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Introduction

In the rainy season South African rivers are expected to be highly turbid and laden with silt and sand. Indeed it is only in restricted areas such as the Natal foothills of the Drakensberg and the mountains of the south-western Cape that increases in stream and river flows are not accompanied by very great increases in turbidity. Some idea of the amount of silt and sand in South African rivers is given by Schwartz & Pullen (1966). They estimate that, depending on the river concerned, between 0.14 and 4.25% of the annual flow of South African rivers consists of sediment. Data given by these authors for rivers mentioned later in this paper include 0.31% sediment for the Vaal River just before it reaches Vaal Dam and 0.24% for the Wilge River (whose confluence with the Vaal River is submerged by Vaal Dam) also shortly before it enters Vaal Dam.

Hynes (1960) described the two principal ways in which the fauna of streams and rivers may be affected by inert solids. Firstly, when the solids are suspended in the water, they may render all plant and algal growth impossible through reducing the penetration of light. There is then no food for herbivores and the detritus feeders have to rely on detritus of an allochthonous origin. Secondly,

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where inert solids settle out of the water, they not only smother algal growths and kill rooted plants and mosses but they also alter biotopes in other ways. For instance the interstices between stones in the current may become clogged, obliterating the habitat of many animals.

The effects of silt and sand on individual species

ELLIS (1936) found that freshwater mussels could not tolerate a deposit of silt from $\frac{1}{4}$ to 1 inch thick on top of otherwise suitable sediments. When they were held in cages above the sediments where they were killed by sedimenting silt they were not adversely affected, showing that it was the accumulation of fine particles on the bottom and not the nature of the water which was unsuitable for the mussels. ELLIS also studied the effect of very silty water on mussels in the laboratory and found that the silt interfered with their feeding and respiration.

HARRISON & FARINA'S (1965) observations of egg-laying and the subsequent development of the eggs in three African Planorbid snails, in relation to very finely divided suspended solids, showed that each species had a different reaction to the turbid water. The snails were kept in aquaria in naturally occurring waters with a suspended solids content of either 360 ppm or 190 ppm. The suspended material was in fine colloidal suspension and consisted of a mixture of kaolin and illite or sericite, or both. *Lymnaea natalensis* (KRAUSS) eggs developed naturally in both types of water. *Biomphalaria pfeifferi* (KRAUSS) did not lay eggs in the water with 360 ppm suspended solids, but did so on both vegetation and the glass walls of the aquarium in the water with 190 ppm suspended solids. These developed normally. *Bulinus (P.) globosus* (MORELET) egg development showed a peculiar relationship to the suspended solids. The capsules of eggs laid on vegetation at both concentrations of suspended solids were normal and subsequent embryo development was normal. However egg capsules placed on glass swelled in the 360 ppm water, and were slightly distorted and fell off the glass in 190 ppm water. In either event the result was that the embryos died. In control tests in which the suspended solids were removed from the water by centrifuging, egg capsules and embryo development in both *B. pfeifferi* and *B. globosus* were normal. Exactly how turbid waters affected these two species was not clear, but from the point of view of this paper the important point is that suspended material adversely affects both species.

WU (1931) carried out some field experiments with *Simulium* larvae. Sticks and vegetation with attached *Simulium* larvae were moved about in streams and it was found that *Simulium* larvae move away from parts of supports on which silt is deposited, even though current speed and other factors might be suitable for them. For instance WU observed that the larvae would move to the underside of sticks and leaves as sediment accumulated on them. HARRISON & ELSWORTH (1958) found the nymph of the mayfly *Pseudocloeon vinosum* (BARNARD) only on "clean" vegetation – that is vegetation without a coating of silt and matted algae and diatoms. Neither *Simulium* larvae nor *P. vinosum* tolerate silty surfaces though they are apparently not adversely affected by silty water.

The effects of silt and sand on invertebrate communities

Most of the literature concerned with the effects of silt and sand on the aquatic fauna has dealt with cases in which there has been partial or complete smothering of biotopes. CORDONE & KELLY (1961), in a review of the literature on the effects of silt and sand, deal entirely with cases in which stony bottom biotopes were altered by the deposition of material. These studies were all made in North America and all were concerned with clearly defined sources of fine material, such as gravel or sand washing plants, placer mining or logging which brings about considerable bank erosion. In many instances the density of the fauna of the stream bed was considerably reduced where there was sedimentation, though none of these studies were sufficiently detailed to show whether particular groups of animals were more affected than others. The quantitative data do not reveal whether the fauna normally to be associated with sediments, that is animals such as the Tubificidae and Chironomidae, appeared, though in certain cases of cursory faunal examinations it was suggested that they did. Another study of the effect of silt and sand on a stream fauna is that of BARTSCH (1960) who gives data on the number and volume of the fauna per unit area. Although BARTSCH's data are interesting because they show how the numbers and volume of the fauna declined sharply where a sand washing plant effluent reached the river, and then slowly recovered downstream from the effluent, they are of limited usefulness as BARTSCH gives neither the type of netting he used, nor the types of animals he collected.

HERBERT et al. (1961) studied trout streams in Cornwall variously affected by china-clay wastes. The amount and particle size of the suspended materials were carefully measured, but unfortunately from the point of view of this paper, HERBERT et al.'s interest was mainly in the effect of the china-clay wastes on trout. The remainder of the fauna was studied only as trout food. Their sampling methods have an important bearing on the interpretation of their results. They sampled the invertebrates of stony bottoms with a SURBER sampler (SURBER, 1936) and those of the finer bottoms (fine gravel, sand, silt or mud) with a scoop. The standing crop of these two types of bottom at each sampling point was estimated and then the standing crop (in weight per unit area) for each sampling point was calculated taking the relative abundance of each of the two types of sampling biotope into account. HERBERT et al. presented only the standing crop per sampling point. These data showed that the standing crop of the control streams was 19 times greater than that of the streams most affected by china-clay wastes. This method of presenting the data is most suited to assessing the relative abundance of potential food organisms for trout, but it reveals nothing about how the fauna of the individual biotopes reacted to the china-clay wastes. If the standing crop of stones in current biotopes is far greater than that of finer sediment biotopes, then the standing crop changes associated with the china-clay may to a large extent be due to changes in the relative abundance of the two types of biotope. HERBERT et al. do mention some of the changes which took place in the fauna of the polluted streams. Gastropoda were found at all control sampling points, but at none of the sampling points affected by the china-clay. Bivalve Molluscs were also absent from the polluted stations, but for this group the association of presence with unpolluted waters was less close, since bivalves were not present at all the control sampling points. HERBERT et al. concluded that apart from the absence of molluscs from the polluted stretches, the main effect of the china-clay was to reduce the abundance of the fauna without greatly altering its gross composition. They suggested that the growth of encrusting algae in the polluted streams was so adversely affected that there was insufficient food for the Gastropoda and this was why these animals disappeared. However HARRISON & FARINA's (1965) study suggests that the snails may have been affected in other ways.

A stream into which there was a discharge of a turbid water from which sand particles had been removed by sedimentation was studied by HAMILTON (1961). This stream was shallow and fast-flowing with the result that biotopes were not smothered by the silt and there were, in places, abundant growths of filamentous algae. HAMILTON gave a more comprehensive list of the animals he found above and below the discharge than the other workers whose investigations have been recorded here. However he revealed little about his sampling method, though he was able to suggest that there were some faunal changes. A Baetid mayfly and a Plecopteran nymph were not found in the turbid water, *Baetis* spp. were less abundant in the turbid water than in the clear and *Nais* sp., *Stylaria* sp. and *Ephemerella ignita* PODA occurred in greater numbers where the water was turbid than where it was clear. Otherwise the fauna of the turbid water was similar to that of the clear water. HAMILTON concluded that the high turbidity produced by finely divided inorganic material does not adversely affect the bottom fauna in a shallow, lotic environment. Moreover he suggested that it is only when a thick layer of such material covers the river bottom, in other words when the normal stones in current biotope is completely smothered, that a normal fauna cannot be found.

Silt and sand and the communities of South African lotic biotopes

In South African rivers the main accrual and transport of silt and sand occurs in a clearly defined rainy season. Hence workers on the seasonal occurrence and distribution of the invertebrate fauna of streams and rivers in South Africa have concluded that silt, sand and turbidity play an important part in the seasonal variation and distribution of the fauna (HARRISON & ELSWORTH 1958, HARRISON 1961, 1965, OLIFF 1960, OLIFF & KING 1964). However such has been the nature of the rivers worked on and the sampling programmes followed that it has not been possible to separate the effects of silt and sand from those of other variables such as temperature, flow and water chemistry.

Recently completed studies in the Vaal River and its tributaries, have, owing to the unusual profile of the river and the fact that there are three impoundments, which serve as massive silt and sand traps, along its course, begun to show how the invertebrate fauna of a river is affected by silt and sand (CHUTTER, 1967). The three impoundments in the Vaal River are Vaal Dam, almost immediately below it, the Vaal Barrage, and some 500 km below the Barrage, the Vaal Hartz Diversion Weir. Streams and rivers in the Vaal Dam catchment were studied in detail. A variety of zones was found in these. First there was a Source zone which was swampy and of limited extent. The remainder of the courses of the streams and rivers could be divided into two principal zones (Fig. 1). These were an Eroding Zone and a Depositing Zone. The Eroding Zone occurred after the Source Zone. Here the streams and rivers were cutting back into their beds, the stream profiles were steep and there was little deposition of sediments in the stream beds. There was little rooted aquatic vegetation, but the natural erosion of the stream beds being a slow process, the stream banks were not strongly eroded and there was often vegetation trailing from the banks into the water. The Depositing Zone was where the stream profiles flattened out below the Eroding Zone (Fig. 1). It was variable in respect of the fully aquatic and fringing vegetation present. At the upstream end of the

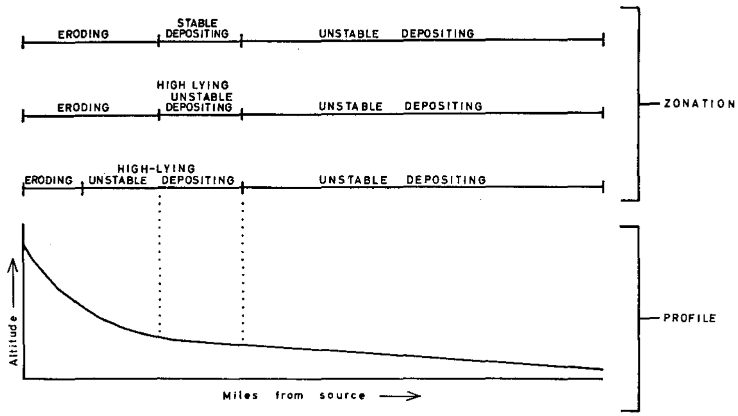

Figure 1. A diagram of the profile of a Vaal Dam Catchment River showing the types of zonation which could be found in it.

Depositing Zone there were sometimes profuse growths of fully aquatic plants such as *Potamogeton* and *Lagarosiphon* and the banks supported fringes of emergent plants such as *Cyperus* and *Phragmites*. This part of the Depositing Zone was called the Stable Depositing Zone and the vegetation there was in marked contrast to the vegetation found in the remainder of the Depositing Zone which was called the Unstable Depositing Zone. In the Unstable Depositing Zone there was little or no aquatic vegetation, the banks were often eroded and there were large stretches without fringing vegetation. In the Stable Depositing Zone there were small deposits of silt and sand, but these were covered by plant growths and were rich in organic detritus. In the Unstable Depositing Zone there were extensive sand and mud banks. The marked change in the streams and rivers which took place between the Stable and the Unstable Depositing Zones must have been due to greatly increased amounts of silt and sand reaching the rivers. This would be accompanied by an extensive transport of sediments in the wet season and high turbidities, both of which would be inimical to aquatic or fringing vegetation. The position of the Stable Depositing Zone between the Eroding and the Unstable Depositing Zone shows that the large amount of silt and sand present in the Unstable Depositing Zone was not eroded from higher up the rivers, but rather that it was being carried into the rivers below the Stable Depositing Zone.

In some streams and rivers there was no Stable Depositing Zone and the Eroding Zone was followed by an Unstable Depositing Zone. In others the Unstable Depositing Zone extended up into parts of the streams and rivers which would otherwise have been expected to be in the Eroding Zone. Unstable Depositing Zones occurring where Stable Depositing or Eroding Zones should have been expected, were termed high-lying Unstable Depositing Zones (Fig. 1).

Three biological seasons were recognised in the streams and rivers of the Vaal Dam Catchment. They were the winter, when flows and temperatures were low and the water clear in all zones, the dry early summer, when flows were low, the water clear but the temperature very much warmer than in the winter, and the summer, when temperatures were highest, flows greatest and the water was turbid.

Water temperature data collected during the study of the streams and rivers of the Vaal Dam Catchment showed that there was little likelihood that temperatures differed sufficiently from zone to zone to bring about the large faunal differences found from zone to zone. In the dry early summer and the summer seasons, the Stable Depositing Zone mean temperatures were lower than those from the Eroding or Unstable Depositing Zones, but in the winter mean temperatures rose from 10°C in the Eroding Zone to 11.4°C in the normal Unstable Depositing Zone. Even in this season the lowest temperature recorded from the Unstable Depositing Zone (4.5°C) was only 0.3°C warmer than the lowest recorded in the whole catchment.

Current speeds in the sampled stones in current biotopes did not vary very greatly. An analysis of the large amount of data from this biotope in the streams and rivers of the Vaal Dam Catchment failed to show that the abundance of any animals from sampling point to sampling point was related to current speed variation.

In the stones in current fauna of the streams and rivers of the Vaal Dam Catchment there were marked changes in the numbers of

TABLE I

Stones in current biotopes in unpolluted streams and rivers in the catchment of Vaal Dam. The mean number of kinds of animals recognised per sample, season by season and zone by zone, with the number of samples on which the mean is based shown in brackets after the mean.

Zone	Mean number of kinds of animals		
	winter	dry early summer	summer
Eroding	37(8)	41(6)	30(10)
Stable Depositing	46(11)	40(8)	42(10)
Unstable Depositing	37(14)	32(11)	22(18)
high-lying Unstable Depositing	28(10)	23(7)	22(6)

different kinds of animals found from zone to zone (Table I). The greatest variety of animals was found in the Stable Depositing Zone, where there was no decline in the variety of the fauna in the summer. The fauna of other zones was less varied than that of the Stable Depositing Zone and this was most marked in the summer in the two Unstable Depositing Zones. The presence of large amounts of silt and sand therefore coincided with a marked reduction in the variety of the stones in current fauna. The density of the stones in current fauna (Table II) was also greatest in the Stable Depositing Zone in all

TABLE II

Stones in current biotopes in unpolluted streams and rivers in the catchment of Vaal Dam. The mean number of animals per 0.1 sq. m. of bottom, season by season and zone by zone, with the number of samples on which the mean is based shown in brackets after the mean. Cladocera and Copepoda are not included.

Zone	Mean number of animals per 0.1 sq. m.		
	winter	dry early summer	summer
Eroding	934(7)	1069(3)	473(5)
Stable Depositing	1189(11)	1330(3)	757(7)
Unstable Depositing	862(11)	998(3)	666(7)
high-lying Unstable Depositing	448(1)	447(1)	453(4)

seasons. Except in the high-lying Unstable Depositing Zone, where too few samples were available from the winter and dry early summer to make a reasonable assessment of seasonal changes in the density of the fauna, the density of the fauna was lowest in the summer. There was little difference between the summer density of the Stable Depositing Zone fauna and the Unstable Depositing Zone fauna or between the Eroding Zone fauna and the high-lying Unstable Depositing Zone fauna. The silt and sand in the two Unstable Depositing Zones therefore had no recognisable effect on the density of the fauna as a whole.

However many of the separate groups of animals (Table III) showed density changes which followed the zonation of the rivers closely. Large numbers of the first three groups shown in the table, *Nais* spp., Ostracoda and *Burnupia* spp. (Ancylidae) were recorded only in the Stable Depositing Zone in the summer. Indeed *Burnupia* was never very common in zones other than the Stable Depositing Zone. Since the summer numbers of these groups were low in the

TABLE III

Stones in current biotopes in unpolluted streams and rivers in the catchment of Vaal Dam. Mean numbers of individuals per 0.1 sq. m. of bottom, group by group, season by season and zone by zone.

Group	Season*	Mean number of individuals per 0.1 sq. m. in:			
		Eroding Zone	Stable Depositing Zone	Unstable Depositing Zone	high-lying Unstable Depositing Zone
Nais spp.	W	6	118	11	(0)**
	D	57	172	113	(58)
	S	1	26	2	1
Ostracoda	W	1	4	14	(0)
	D	118	91	141	(1)
	S	3	23	1	1
Burnupia spp.	W	1	7	1	(0)
	D	1	10	1	(0)
	S	1	6	2	0
Tricladida	W	14	20	15	(0)
	D	54	33	15	(0)
	S	27	25	4	4
Chironomidae	W	126	553	190	(48)
	D	57	189	70	(85)
	S	51	129	3	8
Neurocaenis spp.	W	15	2	4	(1)
	D	23	2	33	(0)
	S	46	29	299	264
Hydrachnellae	W	9	47	1	(9)
	D	40	29	1	(3)
	S	20	30	2	9
Caenidae	W	21	68	1	(1)
	D	79	248	4	(1)
	S	18	94	2	10
Elmidae	W	15	65	15	(0)
	D	60	137	4	(0)
	S	22	101	3	2

* W – winter, D – dry early summer, S – summer.

** These mean densities are based on the same numbers of samples as the data shown in Table II. The brackets around data for the winter and dry early summer in the high-lying Unstable Depositing Zone emphasise that these are based on single samples and may therefore be inaccurate.

TABLE III (Continued)

Group	Season*	Mean number of individuals per 0.1 sq. m. in: Eroding Zone	Stable Depositing Zone	Unstable Depositing Zone	high-lying Unstable Depositing Zone
Baetidae	W	437	31	168	(209)
	D	144	16	175	(260)
	S	88	96	116	64
Choroterpes (*Euthraulus*) sp.	W	33	104	114	(0)
	D	207	160	183	(0)
	S	52	46	25	15
Hydropsychidae	W	19	58	183	(4)
	D	43	13	152	(3)
	S	70	121	160	46
Simuliidae	W	215	118	65	(165)
	D	106	144	13	(31)
	S	59	9	19	19

Eroding as well as the two Unstable Depositing Zones, it cannot be said that they were adversely affected only by silt and sand. In the Tricladida and Chironomidae summer densities were very low in the two Unstable Depositing Zones, but they were not excessively low in the Eroding and Stable Depositing Zones, suggesting that these two groups were adversely affected by the silt and sand of the summer. Moreover Chironomidae were found in reasonable numbers in the winter and dry early summer in the two Unstable Depositing Zones, showing that it was only in the summer that these two zones were unsuitable for them. Hydrachnellae, Caenidae (Ephemeroptera) and Elmidae (Coleoptera) were found in large numbers in all seasons in the Eroding and Stable Depositing Zones but were scarce in the two Unstable Depositing Zones in all seasons. The low numbers of these groups in the high-lying Unstable Depositing Zone and their high numbers in the Eroding Zone, suggest that their low numbers in the Unstable Depositing Zones were due to the adverse effects of silt and sand and not to other factors which may have changed along the course of the rivers.

Neurocaenis spp. (Ephemeroptera) which was previously known as *Tricorythus* spp., was the only group to show an increase in density in those zones where there was an increase in the amount of silt and sand in the river beds. These nymphs have very hairy mouthparts and it is possible that they use these to strain their food material from the water. Silty waters may contain an abundant supply of food for them. In the remaining four groups shown in Table III, that is the Ephemeroptera Baetidae and *Choroterpes* (*Euthraulus*) sp., the Hydropsychid Trichoptera and the Simuliidae density changes were not clearly related to changes in the silt and sand in the river beds. However when the Baetidae are considered as separate species some response to the nature of the river beds does become apparent. *Baetis harrisoni* BARNARD and *Centroptilum sudafricanum* LESTAGE were found in all seasons in the Eroding Zone and these were replaced by *Baetis glaucus* AGNEW and *Centroptilum excisum* BARNARD in the normal Unstable Depositing Zone. In the high-lying Unstable Depositing Zone the winter and dry early summer Baetidae were like those of the Eroding Zone, that is they were *B. harrisoni* and *C. sudafricanum*, but in the summer they tended to be replaced by the typical Unstable Depositing Zone species, *B. glaucus* and *C. excisum*. *B. harrisoni* and *C. sudafricanum* are apparently unable to tolerate large amounts of silt and sand in the summer.

Summer densities of *Choroterpes* (*Euthraulus*) sp. were lower in the two Unstable Depositing Zones than elsewhere, but in this animal the change in density with the presence of silt and sand was not as great as it was in other animals such as the Tricladida and Chironomidae. Hydropsychidae did not occur in large numbers in the high-lying Unstable Depositing Zone, but there were considerable changes in the specific composition of this group down the rivers. *Cheumatopsyche afra* (MOSELY) usually occurred in larger numbers than *Cheumatopsyche thomasseti* (ULMER) in the Eroding Zone, but in the normal Unstable Depositing Zone *C. thomasseti* was the more abundant species. However in the high-lying Unstable Depositing Zone *C. thomasseti* was often more abundant than the *C. afra*, suggesting that the relative abundance of these two species may be influenced by the amount of silt and sand in the river bed. The species of Simuliidae also changed markedly down the course of the streams and rivers but there is no definite evidence that they were adversely affected by silt and sand. Lower down the Vaal River at Warrenton (CHUTTER, 1967) large numbers of Simuliidae and Hydropsychid caddis were not found in the same places, and indeed the data shown in Table III for these two groups tend to confirm this. However in the high-lying Unstable Zone the densities of both groups were low in the summer. This is unusual and suggests that one or other of the two groups was adversely affected by the large amounts of silt and sand.

Among the rarer animals, which have not been shown in Table III, there were not many cases of changes in distribution following the amount of silt and sand in the stream beds. *Afronurus* spp. (Ephemeroptera) were not recorded from the sampling points in the high-lying Unstable Depositing Zone, but they were regularly found in the other zones. The bivalve Molluscs, *Pisidium* spp. and *Corbicula africana* (KRAUSS), were also not recorded from the stones in current biotopes in the high-lying Unstable Depositing Zone, though they were found fairly often in the other zones.

The fauna of the Vaal River immediately below the Vaal Barrage was peculiar on account of the large amounts of plankton carried in the waters released from the impoundment (CHUTTER, 1963). However this effect was localised and the fauna was more normal at Lindeques' Drift, about 8 km below the Barrage. The effect of the stability in flow and reduction of silt and sand due to the two impoundments above Lindeques' Drift, Vaal Dam and the Vaal Barrage, was evident in the fauna recorded from the stones in current at this sampling point. Thus *Neurocaenis* sp. (recorded by CHUTTER as *Tricorythus discolor*) made up only a small part of the fauna, Caenidae were a larger part of the fauna than they were in the Unstable Depositing Zones, Chironomidae were relatively abundant in the summer and *Burnupia* and *C. afra* made up a larger part of the fauna than they did in the normal Unstable Depositing Zone above Vaal Dam. Unfortunately there were no quantitative data from Lindeques' Drift and it is not possible to compare densities of animals from above Vaal Dam with those from Lindeques' Drift.

In a study of the Vaal River below the Vaal Hartz Diversion Weir the stones in current fauna was examined at four sampling points, the nearest to the weir being about 10 km below it and the furthest away from the weir being about 120 km downstream (CHUTTER, 1967). Below the Weir the river was relatively free of silt and sand, but at the sampling point furthest from the weir there were extensive areas of silt and sand. Due to varying sampling methods faunal densities in this lower part of the Vaal River may not be compared with those recorded above the Vaal Dam. However results from station to station below the Vaal Hartz Diversion Weir are comparable and are of interest for the way the fauna changed with the changing conditions in the amount of silt and sand in the river bed.

In the summer Ostracoda were found in large numbers only at the sampling point nearest to the Diversion Weir. Other groups which occurred in larger numbers in the Stable Depositing Zone than in the Unstable Depositing Zones above Vaal Dam, and which were commonest in the lower river at the sampling point nearest to the Diversion Weir were Hydrachnellae, *Afronurus* spp., Elmidae, Chironomidae and *Burnupia* spp. *Neurocaenis* sp. was commonest at the sampling point furthest from the Diversion Weir, showing a preference for the sampling point where silt and sand were most abundant, as was its preference among the river zones above Vaal Dam.

The fauna found at Lindeques' Drift and below the Vaal Hartz Diversion Weir, which were both places where it may be assumed that the amounts of silt and sand moving down the river bed were not as great as in the Unstable Depositing Zone, therefore approached that found in the Stable Depositing Zone. This suggests that many of the differences between the fauna recorded from the two zones in the catchment of Vaal Dam were indeed due to silt and sand, and not to some other unrecognised factors.

Marginal vegetation and stony backwater biotopes were also sampled in the streams and rivers of the Vaal Dam Catchment, but the fauna found in the various zones in these biotopes will not be described here. This is because conditions in these biotopes tended to be very variable even within zones, and faunal differences following zonation were often obscured. Moreover the marginal vegetation fauna proved to be made up of many species able to tolerate a wide range of ecological conditions, confirming an earlier conclusion about the fauna of this biotope (CHUTTER, 1963).

The other biotope studied in the catchment of Vaal Dam was the sediments themselves. This was also a biotope which varied, but in this case the most important variable, the physical nature of the sediments, was measured (following MORGANS' (1956) methods). The coarser sediments were the better sorted (that is were each more uniform in particle size), always contained a very small fraction of silt and clay and were poor in sulphides and organic matter (CHUTTER, 1967). The fine sediments were, on the other hand, not well sorted, contained a large silt and clay fraction and were usually rich in sulphides and organic matter. In describing the fauna of this biotope animals such as the Baetid Ephemeroptera and Corixid Hemiptera, which were often collected in sediment samples, but which are essentially transient occupiers of the biotope and move freely between it and other biotopes, have been omitted. In both fine and coarse sediments the density of the fauna was very much reduced in summer (Table IV). However this reduction was not as marked in the Source and Stable Depositing Zones as it was in the other zones where summer conditions were less stable. The smallest summer faunas were found in the coarse sediments of the Eroding, Unstable Depositing and high-lying Unstable Depositing Zones. Sediments in the Eroding Zone might be expected to be harsh biotopes in the summer, for the profiles of the streams and rivers are steep in this zone, where the overall tendency is for the flowing water to cut back into its bed. The density of the coarse sediment fauna in the two Unstable Depositing Zones shows that conditions became

TABLE IV

Sediment biotopes in unpolluted streams and rivers in the catchment of Vaal Dam. The density of the fauna and the percentage of surface dwelling forms in coarse and fine sediments, season by season and zone by zone. The numbers of samples on which the data are based is shown in brackets.

Sediment type	Coarse			Fine		
Median Phi Value	< 3			> 3		
	Winter	Dry early summer	Summer	Winter	Dry early summer	Summer
Mean number of animals per 0.1 sq. m. in:						
Source Zone	—	—	—	4922(5)	5551(4)	2349(7)
Eroding Zone	4588(3)	2158(1)	671(7)	—	—	—
Stable Depositing Zone	2082(7)	4551(6)	1259(5)	3062(1)	5412(2)	1675(2)
normal Unstable Depositing Zone	2327(8)	2598(3)	445(7)	1905(8)	7113(6)	959(9)
high-lying Unstable Depositing Zone	526(3)	1946(5)	211(5)	7020(5)	3272(4)	906(4)
Surface dwelling forms as a percentage of the fauna:						
Source Zone	—	—	—	3(5)	5(4)	7(7)
Eroding Zone	67(3)	50(1)	35(7)	—	—	—
Stable Depositing Zone	15(7)	26(6)	22(5)	21(1)	12(2)	18(2)
normal Unstable Depositing Zone	48(8)	50(3)	43(7)	33(8)	33(6)	8(9)
high-lying Unstable Depositing Zone	62(3)	74(5)	30(5)	59(5)	48(4)	11(4)

even more unsuitable for the fauna in the summer than they had been in the Eroding Zone.

The fauna of sediments includes many groups of animals in which it is not at this stage possible to identify the individual species present. For this reason the fauna does not lend itself to the type of analysis which was made in Table III for the stones in current fauna. However, meaningful results do become apparent when the fauna is divided into groups which live on the surface of the sediments (*Ilyocryptus* (Cladocera), *Paracyclops* (Copepoda), Ostracoda and the Chironomid groups Tanytarsini and Orthocladiinae) and those which burrow into the sediments (the remaining animals including the Nematoda, Oligochaeta and Chironomini). In both the fine and the coarse sediments the surface dwelling forms formed a very much greater part of the fauna in the zones where conditions were unstable (the Eroding and two Unstable Depositing Zones) than in zones where conditions were stable (the Source and Stable Depositing Zones). In the coarse sediments the surface dwelling forms were mostly Tanytarsini and Orthocladiinae, but in the fine sediments they were mainly *Ilyocryptus*, *Paracyclops* and Ostracoda. The fine sediment surface dwelling forms would be particularly easily swept away by currents as they are free-living, whereas the coarse sediment surface forms live in tubes on the surface of the sediment and are less exposed to any current moving over the sediment. In part this explains why the percentage of the surface dwellers declined so sharply in the summer in the fine sediments of the unstable zones, but did not do so in the coarse sediments of these zones. However in the unstable zones the density of the burrowing forms in the summer was much higher in the fine sediments than in the coarse sediments (Table IV). This suggests that fine sediments were more stable than coarse and less likely to be disturbed at depth than the coarse. Indeed this might be expected, since finer sediments will settle only where current conditions are quiet, but coarse, well-sorted sediments will settle out in less quiet conditions. However the least disturbed sediments were very clearly associated with the Source and Stable Depositing Zones, for here not only did the density of the fauna decline less in the summer, but also the proportion of surface dwelling forms was no lower in the summer than in the other seasons, irrespective of the type of sediment.

Given that from the very nature of the Eroding Zone, sediments are likely to be very unstable, it is not at all surprising either that the Eroding Zone sediment fauna was unlike the Stable Depositing Zone fauna or that the high-lying Unstable Depositing Zone coarse sediment fauna was like the Eroding Zone fauna. However comparison of the Stable Depositing Zone fauna with the normal Unstable Depositing Zone fauna shows that the presence of large amounts of silt and sand in the river beds did result in a depletion of the sediment fauna in the summer. This was probably the result not so much of the presence of this sedimentary material but rather the result of the amount the sediments moved due to the general instability of the river bed.

The fauna of sediments was not studied in the Vaal River below the Vaal Barrage nor in the river between the Vaal Hartz Diversion Weir and Barkley West, so that the response of the sediment fauna to the artificially stable conditions below the barrage and the weir is unknown. However HARRISON et al. (1963) studied the sediment fauna in the waters held back by the Vaal Barrage. This was found to be very sparse and it was suggested that a constant rain of settling fine clayey particles could have been an important factor bringing this about.

DISCUSSION

When biotopes are completely smothered by silt and sand it is easy to understand why the fauna disappears. However when biotopes are not smothered the effects of silt and sand are less obvious and the studies on the separate species show a number of ways in which animals are affected by the changed environment. For instance HARRISON & FARINA's studies on Gastropods show that the egg stage may be adversely affected. ELLIS's study of bivalve Molluscs shows that in other animals feeding and respiration are interfered with and WU's observation of *Simulium* larvae and HARRISON & ELSWORTH's on *Pseudocloeon vinosum* suggest that some animals require an extremely silt-free environment. It is easy to understand why *Simulium* larvae find silt covered surfaces unsuitable, for they are sedentary and attach themselves to solid surfaces, always in a current. Then again it is easy to visualise that some animals would be particularly sensitive to sand abrasion and that others would find the food resources of the biotope unsuitable because of the reduced growth of minute plants in highly turbid waters. In these and doubtless many other ways the fauna of unsmothered biotopes may be affected by silt and sand.

The stones in current biotopes in the Vaal Dam Catchment were not smothered by silt and sand and even in the Unstable Depositing Zones there was little sand among the stones in the current. Hence the author cannot agree with HAMILTON's (1961) conclusion that it is only when a thick layer of finely divided inorganic material covers the river bottom that normal fauna cannot be found.

Since the suggested effects of silt and sand on the fauna of the streams and rivers of the Vaal Dam Catchment have been arrived at from field observations only, it must be admitted that it is very probable that some of the faunal changes ascribed to silt and sand in this paper were due to other factors. For instance temperature records in this study were not as detailed as is desirable and one wonders whether some of the faunal change where there was a lot of silt and sand was not due to a change in the temperature regime of the streams. It is easy to conceive that where there is a lot of silt and sand in a river bed the water may be shallower and therefore more influenced by air temperature changes than that in a normal stream. One might therefore predict that the diurnal range of temperature fluctuation would be greater in a high-lying Unstable Depositing Zone stream than in an Eroding Zone stream. This might bring about several changes in the composition of the fauna of the streams. It is hoped that this interpretation of the interrelationships between fauna and environment in the Vaal Dam Catchment will encourage others to take up these observations and investigate them further by detailed studies under both field and laboratory conditions.

Finally it is obvious that where man mismanages the land so that there is soil erosion, large quantities of silt and sand will find their way into the water courses. This will adversely affect the majority of the stream animals and it is in this way that the subject matter of this contribution fits into the subject of the symposium as a whole. However the author hesitates to suggest that the natural state of the present-day normal Unstable Depositing Zone in the Vaal River system would be for it to be similar to the present-day Stable Depositing Zone. Certainly in an account of a visit to the Orange River (BARROW, 1801) before intensive agricultural development of its catchment, one may read of a very large flood of muddy water, indicating that the natural intensity of soil erosion in South Africa may be higher than it is in parts of the world with a more evenly distributed rainfall.

SUMMARY

Most of the literature concerned with the effects of silt and sand on the invertebrate fauna of streams and rivers has described changes taking place when biotopes are completely smothered by silt and sand. In few of these studies were the kinds of animals found recorded. There have been few studies of the effect of silt and sand on individual species. The invertebrate fauna of two biotopes in the streams and rivers of the Vaal River system, South Africa, changed with the amount of silt and sand in the watercourses. Where there were large amounts of silt and sand the variety of animals recorded from the stones in

current biotopes was reduced, but the density of the fauna as a whole did not change (Tables I and II, Unstable Depositing Zones, summer). However the density of many groups of animals was affected (Table III). Some of the animals adversely affected by silt and sand appeared in larger numbers below impoundments in which silt and sand would settle. In the sediment biotopes the summer density of the fauna was lowest where there was a lot of silt and sand (Table IV, the two Unstable Depositing Zones). Large amounts of silt and sand were associated with large summer declines in the surface dwelling animals as a proportion of the whole sediment fauna (Table IV). Differences between the summer proportions of surface dwelling forms in fine and coarse sediments were due to faunal differences. Sediments were not studied below impoundments.

It is concluded that there may be considerable changes in the composition of the stones in current fauna due to silt and sand without the biotope being smothered, and that increases in the amount of silt and sand in river beds lead to increased instability of the sediments, which adversely affects their fauna.

ZUSAMMENFASSUNG

Die Abhandlungen, die sich mit dem Einfluß von Schlamm und Sand auf die Invertebratenfauna von Bächen und Flüssen befassen, haben meistens die Veränderungen beschrieben, die sich ergeben, wenn Biotope ganz von Schlamm und Sand erstickt werden. In wenigen dieser Forschungen werden die Arten der gefundenen Tiere eingetragen. Es gibt wenige Arbeiten über den Einfluß von Schlamm und Sand auf einzelne Arten.

Die Invertebraten-Fauna zweier Biotope in Bächen und Flüssen des Vaalsystems, Süd-Afrika, hat sich mit der Menge von Schlamm und Sand in den Flüssen geändert. Wo es große Mengen von Sand und Schlamm gab, ist die Verschiedenartigkeit der Tiere von Steinen in flüssigem Biotop vermindert worden, aber die Dichte der ganzen Fauna ist dieselbe (Tabellen I und II, „Unstable Depositing Zones, Summer"). Jedoch die Dichte vieler Tiergruppen ist beeinträchtigt worden (Tabelle III). Einige von Schlamm und Sand ungünstig beeinflußte Tiere erscheinen in größerer Anzahl unter Einsperrungen, wo Schlamm und Sand sich niederschlagen können. In Niederschlagbiotopen ist die Sommerdichte der Fauna am niedrigsten, wo es viel Schlamm und Sand gibt (Tabelle IV, Die zwei „Unstable Depositing Zones"). Große Mengen von Schlamm und Sand gehen mit großen Sommerabnahmen der oberflächlich lebenden Tiere im Verhältnis zu der ganzen Niederschlagfauna zusammen (Tabelle IV).

Unterschiede zwischen den Verhältnissen oberflächlich lebender Formen in feinen und groben Niederschlägen im Sommer sind die Folge faunaler Unterschiede. Niederschläge unterhalb von Einsperrungen sind nicht untersucht worden.

Es wird geschlossen, daß es beträchtliche Änderungen in der Zusammenstellung der Fauna der Steine in Flüssen wegen Schlammes und Sandes geben kann, ohne daß der Biotop erstickt wird, und daß Steigerungen der Menge von Schlamm und Sand in Flußbetten zu vermehrter Instabilität der Sedimente führt, welche ungünstig auf die Fauna einwirkt.

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