 38, 40) and one in the Eroding Zone (Station 9a) where the percentages and sometimes the densities (Stations 9a, 14, 40) of Paracyclops were high in the dry season in the absence of any obvious organic enrichment and also in the absence of any other faunal changes indicative of organic enrichment. The reasons for this are not at all clear. Paracyclops vanished from these streams in the summer. Its high percentages and sometimes densities might be due to its powers of recolonization or of surviving the unfavourable season being better than those of its competitors in more normal conditions. Ostracod densities were high in all the Stable Depositing and normal Unstable Depositing Zone sediments sampled in the winter or dry early summer, no matter what their median Phi value, subsieve fraction, sulphide concentration or amount of detritus and at Stations 19 and 40. They were recorded in low numbers, or not at all, from the sediments in the Source Zone (Station 1) and the Eroding Zone and from the coarser sediments in the high-lying Unstable Depositing Zone, except for that at Station 40. The situation at Stations 1 and 8 was exceptional since Ostracoda were very common in the marginal vegetation (Tables 31 and 35) but rare in the sediment. It is unlikely that this was due to systematic differences between the inhabitants of the two biotopes for Ostracoda are usually tolerant of a wide range of ecological conditions (Pennak, 1953, p. 415) and the genera found in the sediments were all found in the marginal vegetation. The factor limiting the number of Ostracods to a low level in the sediments was therefore likely to be some biotic factor effective in the sediment biotope but less important in the marginal vegetation. At Station 1 this could have been predation by Procladius and Tanypus larvae which were found in large numbers in the sediment but not in the marginal vegetation.

At other sampling points where the Ostracoda were abundant in sediments they were found in large numbers in other biotopes too. In all biotopes at most stations they became rare in the summer showing that they were unable to tolerate summer conditions. However, their numbers did not decline in the summer in the Vaal River Stable Depositing Zone (Table 43, Station 2a) or in the Russespruit (Table 45, Station 41). Conditions had been stable for some time before Station 41 was sampled and Station 2a was of course in the zone where conditions were least unstable in the summer. This suggests that it was the instability of river flow and not other factors such as temperature which brought about the decline in Ostracod densities in all biotopes. This is supported by the fact that in the most unstable zones, the Eroding and the high-lying Unstable Depositing, there were many sampling points where Ostracoda were not found in any biotopes even in the winter and dry early summer, when flow conditions are usually stable in all zones. Here it would seem that summer conditions were so unstable that the Ostracoda disappeared permanently.

Pisidium was rare at Station 1 (Table 42) possibly as a result of the poorly buffered, calcium poor water there. It was not recorded from any of the coarser sediments in the high-lying Unstable Depositing Zone (Table 44). This was unusual for while larger densities of this animal were associated with the finer sediments, there were many coarse sediments in other zones where it did occur, albeit in low densities. The extreme instability (e.g. Plate XII) of sediments in the high-lying Unstable Depositing Zone probably accounted for the absence of Pisidium.

Seasonal variation

Pisidium densities were often as high in the summer as they were in the other seasons. At several sampling points (Stations 2a, 3, 5, 5a, 13) they were clearly highest in the summer, suggesting that this is the season when reproduction takes place.

All the other animals found in the sediments tended to decline in density in the summer and the overall effect of this was that the density of the fauna as a whole was lowest then (see above). However, when the fauna is divided into predominately surface-dwelling forms (Ilyocryptus, Paracyclops, Ostracoda, Tanytarsini and Orthocladiinae) and burrowing or interstitial forms (the other animals) it is clear that in the summer there was a disproportionate decrease in the density of the surface dwelling forms (Table 58) in the Eroding Zone and in both Unstable Depositing Zones. The surface dwelling forms would of course be the most exposed to washing away.

What is interesting is that in the Source and Stable Depositing Zones and also at Station 41 where summer conditions were stable, the proportion of the surface dwelling forms in the fauna as a whole did not decline. However, this discussion has so far been limited to sampling points which were sampled in more than one season. Among the sampling points sampled only in the summer there were some (Stations 25, 26, 33, 29, 44, 30 and 34) where the percentages of the Tanytarsini or Orthocladiinae or both were very high indeed (Tables 43,44,45). The sediments at these sampling points were well sorted, coarse and had low subsieve fractions, sulphide concentrations and small amounts of detritus. The density of the fauna was exceptionally low at Stations 26, 33, 29, 44 and 34. It was very high at Station 25 for reasons which have already been explained. The results therefore show that when conditions become moderately unstable the proportion of surface dwelling animals declines, but when they are very unstable the proportion of these animals rises again. The most likely explanation for this is that when conditions are moderately unstable currents over the sediment sweep away the surface dwelling animals, and there may be some surface movement (erosion or deposition) of the sediment particles which could also be detrimental to the surface dwelling forms. In these circumstances the proportion of burrowing animals rises, for being buried in the sediment, they are protected from events occurring on the sediment surface. When, however, conditions are highly unstable as for instance they must have been at Station 14 (Plate XII) it seems that there is massive sediment movement. Here the sediments would be moved to great depths and conditions would be highly unfavourable for the burrowing forms. These are the sediments where the surface dwelling Chironomid proportions rose. Rearing of larvae showed that species belonging to the Tanytarsini and Orthocladiinae were often recorded from several biotopes and this is an important clue as to why they should be so comparatively successful in sediments where conditions were particularly severe in the summer. So wide is their larval biotope tolerance that they seem to survive somewhere in even the most severely eroding or unstable rivers and then quickly re-invade the sediments when conditions are less unfavourable. In this they would be at a great advantage in having a non-aquatic adult stage, so that not only would a part of the population be very likely to be in this non-aquatic stage when the aquatic conditions are temporarily highly unfavourable, but also dispersion and reinvasion would probably be achieved more rapidly than in fully aquatic animals such as the Oligochaeta or the Ostracoda.

The fauna of sediments where the chemical quality of the water was affected by effluents

The density of the sediment fauna at sampling points where the chemical quality of the water was affected by effluents varied rather widely (Table 59) due to the variability of conditions from sampling point to sampling point. As at sampling points where the chemical quality of the water was normal the highest densities were recorded in the dry early summer, and the summer densities were much lower. The lower summer densities must in part have been due to the same factors which brought about the summer reduction in density at other sampling points, but a greater dilution of effluents and a more rapid transport of organic food downstream may also have been important. Sulphide concentrations fell in the summer at these sampling points (Table 51) which probably indicates an increase in the aeration of the water above the sediments.

Generally the greatest densities of animals were at Stations 4, 5 (Vaal River, Standerton) and 11a (Wilge River, Harrismith), which were below direct inflows (Station 4) or seepages (Stations 5 and 11a) of waters rich in organic matter and may therefore be ascribed to increases in the amount of food material. At Stations 11b and 11c summer densities were very low, but this was probably due to the very unstable river bed at these sampling points. Dry early summer densities at these sampling points were not as high as at Station 11a, but, as is described below, this was not due to a return of conditions to greater normality. Densities were not unusual at Station 17 (Waterval River), which was in a recovery zone several kilometres downstream from where effluents ran into the river. The sediment was in a sheltered position and contained a lot of detritus, both of which help to account for the relatively high summer density. At Station 7 the sediment was more exposed and the summer density was consequently low.

The abnormal chemical quality of the water at Station 4 (Standerton) brought about several well defined changes in the fauna (Table 42). Firstly there was a very great increase in the density of Nematoda, Limnodrilus, Dero (Dero) and Ilyocryptus. Chironomus larvae appeared. Batracobdella tricarinata, a leech which was usually seldom encountered, was regularly collected, though in numbers too small to include in Table 42. Increased numbers of leeches have often been recorded in European rivers where they are altered by effluents rich in organic matter (Hynes, 1960). Ostracoda and Pisidium were rare and none of them were significant, although physically the sediment was suitable for them. Numbers of Chironomidae other than Chironomus and of Bezzia were lower than in normal sediments. The changes in the fauna were due to the appearance of an unusually rich supply of an unusual type of food and probably also to a lowering of the oxygen content of the water in and near the sediment. At Station 5 there was some recovery of the fauna. Dero (Dero) and

Chironomus percentages were more normal and *Batracobdella tricarinata* was no longer recorded. The Ostracoda were more frequently found than at Station 4 and in particular the occurrence of *Ilyocypris* was normal. However, *Branchiura sowerbyi* made up an unusually large part of the fauna and there was a bloom of *Paracyclops* in the dry early summer. *Pisidium* and Chironomidae other than *Chironomus* were still rare.

At Station 17 there were large numbers of *Paracyclops* in the winter (Table 46), but bearing the physical nature of the sediment in mind, there were no other faunal peculiarities which could be related to the abnormal chemical quality of the water. At Station 7 too the fauna was, apart from large numbers of *Paracyclops*, normal. In the Wilge River conditions were somewhat more complicated. At Station 11a the fauna resembled that at Station 4. Densities of *Limnodrilus*, *Ilyocryptus* and *Paracyclops* were high. As at Station 4 percentages of Ostracoda and *Pisidium* were low and *Chironomus* appeared. The percentages of all the Chironomidae apart from the Chironomini were low. The fauna at Station 11b was almost entirely *Nais* in the dry early summer. In the summer the faunal diversity was more normal and *Limnodrilus* and Tanytarsini were the most abundant animals. In the dry early summer there were about 65 animals/0.1 sq. m. other than *Nais*. This is a very low faunal density for this season and indicates that the effluent reaching the river above Station 11b contained substances poisonous to most sediment animals. The effluent contained wool dyes so that this is quite likely. In the summer when dilution was greater the fauna was more varied, though very sparse probably on account of highly unstable conditions in the river bed.

In the dry early summer considerable recovery of the sediment fauna took place between Stations 11b and 11c, and at the latter station the fauna was more or less normal for a sampling point in the Unstable Depositing Zone (Table 46). However, conditions were highly unstable at this sampling point in the summer and the fauna was very poor indeed.

Special conditions at certain sampling points

In this section cases of unusual combinations of fauna and sediment type are examined and attempts are made to account for these.

In spite of the fact that conditions at Station 8 (Sandspruit) were, due to a weir, artificially stable, there was a great difference between the density of the summer and of the dry early summer fauna (Table 44). All the common animals were very much less abundant in the summer than in the dry early summer. As the sediment was in a quiet sheltered backwater it is not likely to have been direct disturbance by currents which brought about this density decline. It may be that the fauna was adversely affected by a high summer rate of silt deposition. Harrison et al (1963) attributed the general sparsity of the sediment fauna in the Vaal Barrage to silt deposition. Station 19 (Kafferspruit) was another sampling point where the sediment was very fine, and here too the summer fauna was very much less dense than that of other seasons (Table 44). In this case the lower summer density was due to some animals and not others. Abundant animals whose numbers did not change were Nematoda and Bezzia, but the numbers of other important animals - Ilyocryptus, Paracyclops, Ostracoda, Chironomidae and Pisidium - were low in summer. It is possibly true that Nematoda and Bezzia burrow deeper into sediments than the other animals. The lower numbers of the other animals might then have been due to adverse conditions at the surface of the sediment, such as erosion or excessive sedimentation. Considering that the sediment at Station 19 was fine, with a large subsieve fraction, a lot of organic detritus and a high sulphide concentration, Limnodrilus was unusually sparse and, in winter, Tanytarsini were unusually abundant. There is no obvious reason for the large numbers of Tanytarsini, unless the species concerned differed from the species usually found and had different sediment preferences. In the case of Limnodrilus it seems likely that numbers were low because the sediment was particularly soft, as has already been described (p. 53). The sediment at Station 27 was also very soft and there too Limnodrilus numbers were low (Table 45). Harrison et al (1963) recorded very small numbers of Limnodrilus from the finest sediments in the Vaal Barrage. (Brinkhurst's (in press) work has shown that Harrison et al misidentified Limnodrilus, recording it as Lumbriculus).

The high percentages of Limnodrilus from the comparatively coarse sediments at Stations 34 and 14 (Table 44) do not, as will be seen from the total numbers of animals at the foot of the table, indicate high densities. At Station 39 (Plate XIII) two samples were taken on the same day, one from sand in the current and the other from sand out of the current. Sand particles could be seen to be moving across the top of the sediment in the current. Physically the two samples were practically identical. Sulphides could not be detected in the sediment in the current, which had a subsieve fraction of 1.1 per cent: the sediment out of the current had 0.5 ppm sulphides and a subsieve fraction of 1.8 per cent. The fauna of the moving sand was extremely impoverished compared to the fauna of the sand out of the current (Table 44) showing the effect of unstable conditions. The Klerkspruit at Station 40 had very nearly stopped flowing when the dry early summer sample was taken. A bloom of Eucypris was found in these conditions (Table 44).

At Station 35 (Table 45) the sediment sampled was fine, with a large subsieve fraction but a low sulphide concentration and very little organic detritus. The low faunal density was probably due to a lack of food material, which was unusual for so fine a sediment.

Summarizing remarks - the sediment fauna

The main factor governing the distribution and relative abundance of sediment animals in the Vaal Dam Catchment was the instability of conditions in the river beds. In the high-lying Unstable Depositing Zone where conditions were most unstable, sediments were usually coarse, well sorted and contained little fine material and detritus. The fauna of such sediments was very poor and was often largely made up of surface dwelling Chironomids which probably occurred in other biotopes too. Burrowing animals were not abundant, probably because sediments moved a lot. Conditions were most stable in the Source and Stable Depositing Zones where even in the summer, when conditions were most unstable in all zones, the proportion of surface dwelling to burrowing animals remained the same as in the other seasons. All sediments in these zones contained a lot of detritus and faunal densities were high. However, the fauna of sediments in the Eroding and normal Unstable Depositing Zones showed another type of seasonal variation. Here the surface-dwelling forms, which were more varied than in the high-lying Unstable Depositing Zone, tended to disappear.

There were only two groups of animals in which the instability of conditions in the river beds was not the main factor governing their seasonal abundance and distribution. These were Pisidium whose greatest number tended to be recorded in the summer probably because it breeds then and Branchiura sowerbyi which was not found in the upper reaches of the rivers, possibly because temperatures were unsuitable. However, taxonomic knowledge of sediment animals is poor

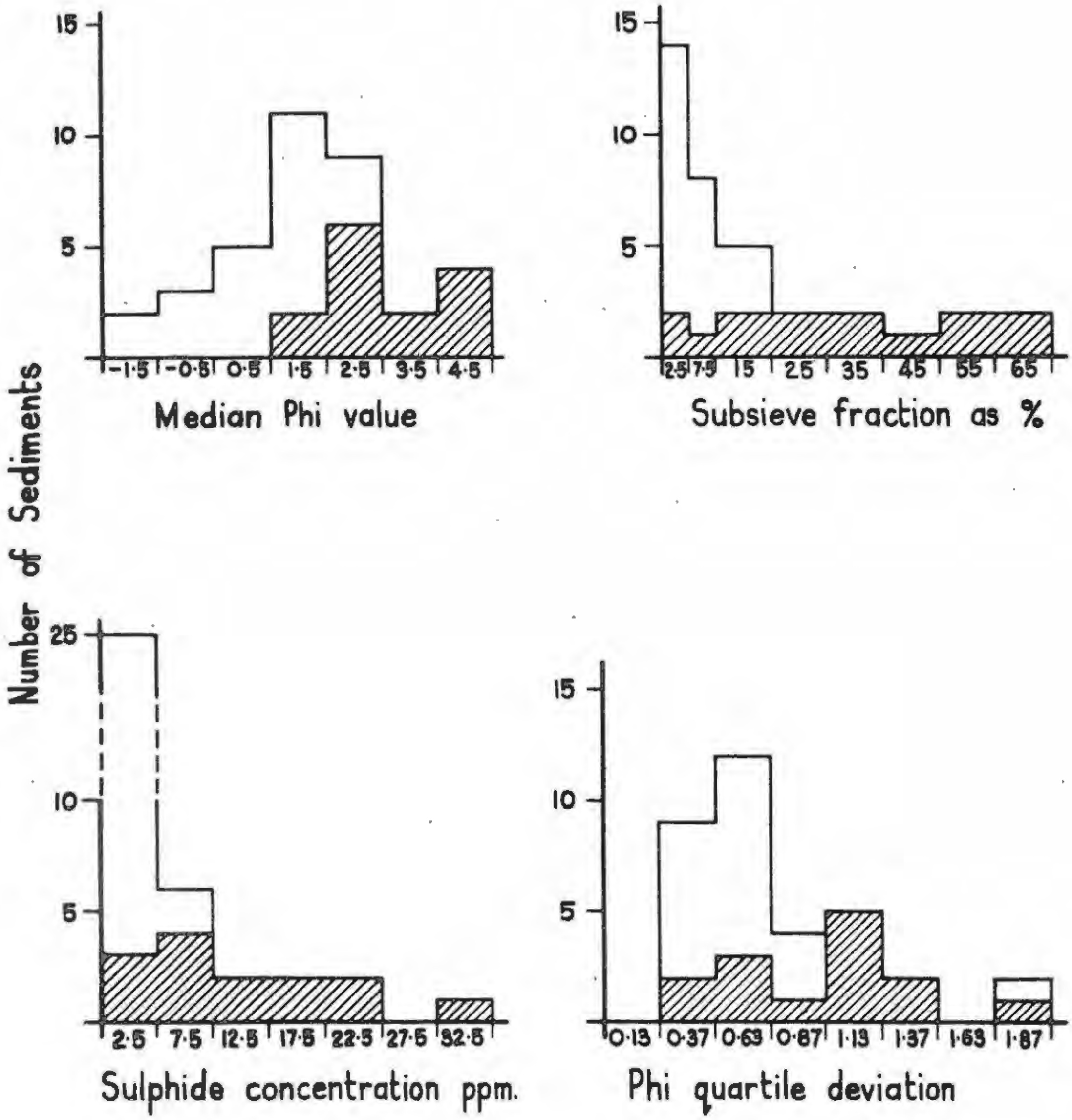


Figure 27. The physical characteristics of sediments where <u>Limnodrilus</u> densities were >500 per 0·1 sq.m. (shaded) and where they were <500 per 0·1 sq.m. (unshaded). Data for 3 stations were omitted as explained in the text.

and there were probably more instances of seasonal and zonation variation which went unnoticed because the animals could not be recognised at the species level.

The effect of effluents rich in organic matter on the sediment fauna was recognisable, most clearly by a very great increase in the density of the fauna. As in other biotopes some animals appeared and others disappeared. At a sampling point where there was good reason to suspect that an effluent was toxic, the fauna was very largely made up of Nais.

Kennedy (1965) studied the spatial and temporal variation in the abundance of Limnodrilus in sediments in four English localities. He found that this variation could not be related to observed changes in any abiotic factors, which included the nature of the sediments "as viewed visually", their vegetation cover and depth. This is of course in marked contrast to the situation in the Vaal Dam catchment sediments where larger numbers of Limnodrilus were found mainly in the more poorly sorted fine sediments with a large subsieve fraction, sulphide concentration and amount of detritus, provided that they were not soft (Tables 55 and 56). The data on which the mean values of sediment variables in Table 55 were based have been plotted in Figure 27 omitting data for the soft sediments (Stations 19 and 27) and for the only fine sediment without a lot of detritus (Station 35). Figure 27 shows the close association between high densities of Limnodrilus and finer sediments (i.e. those with high median Phi values). A small proportion of the better sorted sediments with low subsieve fractions and sulphide concentrations supported large Limnodrilus populations but as the sediments became less well sorted with higher subsieve fractions and sulphide concentrations, so the proportion of large Limnodrilus populations rose. It seems that none of Kennedy's samples were drawn from coarse well sorted sediments with little organic matter, exposed to marked seasonal variations in flow, current speed and stability, nor did he have as many analyses on which to base his conclusions as were available from the Vaal Dam catchment. These two factors possibly explain why Kennedy did not find any relationship between sediment type and Limnodrilus density. The variability of individual results from single sampling points was high in the Vaal Dam catchment too. In these there was no correlation between sediment variability and Limnodrilus numbers. This was also true of all of the sediment animals. It was only when values were averaged and then compared from sampling point to sampling point that the trends described here became clearly apparent. This suggests, perhaps, that the density of the fauna in sediments is patchy. However, it would be imprudent to ascribe such patchiness to abiotic or to biotic factors alone until a lot more is known about the variability of the sediments themselves. In this connection it is important to remember that the sediment samples analysed physically in the Vaal Dam catchment were collected next to the sediment samples examined for animals. If, as might well often be the case in rivers, the physical composition of the sediments varies within small areas, and if patchiness in density is due to sediment type a close correlation between fauna and sediment type cannot be expected to be apparent in a series of single monthly samples taken in this way.

Discussion

Factors which contribute to the zonation of the fauna in the Vaal River

As a result of their studies in the Great Berg River, Harrison and Elsworth (1958) concluded that the upper river fauna was limited to the upper river by high summer temperatures in the lower zones, by increasing silt loads during floods and also by the deposition of silt after floods. Species found in the lower river could tolerate summer temperatures and silting and some of them were limited to the lower regions by their food requirements. As examples of such animals they quoted Neurocaenis discolor (as Tricorythus), Pseudocloeon maculosum and Cheumatopsyche thomasseti (as C. zuluensis). From his study of the Tugela River Oliff (1960a) concluded that it was mainly temperature which was responsible for the zonation, though in his study of the Mooi River (Oliff & King 1964) he placed greater emphasis on the importance of other factors, in which he included silt, current speed and changes in the nature of the substratum.

The studies on the streams and rivers of the Vaal Dam catchment, taken together with the studies on the Vaal below the Vaal Barrage (Chutter, 1963) and at Warrenton, provide a large variety of combinations of environmental variables. However in the Vaal Dam catchment these were set against a background which was unusually constant in respect of certain variables. Current speeds in the stony runs of the Klein Vaal/Vaal River were remarkably constant from zone to zone, and temperatures differed little. In fact the Eroding Zone was followed downstream by a zone in which mean temperatures were lower in two of the three seasons (Table 12). These temperature differences are of vital importance in the assessment of the relative importance of temperature and other environmental factors which will be made below and it will therefore be as well to examine them in some detail. Most of the temperature records from the Eroding and Stable

Depositing Zone were made at Stations 21a, 20, 21 and 2a. Unfortunately there were never simultaneous readings at all four sampling points, but the times of the day when temperatures were read varied from month to month and the sampling points were not visited in the same sequence from month to month. It is therefore considered that the means shown in Table 12 do show meaningful trends and that the temperatures at Stations 21a and 20 (the Eroding Zone) were higher than those at Stations 21 and 2a (the Stable Depositing Zone). This is almost undoubtedly due to the deeper pools and lesser insolation associated with higher banks and, at Station 21, more shade cover due to trees in the Stable Depositing Zone.

Set against this temperature background it is obvious that the decline in the importance of Eroding Zone animals from Station 21a to Station 21 cannot be ascribed to rising temperatures, and must have been due to other factors, of which the most likely were changes in the nature of the river bed and an increase in the siltiness of the environment. The high-lying Unstable Depositing Zone fauna is important in this respect as it shows that many of the Eroding Zone animals disappear where large amounts of silt and sand find their way into the streams. The precise way in which the silt and sand affect the fauna is not clear though it is reasonable to assume that some animals will be affected directly by an interference with respiration or by abrasion, but in others, and probably the majority, the effect will be more indirect through the smothering of microhabitats and the alteration of the food resources of the environment, through the generally higher turbidities and instability of the river bottom affecting the growth of epiphytic algae.

However there remains the question of why the Stable and Unstable Depositing Zone animals do not invade the Eroding Zone. This would seem to be largely a question of the food available in the various zones, and is shown rather clearly by the animals from stones in current. The distinctive feature of the Stable Depositing Zone fauna was the increase in the numbers and variety of animals such as the Elmidae, Argyractis periopis and the Chironomidae which would be likely to feed on the abundant aquatic vegetation, either directly, or as it decayed or on its aufwuchs. This supply of food would be scarce in the Eroding Zone and also in the Unstable Depositing Zone. It does, however, seem likely that some of the characteristic lower river animals, in this case the Unstable Depositing Zone animals, are also restricted to the lower zones by their food requirements, as Harrison and Elsworth suggested. The lower river species of Neurocaenis (p. 114) was found in large numbers only where there were large amounts of silt, that is in the normal and sandy high-lying Unstable Depositing Zones. It was not found at Station 19, that is the silty high-lying Unstable Depositing Zone, possibly because conditions were too silty even for it. Be that as it may, data on Neurocaenis from further down the Vaal River lend support to the idea that the lower river species requires large amounts of silt. Vaal Dam and the Vaal Barrage, which is almost immediately below the dam, act as large silt traps and also stabilize the flow of the river. Immediately below the Barrage the stones in current fauna is profoundly affected by the plankton leaving the impoundment (Chutter, 1963) and it is necessary to consider the more normal fauna found a little way further downstream at Lindeques Drift, where there was no plankton effect. Here Neurocaenis made up only a small part of the fauna (Chutter 1963, Table 14), presumably because conditions were not sufficiently silty for it. Again at Warrenton the Vaal Hartz Diversion Weir would act as a silt trap and Neurocaenis numbers were high only at Station 56 (Table 6) which was the sampling point farthest from the Weir and where there had consequently been more opportunity for the river to pick up silt below the Weir. Neurocaenis larvae have very hairy mouth parts and it seems likely that they strain their food out of the water. There would be likely to be more of this kind of food in the Unstable Depositing Zones since the relationship between 4-hour oxygen absorbed and turbidity indicates that there is more organic material where the turbidity is higher (Figure 16). The other major group of animals which increased in the Unstable Depositing Zone was the Hydropsychidae (Trichoptera). These are filter feeders, but the presence of large amounts of filterable food may in their case be less closely related to river zones than it was in Neurocaenis. There are indications, such as the large numbers of these animals at Station 26 in the Eroding Zone, that their numbers are related to the size of the river and the distance it has flowed from its source. This would seem to indicate that the concentration of filterable food matter increases in the water the further it is from the source of the river.

Hynes (1963) suggested that a most important source of food for animals found in the upper reaches of rivers is the organic material washed into the river bed. The animals whose distribution has been described here tend to show that the importance of allochthonous organic matter increases down the course of the river. However Hynes was evidently mainly discussing the fauna of streams situated in close proximity to large deciduous forests, for an important source of the food material he described was the autumn leaf fall. The high interior plateau of South Africa, in which the catchment of Vaal Dam lies, consists of grass lands. There are no riverine forests and practically the only trees found along the river banks are exotics, of which the weeping willow, Salix babylonica, is the most important. Hynes showed that the animal productivity of the Afon Hirnant (Hynes 1961) is far greater in the winter, when it is based almost entirely on allochthonous material, than it is in the summer, which was the only season when algal growth could have played a significant role. It appears that the situation is very different in the Vaal Dam Catchment. In this summer rainfall area the only period when allochthonous material would naturally reach the river in large quantities would be the summer, when it would be washed in by the rains. With the coming of the willow trees this may have changed somewhat, but the question then arises as to whether any of the Vaal River fauna has adapted itself to exploit the leaf fall as a source of food material. To judge by the quantitative data on the fauna of stones in current and marginal vegetation biotopes at Stations 21 and 3 (Tables 27 and 39 to 41), the stations regularly sampled where willow trees were plentiful, it seems that if there was a faunal response to leaf fall, it was not detectable by the admittedly not very refined methods used in this study. On the other hand the dry early summer was the period when autochthonous production of organic matter in the streams reached a peak and algae were most plentiful. The dry early summer is the period when the water is low, clear and warming up after the cold winter temperatures. The interesting point about this is that the density of nearly all the groups of animals recognised in all the biotopes studied was highest in the dry early summer. This suggests that the fauna as a whole may depend more on autochthonous organic matter as a food resource than does the fauna of streams in parts of the world where the rainfall is more evenly spread through the year and where there is an abundant leaf fall. Leaving aside those sampling points where the fauna was unusual due to chemical changes in the quality of the water, the only animals whose numbers seemed to respond to the increase in the amount of allochthonous material were Neurocaenis and only at some sampling points, the Hydropsychidae, described by Hynes as 'indiscriminate eaters of anything they catch'. Baetis bellus was also a summer animal, but it is difficult to visualise this animal living mainly on allochthonous material, for it is not a filter feeder and lives in vegetation exposed to the current, which in the Vaal Dam Catchment usually consists of Scirpus in which detritus does not easily become entangled. An observation made at Station 20, which is to be written up elsewhere, has a bearing on the importance of autochthonous organic matter on stream productivity in the Vaal Dam Catchment. At this station (near Station 21a, Fig. 9) the entire fauna was poisoned (probably by water from a cattle dipping tank) just before a sampling visit and dead fish and crabs were lying on the margin of the stream. Up to this time there had been no obvious algal growths on the stones. The subsequent recolonisation was followed up and the observation made that a month after the poisoning there was very little fauna, but the stones were covered by a mat of aufwuchs. This gradually decreased in amount as the fauna returned, suggesting that the grazing rate and the algal growth rate are normally high in stones in current in the Vaal Dam Catchment, as there was no evidence that the algal growth was due to a chemical change in the water.

The zonation of the Vaal River

The zonation of the streams and rivers in the catchment of Vaal Dam has been described, and the river below Vaal Dam will be considered in this section. As far as the fauna of the various biotopes was studied in the lower reaches of the Vaal, it seems that the river was faunistically in the same zone at Station 3, below the Vaal Barrage, at Lindeques Drift (Chutter, 1963) and also at Warrenton. In the stones in current there were local disturbances of the relative abundance of the different kinds of animals. Below the Barrage these took the form of an increase in the abundance of the filter feeding caddis and Simuliidae, and they were associated with the rich plankton being carried by the water from behind the Barrage. At Warrenton the disturbance was due to the large numbers of Simuliidae. Between the Unstable Depositing Zone and Warrenton a few groups or species disappeared: Caenidae (?Austrocaenis), Stenelmis thusa and Simulium griseicolle, and a few appeared: ?Caenodes, Hydropsyche sp., Helminthopsis elongata, Pachyelmis rufomarginata nigra and Simulium gariepensis. Apart from a decrease in Choroterpes (Euthraulus) and a very great increase in Simulium chutteri, the stony run fauna at Warrenton, which included large numbers of Baetis glaucus, Neurocaenis, Amphipsyche scottae and Cheumatopsyche thomasseti, was similar to that at sampling points such as Stations 3, 5a and 13 in the Vaal Dam Catchment. The available temperature records show that the minimum Warrenton temperatures were probably about 5°C higher than in the Unstable Depositing Zone above Vaal Dam, but that there was little difference in the maximum temperatures, showing how cold tolerant the majority of the species found at Warrenton are. An important point to be noted here, which is commented on in the next section, is that at Warrenton the Vaal River enters a Rejuvenation Zone from the point of view of its profile. It is obvious, however, that this is not a distinctive faunal zone.

One of the characteristics of the Stable Depositing Zone is that it is a zone where there are not excessive amounts of silt and sand. Floods do not scour out the vegetation. In some respects the effect of large impoundments across the Vaal River has been to alter the Unstable Depositing Zone conditions towards Stable Depositing Zone conditions. The flow is regulated below the Vaal Dam so that floods are a rare occurrence in the area immediately below the dam. There is thus less silt and sand moving down the river. The waters held back by Vaal Dam are, however, always turbid (Chutter 1963,

Fig. 3, suspended solids) and although in certain flow conditions the water clears considerably in the lower parts of the Vaal Barrage, it is never as clear as it is in the winter and dry early summer in the Stable Depositing Zone. The result of this is that there are not particularly profuse growths of aquatic plants in the river below the Barrage, but there is very much more fringing vegetation than in the Unstable Depositing Zone. The changes at Warrenton were different, for here there is an imposed instability of flow for the greater part of the year. Nevertheless a reduction in the amount of silt probably still takes place. The effects of these changes have been described in regard to Neurocaenis. Another species in which changes in occurrence between the Unstable Depositing Zone and Lindeques Drift might have been due to changes in the environment associated with the impoundments was Pseudocloeon vinosum. This marginal vegetation animal was found in all three seasons in the Eroding Zone, but not in the summer in the other zones in the catchment. Below the Vaal Barrage, however, it was present in the summer, which suggests that above Vaal Dam its summer distribution is limited by silt. However this is a species which Harrison and Elsworth (1958) found in large numbers in the Great Berg River in the winter even where the river was very silty. It may be that the animal's ability to withstand silty conditions is related to the water temperature.

General comments on river zonation

Harrison (1965a) suggested that the streams and rivers of South Africa, including the Vaal, could be fitted into Illies' (1961) classification of flowing waters. Insofar as the Vaal River is concerned Harrison suggested that what has been described here as the Eroding Zone corresponded to Illies' Rhithron and the Stable Depositing and normal Unstable Depositing Zones corresponded to the Potamon.

However the importance of silt and sand in the zonation of Vaal Dam Catchment streams and rivers had not at that time been appreciated, and so Harrison made no provision for the Stable Depositing and the high-lying Unstable Depositing Zones. In fact Harrison stated that it would be difficult usefully to divide the epipotamon. Nevertheless the division of the epipotamon or Depositing Zone into Stable and Unstable parts has aided considerably in understanding the relationship between the fauna and the environment in the catchment of Vaal Dam. This is surely the main point of any river zonation. Nevertheless it is not at all unlikely that in most rivers the epipotamon is either Stable or Unstable and, as indeed was the case in the Vaal Dam Catchment, few rivers have both types of conditions. In the Tugela system, the Mooi (Oliff and King 1964) was the only river which included a zone (above the village of Mooi River) in which conditions approached those of the Stable Depositing Zone.

It is clear that neither Harrison nor Illies had experience of river systems in which silt and sand were such important environmental factors as they are in the Vaal Dam Catchment, and for this reason they both pinpoint temperature as being the main factor limiting the downstream distribution of the typical mountain fauna. The Vaal Dam Catchment studies have shown the downstream distribution of some of these animals was limited by silt and sand, before temperature became limiting. This was particularly clear in the sandy high-lying Unstable Depositing Zones and in the Klein Vaal River. However, in saying that temperature is not the main factor governing the downstream distribution of the mountain animals in the Vaal Dam Catchment, the author wishes to avoid giving the impression that he does not realize that in other rivers (including some of the Vaal Dam Catchment rivers such as the Klip or the Elands which he did not have an opportunity to study in detail) temperature may clearly be the most important factor limiting the downstream distribution of the fauna.

The Stable Depositing Zone, or a zone similar to it, has not been recognised in any of the other South African rivers so far studied. It seems, however, that it may be more similar to the upper Potamon of streams and rivers in parts of the world in which there are not the strongly seasonal rainfall, scouring floods and heavy soil erosion that are the norm in South Africa, than are either the Foothill Sand Bed Zone (Tugela River), the Foothill Soft Bottom Zone (Great Berg River) or the Unstable Depositing Zone (Vaal River). Here it would seem that the extent of soil erosion and the violence of the floods is a more important factor than the seasonal rainfall. Certainly some of the large rivers towards central Africa, such as the Okavango, show a seasonal variation in flow but their depositing or potamon zone is stable and full of aquatic plants.

The author agrees with Harrison and Illies that the sharpest change in the faunal zonation of a normally zoned river such as the Great Berg occurs between the Rhithron and the Potamon. Where the river changes from Rhithron to Potamon, the fauna of comparable biotopes such as stony runs or fringing vegetation in current changes. Where, however, the recognition of the epi-, meta- and hypo- rhithron are concerned, it seems that the zones are frequently recognised rather by the general appearance of the river and the presence of certain types of biotopes (cascades, waterfalls, stony backwaters, soft bottoms, sandy bottoms) than by sharp changes in the composition of the fauna of single comparable biotopes, such as stony runs. In fact the most striking points about Harrison and Elsworth's Table 16 are firstly, the way in which there is a sharp discontinuity in the distribution or percentages of many animals at the end of Zone IIIB, and secondly the way in which percentages of animals change gradually from station to station in Zones II, IIIA and IIIB. Some species or groups have their highest percentages in Zone II and disappear before

Zone IIIB, others persist in gradually declining percentages down to the end of Zone IIIB. The highest percentages of other species is in Zone IIIA or IIIB and their percentages may fade out both upstream and downstream. Oliff (1960a) also found that the greatest discontinuity in the distribution of the Tugela River fauna occurred where the river changes from the Foothill Torrent Zone to the Foothill Sand Bed Zone, that is, where it changes from Rhithron to Potamon. However Oliff presented his data in such a way that it is difficult to follow the faunal changes along the river, particularly insofar as gradual decreases or increases in the abundance of species are concerned. As far as one can see from the data presented by Oliff, his Rejuvenated River Zone, while it was clearly distinguishable from the river profile, did not really have a distinctive fauna of its own, just as the Rejuvenated River Zone in the Vaal at Warrenton did not have its own distinctive fauna. What appears to happen in these rejuvenated zones is that the stones in current biotopes lie closer together than in other zones, and that current speeds in them may be higher than in the stones in current in the normal epipotamon (compare Tables 5 and 18). These changes alone are, however, not sufficient to bring about marked changes in the composition of the fauna.

These gradual changes in the fauna of comparable biotopes within the Rhithron or the Potamon must be ascribed to gradually changing environmental variables such as temperature and possibly dissolved oxygen. The sharp change from Rhithron to Potamon definitely appears to be associated with the deposition of silt in the river bed. In the Vaal Dam Catchment it would seem that the Rhithron is not only a zone where there is little silt deposition, but also that it is a zone where the amount of silt and sand moving down the river bed is not great. This suggestion has important consequences for it cuts across the concept that the material deposited in the Potamon is eroded from the Rhithron and that it is only in the Potamon that current conditions are sufficiently quiet for its deposition. While this may be true of such material as is eroded in the Rhithron, the suggestion being made here is that large quantities of silt and sand are not washed into the river beds until the Potamon is reached. Such additions of silt and sand are due mainly to human interference, for it is only where the river profile and the countryside have flattened out that agriculture dependent on the plough is normally practised, and these seem to be the areas where soil erosion is most widespread in the Vaal Dam Catchment. There are, however, parts of the Rhithron where soil erosion is also heavy, probably due to the denudation of the grass cover by overstocking with sheep and cattle, and in these areas, the high-lying Unstable Depositing Zones, large quantities of silt and sand do appear. As has been described earlier in the paper, the fauna in these high-lying areas changes, and becomes like that of the normal Unstable Depositing Zones, showing that the Rhithron fauna cannot tolerate large amounts of silt and sand. These the Rhithron fauna would have to tolerate if the sediments of the Potamon normally had their origins in the Rhithron. The presence of silt and sand also helps to explain why the Rejuvenation Zones do not have faunas more like those of the Rhithron than of the Potamon, as the amounts of eroded material passing down the river in the Rejuvenated Zones would be considerable and unsuitable for the Rhithron animals. Temperature would obviously also be important in such Rejuvenated Zones.

Changes in the fauna associated with effluents

Generally speaking, changes in the fauna of the streams and rivers of the Vaal Dam Catchment due to effluents were minor, and nowhere was the fauna as much changed as was the case in the

Little Bushmans (Oliff 1960b) or Jukskei Rivers (Allanson 1961). This was because the amounts of organic matter entering the streams and rivers in the Vaal Dam Catchment were not as great as they were in the Little Bushmans and the Jukskei. Most types of change taking place in the fauna of the Vaal Dam Catchment streams have their parallels in some other South African river. Thus the increase in the Simuliidae and the Hydropsychid Trichoptera found at Station 17, was similar to that found by Oliff (1963) in parts of the Buffalo River system. Increases in the density of Nais, Chironomidae and Burnupia, such as were found in the stones in current at Stations 4 and 5, were similar to the changes taking place in the same biotope of the Great Berg River in the Paarl and Wellington section (Harrison 1958b), though in the Great Berg River the Ancylid snail was Ferrissia and not Burnupia. At no sampling points in the Vaal River system, however, did the addition of effluents to the river result in the large numbers of Baetis harrisoni which were found by Allanson in the Jukskei River.

The main effect of effluents on the marginal vegetation fauna was that there was an increase in the percentages and also in the density of the Cladocera and Copepoda at those sampling points where there was shelter from the current. Generally speaking, however, the changes in the marginal vegetation fauna associated with effluents were slighter than were the changes in the stones in current fauna. This has been previously reported (Harrison 1958b, p. 309), while comparisons of the marginal vegetation fauna from several rivers (Chutter 1963, Discussion) or from different zones in the same river (Oliff 1960a, p. 327) have shown that it varied less from river to river or from zone to zone than did the stones in current fauna. This all points to the fact that the animals from the marginal vegetation are tolerant of a wider range of ecological conditions than the animals from the stones in current: some possible reasons for this have been discussed in an earlier paper (Chutter 1963).

The most marked changes in the fauna of a sediment, due to an effluent, was found at Station 4. In this biotope the changes brought about by effluents containing organic matter were largely quantitative and so at Station 4 the main way in which the fauna differed from that at other sampling points was in the density of the fauna, particularly Limnodrilus spp. At Station 17, which was in a recovery zone and some way from the point where the effluent entered the river the fauna of the sediment was less affected by the changed conditions than was the fauna of other biotopes.

The effect of the effluent at Station 11b, which resulted in a fauna made up of the kinds of animals usually associated with large amounts of organic matter and a decrease in the amount of oxygen available, clearly showed the importance of quantitative data. It was only because the numbers of animals could be related to the area from which they were collected, and then compared with normal sampling points, that it was apparent that the changes in the fauna at Station 11b were more likely to be due to toxic substances than to organic matter and deoxygenation.

The largest and most permanent changes in the chemical quality of the water in the catchment of Vaal Dam were seen in the Waterval River, where they were due to increases in the mineral salts in the water. These could not, however, be shown to have had any effect on the fauna. In all the other instances of effluents reaching rivers in the Vaal Dam Catchment, the effect they had on the fauna was local and they could not be traced in the water at the sampling points (Station 5a and 13) nearest to Vaal Dam.

In the majority of instances where effluents resulted in changes in the fauna, chemical changes in the river water could not be detected. This must to a large extent be due to the fact that unusually long field trips had to be undertaken and Hellwig's (1964) method for the preservation of water samples had not yet been developed. The 5-day Biochemical Oxygen Demand test, which Harrison and Elsworth (1958) found most useful, could not be used because of the duration of the field trips. In these circumstances the fauna was a better indication of the organic enrichment of the water than were the water samples for chemical analysis.

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APPENDIX · TAXONOMY

The full names of most of the animals mentioned here may be found in the systematic list given by Chutter (1963), and many of the publications used in the identification of material are also listed there. The animals listed here are firstly those whose names have changed since the publication of the 1963 list and secondly animals which do not appear in the 1963 list. Finally a list of additional taxonomic papers used in the identification of the animals is presented, together with papers which include descriptions of animals from the areas studied.

Animals whose names have changed since the publication of the 1963 list.

Name in Chutter 1963	Current name
Branchiura sp.	Branchiura sowerbyi Beddard
Iloycythere sp.	Ilyocypris sp.
Austrocloeon sp. nov.	Cloeon crassii Agnew
Baetis sp. I	Baetis glaucus Agnew
Baetis sp. 2	Baetis latus Agnew
Tricorythus spp.	Naurocaenis spp.
Euthraulus sp.	Choroterpes (Euthraulus) sp.
Notonurus ? cooperi Crass	Compsoneuriella ? cooperi (Crass)
Elmid 'type H'	Stenelmis spp.
Haplochromis moffati	Haplochromis philander M. Weber

A systematic list of the animals not shown in Chutter 1963

Annelida	Hirudinea		Batracobdella nilotica (Johansson)
			Batracobdella tricarinata (Blanch.)
			Salifa perspicax Blanchard
Crustacea	Cladocera	Chydoridae	Acroperus sp.
	Ostracoda		Eucypris sp.

Insecta	Ephemeroptera		
		Baetidae	Centroptilum sudafricanum Lestage
			Centroptilum sp. nov. I
			Centroptilum sp. nov. II
		Leptophlebiidae	Adenophlebia sp.
	Odonata	Coenagriidae	Pseudagrion vaalense Chutter
		Gomphidae	Paragomphus cognatus (Rambur)
	Hemiptera	Naucoridae	Laccocoris limigenus (Stal)
	Trichoptera		
		Polycentropodidae	? Nyctiophylax sp.
		Leptoceridae	Athripsodes harrisoni Barnard
		Hydroptilidae	Oxyethira sp.
			Hydroptilid sand grain case
	Lepidoptera		
		Nymphulidae	Argyractis periopis Hampson
	Coleoptera	Elmidae	Microdinodes pilistriatus Delève
			Microdinodes transvaalicus Grouvelle
			Pachyelmis convexa Grouvelle
			Pachyelmis rufomarginata Delève
			Helminthopsis bifida Delève
			Helminthopsis ciliata Delève
			Leptelmis fragilis Delève
			Lobelmis harrisoni Delève
			Helminthocharis cristula Delève
			Stenelmis gades Hinton
			Stenelmis thusa Hinton
		Haliplidae	
		Psephenidae	? Eubrianax sp.

Diptera	Simuliidae	Simulium bequaerti Gibbins
		Simulium ? bovis de Meillon
		Simulium chutteri Lewis
		Simulium griseicolle Becker
		Simulium medusaeforme Pomeroy
		Simulium wellmanni Roubaud
		Simulium unicornutum f. touffeum Gibbins
		Simulium vorax f. rotundum Gibbins
	Rhagionidae	? Atherix sp.

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