WATER QUALITY
and
ABATEMENT of POLLUTION
in
NATAL RIVERS

Part III

THE TUGELA RIVER AND ITS TRIBUTARIES –

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1. INTRODUCTION

The survey of the Tugela river was undertaken by the National Institute for Water Research of the South African Council for Scientific and Industrial Research on behalf of the Natal Town and Regional Planning Commission under the terms of a Rivers Research Fellowship. Studies of the main Tugela river were made by Mr. W.D. Oliff as Research Fellow during the period 1953 - 1955. This river was the first river in Natal to be surveyed in this way, the emphasis in this early period being on the hydrobiology of the water.

Subsequently various tributaries of the Tugela were studied - the Bushmans river in 1956 - 1957, the Buffalo river in 1959 - 1960, the Mooi river in 1961 and the Sundays river and other streams that drain the Natal coalfields in 1960 - 1963. Various analysts assisted with the chemical work in the early phases of the survey, but subsequently a chemist, Mr. P.H. Kemp, became a permanent member of the Rivers Research Team in Natal and was solely responsible for the analytical work and some of the later river surveys.

In 1965 Mr. P.A.J. Brand, appointed under a separate Research Fellowship to study the bacteriology of rivers of Natal, undertook a bacteriological survey of the whole of the Tugela Basin. At the same time he carried out a number of chemical tests to determine whether any appreciable changes had occurred in the rivers since the time they were first studied. The results of his work have filled in certain gaps in the earlier studies and have led to a fuller picture of water quality in the Tugela system.

The methods and techniques used in the survey have already been described in Part I, as have the criteria used for assessing water quality. The present volume draws on the results of all the work which has been carried out on the Tugela system and utilizes data included in the various papers that have been published (17,19,20, 21,22,23) as well as data from more recent reports not hitherto released. The opportunity has been taken to reinterpret some of the earlier results in the light of our, now, much wider experience of rivers research in Natal and to alter the emphasis so that it bears more upon water quality. In particular, Mr. S.J. Pretorius, using some of the dry season faunal analyses, has expressed water quality as far as possible, in terms of the biotic index (see Part I).

2. GENERAL DESCRIPTION OF THE TUGELA BASIN

Very full details concerning most features of the Tugela basin have been published by the Natal Town and Regional Planning Commission (24,25) and it is therefore unnecessary to present more than a very brief summary here.

The Tugela Basin, with an area of 11 200 square miles, occupies the central third of Natal, between the Drakensberg mountains on the west and the Indian Ocean on the east. Within a few miles of the source near Mont-aux-Sources, a few miles back from the edge of the Basutoland Escarpment, the mountains fall away rapidly to a wide, gently sloping, shallow valley which extends roughly half way down the basin. Below this, the valley is incised by younger river valleys and the topography is rugged and hilly, except for very narrow bottom lands at places on the banks of the rivers. The lower part of the basin in the Ngubevu - Mfongosi area is also very rugged and broken, but towards the coast the valley widens and rolling hills descend to the sea.

A general map of the Tugela catchment is given in Figure 1, while Figure 2 is a simplified topographical map.

The Tugela river has many tributaries, the most important and interesting of which are the eight rivers listed in Table 1, in which the Tugela river itself is included for comparison.

TABLE 1

Rivers of the Tugela Basin

River	Catchment area, square miles	Length, miles	Average flow cusecs
Sandspruit	64	17	10
Little Tugela	526	46	450
Klip	864	60	300
Bloukrans	293	40	50
Bushmans	750	85	500
Sundays	970	80	300
Mooi	1150	153	600
Buffalo	3990	190	1600
Tugela	11200	320	6500

The geology of the Tugela Basin is shown in Figure 3, which is taken from the 1 : 1,000,000 geological map of South Africa published by the Geological Survey. The upper five-sixths of the Basin lies on formations of the Karoo System while the remainder towards the coast lies upon beds of the Primitive System and the Table Mountain Series of the Cape system. The latest lavas of the Stormberg Series lie uppermost, and the oldest formations of the Primitive System lie below. Downstream along the main river the following rocks are exposed:

(a) The basaltic and rhyolitic lavas of the Drakensberg;

(b) beds of the Stormberg series in the foothills of the Drakensberg mountains;

(c) beds of the Beaufort Series in the flatter upper half of the Basin;

(d) beds of the Ecca Series in the middle portion;

(e) old granites and gneisses of the Primitive System which have been exposed by faulting in the lower portion, and

(f) beds of the Table Mountain Series of the Cape System towards the coast.

The upper catchments of most tributaries in the Basin, including the Bushmans and Mooi rivers and the Sandspruit and Venterspruit streams on the western margin of the basin, all commence high on the face of the basaltic and rhyolitic lavas of the Drakensberg. These formations give way to sandstones and shales of the Red and Molteno beds of the Stormberg series at the foot of the mountains and then to sandstones and shales of the Beaufort Series which build the greater part of the catchments away from the mountains.

In contrast, the upper half of the Buffalo river catchment, that of the Sundays river in the north, those of the lower Mooi and Bushmans rivers in the south, and the local catchments in the middle of the Basin around Colenso, Nkasini and Tugela Ferry, all lie upon rocks of the Ecca Series. The lower Buffalo, Mfongosi, Insuzi and Inadi catchments and local areas in the middle and eastern parts of the Basin around Ngubevu and Middledrift all lie upon Dwyka rocks and the old granites and gneisses of the Tugela and Mfongosi Systems. Finally, the more coastward, eastern part of the main river catchment below Middledrift is composed of rocks of the Table Mountain and Ecca series. The Tugela Basin receives most of its rainfall (approximately 80 per cent) in summer, although there is considerable variation mainly due to topographical effects. The winter is comparatively dry. Heavy rains (as much as 75 inches per annum) fall on the higher points of the escarpment. At lower altitudes the rainfall is considerably less, and in the sheltered valleys and depressions of the lower part of the Basin it is as low as 25 inches.

The mean annual rainfall over the whole Basin may be estimated as 33.2 inches. The coastal portion receives somewhat more (43 inches). That in tributary catchments ranges from 30 to 37 inches except in the Mlambonjwa and upper Tugela catchments where it is greater as a result of the exceptionally high rainfall at the face of the Drakensberg escarpment. Figure 4 shows the mean annual rainfall over the Tugela Basin.

Mean air temperatures near the mountains are 45°F in July and 64°F in January (7° and 18°C respectively), the corresponding figures at the coast being 63°F in July and 72°F in January (16° and 22°C). Extremes are encountered in the river valleys, particularly in the lower half of the Basin, where temperatures reach 90°F (32°C) in summer and fall to several degrees below freezing point in winter.

The agro-ecological regions of the Tugela Basin are shown in Figure 5, which has been redrawn from Acocks (1). The Highland Sourveld covers the high ground bordering the catchment. At somewhat lower altitudes this gives way to the Tall Grassveld, which reaches its greatest extent in the upper Tugela valley, while in the northern part of the Buffalo river catchment (in the Newcastle-Utrecht-Dundee region) this is replaced by Sandy Sourveld. Short Acacia Savanna occurs in the main Tugela valley from a point above Colenso almost to the mouth, and also in the lower portions of the valleys of most of the tributaries. The Coast Forest extends across the lower part of the Tugela Valley, and this area is mostly devoted to the cultivation of sugar cane.

The agriculture practised in various regions of the Tugela Basin has been discussed in reports published from time to time by the Natal Town and Regional Planning Commission (15,24,25).

3. POPULATION, TOWNS AND INDUSTRIES

Some idea of the distribution of population in the Tugela Basin may be obtained from the data given by Burrows (7) based on the 1957 population census. Table 2 shows the population densities in the various magisterial districts which lie wholly or partly in the Tugela Basin.

TABLE 2

Population densities in the Tugela Basin

Magisterial District	Population density, persons per square mile				
	European	Bantu	Indian	Coloured	Total
Lower Tugela	7.3	98.0	62.5	1.6	169.4
Mapumulo	-	118.2	-	-	118.2
Mtunzini	2.1	83.3	3.1	-	88.5
Eshowe	2.7	78.9	-	-	81.6
Msinga	-	84.7	-	-	84.7
Nqutu	-	63.7	-	-	63.7
Nkandhla	-	63.6	-	-	63.6
Kranskop	1.0	61.1	-	-	62.1
Dundee	9.8	58.6	6.9	-	75.3
Newcastle	4.5	43.7	3.9	-	52.1
Klip River	5.1	40.2	2.9	-	48.2
Weenen	1.9	44.4	-	-	46.3
Estcourt	3.4	27.3	1.4	-	32.1
Bergville	1.5	27.5	-	-	29.0
Helpmekaar	1.1	27.8	-	-	28.9
Utrecht	1.4	19.8	-	-	21.2

It is clear from this table that there are three distinct population areas in the Basin:

(a) The densely population coastal region (Lower Tugela, Mapumulo, Mtunzini and Eshowe).

(b) The predominantly Bantu areas just inland from the coast (Msinga, Ngutu, Nkandhla, and Kranskop).

(c) The less densely populated northern and western section of the Basin.

The total population of the Tugela Basin was estimated as 507 122 in 1946 (10), which at that time amounted to 23.0 per cent of the population of Natal.

The 1960 census showed that 15 towns in the Tugela Basin had a population exceeding 1000. These were:

Charlestown (pop. 5 152), the border town of Natal in the extreme north-west with textile and clothing factories.

Colenso (pop. 2 034), the site of an Escom power station of 165 000 kW capacity.

Dannhauser (pop. 1 894), a large coal producing and farming centre; bricks and tiles are also made.

Dundee (pop. 10 943), an important farming and coal mining centre where there are also factories producing milk products, soap, chemicals, bricks and tiles, mineral water, toys, concrete and engineering products.

Estcourt (pop. 8 959), with factories for curing bacon, for processing meat, milk and food products, and for manufacturing wood pulp and nylon stockings.

Glencoe (pop. 8 317), an important railway junction in a coal mining area noted for cattle and stock breeding.

Ladysmith (pop. 22 997), the third largest town in Natal and the distributing centre for Northern Natal, the O. F. S. and Transvaal with large railway marshalling yards and SAR workshops. Yarn spinning is also carried out, and the production of milk products. Cattle and horse breeding and sheep farming are undertaken in the surrounding district.

Mandini (pop. 2 284), has developed around a pulp and paper mill which has established its own township on a 2 200 acre site.

Mooi River (pop. 2 655), with factories for bacon curing, for processing meat, milk and cheese products, and for manufacturing textiles. Horse, cattle and sheep stud farms are established in the surrounding district.

Newcastle (pop. 17 418), a coal mining centre which also produces wire, steel, red oxide, bricks and monumental masonry.

Nottingham Road (pop. 1 062), is a holiday resort where, periodically, important cattle fairs are held.

Talana (pop. 1 213), is virtually an extension of Dundee and possesses a large bottle and glass factory.

Utrecht (pop. 5 490), a coal mining centre; stock farming, particularly sheep, is carried on in the district.

Washbank (pop. 2 374), lies in the coal mining area and has a coal-tar by-product factory; groundnuts are grown locally.

Weenen (pop. 3 668), stands in the most productive vegetable growing area in Natal; groundnuts and citrus are also grown.

Volksrust (pop. 8 096), although in the catchment of the Buffalo river, lies just over the border in the Transvaal. It is the centre of a pastoral district and a dairying industry.

Mention should also be made of Bergville, a dairying and tourist centre where a condensed milk factory is established; Ballengeich where there is a large coal mine and factories producing calcium carbide and acetic acid; and Muden, where intensive agriculture is practised and large citrus estates are established.

Fuller accounts of the agriculture and industry of the Tugela basin are to be found in the literature (15,16,24,25).

4. WATER USE

Very little use is made of the large water reserves of the Tugela river system. Although the average total flow of the Tugela is about 6500 cusecs (Table 1), only about 36 cusecs are abstracted by towns and industries, viz:

Bergville (Tugela river)	1	cusec
Colenso (Tugela river)	4	"
Mandini (SAPPI) (Tugela river)	20	"
Ladysmith (Klip river)	3	"
Mooi River (Mooi river)	1	"
Estcourt (Bushmans river)	4	"
Newcastle (Buffalo river)	3	"

while an estimated 405 cusecs are used to irrigate some 45 square miles of land in the Tugela Basin (8).

Since is it estimated that 98 per cent of industrial, 90 per cent of domestic and 40 per cent of irrigation water abstracted from a river ultimately returns to the river (23), it is clear that present water abstraction from the Tugela system is not only of quite minor proportion but also that in general river pollution would not be expected to be either widespread or pronounced in the Tugela catchment.

5. ZONATION OF THE TUGELA RIVER AND TRIBUTARIES

The profile of the main Tugela river is shown in Figure 6. This departs from the typical form of a mature river in that (a) there is no recognizable flood-plane zone of deposition and (b) torrential stretches recur in the middle region between Colenso and Ngubevu. These are the consequences of rejuvenation of the lower reaches brought about by the elevation of the coastal plain, hard rock strata having been uncovered as the river eroded its bed downwards, causing rapids to form. This is a feature not uncommon in large rivers (14).

The systems of zonation suggested by Carpenter (9) (fauna) and Butcher (8) (flora) cannot be applied to the Tugela because the fauna and flora on which they are based do not occur in this river. Consequently a system based on the gradient of the river and the actual associated fauna was adopted and led to the demarcation of the eight distinct zones shown in Table 3 and indicated in Figure 6.

TABLE 3

Zonation of the Tugela river

River zone	Length in miles	Altitude in feet	Position
Source zone	0.8	10 400 - 10 000	Drakensberg plateau
Waterfall zone	1.5	10 000 - 7 500	Drakensberg escarpment
Mountain torrent zone	4.3	7 500 - 5 000	To above Natal National Park hostel
Foothill torrent zone	10.5	5 000 - 4 000	To the Caverns' Causeway
Foothill sand bed zone	106	4 000 - 3 000	Caverns' Causeway to Harts' Hill
Rejuvenated river zone	71	3 000 - 1 380	Harts' Hill to Ngubevu
Valley sand bed	125	1 380 - 10	Ngubevu to Estuary
Estuary	0.5	10 - 0	-

The first four zones, where the river is predominantly a mountain torrent, extend from the source to the vicinity of the Caverns' Causeway, a distance of about 17 miles. They comprise:

(1) The source zone which lies between 10 400 and 10 000 ft above sea level and is about 0.8 mile long. The river rises on top of the basaltic lavas of the Drakensberg escarpment at Mont-aux-Sources and drains a sponge of rather shallow, black turf soil. Here it is a small stream with an average gradient of about 150 ft/mile.

(2) The waterfall zone begins where the river plunges 2 500 ft over the face of the escarpment in a series of waterfalls. This zone covers about 1.5 miles.

(3) The mountain torrent zone follows below 7 500 ft where the river flows in a steep-sided gorge over a series of small falls and rapids at the foot of the mountains, on sandstones of the Stormberg Series. It extends about 4.3 miles and the average gradient is 186 ft/mile. The vegetation of the banks is Highland Sour Veld with krantzes largely covered by forest and scrub-forest. Lower in this zone the scrub-forest thins and the dominant shrub is Leucosidea sericea. There is little true emergent aquatic vegetation.

(4) The foothill torrent zone commences below 5000 ft where the valley widens and the river runs rapidly down a steep boulder bed in foothills of the Stormberg Series. This zone extends for about 10.5 miles to the vicinity of the Caverns' Causeway at about 4000 ft. It is more stable, and occasional pools, sandbanks and patches of fringing vegetation occur, usually Cyperus marginatus or grasses such as Hyparrhenia glauca, H. hirta and Pennisetum natalense. The average gradient of the bed is about 100 ft/mile.

The remaining four zones extend from Caverns' Causeway to the sea, a distance of 303 miles. Here the river is more stable, and the rate of flow is generally reduced compared with that in the mountain river region. There are considerable areas with a bed of sand or mud, and there is a margin of riverine vegetation which usually includes Cynodon dactylon, Cyperus marginatus, Hemarthria altissima and Phragmites communis. Some rapids occur in places.

(5) The foothill sand-bed zone extends from the Caverns' Causeway, above the Oliviershoek road bridge, to Harts' Hill below Colenso, a distance of about 106 miles. The river drops gently to an altitude of 3000 ft at Harts' Hill, at an average gradient of 10 ft/mile. It flows in meandering reaches over a wide, rather featureless, flat valley of Tall Grassveld and farming lands. In this stretch the bed consists of sand and mud and rapids do not occur frequently. Besides the emergent aquatic vegetation mentioned above as typical of the region, there are some grasses, including Cynodon dactylon and, in the slow-flowing stretches, Polygonum setulosum, and the aquatic plants Potamogeton crispa, Chara sp. and Najas sp. appear in winter. The zone ends where the river flows over beds of Ecca shales at Colenso.

(6) The rejuvenated river zone extends from Harts' Hill for some 71 miles to Ngubevu at an altitude of about 1380 ft. The river traverses hilly, drier and warmer Thornveld areas. This zone contains two regions of relatively steep gradient where rapids and torrents predominate, leading into typical sand bed regions of gentle gradient. One series of rapids, with an average gradient of about 43 ft/mile, occurs at the beginning of the zone below Harts' Hill and extends about 14 miles to the farm Gannahoek 1817, above Nkasini at an altitude of 1800 ft. The other, with an average gradient of 27 ft/mile, extends for 21 miles below Tugela Ferry. In these areas the river flows in extensive rapids over beds of the Beaufort Series, while slower sandy reaches occasionally intervene. Elsewhere in the zone the reverse is true, and long, meandering, slow reaches predominate with an average gradient of about 10 ft/mile.

(7) The valley sand bed zone constitutes a second foothill sand bed zone below Ngubevu, extending through the broken Thronveld of the lower valley of the coastal belt. The river valley is rugged, wide and deep, and the ancient granites and gneisses have been exposed and much moulded by the river. Any rapids that occur are short and become less frequent in the lower reaches. They are composed mainly of boulder beds and rock bottoms without loose stones.

(8) The estuary occurs in country composed largely of rolling hills without great differences in altitude, since, as already mentioned, there is no floodplane zone. The extent of the estuary depends upon the flow of the river, but it is always limited; when the river is in flood it hardly exists, and when the river is low it reaches back half a mile from the mouth.

Among the tributaries, the Mlambonjwa and Little Tugela rivers, which join the Tugela in its upper catchment, are somewhat similar to the main river itself. They rise in the Drakensberg mountains and follow similar courses through upper river zones in mountainous country with a high rainfall. They have short middle-river regions where they flow across the wide Bergville valley before joining the main river.

The Bushmans river, which rises at Giants Castle in the Drakensberg, differs from the Tugela in some respects. Its upper river valley is comparatively narrow and the gradient is not quite so steep, so that the upper river zones are longer. The foothill sand-bed zone continues to Estcourt, and a rejuvenated zone extends from Estcourt to its confluence with the Tugela.

The Mooi river, which also rises at Giants Castle, has a very long foothill sand-bed zone with a gentle gradient extending downstream as far as Middlerest. The slow rate of flow in this zone results in a fauna and flora which differ in a number of respects from those of the Tugela. Below Middlerest the river drops into the Tugela river valley where it closely resembles the main river.

The Klip and Sundays rivers rise in relatively drier areas and flow by gentle gradients to the main stream; although they have basic resemblances to the Tugela, they are rather unusual on account of their gentle gradients.

The Buffalo river is the largest and most important tributary of the Tugela, and in comparison with the Tugela river its catchment is relatively dry. Its foothill sand-bed zone stretches about as far as Ingogo, and below this the river falls in rapids to a long valley sand bed zone of gentle gradient. Finally, below Vants' Drift the river descends more quickly, and a mixed zone of rejuvenation extends as far as its confluence with the Tugela river.

The lower Tugela river, below the Buffalo river, has a number of tributaries such as the Insuzi, Mfongosi and Inadi which rise in the highlands, from which they flow rapidly and sometimes precipitately down to the Tugela. In general the zonation of the Tugela river is repeated in miniature in these streams, though the relative lengths of the zones are different.

6. RIVER FLOWS:

The average flows at various points in the Tugela river system, based on data obtained from the Department of Water Affairs, are shown in Table 4. Not all the gauging stations are rated for full river flow. In fact only three full-flow weirs were in operation on major rivers of the system at the time of the survey of the main Tugela river; these were

No. 153	Tugela at Tugela Ferry
No. 344	Buffalo at De Jager's Drift
No. 213	Mooi at Muden

The total discharge of the Tugela was therefore estimated from the data for the three stations. The values for the three were summed to obtain the contribution from 75 per cent of the total catchment area and to the result was added one third of the sum as an estimate of the probable contribution from the remaining ungauged portion of the area, on the assumption that its contribution is proportional to its area. A gauging weir was established at Mandini in 1956, and data obtained from this have subsequently shown that the actual total flow may be from 5 to 20 per cent greater than this estimate. Similarly it was found that the flow at Bergville was about 15per cent of the total.

From these results and by making use of some of the estimated averages in Table 1, the sources of the water flowing in the Tugela system can be computed to be as shown in Table 5. Some 38 per cent of the water comes from that part of the Tugela Basin above Colenso, where the annual rainfall is greatest; 35per cent comes from the large Buffalo sub-catchment; 15per cent from that part of the Tugela Basin (excluding the Buffalo) below Tugela Ferry and only 12 per cent from the region and tributaries between Colenso and Tugela Ferry even though the drainage area in this part of the catchment is over twice as great as that above Colenso.

The data of Table 4 are plotted as histograms in Figure 7(a). These clearly show the enormous increase in flow that occurs in all the rivers in the rainy season. The speed of the current in the main Tugela increases between two and five-fold during summer floods compared with the winter dry season, and a wholesale movement of the river bed results. In rapids, boulders roll and shift, and the river often changes course within its bed. It was not uncommon during the survey after summer storms to see a wall of muddy water 3 - 5 ft high advancing downstream, bearing trees, animals and detritus. Changes in the volume of the river naturally cause changes in the area of the bed, so that when full the water covered about four times the area it did when at its lowest in the dry season.

Table 6 shows average flow data for the Buffalo river and some of its tributaries, the total discharge for the Buffalo being estimated as 1.761 times that at De Jager's Drift. From these figures it appears that some 12 per cent of the water of the Buffalo comes from the Slang catchment, another 12 per cent from the Incandu - Ingagane - Horn sub-system which is over twice the area of the Slang catchment but experiences only about half the annual rainfall; 33 per cent from the rest of the Buffalo and its tributaries above De Jager's Drift and 43 per cent from the catchment below De Jager's Drift. The catchment of the Buffalo river and its tributaries constitute 43 per cent of the total catchment area.

TABLE 4

Average flows in the Tugela system
(cusecs)

	Month											
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
Tugela Ferry (153)	1401	2382	4237	5793	7582	8190	3004	1433	932	751	671	806
Bushmans river (Estcourt 211)	63	206	457	305	608	509	211	130	81	57	39	37
Mooi river (Muden 213)	88	226	632	1082	923	1762	492	199	84	64	93	82
Buffalo river (De Jager's Drift 344)	668	1219	1268	1460	2500	1771	1100	526	237	367	149	516
Sundays river ([illegible] 459)	11	190	188	219	446	233	110	49	22	59	19	96
Calculated total Tugela river	2876	5103	8183	11113	14673	16964	6128	2877	1671	1576	1217	1872

TABLE 5

Sources of water in the Tugela System

River	% of total discharge
Tugela above Bergville	15
Little Tugela	4
Tugela from Bergville to Colenso	19
Klip	2
Bloukrans	0.5
Bushmans	3.5
Sundays	2
Tugela from Colenso to Tugela Ferry	4
Mooi	6
Buffalo *	35
Tugela below Tugela Ferry	9

* Total discharge for the Buffalo river is estimated as 1.761 times that at De Jager's Drift.

TABLE 6

Average flows in the Buffalo catchment in cusecs

		Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
Slang	(335)	211	470	584	541	702	303	97	39	14	65	22	26
[illegible]	(362)	23	84	68	115	104	93	38	19	8	11	5	15
[illegible]	(266/1)	4	76	46	122	45	59	48	16	4	3	2	2
Ingagane	(230)	84	152	147	242	275	233	205	88	33	38	16	41
[illegible]	(361)	28	43	47	48	82	57	42	19	17	15	8	11

The histograms in Figure 7(b) display the data of Table 6 and illustrate the great differences in seasonal flow in these streams.

7. THE SURVEY RESULTS

A. Scheme of presentation

There are various difficulties in compiling any readable and rational comprehensive account of the Tugela survey results. One of these is the complexity of the Tugela river system itself. A second is the fact that several different workers were responsible for the practical work at various times, each having his own particular interest and his own method of reporting. But perhaps the greatest difficulty of all is that the Tugela was the first river system to be surveyed in Natal. Subsequent work on other river systems has evolved along different lines and in the light of later experience better interpretation of the data is now possible.

The following scheme of presentation has been adopted: Firstly, the main tributaries of the Tugela river, i.e. the Buffalo, Sundays, Bushmans and Mooi rivers, are considered, then the minor tributaries, the Sandspruit, Little Tugela, Klip, and Bloukrans rivers, the discussion being confined in each case to the earlier work carried out before 1965. Next, the main Tugela river is considered, although this was, in fact, surveyed first. Finally the bacteriological and chemical results obtained in 1965 are presented, so that a general discussion of water quality throughout the Tugela Basin can follow naturally in chapter 8.

All sampling stations referred to specifically in the text are shown on the general map of Figure 1.

The chemical, hydrobiological and bacteriological criteria used for assessing the quality of the water of Natal rivers have been discussed in Part I and need not be repeated here. However, some comments on the application of the biotic index to the interpretation of the Tugela hydrobiological data are necessary.

The biotic index was based on the data obtained during the Three Rivers Region survey and depends on the presence or absence of the Baetidae and the numerical abundance of animals in the samples. It is therefore necessary, if faunal data are to be classed according to the index scheme, that the samples should be similar. Unfortunately, the marginal vegetation faunal samples of the Tugela river survey were different from those used in the survey of the Three Rivers Region. The Tugela river samples varied in that they were taken from 5 to 30 feet of marginal vegetation, the results being arithmetically adjusted by multiplication or division to a standard length, e.g. 5 foot or 10 foot, but not the same for all the Tugela streams. One aspect of the biotic index values is based on a standard 10-foot sweep of marginal vegetation. As none of the errors involved has been determined, rigid comparison is not possible.

A net with a larger mesh size than that used in later surveys was used in the main Tugela river survey, which again limits biotic index interpretation to some degree in that fewer animals were sampled than in the later surveys.

In spite of these limitations Mr. S.J. Pretorius has made an attempt to use the biotic index in interpreting the data, in order to achieve uniformity of presentation in this series of volumes. The detailed hydrobiology of the rivers has already been described in scientific publications (18, 19, 20, 21, 22).

The outcrop percentages of the different rock formations at the various sampling stations on the Tugela river system given in Table 7 are used in calculating "expected" water analyses, as explained in Part I.

B. THE BUFFALO RIVER

The Buffalo river is by far the most important tributary of the Tugela, its catchment amounting to almost 36 per cent of the total area of the Tugela Basin and its flow to about 35 per cent of the total discharge of the Tugela river. Its own tributaries include the Slang, the Ingogo, the Incandu, the Ingagane (itself a tributary of the Incandu), the Dorps, the Blood and the Umzinyatshana rivers.

Table 8 gives the average results of the chemical analyses of samples taken at various stations on the main Buffalo river. At station 58 there was clearly pollution from the Volksrust area, as shown by the pH, conductivity and BOD results and confirmed by the absence of Baetidae in the sample from the marginal vegetation (see Table 9), which indicated a biotic index of less than 5. Samples taken above Volksrust showed the average values, pH 7.9, conductivity 104 micromho and BOD 0.6 ppm, so that the pollution was both organic and inorganic in nature. Since the flow of the Buffalo at station 54 is only of the order of 0.5 cusecs, whilst the average discharge of the Slang is about 300 cusecs, it is clear that the pollution can have no effect upon the Buffalo below the entry of the Slang, about 4 miles below Volksrust. This was confirmed by the hydrobiological results at stations 59 and 60, below the entry of the Slang – Baetidae present in the samples from the marginal vegetation indicating a biotic index of not less than 5 (see Table 9). Elsewhere in the Buffalo there was no evidence of organic pollution, but at station 62 the hydrobiology showed toxic conditions, the fauna in the marginal vegetation being virtually eliminated (biotic index 0). It should be noted, however, that the hydrobiological samples from station 66 and 67, unlike those for the other stations, where collected in May and not in August.

The observed and expected results of chemical analyses, expressed as percentages, of samples taken at stations 63, 64, 66, and 67, are as shown in Figure 8. At stations 63 and 64 there was reasonable agreement with expectation, i.e. with what would be expected from the rock formations traversed by the river, except for the higher observed calcium concentrations (which were also found in the samples from the tributaries). The high concentration of sulphates carried into the Buffalo by the Umzinyatshana between stations 63 and 64 clearly has no effect upon the water of the Buffalo and again this must be attributed to the relatively low average flow of the Umzinyatshana (order of 10 cusecs) as compared with the Buffalo at this point (order of 1000 cusecs). At stations 66 and 67 the proportion of sulphates in the water was appreciably greater than the expectation and certainly greater than that observed at the stations upstream. This effect becomes manifest too far down the river for it to be attributed to the direct entry of pollution from the coalfields but it may be due to groundwater seeping into the river in the lower part of its valley.

Samples were taken from the <u>Slang river</u> at station 70 for chemical analysis. The average results of analyses are given in Table 10 and are represented graphically in percentage form, in Figure 9.

TABLE 7

Outcrop percentages for various sampling stations on the Tugela river system

Station No.	Stormberg	Beaufort	Ecca	Dwyka	T.M.S.	Granite
Main Tugela river						
2	70	30	-	-	-	-
4	40	60	-	-	-	-
5	40	60	-	-	-	-
6	45	55	-	-	-	-
7	30	70	-	-	-	-
8	29	78	3	-	-	-
9	28	67	5	-	-	-
10	20	60	20	-	-	-
11	16	60	24	-	-	-
12	12	44	44	-	-	-
13	11	42	47	-	-	-
14	7	22	69	1	-	1
16	7	21	68	1	1	2
18	7	21	65	1	2	4
Sandspruit						
19	-	100	-	-	-	-
Little Tugela						
20	-	40	60	-	-	-
Bloukrans						
21	-	100	-	-	-	-
Bushmans						
22	30	70	-	-	-	-
23	25	79	-	-	-	-
24	25	75	-	-	-	-
25	25	75	-	-	-	-
26	20	80	-	-	-	-
27	20	80	-	-	-	-
29	16	68	16	-	-	-
Mooi						
41	30	50	20	-	-	-
42	30	50	20	-	-	-
43	27	46	27	-	-	-
45	17	38	45	-	-	-
46	15	33	52	-	-	-
Klip						
47	-	30	70	-	-	-
Sundays						
51 - 57	-	-	100	-	-	-
Buffalo						
63	-	10	90	-	-	-
64	-	5	95	-	-	-
66	-	3	97	-	-	-
67	-	2	96	2	-	-
Slang						
70	-	40	60	-	-	-
Ingogo						
72	-	10	90	-	-	-
Incandu						
77	-	20	80	-	-	-
Ingagane						
80 - 84	-	-	100	-	-	-
Dorps						
85 - 90	-	-	100	-	-	-
Blood						
91 - 94	-	-	100	-	-	-
Umzinyatshana						
96 - 101	-	-	100	-	-	-

TABLE 8

Average chemical analyses of water from stations on the Buffalo river

Station No.	58	63	64	65	66	67
pH value	9.0	7.7	8.1	8.1	7.8	8.4
Conductivity, in micromho	408	162	182	116	242	198
TDS, ppm	-	88	80	124	159	145
BOD, ppm	7.1	0.6	1.0	0.8	0.8	0.08
Nitrates, as ppm N	0.04	0.13	0.08	0.06	0.28	0.08
Phosphates, as ppm PO_4	0.60	0.15	0.20	0.23	0.23	-
Total alkalinity, as ppm $CaCO_3$	-	63	50	-	110	103
Total hardness, as ppm $CaCO_3$	-	53	48	-	95	90
Calcium, as ppm Ca	-	12.0	13.0	-	20.0	17.3
Magnesium, as ppm Mg	-	5.5	3.6	-	10.8	11.3
Sodium, as ppm Na	-	9.9	7.7	-	12.4	20.3
Potassium, as ppm K	-	2.5	2.0	-	3.1	3.0
Sulphates, as ppm SO_4	-	6.3	2.0	-	22.3	22.8
Chlorides, as ppm Cl	-	3.2	5.6	-	8.0	7.8

TABLE 9

Buffalo river : Faunal analyses of samples from the marginal vegetation

August, 1959. (5-foot sweep)

	58	59	60	61	62*	63*	64	65	66	67
Prostoma sp.			6			10			5	
Nematoda	20	10	5	5		10				
Chaetogaster sp.	100	40				10				5
Nais sp.	440			5						
Pristina sp.	20									
? Tubifex sp.	20	30								
Simocephalus vetuloides			930			20				
Macrothrix propinqua	10		5	5			25			
Alona quadrangularis			5							
A. sp.				20						
Chydorus gibson			75							
Pleuroxus aduncus			55	5						
Macrocyclops albidus			46	10		80	50	20		
Tropocyclops confinis	112		12	25		110			5	
Encyclops sp.	184		7	90		40		10	15	
Paracyclops poppei	70			50			75	10		
P. fimbriatus									20	
Microcyclops varicans			36			80	75		10	
Ilyocypris australiensis				115		150	200	130	20	10
Cypridopsis hirsuta			10				175	20		
Gomphocythere obtusa							10			
Austrocloeon virgiliae			21	1						
Pseudocloeon vinosum		3					75			
Baetis bellus		35							4	18
B. latus		31	20	57				167	8	
Centroptilum excisum		38	1	61		10	1	1	1	44
C. pulchrum			6							
Austrocaenis sp.										1
A. sp.			5	1			25	10		16
Pseudagrion spp.			2	5			25	2	4	3
Trithemis sp.								1	1	22
Micronecta sp.									1	
Laccocoris limnigenus			14	15	10		1			
Diplonychus nepoides									6	1
Athripsodes sp.				1						7
Hydroptila capensis			1	1		7				
Aulonogyrus sp.										15
Amarodytes peringueyi			2							
Berosus sp.									1	
Limnobius sp.			5						1	1
L. sp.		10	1	3						
Hydraenidae							25			
Simulium sp.				5						
Pentaneura sp.								10		
P. sp.						20		10	5	5
Corynoneura sp.		11						11		
Orthocladinae sp.		10	17				203		25	
O. sp.		20	45	40						
O. sp.		213	5	5		10	50	50		
O. sp.		20	5	10					1	
Tanytarsus (Rheotanytarsus) sp.							25			5
Chironomidae sp.		20		35			100	60	10	
C. sp.							25	10		
C. sp.	10	60		20				10	5	
Chironominae sp.		51	11	30						
Chironominae sp.		30	10	35		20	101	100		
Ceratopogonidae		20					20			
Burnupia sp.						1				
Pisidium sp.		1								
Rana fuscigula						1			1	14
Total:	986	653	1363	655	10	579	1286	632	129	171

* Sampled in May, 1959.

TABLE 10

Average chemical analysis of water from the Slang river

Station No.:	70
pH value	7.5
Conductivity, micromho	84
TDS, ppm	63
BOD, ppm	0.7
Total alkalinity, as ppm $CaCO_3$	40
Total hardness, as ppm $CaCO_3$	32
Calcium, as ppm Ca	7.0
Magnesium, as ppm Mg	3.5
Sodium, as ppm Na	6.2
Potassium, as ppm K	1.6
Sulphates, as ppm SO_4	1.0
Chlorides, as ppm C1	2.8

The agreement between observation and expectation was fairly good, and there were no indications of disturbance.

The faunal analyses of samples from the marginal vegetation taken in May at this station and also at stations 68 and 69 are given in Table 11. The presence of Baetidae at each station indicates a biotic index of not less than 5, i.e. normal conditions. Baetidae were also present at station 70 in August, indicating similar conditions, but August samples were not taken from the other two stations.

Water from the Ingogo river was taken for chemical analysis at station 72, and the average results of analyses are given in Table 12 and are represented graphically in percentage form in Figure 10. Again the agreement between observation and expectation is fairly good and there are no indications of disturbance.

In May samples were taken from the marginal vegetation at this station and also at stations 71 and 73. The results of the faunal analyses are given in Table 13. The presence of Baetidae indicated normal conditions, the biotic index being not less than 5. In August, samples again indicated normal conditions at station 70. but the other two stations were not sampled.

TABLE 11

Slang river : Faunal analyses of samples from the marginal vegetation

May, 1959

(5-foot sweep)

	Stations		
	68	69	70
Nematoda	15		
Alona affinis			10
Pleuroxus assimilis		10	
Eucyclops sp.	60		5
Paracyclops fimbriatus			20
Cyclops sp.		10	
Cypriodopsis hirsuta	5	10	
Austrocloeon virgilae		30	
Pseudocloeon vinosum	5	4	6
Baetis bellus	5	28	
Baetis latus			39
Centroptilum excisum	36	11	1
C. pulchrum			83
Pseudagrion spp.	3	5	1
Trithemis sp.			5
Gerris sp.	1	1	
Micronecta sp.	1	26	15
Corynoneura sp.			5
Orthocladinae sp.	40	10	
O. sp.		5	10
Chironomidae sp.			15
C. sp.	30	30	15
Biomphalaria sp.	6	6	
Burnupia ponsobyi	8	6	
Pisidium sp.			5
Rana fuscigula			1
Total	215	192	236

TABLE 12

Average chemical analysis of water from the Ingogo river

	Station
	72
pH value	7.4
Conductivity, micromho	84
TDS, ppm	63
BOD, ppm	0.5
Total alkalinity, as ppm $CaCO_3$	40
Total hardness, as ppm $CaCO_3$	40
Calcium, as ppm Ca	8.0
Magnesium, as ppm Mg	4.8
Sodium, as ppm Na	4.0
Potassium, as ppm K	1.2
Sulphates, as ppm SO_4	5.1
Chlorides, as ppm Cl	3.5

TABLE 13

Ingogo river : Results of faunal analyses of samples from the marginal vegetation

May, 1959

(5-foot sweep)

	Stations		
	71	72	73
Chaetogaster sp.			10
Macrothrix propinqua		3	33
Alona sp.			33
A. quadrangularis		57	17
Macrocyclops albidus	1		150
Tropocyclops confinis	1		17
Eucyclops sp.	19		250
Paracyclops poppei			150
Microcyclops varicans			17
Cypridopsis hirsuta			17
Austrocloeon virgiliae	3		59
Pseudocloeon vinosum		1	
Baetis bellus	2		17
B. latus	27	48	
Centroptilum sudafricancum		6	
C. excisum	1	10	
C. pulchrum			1
Austrocaenis sp.	1	13	10
Pseudagrion spp.	1		6
Sympetrum sp.			1
Trithemis sp.			3
Microvelia major	1		
Rhagovelia nigricans		1	
Plea pullula	4	5	2
Micronecta sp.		7	
Micronecta juv.			10
Ranatra sp.			1
Orthotrichia sp.		3	
Dytiscidae	1	1	5
Limnobius sp.	4	13	2
Pentaneura sp.	3	3	
P. sp.	10	17	17
Corynoneura sp.		7	
Tanytarsus sp.	7	10	
Chironomidae sp.		7	
C. sp.		17	13
Hydracarina			1
Lymnaea natalensis		3	
Rana fuscigula			1
Pisces		1	
Total	86	233	843

TABLE 14

Average chemical analyses of water from the Incandu river

	Stations	
	76	77
pH value	7.0	7.2
Conductivity, micromho	67	94
TDS, ppm	60	82
BOD, ppm	0.5	0.5
Total alkalinity, as ppm $CaCO_3$	28	28
Total hardness, as ppm $CaCO_3$	22	29
Calcium, as ppm Ca	6.0	7.0
Magnesium, as ppm Mg	1.7	2.8
Sodium, as ppm Na	5.0	5.8
Potassium, as ppm K	1.0	2.8
Sulphates, as ppm SO_4	2.6	5.0
Chlorides, as ppm Cl	2.4	3.7

The Incandu river was sampled above and below Newcastle (stations 76 and 77) and the analyses gave the average results shown in Table 14. These results, in percentage form, are shown graphically in Figure 11. The analyses show that at station 77 the water departs more from the expectation that at station 76. Further, although the two stations are not more than 5 miles apart, the conductivity of the water at station 77 is about $1\frac{1}{2}$ times that at station 76. This is evidence of mineral pollution from the Newcastle area. The water from an effluent stream from a factory in this area was found to have the following analysis:

pH value	8.5
Conductivity, micromho	2040
TDS, ppm	2011
Total alkalinity as ppm $CaCO_3$	124
Total hardness, as ppm $CaCO_3$	694
Sodium, as ppm Na	118
Potassium, as ppm K	302
Sulphates, as ppm SO_4	574
Chlorides, as ppm Cl	29

The greater proportion of potassium at station 70 appeared to be due to this effluent.

No hydrobiological samples were taken in August at station 74, but the faunal analysis of a sample from the marginal vegetation taken in May revealed normal conditions (biotic index not less than 5). Baetidae were present at stations 75 and 76 in August, indicating normal conditions (biotic index not less than 5). At station 77 pollution was detected - Baetidae were absent, indicating a biotic index less than 5 (see Table 15).

TABLE 15

Incandu river : Faunal analyses of samples from the marginal vegetation

August, 1959

(5-foot sweep)

	Stations			
	74*	75	76	77
Prostoma sp.	10			
Nematoda	5			40
Chaetogaster sp.		5		30
Nais sp.		6		
? Limnodrilus sp.	30			
Simocephalus vetuloides			98	190
Alona quadrangularis	15			
A. affinis		15		
Leydigia quadrangularis	15			
Chydorus gibsoni		5		
Macrocyclops albidus	1	25	20	
Tropocyclops confinis	15	1	72	40
Eucyclops sp.	20	1	14	160
Paracyclops poppei	1			
Microcyclops varicans			66	
Caridina nilotica			1	
Austrocloeon africanum		29		
A. virgiliae	33	47	22	
Pseudocloeon vinosum		45		
Baetis harrisoni	1	4		
B. bellus	12	6		
B. latus		12		
Centroptilum sudafricanum			1	
C. excisum	28	2		
C. pulchrum		8		
Austrocaenis sp.		1		
Pseudagrion spp.	1	2		1
Plea pullula	16			
Micronecta sp.			6	
M. sp.		6		
M. scutellaris	42			
Renatra sp.		1		
Diplonychus nepoides	1		1	
Berosus sp.			8	
Dytiscidae	6	11		
Limnebius sp.	1		8	
Pentaneura sp.	10	5		
P. sp.		5	8	
Corynoneura sp.	45	8		
Orthocladinae sp.	10	25	14	10
O. sp.	5	5		
O. sp.		85		20
Tanytarsus sp.		25	8	
Chironomidae sp.		90		
C. sp.		95	34	10
Ceratopogonidae	15	22		
Hydracarina	5	10	1	
Biomphalaria sp.	9			
Burnupia sp.	5			
	357	607	382	501

* Sampled in May, 1959

The Ingagane river was sampled for purposes of chemical analysis at five points: the average results of these analyses are shown in Table 16 and, expressed as percentages, are represented graphically in Figure 12. At station 80 and the stations below that point the water clearly contains a high proportion of sulphates. This can be attributed to the fact that the river crossed one of the main coal outcrops of the Klip River Coalfield a few miles above this station (see discussion of the Blood river, below). Apart from mines in the Dannhauser district, drained by the Alcockspruit (and its tributaries) which enters the Ingagane just below station 80, the drainage from at least six mines in the Ingagane catchment, some active and some abandoned, enters the river and causes the proportion of sulphates to increase progressively downstream, as shown in Figure 12, and also the TDS to become virtually doubled over a relatively short length of flow. The drainage from the mines is in fact responsible for about 50 per cent of the total load of dissolved material carried by the river at the lowest station, although it does not appear to contribute appreciably to the river flow, nor does it raise the concentration of dissolved iron to more than 1 ppm. A discussion of pollution by mine drainage is given in the Appendix.

BOD values at stations 83 and 84 indicated some degree of organic pollution but it is clear that the water quality remained remarkably good.

Hydrobiologically, no pollution was detected at stations 78 and 80 in May nor at stations 79 and 84 in August (see Table 17).

The Dorps river passes through Utrecht where there are two coal mines, the long abandoned Utrecht Municipal Colliery and the active and extensive Utrecht Colliery. The latter is established to the north of the town in an area drained by the small (0.2 cusec) Mhosanispruit. About 5 miles below the town, the Dorps river is joined by the Washbank, a stream of about the same size as the Dorps. The average results of the analyses of these streams are shown in Table 18 and, expressed as percentages in Figure 13. Clearly the Mhosanispruit is minerally polluted, but samples taken at stations on the Dorps and Wasbank show no definite sign of disturbance except for those taken from station 86, below Utrecht, which show an increased BOD (maximum recorded value 1.9 ppm) which indicates some very slight disturbance. The flow of the Mhosanispruit is too small for it to have any appreciable effect on the Dorps river.

TABLE 16

Average chemical analysis of water from the Ingagane river

	Stations				
	80	81	82	83	84
pH value	8.2	7.7	7.7	8.0	7.8
Conductivity, micromho	153	165	205	214	264
TDS, ppm	98	115	126	127	166
BOD, ppm	1.6	1.4	1.5	2.6	1.9
Nitrates, as ppm N	0.05	0.07	0.06	0.06	0.08
Phosphates, as ppm PO_4	0.11	0.11	0.11	0.23	0.10
Total alkalinity as ppm $CaCO_3$	57.2	62.4	60.1	45.1	63.4
Total hardness, as ppm $CaCO_3$	48.4	55.7	68.6	73.1	93.0
Calcium, as ppm Ca	10.9	12.9	15.8	16.1	19.8
Magnesium, as ppm Mg	5.1	9.6	11.9	14.1	17.2
Sodium, as ppm Na	14.4	15.0	17.5	17.9	19.0
Potassium, as ppm K	2.6	2.5	2.3	2.6	2.5
Sulphates, as ppm SO_4	19.8	23.3	26.1	35.0	54.8
Chlorides, as ppm C1	4.2	3.8	4.8	5.0	5.3
Silica, as ppm SiO_2	12.0	10.1	11.1	9.1	8.6

TABLE 17

Ingagane river : Faunal analyses of samples from the marginal vegetation

(5-foot sweep)

	Stations			
	78**	79*	80**	84*
Chaetogaster sp.		80		
Nais sp.		140		10
Simocephalus vetuloides				10
Macrocyclops albidus		26		
Tropocyclops confinis		34	7	25
Paracyclops poppei		46		5
Microcyclops varicans		120		
Austrocloeon virgiliae		56		
Baetis bellus	1	1		
B. latus	174		20	30
Centroptilum excisum	4	18		13
C. pulchrum		18		
Austrocaenis sp.	47			
A. sp.		1	17	
Pseudagrion spp.	6	4	1	
Sympetrum sp.	3			
Rhagovelia nigricans			3	
Micronecta sp.			3	
Diplonychus nepoides		1		1
Leptocerus harrisoni		6		
Orthotrichia sp.		14	23	1
Limnobius sp.			20	
Simulium sp.	17		44	
Pentaneura sp.	7	6	3	
P. sp.		6		5
Corynoneura sp.	3	60	3	10
Orthocladinae sp.	3	14		5
O. sp.		14		10
O. sp.	13	72		5
Tanytarsus sp.	17	40	3	
Chironomidae sp.	20	174	7	35
C. sp.	3	174	3	45
Hydracarina	3			
Rana fuscigula			1	
Total	321	1125	158	210

** Sampled in May, 1959

* Sampled in August, 1959

TABLE 18

Chemical analyses of water from the Dorps river

	Stations				
	85	86	87	89	90
pH value	7.6	7.6	8.1	8.4	8.1
Conductivity, micromho	77	101	136	973	191
TDS, ppm	61	65	99	598	120
BOD, ppm	0.4	1.1	0.3	-	-
Nitrates, as ppm N	0.30	0.28	-	0.52	0.05
Phosphates, as ppm PO_4	0.28	0.25	-	0.21	0.31
Total alkalinity, as ppm $CaCO_3$	38.1	42.1	63	121.3	71.6
Total hardness, as ppm $CaCO_3$	38.2	40.7	67	298.1	64.3
Calcium, as ppm Ca	7.9	8.1	13.0	73.2	15.8
Magnesium, as ppm Mg	3.3	5.0	7.9	28.0	6.1
Sodium, as ppm Na	3.9	5.5	6.3	102.3	14.9
Potassium, as ppm K	0.7	0.7	0.9	3.1	1.4
Sulphates, as ppm SO_4	2.1	5.1	13.0	298.9	19.9
Chlorides, as ppm Cl	0.3	0.3	3.4	7.4	1.0
Silica, as ppm SiO_2	14.6	14.9	-	11.9	17.5

The hydrobiological samples (see Table 19) from stations 86 and 88 showed no significant signs of disturbance as Baetidae were present, indicating that the biotic index was not less than 5. No samples were taken in August at station 85, but a May sample indicated a disturbance since Baetidae were absent (biotic index less than 5).

The Umzinyatshana river was also sampled at several places, and the average analyses together with data for the Steenkoolspruit tributary below Dundee are shown in Table 20 and represented graphically in percentage form in Figure 14. Only the water from the upper reach of the river (station 96) shows anything like normal composition, as elsewhere the concentrations of sulphates were found to be raised at the expense of carbonates. There are at least ten coal mines in the catchment, both active and abandoned, and the ruinous effect of the drainage from them on the river water is very marked (see Appendix). In addition, the Steenkoolspruit is heavily polluted by sewage as evidenced by the high BOD and phosphate concentrations. The high BOD at station 97 (maximum recorded 3.7 ppm) has not been accounted for.

The faunal analyses of samples from the marginal vegetation at stations on the Umzinyatshana river and the Steenkoolspruit are given in Tables 21 and 22. The presence of Baetidae at station 88 indicated normal conditions (biotic index of not less than 5). On the other hand, their absence at stations 89 and 90 indicated polluted conditions (biotic index less than 5). At station 91 the virtual absence of fauna indicated toxic conditions (zero biotic index). In the Steenkoolspruit, polluted conditions arose at stations 100 and 101, as indicated by the absence of Baetidae, and the high total numbers of animals (biotic index less than 5). At station 102, however, conditions were normal; Baetidae were present, indicating a biotic index of not less than 5.

The Blood river gave some particularly interesting results. This river has its origin at the junction of two streams, the Ncosaspruit and the Guntерspruit. Both these streams and their tributaries cross the main coal outcrop about 10 miles east of Utrecht before they join to form the Blood river. The Ncosaspruit was sampled near its source (station 91) and the Blood river proper was sampled just below the confluence of the two headwater streams (station 92) at Blood River town (station 93) and just above its confluence with the Buffalo at Vants' Drift (station 94). The chemical analyses of these samples are given in Table 23, and, expressed as percentages, in Figure 15. Sulphates were not detectable in the upper Ncosaspruit but were present in appreciable proportions at station 92, demonstrating quite clearly that natural coal outcrops can act as a source of sulphates in the streams that drain them, which confirms the supposition made with regard to the sulphates in the Ingagane river. (Page 22).

There are no mines in the Blood river catchment, nor do many of the other tributaries of the Blood river cross coal outcrops. It is therefore only to be expected that the proportion of sulphates in the water should decrease after station 92, as indeed it does (Figure 15).

In the faunal analyses of samples taken in May from stations 93, 94 and 95 (see Table 24), Baetidae were present, indicating undisturbed conditions (biotic index not less than 5).

TABLE 19

Dorps river : Faunal analyses of samples from the marginal vegetation

August, 1959 5-foot sweep

	Station		
	85*	86	88
Nematoda		10	25
Chaetogaster sp.		10	50
Nais sp.		2560	50
Pristina sp.		35	10
Macrothrix propinqua		70	
Leydigia quadrangularis		70	
Alona rectangula			20
Macrocyclops albidus		5	20
Tropicyclops confinis	110	35	80
Eucyclops sp.		65	190
Paracyclops poppei	10		
Microcyclops varicans	10		
Ilyocryptus australiensis		125	10
Austrocloeon virgiliae		1	
Baetis latus		1	20
Centroptilum excisum		32	105
Austrocaenis sp.	7		
A. sp.	20	23	
Pseudagrion spp.	1	3	13
Trithemis sp.	20		
Rhagovelia nigricans	10		
Plea pullula			20
Diplonychus nepoides			1
Dytiscidae	10		
Limnobius sp.	20	20	
Culex sp.	30		
Pentaneura sp.		10	
P. sp.	1	21	10
P. sp.	20		
Procladius sp.			30
Corynoneura sp.		10	
Orthocladinae sp.			10
O. sp.	10	525	110
O. sp.		10	
Tanytarsus sp.		5	50
Chironomidae sp.		10	
C. sp.		65	
C. sp.		35	90
Ceratopogonidae sp.			30
C. sp.		40	
Ephydridae		15	
Hydracarina		1	
Total:	279	3812	944

* Sampled in May 1959.

TABLE 20

Average chemical analyses of water from the Umzinyatshana river

Station No.	Umzinyatshana			Steenkool-spruit
	96	97	98	101
pH value	7.9	8.0	7.7	6.5
Conductivity, micromho	254	1376	851	1360
TDS, ppm	190	790	594	851
BOD, ppm	0.6	2.3	0.5	15.1
Nitrates, as ppm N	0.24	0.18	0.17	0.12
Phosphates, as ppm PO_4	0.85	0.42	0.32	2.00
Total alkalinity, as ppm $CaCO_3$	164	322	114	143.0
Total hardness, as ppm $CaCO_3$	126	155	289	533.0
Calcium, as ppm Ca	31.5	31.3	65.5	141.0
Magnesium, as ppm Mg	11.3	18.5	30.0	43.4
Sodium, as ppm Na	21.1	270.1	76.0	60.0
Potassium, as ppm K	1.5	3.5	2.9	4.9
Sulphates, as ppm SO_4	3.5	149.3	322	483
Chlorides, as ppm Cl	6.0	8.0	12.5	17.1

TABLE 21

Umzinyatshana river : Faunal analyses of samples from the marginal vegetation

August, 1959

(5-foot sweep)

	Stations			
	96	97	98	99
Prostoma sp.			560	
Nematoda sp.			80	
Chaetogaster sp.		1360	40	
Nais sp.		120		
Nais sp.		80		
Schmardaella sp.			80	
Simocephalus vetuloides		80		
Alona quadrangularis		1200		
Pleuroxus aduncus	300	3000		
Tropocyclops confinis	350	1600	80	
Eucyclops sp.	400	1760		
E. sp.		1		
Paracyclops fimbriatus		240		
P. poppei	150			
Ectocyclops phaeleratus		160		
Microcyclops varicans			80	
Cypridopsis hirsuta	250		240	
Austrocloeon virgiliae	50			
Centroptilum exisum				1
Pseudagrion spp.	100	8	1	
Trithemis sp.	50			
Diplonychus nepoides	52			
Hydroptila capensis				60
Limnobius sp.			40	
Pentaneura sp.	50			
Orthocladinae sp.	350	80		
O. sp.	50			
Chironomidae		40		
Ceratopogonidae sp.		80	40	
C. sp.	100			
Total:	2252	9809	1241	61

TABLE 22

Steenkoolspruit : Faunal analyses of samples from the marginal vegetation

August, 1959

(5-foot sweep)

	Stations		
	100	101	102
Nematoda		1000	10
Chaetogaster sp.		11000	10
Naididae		1000	
? Limnodrilus sp.	560	4	
Simocephalus vetuloides			40
Chydorus gibsoni			220
Pleuroxis aduncus			20
Tropocyclops confinis	280		90
Eucyclops sp.	10920		50
E. sp.		8800	
Paracyclops poppei	1400		
Austrocloeon africanum			6
Pseudagrion sp.			3
Enallagma glaucum			2
Aeshna minuscula			2
Orthetrum sp.	4	4	
Plea pullula			20
Diplonychus nepoides			4
Psychoda alternata	560	240	
Culex sp.		20	11
Orthocladinae	80		20
Tanytarsus sp.		320	
Chironominae			30
Chironomus sp.	280		
Rana fuscigula		2	
Total:	14084	22390	538

TABLE 23

Chemical analyses of water from the Blood river

	Stations			
	91	92	93	94
pH value	8.0	7.5	7.3	8.1
Conductivity, micromho	25	51	87	136
TDS, ppm	20	38	55	84
BOD, ppm	-	-	0.9	0.5
Nitrates, as ppm N	0.05	0.09	0.05	-
Phosphates, as ppm PO_4	0.07	0.12	0.13	-
Total alkalinity, as ppm $CaCO_3$	10.3	21.9	33.5	55.0
Total hardness, as ppm $CaCO_3$	7.9	20.2	23.2	50.0
Calcium, as ppm Ca	1.5	3.8	5.8	12.0
Magnesium, as ppm Mg	1.0	2.6	2.8	4.8
Sodium, as ppm Na	2.6	3.1	4.5	6.8
Potassium, as ppm K	0.2	0.4	1.4	1.7
Sulphates, as ppm SO_4	Nil	4.1	4.1	4.1
Chlorides, as ppm Cl	Nil	Nil	2.5	5.4
Silica, as ppm SiO_2	10.1	14.6	13.9	-

TABLE 24

Blood river : Faunal analyses of samples from the marginal vegetation

May, 1959
(5-foot sweep)

	Stations		
	93	94	95
Macrothrix propinqua			1
Tropocyclops confinis			1
Microcyclops varicans	150		
Caridina nilotica	18		
Pseudocloeon vinosum	69		
Baetis harrisoni			4
B. bellus		27	32
B. latus		9	35
Centroptilum excisum		3	16
Austrocaenis sp.	30		
Lestes ? plagiatus	1		
Pseudagrion spp.	13		
Rhagovelia nigricans		3	
Leptocerus harrisoni	6		2
Pentaneura sp.	6		
Coryneura sp.			1
Orthocladinae sp.	30		1
O. sp.	30		
O. sp.	1		
Tanytarsus sp.	34		
Chironominae			2
Total :	388	42	95

C. THE SUNDAYS RIVER

The Sundays river drains an area to the south and east of Glencoe and Dundee, which forms part of the Klip River Coalfield. Its main tributary is the Wasbank river, which obtains most of its water from its own tributary, the Ebusi. The Ebusi itself is fed mainly by drainage water from two disused mines a few miles east of Glencoe. The Inkunzi river, which passes disused and active mines, is the second major tributary of the Sundays.

Samples taken for chemical analysis from four points on the Sundays river (stations 51, 52, 53 and 54), from the Inkunzi river just above its confluence (station 56) and from the Wasbank river below Wasbank township (station 57 gave the average analyses shown in Table 25. These results are represented graphically, after calculation to percentage form, in Figure 16.

The chemical analyses of samples from the two upper stations on the Sundays river (stations 51 and 52) show water compositions in fair agreement with expectation, though their conductivity values are relatively high. The Inkunzi river (station 56) is clearly affected by mine drainage (mineralization and high sulphate content), but this evidently has very little influence on the Sundays river at station 52 (since the average flow of the Inkunzi river is of the order of less than 10 per cent that of the Sundays river, this is only to be expected). At station 53, however, the Sundays river was also apparently affected to some degree by mine drainage, which doubtless arose from the entry of streams polluted by drainage from the mines in the Elandslaagte area. The Wasbank river (station 57) showed very heavy mineral pollution of this nature, and its effect on the Sundays river at station 54 was clearly evident.

The situation in the Sundays river catchment with respect to mineral pollution is, in fact, very similar to that in the Umzinyatshana river catchment (page 26). Further discussion on mine drainage in the Natal Coalfields is to be found in the Appendix.

The absence of Baetidae in the marginal vegetation at stations 51, 52 and 53 on the main river and stations 55 and 57 on the Ebusi and Wasbank rivers (see Table 26) suggests disturbed conditions of an organic nature. The chemical results, however, showed inorganic disturbance of the water and no sign of organic disturbance in this river system. On this evidence, therefore, interpretation according to the biotic index parameters tends to be ambiguous. The absence of Baetidae may be the result of the inorganic pollution but as exact data on this are not available consideration of the faunal analysis is not permissible.

D. THE BUSHMANS RIVER

The Bushmans river passes through Estcourt where industrial activity gives rise to pollution. Chemical analyses of the water at seven stations on this river showed the average results given in Table 27 which are represented graphically in percentage form in Figure 17. Apart from a progressive increase of TDS and conductivity downstream, the composition of the water was evidently much the same all down the river. Moreover, it was in fair agreement with what would be expected for a stream whose catchment is formed mainly of Beaufort rocks.

TABLE 25

Average chemical analyses of samples from the Sundays river

Station No.	Sundays				Inkunzi	Wasbank
	51	52	53	54	56	57
pH value	8.2	8.1	6.7	7.7	7.3	7.7
Conductivity, micromho	127	146	272	359	445	1238
TDS, ppm	85	93	121	213	242	850
BOD, ppm	1.0	0.7	0.5	-	0.5	0.6
Nitrates, as ppm N	0.03	0.03	0.18	-	0.65	0.45
Phosphates, as ppm PO_4	0.13	0.11	0.07	-	0.07	0.07
Total alkalinity, as ppm $CaCO_3$	66.1	71.9	44.7	112.7	77.5	120.4
Total hardness, as ppm $CaCO_3$	53.2	62.9	120.3	107.4	148.0	371.8
Calcium, as ppm Ca	11.0	13.4	25.0	21.0	30.6	85.3
Magnesium, as ppm Mg	6.3	6.5	13.9	13.2	17.1	38.0
Sodium, as ppm Na	6.9	7.6	11.8	32.6	31.9	127.9
Potassium, as ppm K	1.2	1.4	1.3	2.5	1.9	7.6
Sulphates, as ppm SO_4	2.9	3.8	22.3	40.7	90.8	495.6
Chlorides, as ppm Cl	0.7	2.1	6.1	18.7	8.1	16.2
Silica as ppm SiO_2	16.1	17.8	12.5	-	14.5	6.9

TABLE 26

Sundays river : Faunal analyses of samples from the marginal vegetation
(July, 1962)

	Stations						
	49	50	51	52	53	55	57
Hydra sp.					2		
Planariidae	1						
Prostoma sp.						64	20
Nematoda		5				40	
Tardigrada							10
Chaetogaster sp.				60	10	340	
Nais sp.	16	20	21	10	20		
Lumbriculus sp.				4			
Alona sp.	48						
Copepoda	162	25	14	10			
Tropocyclops sp.	264		7	20	1		
Ostracoda		1			1	20	10
Collembola				40			10
Austrocloeon virgiliae	430						
Pseudocloeon vinosum	12						
Baetis latus		1					
Centroptilum excisum	24	96					
Austrocaenis sp.					1		
A. sp.	2	26		13			
A. sp.	4				1		
Adenophlebia sylvatica	1						
Choroterpes (Euthralus) elegans	9						
Afronurus sp.					1		
Pseudagrion natalense	7	2	2	6	1	14	3
Mesomgomphus sp.	1				2		
Ceratogomphus sp.						1	
Mesovelia sp.						2	
Veliidae	1	1					
Enithares sobria						1	
Plea pullula	7	1				1	
Micronecta sp.	28	17					
Laccocoris limigenus			1				1
Ranatra sp.	1						1
Diplonychus nepoides						1	
Oecetis sp.		4					
Athripsodes prionii	23	1		1			
Trianodes sp.		2					
Hydroptila capensis		2					
Ochronichia sp.		2					
Dytiscidae			1	1		1	
Berossus sp.		2	1		1	1	
Guignotus harrisoni				11			
Laccophilus lineatus	2			3			
L. sp.				1			
Yola subopaca		1					1
Hydrophilidae	1						

Table 26 (continued)

	Stations						
	49	50	51	52	53	55	57
Hydrainidae	8	2	9	4	1	1	1
Helminthidae	2			2			2
Chrysomelidae			1	3			
Curculionidae							1
Trimera sp.				4			
Dixa sp.	25						
Anopheles sp.	1					1	
Culex sp.				10		1	
Simulium sp.					1		
Chironomidae	776	205	56	101	160	232	2
Pentaneura sp.			1		20		1
Corynoneura sp.	88	1					
Bezzia sp.		1		10	10		
Palpomyia sp.	41	3		10	20	40	
Wiedemannia sp.		1					
Atherix sp.				1			
Psilopa sp.				1			
Hydracarina sp.	8	15					
Lymnaea sp.						2	
Burnupia caffra	3						
Pisidium sp.	6						
Rana fuscigula		2	1				
Anura					2		
Total:	2002	439	115	326	255	763	63

TABLE 27

Average chemical analyses of water from the Bushmans river

	Stations						
	22	23	24	25	26	27	29
pH value	7.19	7.28	7.26	7.34	7.20	7.47	8.00
Conductivity, micromho	66	67	70	80	76	87	140
TDS, ppm	59	64	61	65	78	80	104
DO, % saturation	98	97	98	105	96	101	-
BOD, ppm	0.6	0.7	1.2	1.2	0.8	1.6	-
OA, ppm	1.7	1.2	1.5	2.1	3.4	2.4	1.0
Ammonia nitrogen, ppm	0.001	0.002	0.002	0.010	0.004	0.007	0.001
Nitrites, as ppm N	0.03	0.07	0.02	0.06	0.03	0.06	Nil
Nitrates, as ppm N	0.1	0.1	0.1	0.1	0.1	0.1	0.3
Total alkalinity, as ppm $CaCO_3$	45.5	45.7	46.5	47.8	49.6	55.8	78.0
Total hardness, as ppm $CaCO_3$	33.0	33.7	36.9	38.8	43.7	46.7	67.7
Calcium, as ppm Ca	7.7	7.8	8.5	9.0	9.5	10.4	15.5
Magnesium, as ppm Mg	3.3	3.4	3.8	3.9	4.8	5.0	7.0
Sodium, as ppm Na*	7.2	7.1	6.3	7.8	6.3	8.2	10.2
Sulphates, as ppm SO_4	1.3	1.7	1.9	2.1	1.8	2.6	5.2
Chlorides, as ppm Cl	2.8	2.8	3.0	5.7	5.7	5.9	6.2

* Calculated from the analyses, assuming a potassium concentration of 1.7 ppm.

The faunal analyses of samples from the marginal vegetation (Table 28) indicated undisturbed conditions at station 22 (biotic index not less than 5). At station 24 Baetidae were absent, indicating pollution (biotic index below 5). The presence of Baetidae at stations 25, 26 and 27 did not suggest any appreciable disturbance, but the high total numbers of animals indicated slight organic pollution (biotic index not less than 5).

A special study was made of the industrial pollution from Estcourt, most of which enters the Bushmans river by way of the Little Bushmans river, between stations 23 and 24. Water samples from six stations on this tributary gave the average chemical analyses shown in Table 29. It is clear that this river suffers heavy organic pollution (BOD and OA values) and some mineral pollution - the average conductivity increased from 86 to 145 micromho over a distance of only 7 miles. This is confirmed by the faunal analyses of samples from the marginal vegetation and bottom sediments (see Table 28) for which, except at the uppermost station, the biotic index was 1.

Deep beds of sludge were observed in the river below the points of entry of some of the effluents. Between stations 31 and 32 a channel carried waste from a boiler house and a water-borne ash-recovery plant into the river. The flow in this channel was approximately 0.2 cusec at the time these observations were made, whereas the flow of the Little Bushmans river was about 5 cusecs; on an average, the flow of this tributary appears to be about 1/5 of that of the main river at Estcourt. The river at this point flowed slowly through pools about 2 ft deep, where ash and fibre from the effluent settled and formed a large sludge bed extending some 50 ft downstream. Between station 32 and 33 a second channel discharged surface drainage from a factory area and water treatment plant, together with some surface drainage. The flow was of the order of 0.01 cusec, and a second sludge bed was formed below the point of discharge. Between stations 33 and 34 waste from another factory entered the river. This was composed of condensate and floor washings and often carried a load of suspended organic residues. Often it was at a temperature about 15°C above that of the river. The average flow was about 0.65 cusec, and below its point of discharge, sludge banks were formed, which extended 50 to 100 yds downstream.

Analyses of single samples from these sludge deposits are given in Table 30. They were rich in both organic and inorganic material and formed sources of polluting substances in the bed of the river. For example, at station 32 during September 1956 the rise of temperature in early spring seemed to accelerate the anaerobic decomposition of the material and the gas evolved effectively lifted and stirred it. As a result, a very high OA of 50 ppm and a BOD exceeding 73 ppm were shown by the turbid river, while the DO fell to 32 per cent saturation.

Some few comparisons made on particular occasions indicated that the daily load of suspended solids in the river decreased by about 100 lbs between stations 32 and 35. This material must have settled on the bed, and deposition at this rate would result in the accumulation of about four tons of sediment in three months. Approximate measurements of the extent of the sludge beds in the river indicated that this was actually the order of magnitude of the sediments.

TABLE 28

Bushmans and Little Bushmans rivers : Faunal analyses of samples from the marginal vegetation
September, 1956
(10 foot sweep)

	Stations									
	30	32	33	34	35	22	24	25	26	27
Planariaidae							40			
Microstomium sp.		2940		562500			40			
Sorocelis sp.				15000						
Nematoda	40	5340	98400	30000	69120	30	6240	14160	80	20
Chaetogaster sp.	240	1020	12000	15000	7200		160	44160	160	
Nais sp.	760	780	148800	22500	47280		2400	2640		
Pristina sp.									60	
Tubifex sp.					3					
Limnodrilus sp.		720		7500	4560					
Alona costata				45000	46800		2040	4320		
A. guttata				4500	2880					
Chydorus gibsoni					46560		21840	12000	40	
Ceriodaphnia quadrangula							80			20
Pleuroxus assimilis				9000						
Simocephalus vetuloides					9840	20	480	6480	520	
Cyclops ? agilis	500						1160		240	
C. albidus						60	200	3120	520	
C. ? subiaevis						30				150
C. fibriatus poppyi		3420	6000	70500	11040					75
C. prasinus	500					130			300	75
Nitocra dubia									40	
Cypretta sp.								240		
Cyproidopsis reniformis										20
Eucypris sp.										20
Potamon sidneyi					3					
Austrocloeon virgiliae						1			1	
A. africanum								240		
Austrocaenis capensis	40						40		2	2
A. sp.										1
Baetis bellus	80					1				2
B. glaucus										1
B. harrisoni	40					2				
Choroterpes (Euthralus) elegans										1
Centroptilum excisum						1			7	
Pseudocloeon vinosum						58			184	94
Leptocerus harrisoni						1		3	20	
L. sp.						2	86			
Pseudagrion salisburyensis	4				21	19	6		1	6
P. sp.	2									
Trithemis sp.					3				40	
Berosus sp.						11	2		20	20
Dytiscidae							2			
Helminthidae						1				1
Gyrinidae	2									
Hydaticus sp.	2									
Hydropus sp.	80									
Hydrophilidae						1				
Ochthebius sp.	80					1				1
Notonectidae								480		1
Microvelia sp.	40									
Ceratopogonidae						10			40	20
Anopheles sp.								240		
Chironomidae	1160	60				91	640	1200	60	60
Culex sp.									20	
Corynoneura sp.	80					30		240	80	20
Pentaneura sp.										20
Tanypus sp.	80						2		101	
Bufo regularis								5040		145
Rana sp.	2				3		2		80	30
Pisidium sp.										1
Total:	3732	14280	265200	781500	245313	500	35462	94563	2616	806

TABLE 29

Average analyses of water from the Little Bushmans river

	Stations					
	30	31	32	33	34	35
pH value	7.18	7.44	7.74	7.78	7.19	7.57
Conductivity, micromho	86	112	135	123	122	145
TDS, ppm	66	87	120	103	100	105
DO, % saturation	94	95	70	95	78	99
BOD, ppm	0.7	1.3	$>$ 22	3.1	8.2	6.2
OA, ppm	1.9	2.4	14.2	4.7	5.5	3.5
Ammonia nitrogen, ppm	0.1	0.1	0.1	0.1	0.1	0.1
Nitrites, as ppm N	0.002	0.003	0.002	0.001	0.009	0.026
Nitrates, as ppm N	0.08	0.06	0.06	0.08	0.08	0.04
Total alkalinity, as ppm $CaCO_3$	54.1	67.7	69.7	69.3	67.0	74.3
Total hardness, as ppm $CaCO_3$	43.2	48.1	55.9	55.9	51.9	57.3
Calcium, as ppm Ca	9.0	8.6	13.8	12.4	11.6	12.6
Magnesium, as ppm Mg	5.0	6.4	5.2	6.0	5.2	6.2
Sodium, as ppm Na*	7.5	12.0	11.5	10.2	11.4	13.8
Sulphates, as ppm SO_4	1.7	1.9	5.2	4.2	4.8	5.9
Chlorides, as ppm Cl	3.9	4.5	5.4	4.4	4.7	6.1

* Calculated from the analyses, assuming a potassium concentration of 1.4 ppm.

TABLE 30

Analyses of sludge banks in Little Bushmans river

(Results expressed as % of dry weight)

	Below station 31	Below station 32	Below station 33
Moisture	66.82	90.67	48.66
Ash	14.4	58.0	8.3
Ammonia nitrogen	6.3×10^{-4}	7.5×10^{-4}	13.7×10^{-4}
Organic nitrogen	974×10^{-4}	258×10^{-4}	3360×10^{-4}
Inorganic carbon	0.087	0.39	0.21
Organic carbon	7.16	1.29	2.79
Sulphides, as S	37.5×10^{-4}	180×10^{-4}	-
Oxygen uptake in 5 days	1.2	1.35	-

Two effluents, entering between stations 31 and 32 and between stations 33 and 34 respectively, were each studied at approximately hourly intervals, the first over a period of $9\frac{1}{2}$ hours, the second over $6\frac{1}{2}$ hours, with the results shown in Table 31. From these results, calculations show that the level of dissolved solids in the river at station 32 was eight times higher and the BOD $2\frac{1}{2}$ times higher than could be accounted for, while the BOD at station 33 was three times greater. There are various other sources of pollution of the Little Bushmans river, but in comparison with these two effluents they are of minor importance; hence the above effects can be attributed to the presence of the sludge deposits.

It is evident, however, that the heavy pollution of the Little Bushmans river has no great effect on the Bushmans river. At station 24, below the confluence, the highest BOD recorded was 2.4 ppm.

E. THE MOOI RIVER

The average chemical analyses of water from five stations on the Mooi river are given in Table 32 and are shown graphically in percentage form in Figure 18.

A small degree of pollution is evident at station 42, since the BOD is slightly increased (in the dry season 2.3 ppm was recorded) while the faunal analysis (Table 33) shows high number of animals and a virtual absence of Baetidae (only two individuals), indicating a disturbance resulting in a biotic index of less than 5. The mineral composition of the water also shows a perceptible change (Figure 18). Recovery is rapid, however, for there is no sign of disturbance at station 43. The lower reaches of the river show a rapid rise of conductivity and TDS, although otherwise the chemistry is little changed. This may be partly due to the intensive irrigation practised around Muden, excess water of greatly raised TDS draining back into the river in this area. The faunal analyses indicate no disturbance. As Baetidae are present, biotic index values of not less than 5 may be assigned.

However, it is clear that the quality of the water in the Mooi river remains quite high throughout.

F. MINOR TRIBUTARIES

Four minor tributaries of the Tugela river deserve some consideration.

The Sandspruit rises near Skoenkop on the Natal - O.F.S. border and flows south-eastwards, draining an area of 64 square miles formed mainly from Beaufort rocks before it joins the Tugela just below Bergville. This stream was sampled just above the confluence (station 19) and the analyses gave the average results shown in Table 34. There appears to be little chemical disturbance in this stream, although its conductivity is about double what would be expected and the mean OA is on the high side (maximum recorded value 6.0 ppm) suggesting that it is to some degree organically enriched on occasion. The mineral composition of the water is in good agreement with what might be expected for a Beaufort area (see Figure 19).

TABLE 31

Hourly samples of effluents entering the Little Bushmans river

	Upper effluent		Lower effluent	
	Mean	Range	Mean	Range
Temperature, ^{o}C	31.6	28 - 36	43.6	38 - 46
Conductivity, micromho	299	144 - 880	69	66 - 75
pH value	8.96	7.0 - 9.3	7.12	7.0 - 7.2
BOD, ppm	33.8	3 - 125	7.8	2 - 25
OA, ppm	28.6	7.2 - 81	2.8	0.0 - 11.8
Flow, cusecs	*0.22*	*0.10 - 0.64*	*0.65*	*0.57 - 0.70*

TABLE 32

Average chemical analyses of samples from the Mooi river

	Stations				
	41	42	43	45	46
pH value	7.6	8.1	7.6	7.9	8.2
Conductivity, micromho	50	64	61	142	264
TDS, ppm	33	45	42	86	158
BOD, ppm	0.7	1.6	0.8	0.8	1.1
Nitrates, as ppm N	0.01	0.01	0.01	0.06	0.09
Phosphates, as ppm PO_4	0.10	0.11	0.09	0.12	0.18
Total alkalinity, as ppm $CaCO_3$	30.0	33.0	34.1	69.7	126.5
Total hardness, as ppm $CaCO_3$	21.0	18.5	18.9	51.5	90.8
Calcium, as ppm Ca	5.5	4.8	5.0	11.4	12.9
Magnesium, as ppm Mg	1.8	2.7	1.6	5.3	11.2
Sodium, as ppm Na	3.5	6.7	5.7	10.1	23.9
Potassium, as ppm K	0.7	0.7	0.9	0.9	1.4
Sulphates, as ppm SO_4	6.3	5.4	5.4	7.3	10.0
Chlorides, as ppm Cl	2.9	4.3	4.0	7.5	10.6
Silica, as ppm SiO_2	8.4	7.4	6.7	9.7	12.0

TABLE 33

Mooi river ; Faunal analyses of samples from the marginal vegetation
August, 1961

	Stations										
	36	37	38	39	40	41	42	43	44	45	46
Planariidae					1	25	830	12		2	
Prostoma sp.		1		3	1		30			1	
Nematoda	5	1		30		11	1600	20	10		
Chaetogaster sp.							2400	40		1	
Nais sp.			10	640			200		10		75
Limbriculidae		10									
Daphnia sp.								1			
Simocephalus sp.				10		70					
Leydigia quadrangularis				27				15			
Alona sp.					4						
Alona affinis							200				
A. guttata				26							
A. rectangula						35					
Chydorus gibsoni				27							
C. sphericus							155600	90			
C. sphericus form minor						144					
Macrocyclops albidus				880	32			15			
Tropocyclops confinis		31		880	32	41				70	
Eucyclops euacantus	31	30		880			800				
E. hadjebenis				880							
Paracyclops poppei									90		15
Mesocyclops sp.								15			
Microcyclops varicans						40					
Illyocypris australiensis											38
Herpetocypris chevreuzi			1								
Cypridopsis gregaria							5534				37
C. hirsuta				10	4	3	5534	15	111		
Stenocypris olivicea							5534				
Stenocypris sp.		53						15	110		
Gomphocytheria obtusa								15			
Collembola	20			1							
Austrocloeon africanum	62				8						
A. virgiliae										11	
Pseudocloeon inzingae	1										
P. vinosum	140	246	199		10	80		390	74	11	2
P. maculosum						4					
Baetis harrisoni			1				2	5	38	26	3
B. bellus					1						
B. glaucus										2	
B. latus				210					160	104	150
Centroptilum sudafricanum		50	158					39	20		
C. excisum		1			5	4		171	162	3	4
C. sp.											223
Caenis sp.								465	91		7
C. sp.	27		2	13		3	2	10	1	7	3
C. sp.		3									
Afronurus sp.			1								

Table 33 (continued)

	Stations										
	36	37	38	39	40	41	42	43	44	45	46
Pseudagrion sp.					1		48			20	2
Pseudagrion ? natalense	1			8				2	2		
Chlorocypha sp.										1	
Mesogomphus sp.									5		
Gerridae										3	
Velidae	19	2		12	3						
Rhagovelia nigricans				3							
Plea pullula						2					
Micronecta sp.											2
M. sp.					43	17	40	1			
Sigara sp.					2						
Goenides sp.		1									
Oecetis sp.			1							2	
Athripsodes prionli		4	5		5	8		3		3	
Leptoceridae	1										
Cheumatopsyche thomasetti							2				
Dipseudopsis sp.			2	2							
Ecnomus sp.							6	14			
Hydroptila capensis										4	180
Nymphula sp.					1						
Haliplus sp.						2					
Guignotus harrisoni						1					
Hydroporus sp.							6				
Laccophilus lineatus						2					
Aulonogyrus larvae								2			
Orectogyrus conformis								7			
Hydrophilidae				14							
Berosus sp.					1	1		1			
B. sp.										1	
B. sp.										2	
B. sp.										1	
Laccophilus sp.								1			
Hydroscaphidae				1							
Hydraenid larvae				33	1						
Limnobius sp.				2						1	
L. sp.	1	1				2				1	
L. sp.							6				
L. sp.				2							
Elmidae sp.								1			
E. sp.			1							1	
E. sp.				5							
E. sp.									2	9	
E. sp.					1			22			
E. sp.										1	
E. sp.						5			2		
Ptychoptera sp.			1								
Psychoda sp.											7
Dixa sp.	1			1							
Culex sp.				1							
Culex sp.										40	
Simulium larvae		11				5		20	10	20	
S. unicornutum form rotundum									1		

Table 33 (continued)

	Stations										
	36	37	38	39	40	41	42	43	44	45	46
Chironomidae							200				
Chironomidae sp.								110			
C. sp.										40	
Pentaneura sp.		63									
Pentaneura sp.		1	11	14				120		20	30
Corynoneura sp.	12		22								
C. sp.	5	11	10	1740	9	11		150	20	20	15
Orthocladinae sp.	12					12					
O. sp.		63			64	12		110			20
O. sp.			22	138						41	
O. sp.	12										
Tanytarsus sp.						12					
T. (Rheotanytarsus) sp.								110	120		
Chironominae sp.			22					110			
C. sp.										41	
Chironomus sp.										40	
Chironominae sp.											20
C. sp.	12		22							40	
C. sp.						12					
C. sp.											20
Ceratopogonidae	1		10	1	1	1		10	10	20	
Forcipomyia sp.										1	
Wiedemannia sp.		3									
Atherix sp.			1								
Limnophora sp.											1
Hydracarina			1	10	1	5		20			
Bulinus tropicus							154				
Lymnaea sp.										25	
Lymuaea natalensis					75		122				
Burnupia sp.			8								
Burnupia caffra				15	1	23		25		2	
B. ponsonbyi							2				
Ferrissia sp.						3					
Gyraulus sp.							320				
Pisidium sp.							22		2		
Rana fusigula		1								1	
R. fasciata						1					
Total:	363	587	511	6519	307	597	179194	2172	1051	639	854

The Little Tugela river is the principal tributary of the upper Tugela river, with a flow ranging between 80 and 800 cusecs, i.e. about 4 per cent of the total discharge of the Tugela system. It rises on the Drakensberg between Giants Castle and Champagne Castle and drains an area of 526 square miles, again mainly of Beaufort geology. Table 34 shows the average results of the analyses of samples taken below Winterton (station 20). These show no indication of disturbance and are in quite good agreement with the expectation (Figure 19), even the conductivity being of the correct order of magnitude.

The Klip river rises on the Drakensberg escarpment near Van Reenen. Its flow is less than that of the Little Tugela river although its catchment area is greater (see Table 1). This river supplies water to Ladysmith. Although it was not sampled during the early part of the Tugela survey, it had been studied a few years previously by other workers*, and the average of their results for samples taken below Ladysmith (station 42) is included in Table 34 (the sulphate concentration was estimated from more recent samples taken from tbe Windsor Dam above Ladysmith). These analytical results suggest that the river is disturbed. The conductivity is more than double its expected value and the results of the inorganic analysis (see Figures 19) do not agree very closely with expectation - this may be due to errors in the assumed values in Table 34. OA values up to 4.8 ppm were recorded.

The Bloukrans river, which joins the Tugela below Colenso, is of relatively low flow (see Table 1), often carrying little or no water at all but becoming 'a turbulent and muddy torrent after a heavy storm in the foothills of the Berg' (25), as a consequence of disastrous soil erosion in the upper part of its catchment. The average results from the analyses of samples taken just above its confluence with the Tugela (station 21) are given in Table 34. Clearly the conductivity is very high, and Figure 19 shows that the proportions of sulphate and chloride are greater and that of carbonate lower than might be expected from water derived from a Beaufort catchment. There is, however, no evidence of organic enrichment at this station.

G. THE MAIN TUGELA RIVER

The average results of chemical analyses of samples of water taken at stations on the main river are as shown in Table 35. Unfortunately neither DO nor BOD determinations were made. In no case do the analyses indicate any clear evidence of disturbance of the water. There was no significant difference, apart from concentration, between samples taken in the dry and rainy season, and when the overall average for each station, calculated in terms of percentages, is compared with the expectation for that station, the agreement is very good (see Figure 20). We do not have data for surface waters derived from Stormberg rocks, of which the uppermost regions of the Tugela catchment are composed, but these rocks have been reported (4) to yield waters very similar in composition to those from Beaufort rocks, so that the expectations have been calculated on the assumption that the Stormberg and Beaufort surface waters are identical.

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* CAPLAN, S.R., JACKSON, B.C.M., WEBB, M.M. and MIDDLETON, E.A. River surveys in the Tugela basin. Unpublished report of the Water Treatment Research Division of the National Chemical Research Laboratory, Pretoria, C.S.I.R., 1952.

TABLE 34

Average analytical results of water samples from minor tributaries of the Tugela river

	River/Station Nos.			
	Sandspruit 19	Little Tugela 20	Klip 42	Bloukrans 21
pH value	6.9	7.6	7.5	8.2
Conductivity, micromho	104	59	156	646
TDS, ppm	115	55	166	434
OA, ppm	4.1	1.0	2.3	0.7
Ammonia nitrogen, ppm	0.3	TR	TR	0.2
Nitrite nitrogen, ppm	0.002	0.005	0.014	-
Nitrate nitrogen, ppm	0.09	0.06	0.72	0.08
Phosphates, as ppm PO_4	1.40	0.50	-	Nil
Total alkalinity, as ppm $CaCO_3$	77.0	46.5	78.7	221.0
Total hardness, as ppm $CaCO_3$	54.9	32.0	72.1	245.5
Calcium, as ppm Ca	11.8	7.6	17.7	47.8
Magnesium, as ppm Mg	6.1	3.1	6.7	30.2
Sodium, as ppm Na*	15.5	6.8	9.7	66.8
Potassium, as ppm K*	1.2	1.2	2.0	2.0
Sulphates, as ppm SO_4	6.5	Nil	(7.6)	56.0
Chlorides, as ppm Cl	4.8	1.4	7.0	88.7

* Sodium calculated from the analysis, assuming 1.2 ppm K for the Sandspruit and Little Tugela and 2.0 ppm K for the Klip and Bloukrans.

Baetidae were always present in the faunal samples taken from the marginal vegetation (stations 2, 4, 5, 7, 8, 10, 12, 13, 16 and 18), indicating a biotic index of not less than 5 and hence no significant disturbance of the water. Because a net of larger mesh was used for the samples, the results are not comparable with those of subsequent river surveys; for this reason results of the faunal analyses are not tabulated here. (For further details, refer to Figure 9 of reference 19). According to these results, therefore, there is no evidence of any appreciable pollution in the main Tugela river.

The chemical analyses show that there is a small increase in sulphate and a decrease in carbonate in that part of the river between Colenso (station 9) and Tugela Ferry (station 12) which is not in accordance with expectation, and this is accompanied by an increase in conductivity beyond expectation (see Figure 20). These effects must be due in part to the Buffalo and Sundays rivers which have been shown to run at relatively high TDS and with a proportion of sulphate higher than expectation. However, the increase in TDS in the main Tugela river begins well before the entry of the Sundays river, and hence must, in part, be attributed to the fact that the region between Colenso and Tugela Ferry is the driest part of the Tugela valley (25).

At the same time that the main river was sampled, further samples were taken for chemical analysis from the lower reaches of the major tributaries. The average results of these analyses are given in Table 36, and are in agreement with the results recorded in Tables 8, 25, 27, 32 and 34. From these results (but relying on the data of Table 34 for the Klip river) together with the flow data of Table 5, the sources of dissolved material in the waters of the Tugela system can be computed to be as shown in Table 37. Some 20 per cent of the total load of dissolved material comes from that part of the Tugela basin above Colenso. This section, although giving rise to 38 per cent of the total flow (see Table 5), lies on Stormberg and Beaufort beds which yield surface waters of low TDS. The Buffalo river contributes 39 per cent of the dissolved load, i.e. about the same as its contribution to the total flow. From the region and tributaries between Colenso and Tugela Ferry comes 12 per cent of the total load (again the same as the proportion of the total flow), and 22 per cent of the total load is derived from that part of the basin below Tugela Ferry, excluding the Buffalo river, even though this portion contributes only 9 per cent of the total flow. This is accounted for by the fact that outcrops of Dwyka rocks and granites occur which are known to give rise to surface waters of relatively high TDS.

H. BACTERIOLOGICAL RESULTS

In 1965, twelve years after the commencement of the Tugela river survey, a bacteriological study was undertaken. At the same time, in order to check whether any marked changes had occurred in the water chemistry and to amplify the earlier results, some chemical analyses of the water were carried out. The electrical conductivity, dissolved oxygen (DO), biochemical oxygen demand (BOD) and pH value were measured at each station where bacteriological samples were taken. Such amplification was necessary because the omission of DO and BOD results from the earlier survey had left considerable gaps in the data which would not otherwise be filled.

TABLE 35

Average analytical results of water samples from stations on the main Tugela river

	Station No.													
	2	4	5	6	7	8	9	10	11	12	13	14	16	18
pH value	7.56	7.53	7.48	7.44	7.53	7.50	7.53	7.65	7.80	7.81	7.87	8.26	7.76	7.93
Conductivity, micromho	28	46	50	52	58	69	63	85	124	196	179	203	169	175
TDS, ppm	37	50	52	53	52	65	62	79	106	145	128	128	129	125
OA, ppm	0.1	0.3	1.1	0.9	1.9	1.2	1.3	1.5	1.8	1.7	2.2	1.5	3.3	2.8
Ammonia nitrogen, ppm	TR	Nil	TR	0.3	TR	0.1	0.1	0.1	0.2	0.1	1.2	0.1	0.2	0.2
Nitrite nitrogen, ppm	0.001	Nil	0.001	0.001	0.004	0.009	-	TR	0.001	TR	Nil	0.009	TR	0.005
Nitrate nitrogen, ppm	0.05	Nil	0.03	0.13	0.10	0.03	-	TR	0.12	0.17	TR	Nil	0.24	0.08
Phosphates, as ppm PO_4	0.20	-	0.70	0.70	0.80	0.50	-	-	-	-	-	-	-	-
Total alkalinity, as ppm $CaCO_3$	29.3	37.6	42.6	38.5	39.6	52.4	50.8	60.0	83.2	115.1	92.3	96.9	93.7	91.9
Total hardness, as ppm $CaCO_3$	25.0	30.3	32.3	32.3	32.9	45.8	46.6	53.7	82.3	78.2	84.2	84.8	79.0	82.4
Calcium, as ppm Ca	5.0	6.1	6.6	7.1	7.0	10.3	10.3	11.8	16.9	15.6	18.0	17.4	16.1	16.8
Magnesium, as ppm Mg	3.0	3.6	3.8	3.5	3.7	4.8	5.0	5.8	9.6	9.4	9.4	9.9	9.3	9.7
Sodium, as ppm Na*	3.1	5.9	4.0	5.0	4.2	5.2	4.3	6.8	7.7	29.3	13.8	16.9	16.9	15.6
Potassium, as ppm K*	0.4	0.5	0.5	0.5	0.5	0.7	0.6	0.8	1.1	1.5	1.3	1.3	1.3	1.3
Sulphates, as ppm SO_4	1.0	1.4	1.3	2.6	0.6	2.2	2.2	5.3	7.0	14.6	13.0	14.5	13.3	13.5
Chlorides, as ppm Cl	1.3	3.4	1.9	1.9	1.7	2.3	2.6	2.8	7.0	9.6	7.1	7.9	6.9	8.5

* Sodium calculated from the analysis, assuming a potassium concentration equal to 1% of the TDS

TABLE 36

Average analytical results of samples of water from the major tributaries

(Concurrent with results of Table 35)

River	Little Tugela	Bloukrans	Bushmans	Sundays	Mooi	Buffalo
Station No.	20	21	29	54	46	67
pH value	7.62	8.14	8.08	7.72	7.98	8.12
Conductivity, micromho	63	645	142	359	187	206
TDS, ppm	52	432	115	200	140	140
OA, ppm	1.6	0.8	0.9	5.4	1.2	2.9
Ammonia nitrogen, ppm	0.1	0.2	0.4	0.3	0.2	TR
Nitrite nitrogen, ppm	0.005	0.007	-	0.025	NIL	TR
Nitrate nitrogen, ppm	0.06	0.93	-	0.40	0.10	0.08
Phosphates, as ppm PO_4	0.50	-	-	-	-	-
Total alkalinity, as ppm $CaCO_3$	43.4	208.4	80.9	111.9	108.3	101.1
Total hardness, as ppm $CaCO_3$	36.0	275.4	84.0	109.0	88.5	94.7
Calcium, as ppm Ca	7.9	52.8	17.1	22.6	18.4	18.2
Magnesium, as ppm Mg	3.9	34.4	9.9	12.6	10.2	11.8
Sodium, as ppm Na*	4.2	54.4	5.7	32.1	16.7	18.3
Potassium, as ppm K*	0.5	4.3	1.2	2.0	1.4	1.4
Sulphates, as ppm SO_4	NIL	66.1	7.5	41.9	6.7	23.6
Chlorides, as ppm Cl	1.7	86.5	6.6	18.5	8.0	7.5

* Sodium calculated from the analysis, assuming a potassium concentration equal to 1% of the TDS.

TABLE 37

Sources of loads of dissolved material in the Tugela System

(c.f. Table 5 relating to water flow)

River	% of total load
Tugela above Bergville	6
Little Tugela	2
Tugela from Bergville to Colenso	12
Klip	3
Bloukrans	2
Bushmans	3
Sundays	3
Tugela from Colenso to Tugela Ferry	1
Mooi	7
Buffalo	39
Tugela below Tugela Ferry	22

The bacteriological methods employed were those utilized for the Umgeni river survey described in Part II, the bacteriological work being carried out simultaneously on samples from the Tugela and Umgeni rivers.

Samples were taken in May, June, September and October, 1965 and the results obtained are shown in Table 38. In May and June dry season conditions prevailed, but in September and october much rain had fallen in the catchment of the main Tugela and its southern tributaries, although the northern tributary catchments remained dry.

The plate counts indicated that organic enrichment was fairly general throughout the whole river system. At stations 18, 48 and 58 there was pollution and at stations 6, 24, 41, 42 and 77 there was more pronounced enrichment.

Faecal pollution was found at stations 48 and 58 and, on occasion, at other stations (see Table 38).

Staphylococcus aureus was isolated from most stations but was absent from the northern tributaries during the second and third sampling series (see Table 38). No Shigellae nor Proteus spp. were found at any station, but Salmonellae, Pseudomonas spp. and Paracolobactrum spp. were isolated at some places (see Table 39).

TABLE 38

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Results of chemical and bacteriological analyses of water from different stations on the Tugela River (First Series).

Station No.	Date of sampling	Time of sampling	Stream flow	Appearance of water	Temp. in °C.	pH value	Conductivity in micromho	DO ppm	DO saturation %	BOD ppm	Plate count per 1 ml	Presumptive E. coli I membrane count per 100 ml.	Confirmed E. coli I membrane count per 100 ml.	Confirmed Irregular II membrane count per 100 ml.	Confirmed Irregular VI membrane count per 100 ml.	Pseudomonas spp. in 500 ml of sample	Staphylococcus aureus membrane count per 50 ml.	Salmonellae in in 500 ml of sample
2	11.5.65	1315	15	Clean	19.5	7.95	43	8.2	105	0.6	132 000 E	0	0	0	0		0	
3	11.5.65	1200	25	Clean	17.0	7.85	44	8.7	107	0.1	137 000 E	32	32	0	0		0	
3	11.5.65	1345	25	Clean	19.0	7.53	42	8.7	110	0.7	108 500 E	296	60	238	0	-	0	-
4	11.5.65	1115	65	Clean	16.0	7.95	56	9.2	106	0.5	715 000 E	46	46	0	0		0	
5	11.5.65	0800	90	Clean	14.5	7.68	75	9.3	103	0.5	119 000 E	256	204	52	0		0	
6	11.5.65	1015	100	Slightly turbid	16.5	7.89	55	9.5	110	1.1	2 650 000 P	164	164	0	0		0	
6	11.5.65	1530	100	Slightly turbid	19.0	7.68	63	8.8	107	1.0	335 000 P	128	128	0	0	-	0	-
7	18.5.65	0830	120	Clean	13.0	7.83	60	10.0	106	0.5	180 000 E	30	24	6	6		1	
8	18.5.65	1000	120+	Slightly turbid	14.0	7.93	70	10.0	108	0.7	440 000 E	196	196	0	0		1	
9	18.5.65	1055	120+	Clean	17.0	7.93	76	9.5	110	0.9	145 000 E	92	92	0	0	+	0	-
10	18.5.65	1330	150+	Clean	16.5	7.98	82	9.6	106	0.4	100 000 E	16	16	0	0		0	
11	18.5.65	1525	150+	Slightly turbid	17.0	8.12	131	10.0	111	1.0	360 000 E	58	58	0	0	+	4	-
12	16.6.65	0940	200+	Clean	15.5	8.0	181	10.2	108	1.2	2 365 000 E (?)	193	193	0	0		0	
13	16.6.65	1200	200+	Clean	15.0	8.2	190	9.9	102	0.6	550 000 E	64	64	0	0		1	
15	16.6.65	1445	200+	Slightly turbid	15.5	7.95	190	10.1	104	0.8	700 000 E	54	54	0	0		6	
16	16.6.65	1545	200+	Slightly turbid	15.5	8.2	188	10.3	108	1.3	140 000 E	1 400	1 400	280	0	-	0	-
17	24.5.65	1255	150+	Slightly turbid	20.0	7.89	180	12.2	134	2.6	440 000 P	68	56	0	12		63	
18+	24.5.65	1330	150+	Dirty	21.0	7.92	225	9.0	101	1.3	285 000 P	260	220	0	40	-	525	+
20	11.5.65	0745	35	Clean	14.0	7.94	76	9.8	106	1.5	525 000 E	294	246	48	0		0	
21	18.5.65	1410	6	Clean	20.0	8.78	510	11.0	130	2.2	465 000 E	132	132	0	0		1	
22	8.6.65	1420	40	Slightly turbid	12.5	7.49	53	10.0	107	0.5	125 000 E	0	0	0	0		2	
24++	8.6.65	1530	45	Slightly turbid	11.5	7.76	73	10.6	111	0.9	145 000 E	80	80	0	0	+	10	-
27	18.5.65	1730	30	Dirty	15.5	8.2	169	9.0	99	1.4	450 000 E	600	500	0	100		880	
28	18.5.65	1710	30	Dirty	15.5	8.2	158	9.7	118	1.4	400 000 E	1 500	1 500 F	0	0	+	690	-
29	18.5.65	1550	35	Turbid	18.0	8.3	149	9.8	112	3.0	355 000 E (?)	4 700	2 400 F	2 300	0		125	
41	8.6.65	1625	50	Clean	8.5	7.5	66	10.8	109	2.0	170 000 E (?)	100	80	0	20		2	
42	8.6.65	1655	50	Clean	8.5	7.45	60	10.8	109	2.0	85 000 E (?)	150	120	30	0	-	0	-
45	16.6.65	0845	60	Clean	11.5	7.85	138	10.1	107	0.2	85 000 E	200	200	0	0		0	
46	16.6.65	0925	60	Clean	12.5	8.2	270	8.0	82	0.8	140 000 E	590	494	96	0	-	0	+
47	8.6.65	1200	10	Slightly turbid	11.5	8.12	135	10.7	111	0.6	465 000 E	70	70	0	0		40	
48	8.6.65	1310	12	Slightly turbid	12.5	8.1	144	13.3	142	3.7	115 000 P	28 000	0	16 800	11 200	-	30	-
51	7.6.65	1615	6	Clean	11.5	7.89	74	10.0	107	0.7	130 000 E	64	64	0	0		30	
53	8.6.65	0925	6	Clean	10.0	7.7	152	10.9	113	1.5	70 000 E	14	14	0	0	-	50	-
57	8.6.65	0845	6	Clean	10.5	8.2	2021	10.2	102	0.9	100 000 E	190	190	0	0	+	8	-
58+	14.6.65	1045	1	Dirty	10.0	6.79	392	0.0	0	>31.0	2 710 000 P	86 000	68 800 F	17 200	0	-	20	-
63	14.6.65	1635	20	Clean	12.0	8.45	304	10.4	111	1.2	135 000 E	72	72	0	0	-	0	-
64	14.6.65	1735	30	Clean	13.0	8.28	300	9.2	99	3.0	855 000 E (?)	84	84	0	0	-	0	-
70	14.6.65	0950	12	Clean	7.0	7.8	100	0.7	96	0.9	60 000 E	16	12	4	0		20	
77	14.6.66	1400	-	Slightly turbid	14.0	8.89	514	8.2	91	4.7	345 000 E (?)	116	116	0	0	-	200	-
84	14.6.65	1300	6	Slightly turbid	13.0	7.65	578	10.0	108	0.4	130 000 E	220	220	0	0	-	10	-
93	14.6.65	1610	4	Slightly turbid	11.0	8.06	140	9.4	97	1.0	90 000 E	20	20	0	0	-	35	-

TABLE 38 (CONTINUED)

Results of chemical and bacteriological analyses of water from different stations on the Tugela River (Second Series).

Station No.	Date of sampling	Time of sampling	Stream flow	Appearance of water	Temp. in °C.	pH value	Conductivity in micromho	DO ppm	DO saturation %	BOD ppm	Plate count per 1 ml	Presumptive E. coli I membrane count per 100 ml.	Confirmed E. coli I membrane count per 100 ml.	Confirmed Irregular II membrane count per 100 ml.	Confirmed Irregular VI membrane count per 100 ml.	Pseudomonas Spp in 4 litres	Staphylococcus aureus membrane count per 50 ml.	Salmonellae in 4 litres sample
2	7.9.65	1400	25	Clean	16.5	7.66	38	9.3	112	1.0	11 000	5	4	1	0		13	
3	7.9.65	1445	35	Clean	18	7.70	34	9.1	114	1.0	14 400	65	68	0	17		16	
4	7.9.65	1530	80+	Dirty	17.5	7.60	37	8.7	105	1.1	55 100 E	752	752	0	0		52	
5	7.9.65	1615	100+	Dirty	15	7.35	36	8.8	98	0.9	78 500 E	1 560	1 560 F	0	0		28	
6	7.9.65	1635	100+	Dirty	16	7.40	37	8.8	100	1.1	61 500 E (?)	2 028	2 028 F	0	0		34	
7	8.9.65	0715	120+	Dirty	15	7.39	45	8.7	96	0.5	40 750 E	1 308	1 308	0	0		42	
8	8.9.65	0745	150+	Dirty	16.5	7.70	51	8.6	98	0.2	39 700 E	808	808	0	0		15	
9	8.9.65	0805	150+	Dirty	16.5	7.62	55	9.4	108	1.2	46 700 E (?)	852	710	0	142		21	
10	8.9.65	1030	250+	Dirty	17.5	7.80	72	10.0	113	1.7	46 000 E (?)	690	690	0	0		34	
11	8.9.65	1145	300+	Dirty	19	7.80	95	8.8	101	1.8	40 500 E (?)	648	518	130	0		46	
12	8.9.65	1315	300+	Dirty	20	7.91	88	9.3	108	1.1	69 750 E	1 188	950	238	0		18	
13	8.9.65	1500	400+	Dirty	20.5	7.75	120	8.0	93	0.6	99 500 E	4 000	4 000 F	0	0		3	
15	13.9.65	1550	400+	Turbid	23.5	7.88	158	8.3	101	0.3	43 250 E	554	430	0	124		78	
16	13.9.65	1650	400+	Turbid	24.5	7.93	127	8.2	102	1.5	26 850 E	806	570	0	236		167	
17	14.9.65	1155	450+	Dirty	25	8.25	121	8.5	103	0.5	103 000 P	470	336	0	134	-	0	+
18	14.9.65	1130	450+	Dirty	25	7.90	253	7.8	95	>7.8	398 250 P	50	20	0	30	-	0	+
20	7.9.65	1730	45	Turbid	16	7.69	53	8.9	101	0.9	47 500 E	1 373	1 144	0	229		0	
21	8.9.65	1015	12	Dirty	19	7.75	245	8.7	102	1.4	84 600 E (?)	1 790	1 790 F	0	0		0	
22	13.9.65	0750	45	Slightly Turbid	14	7.87	49	8.9	99	0.1	14 250	2	0	0	2		0	
24	13.9.65	0825	50	Slightly Turbid	15.5	7.30	75	8.8	100	1.2	38 000 E (?)	152	77	0	75		0	
27	13.9.65	0945	55	Slightly Turbid	19	7.70	80	8.2	97	1.1	36 150	708	708	0	0		0	
28	13.9.65	1015	55	Slightly Turbid	19.5	8.10	94	9.8	117	2.0	34 000	1 480	1 324	156	0		0	
29	8.9.65	1100	60+	Dirty	18	8.10	103	9.1	105	1.2	56 600 E (?)	2 320	2 320 F	0	0		5	
29	13.9.65	1055	60	Slightly Turbid	22	8.15	107	8.4	104	1.1	39 750 E (?)	7 200	7 200 F	0	0		335	
41	13.9.65	0620	55	Slightly Turbid	16.5	7.52	38	8.9	106	1.8	45 300 E (?)	187	172	0	15		358	
42	13.9.65	0650	60	Slightly Turbid	17	7.71	36	8.6	105	2.2	41 000 E (?)	238	238	0	0		262	
45	13.9.65	1215	65	Turbid	19.5	7.79	70	7.5	93	0.1	32 550	479	349	130	0		318	
46	8.9.65	1345	80+	Dirty	18.5	7.84	73	8.5	99	2.6	60 550 E (?)	1 021	1 021	0	0		5	
46	13.9.65	1310	70	Turbid	23	7.99	88	8.0	100	0.5	38 550 E (?)	1 290	875	0	415		365	
47	5.10.65	1630	8	Turbid	22	8.41	166	8.6	112	0.8	36 000 E	1 355	1 169	186	0		0	
48	5.10.65	1515	8	Turbid	22	8.19	190	8.9	115	4.8	82 750 P	76 520	60 800 F	0	15 720		0	
51	5.10.65	1220	6	Turbid	18.5	8.25	113	9.0	113	1.3	41 900 E	108	108	0	0		0	
53	5.10.65	1410	6	Dirty	25	7.91	139	7.9	108	0.9	42 300 E	1 750	1 219	531	0		0	
57	5.10.65	1330	3	Clean	30	8.52	2 223	8.6	127	1.2	36 400 E	580	580	0	0		0	
58+	4.10.65	0840	0.25	Dirty	8	6.0	163	0	-	>27.0	3 840 000 P	3 800	760	2 280	760		0	
63	4.10.65	1210	18	Clean	18.5	8.6	298	9.4	116	0.2	12 100	150	150	0	0		0	
64	4.10.65	1340	20	Turbid	18	8.2	330	10.7	129	1.8	61 700 E	291	291	0	0		0	
65	4.10.65	1445	24	Slightly Turbid	18.5	8.63	320	9.2	112	0.9	14 100	19	9	5	5		0	
77	4.10.65	1020	-	Turbid	18	8.15	746	7.5	91	4.1	48 100 E (?)	230	184	46	0		0	
84	4.10.65	0955	8	Slightly Turbid	15	8.15	491	8.8	99	1.0	92 150 E	141	141	0	0		0	
70	4.10.65	0710	12	Slightly Turbid	9	8.16	127	9.0	94	0.7	46 000 E	156	156	0	0		0	
93	4.10.65	1240	4	Turbid	16.5	7.94	117	8.4	98	1.2	49 800 E	126	126	0	0		0	

TABLE 38 (CONTINUED)

Results of chemical and bacteriological analyses of water from different stations on the Tugela River (Third Series).

Station No.	Date of sampling	Time of sampling	Stream flow	Appearance of water *	Temp. in °C.	pH value	Conductivity in micromho	DO ppm	DO saturation %	BOD ppm	Plate count per 1 ml	Presumptive E. coli I membrane count per 100 ml.	Confirmed E. coli I membrane count per 100 ml.	Confirmed Irregular II membrane count per 100 ml.	Confirmed Irregular VI membrane count per 100 ml.	Pseudomonas spp in 4 litres	Staphylococcus aureus membrane count per 50 ml.	Salmonellae 4 litres sample
1	30. 9.65	0930	5	Clean	9.0	7.45	32	9.2	96	0.1	1 020	0	0	0	0		0	
2	20. 9.65	0630	20	Clean	13.0	7.35	41	9.5	107	0.5	17 850	7	4	1	2		0	
2	30. 9.65	1145	18	Clean	15.5	7.39	40	8.4	98	0.5	58 400 E	1	1	0	0		0	
3	20. 9.65	0650	25	Clean	13.5	7.69	41	9.0	102	0.2	25 350	42	42	0	0		5	
4	20. 9.65	0725	60	Turbid	18.0	7.35	40	7.7	94	0.9	75 550 E	2 352	1 680 F	0	672		24	
5	20. 9.65	0755	80+	Turbid	19.0	7.35	42	7.8	94	1.0	90 750 E	2 040	1 700 F	0	340		22	
6	20. 9.65	0920	80+	Turbid	19.0	7.49	43	7.7	93	1.0	67 250 E (?)	796	796	0	0		62	
7	20. 9.65	1035	80+	Turbid	20.0	7.61	57	7.9	97	1.2	112 000 E	892	745	74	73		32	
8	20. 9.65	1150	90+	Turbid	20.0	7.58	69	8.3	101	1.6	82 250 E	901	638	125	138		72	
9	20. 9.65	1125	90+	Turbid	22.0	7.75	61	8.6	110	0.6	49 500 E (?)	376	292	0	84		182	
10	20. 9.65	1530	180+	Dirty	23.0	7.81	86	7.8	98	1.3	151 100 E (?)	4 304	2 462 F	0	1 842		15	
11	20. 9.65	1615	200+	Turbid	23.0	7.75	110	8.1	100	1.3	104 600 E (?)	518	422	48	48		106	
12	21. 9.65	1030	200+	Dirty	18.0	7.95	125	8.0	90	2.0	282 000 E	28 200	28 200 F	0	0		6	
13	21. 9.65	1155	270+	Dirty	19.5	7.91	147	8.1	91	3.7	231 000 E	51 100	36 500 F	0	14 600		40	
15	21. 9.65	1415	300+	Dirty	33.5	8.10	133	8.4	121	2.4	143 050 E	5 008	3 830 F	0	1 178		45	
16	21. 9.65	1530	300+	Turbid	28.0	8.15	128	8.7	113	2.3	301 000 E	1 355	855	250	250		75	
17	22. 9.65	1145	350+	Turbid	25.5	8.43	133	8.4	103	1.4	48 000 P	530	530	0	0		0	
18	22. 9.65	1245	350+	Turbid	26.5	8.41	166	7.8	98	3.3	228 100 P	450	450	0	0		10	
20	20. 9.65	1005	40	Turbid	19.0	7.85	65	8.2	98	1.2	91 950 E	1 568	1 138	0	430		62	
21	20. 9.65	1515	20	Dirty	26.0	8.25	224	7.2	96	3.1	168 550 E (?)	5 740	4 100 F	0	1 640		125	
22	20. 9.65	1235	45	Clean	16.0	8.15	49	8.8	101	0.2	27 250	0	0	0	0		1	
24	20. 9.65	1305	45	Slightly Turbid	17.0	8.13	67	8.9	106	1.0	83 550 E (?)	170	142	0	28		162	
27	20. 9.65	1415	55	Turbid	20.0	7.93	88	8.4	101	0.8	129 700 E	240	120	0	120		210	
28	20. 9.65	1435	55	Turbid	23.0	8.10	106	8.2	104	1.3	103 350 E (?)	476	340	0	136		186	
29	20. 9.65	1545	60	Turbid	23.0	8.45	132	8.1	101	1.6	121 350 E (?)	252	180	0	72		25	
41	21. 9.65	0630	50	Slightly Turbid	16.5	7.80	59	7.7	92	0.7	82 400 E (?)	172	98	0	74		355	
42	21. 9.65	0700	55	Slightly Turbid	16.5	7.67	47	7.3	87	0.7	63 000 E (?)	190	112	0	78		245	
45	21. 9.65	0900	65	Turbid	18.5	8.18	72	9.0	111	1.4	69 100 E (?)	1 394	818	184	392		240	
46	21. 9.65	0950	75	Dirty	13.5	8.05	145	8.8	92	8.7	710 000 E (?)	129 000	129 000 F	0	0		945	
47	11.10.65	0605	16	Turbid	14.0	8.30	173	7.8	86	0.3	41 550 E	3 130	3 130 F	0	0		0	
48	11.10.65	0640	16	Turbid	15.0	8.20	235	6.2	70	4.5	568 000 P	129 600	64 800 F	16 800	48 600		0	
51	11.10.65	0715	4	Slightly Turbid	15.0	8.26	128	8.4	96	1.2	14 250	103	103	0	0		0	
53	11.10.65	0835	4	Dirty	15.0	8.92	175	8.6	96	2.2	65 400 E	520	420	100	0		0	
54	11.10.65	1500	6	Slightly Turbid	25.0	8.50	745	8.8	113	1.1	44 000 E	91	91	0	0		0	
57	11.10.65	0910	2	Clean	20.0	8.39	2 040	7.5	92	0.2	17 250	790	790	0	0		0	
58+	5.10.65	0845	0.25	Dirty	11.5	4.80	211	0	-	>24.5	2 868 000 P	920 000	368 000 F	552 000	0	-	0	-
64	11.10.65	1125	8	Slightly Turbid	20.0	8.42	355	8.6	107	0.7	22 350	454	454	0	0		0	
65	11.10.65	1045	12	Slightly Turbid	20.0	8.59	357	8.8	96	0.5	17 850	320	320	0	0		0	
77	5.10.65	1115	-	Dirty	21.0	7.90	834	8.3	106	2.2	235 100 E (?)	124	113	11	0		0	
84	5.10.65	1040	8	Slightly Turbid	18.0	8.20	469	9.4	114	1.6	92 650 E	1 865	1 865 F	0	0		0	
70	5.10, 65	0810	12	Slightly Turbid	11.5	8.16	119	9.9	109	2.3	32 000	120	120	0	0		0	

F = Faecal pollution E = Organic enrichment P = Organic pollution + Sewage fungus and iron bacteria observed. ++ Sewage fungus observed

* Except for stations TUG 12 - 15, TUG 27, 29 and TUG 35 - 42, all other stations were tested for Salmonella typhi 'phage during the first sampling series, and were found to be negative. This test was not employed during the second and third series.

** Stations TUG 3 (at 1345), 6 (at 1530), 9, 11, 15, 16, 20, 22, 25, 28, 30, 32, 34, 37 and 39 and 39 - 42 were tested for intestinal pathogens during the first series but no Shigellae were isolated in 500 ml of water. At these stations no Proteus spp. were isolated. During the second and third series this test was performed on 4 litres of water but no Shigella spp. and Proteus spp. were isolated.

*** Algae observed at many stations during the first series except TUG 6, 8, - 12, 16, 17, 22, 25, 35, 37, 41, 42. During the second series algae were observed only at TUG 21, 25, 26, 34, 40 and 41; and during the third series only at TUG 21, 26, 30, 31, 33, 34, 38, 40 and 41.

*** Algae observed at many stations during the first series except [illegible] During the second series algae were observed only at [illegible] and during the third series only at [illegible]

Station No.	Date of sampling	Time of sampling	Sub. No.	Culture collection No.	Butt	Slant	H_2S	Urea	Salmonella antisera H	O	MacConkey broth 48 hrs	MacConkey broth 44.5°C	Indole	M.R.	V.P.	Citrate	Gelatin liquefaction	Litmus milk	Slime production	Pigment production	Lactose	Sucrose	Identification
3	11.5.65	1345	1		AG	NC	-	-	-	-	- (14 days)		+	-	+	-	+						Paracolobactrum aerogenoides
			2		AG	NC	-	-	-	-	- (14 days)		+	-	+	-	+						Paracolobactrum aerogenoides
			3		AG	NC	-	-	-	-	- (14 days)		+	-	+	-	+						Paracolobactrum aerogenoides
			4		AG	A	-	-	-	-	AG	-	-	-	+	+	-						Klebsiella aerogenes I
			5		AG	A	+	-			AG	-	-	+	-	+	-						Citrobacter freundii I
			6		AG	A	-	-			AG	-	+	-	+	+	-						Klebsiella aerogenes II
			7		AG	NC	-	-			- (14 days)		+	-	-	-	+						Paracolobactrum aerogenoides
			8		AG	NC	-	-			AG	-	-	-	+	+	-						Klebsiella aerogenes I
6	11.5.65	1530	1		AG	A	-	-			AG	-	-	-	+	-	-						Irregular V
			2		AG	A	-	-			AG	-	-	+	-	+	+						Irregular IV
			3		AG	A	-	-			AG	-	-	-	+	+	-						Klebsiella aerogenes I
9	18.5.65	1055	1		AG	A	-	-	+	+											A	-	Paracolobactrum sp.
			2		NC	NC	-	-	-	-			-			-	+	Peptonised	+	(Blue and (green	-		Pseudomonas aeruginosa
			3		NC	NC	-	-	-	-			-			-	+	Peptonised	+	(Blue and (green	-		Pseudomonas aeruginosa
			4		AG	A	-	-	+	+											A	A	Paracolobactrum sp.
			5		AG	A	-	-	-	-	AG	-	-	-	+	+	-						Klebsiella aerogenes I
			6		A	NC	-	-	-	-	AG	-	+	+	-	-	-						Escherichia coli III
11	18.5.65	1525	1		AG	A	-	-	-	-	AG	-	-	-	+	+	-						Klebsiella aerogenes I
			2		NC	NC	-	-					-			+	+	Peptonised	+	-	-		Pseudomonas aeruginosa
			3		NC	NC	-	-					-			+	+	Peptonised	+	Blue green			Pseudomonas aeruginosa
			4		A	NC	-	-			AG (4 days)		-	-	+	+	-						Paracolobactrum aerogenoides
			5		AG	A	-	-			AG	-	-	-	+	+	-						Klebsiella aerogenes I
			6		AG	A	-	-			AG	-	-	-	+	+	-						Klebsiella aerogenes I
16	16.6.65	1545	1		AG	NC	-	-			AG (10 days)		-	-	+	+	-						Paracolobactrum aerogenoides
			2		AG	NC	-	-			AG (10 days)		-	-	+	+	-						Paracolobactrum aerogenoides
			3		AG	NC	-	-			AG (10 days)		-	-	+	+	-						Paracolobactrum aerogenoides
			4		AG	NC	-	-			AG (10 days)		-	-	+	+	-						Paracolobactrum aerogenoides
			5	113	AG	NC	-	-	+	+													Paracolobactrum sp.
18	24.5.65	1330	1	98	AG	NC	+	-	+	+													Salmonella cero 18: z_4, z_{23}:-
			2	99	AG	NC	+	-	+	+													Salmonella sp.
			3		AG	NC	+	-	-	-	- (14 days)		-	+	-	+	-						Paracolobactrum intermedium
			4		AG	A	-	-			AG	-	-	-	+	+	-						Klebsiella aerogenes I
			5		AG	NC	-	-			AG (7 days)		-	-	+	+	-						Paracolobactrum aerogenoides
24	8.6.65	1530	1		NC	NC	-	-					-	-	-	+	+	Peptonised	+	–	-		Pseudomonas aeruginosa
			2		NC	NC	-	-					-	-	+	+	+	Peptonised	+	–	-		Pseudomonas aeruginosa
25	18.5.65	1710	1		NC	NC	-	-					-			+	+	Peptonised	+	Blue/green	-		Pseudomonas aeruginosa
			2		NC	NC	-	-					-			+	+	Peptonised	+	-	-		Pseudomonas aeruginosa
			3		NC	NC	-	-					-			+	+	Peptonised	+	Blue/green	-		Pseudomonas aeruginosa
			4		AG	A	-	-			AG	-	-	-	+	+	-						Klebsiella aerogenes I
46	16.6.65	0925	1	114	AG	NC	+	-	+	+													Salmonella Oranienburg. 6, 7: m, t:-
			2	115	AG	NC	+	-	+	+													Salmonella infant is 6, 7: +; 1, 5.
			3	116	AG	NC	+	-	+	+													Salmonella Oranienburg: 6, 7. m, t:-
			4	117	AG	NC	+	-	+	+													Salmonella infants 6, 7: + 1, 5.
48	8.6.65	1310	1		A	NC	-	-	-	-	- (14 days)		+	-	+	-	+						Paracolobactrum aerogenoides
53	8.6.65	0925	1		AG	NC	-	-	-	-	- (14 days)		-	-	+	+	-						Paracolobactrum aerogenoides
			2		AG	NC	-	-	-	-	- (14 days)		-	-	+	+	-						Paracolobactrum aerogenoides
57	8.6.65	0845	1		NC	NC	-	-					-	-	-	+	+	Peptonised	+	-	-		Pseudomonas aeruginosa
58	14.6.65	1045	1		AG	NC	-	-			- (14 days)		-	-	+	+	-						Paracolobactrum aerogenoides
			2		AG	A	-	-	-	-	AG	-	-	-	+	+	-						Klebsiella aerogenes I
63	14.6.65	1635	1	108	AG	NC	-	-	+	+													Paracolobactrum sp.
			2		AG	NC	-	-	-	-	AG (5 days)		-	-	+	+	-						Paracolobactrum aerogenoides
64	14.6.65	1735	1	109	AG	NC	-	-	+	+			-	-	+	+	-						Paracolobactrum sp.
			2		AG	NC	-	-	-	-	AG	-	-	-	+	+	-						Klebsiella aerogenes I
77	14.6.65	1400	1		AG	NC	-	-	-	-	- (14 days)		-	-	+	+	-						Paracolobactrum aerogenoides
84	14.6.65	1330	1		AG	NC	-	-	-	-	AG (5 days		-	-	+	+	-						Paracolobactrum aerogenoides
70	14.6.65	0950	1		AG	NC	-	-	-	-	- (14 days)		-	-	+	+	-						Paracolobactrum aerogenoides
93	14.6.65	1610	1		AG	NC	-	-	-	-	AG (5 days)		-	-	+	+	-						Paracolobactrum aerogenoides

TABLE 39 continued/...

Bacteria isolated from some of the Tugela river stations

Station No.	Date of sampling	Time of sampling	Sub. No.	Durban culture No.	Butt	Slant	H_2S	Urea	Agglutination with polyvalent *Salm.* antisera		MacConkey Broth 37^oC 48 hrs	MacConkey Broth 44.5^oC 48 hrs	Indole	M.R.	V.P.	Citrate	Gelatin liquefaction	Litmus milk	Slime medium	Pigment production	Lactose	Sucrose	Identification
									H	O													
17	14.9.65	1155	1	154	A(G)	NC	+	-	+	-											-	-	*Salmonella* sp.
			2	155	AG	NC	+	-	+	-											-	-	*Salmonella* sp.
			3	156	AG	NC	+	-	+	-											-	-	*Salmonella* sp.
			4	157	AG	NC	+	-	+	-											-	-	*Salmonella* sp.
18	14.9.65	1130	5	158	AG	NC	+	-	+	+											-	-	*Salmonella* sp.
			6		NC	NC	-	-					-			+	-	No change	-	-	-	-	*Alcaligenes faecalis*
			7		NC	NC	-	-					-			+	-	No change	-	-	-	-	*Alcaligenes faecalis*
			8		A(G)	NC	+	-	-	-	A (14 days)	-	-	+	-	+	-	Reduced			-	-	*Paracolobactrum intermedium*

The results of chemical tests which were made simultaneously with the bacteriological work, confirm the bacteriological evidence of pollution and in addition agree with the results obtained during the earlier stages of the survey. This was only to be expected, since the development of the Tugela Basin has not progressed appreciably in the intervening years. In the main river the BOD values were higher in the portion below Colenso than in the portion above, being highest in the vicinity of Ngubevu (station 13), although there is no clear explanation for this (it may be of agricultural origin or due to the passage of the river through Bantu reserves). High BOD values in the Klip river at station 48 confirm pollution, while in the Mooi river at stations 41 and 42 they suggest a slight degree of pollution. The Bushmans river appears scarcely disturbed at station 24. The lower Bushmans river (station 28) and the lower Mooi river (station 46), however, show signs of organic disturbance which might be attributed to agricultural activities and irrigation. The lower Sundays river (station 54) was mineralized, clearly owing to the mineral effluents carried into it by the Wasbank tributary (station 57). The Bloukrans river (station 21) was also mineralized and organically enriched, probably effects caused by agricultural activities in its catchment area.

8. POLLUTION AND WATER QUALITY

The survey has shown that sources of water pollution in the Basin are relatively few in number. This is clearly attributable to the absence of any great urban or industrial development. Apart from the Little Bushmans river, where organic pollution has been detected its degree of pollution is nothing as intense as that found associated with industries and towns elsewhere in Natal (see Part II).

In Table 40 is shown the classification according to quality (see Part I) of the water at each sampling station used in the 1965 survey. Figure 21 is a water quality diagram of the Tugela river catchment based mainly on Table 40 but also incorporating the results of earlier surveys.

It will be seen that water of highest quality (Class I) was found only in the uppermost reaches of the main Tugela river. Some of the tributaries in this area may also contain such water, but there is no evidence that it occurs anywhere else in the Tugela system.

The main river for most of its length and most of the tributaries contain water of Class II. The Tugela river system may therefore be said on the whole to carry water of medium quality, soft, potentially corrosive according to its pH_s value and in many instances probably difficult to treat by the usual methods of pH_s correction on account of the low TDS and consequent low buffering power. The water is suitable for drinking after conventional treatment (coagulation, filtration, disinfection) and also for most other uses. The high silt loads often carried by the rivers, especially during times of flood, can prove troublesome to water users, but the flocculation of suspended matter should readily be achieved by the usual processes of water purification.

Most of the instances of pollution detected also show up in Figure 21 as changes in classification.

TABLE 40

Classification of water quality at sampling stations on the Tugela river system (1965 survey)

Station No.	Quality Class	Station No.	Quality Class
1	I	41	II
2	II	42	II
3	II	45	II
4	II	46	V
5	III	47	II
6	III	48	V
7	II	51	II
8	II	53	II
9	II	54	II
10	II	57	IV
11	II	58	VI
12	II	63	II
13	III	64	II
15	II	65	II
16	II	70	II
17	II	77	III
18	V	84	III
20	II	93	II
21	III		
22	II		
24	II		
27	II		
28	III		
29	III		

Class III waters are found in the main river and in the Sandspruit near Bergville, in the main river near Ngubevu, in the Incandu, Ingagane and Umzinyatshana rivers as well as probably the lower reaches of the Klip river, in each case as a consequence of pollution of one kind or another. The Bloukrans river also falls in this group because of the mineralization of its water.

The Wasbank tributary of the Sundays river contains water of Class IV, as also does the Umzinyatshana tributary. This is because of the higher degree of mineralization of these streams caused by effluents from working and abandoned coal mines. Many of the smaller streams of the coalfields must also be placed in this Class for the same reason.

Class V waters occur in the Klip river below Ladysmith (organic pollution); in the Little Bushmans river at Estcourt (heavy organic pollution); in the lower reaches of the Mooi river (mineral and organic pollution); in the Steenkoolspruit at Dundee (mineral and organic pollution), and in the lower reaches of the main Tugela river below Mandini (mainly organic pollution). Only in the Buffalo river below Volksrust were waters of Class VI detected.

In several of these cases the introduction of relatively simple and economic means of effluent elimination and treatment would result in an improvement of the water quality. It should certainly be possible to reduce organic pollution in the Tugela river system so that most of the Class V and VI waters become no worse than Class III, while the Class III water at Bergville should be open to improvement to Class II since the existing pollution there is not of high degree. However, the elimination of organic pollution from the Steenkoolspruit at Dundee would only bring this stream to Class IV, since it also carries mineral pollution. At the present time the existing cases of Class IV water cannot be improved because there is no known means of dealing effectively with mineral pollution from coal mines.

The state of affairs that would result should measures of this kind be implemented is shown in Figure 22. The improved water quality shown in Figure 22 should be the target for future pollution abatement schemes in the Tugela Basin. However, the conclusion drawn from the discussion of mineral pollution from coal mines in the Appendix to this report must be borne in mind when considering the future of the Tugela Basin (see page 73). On the basis of field observations it has been found that whenever a stream passes any active or disused mine, its water is usually polluted by mineral materials. In many areas small streams in the Natal coalfields are so heavily mineralized from such sources that their waters have become quite unfit for any use at all, and as long as coal mining continues at its present rate of output this kind of pollution, of necessity, becomes progressively worse. In 20 - 40 years time it may well be that most of the smaller streams of this part of Natal will be made useless in this way and even the larger rivers, which at present are fortunately hardly affected at all, will show appreciable pollution. Planning, research and the development of a regional pollution abatement scheme will be necessary to prevent such a situation arising, and 20 years is all too short a time in which to do this.

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APPENDIX

MINERAL POLLUTION FROM COAL MINES

1. NATURE AND ORIGIN OF THE PROBLEM

The pollution of surface waters by the drainage from working and disused coal mines is a problem which always arises wherever coal mining is undertaken and one which has been studied in many countries of the world. Pollution from this source adversely affects the aesthetic appearance of streams and rivers, destroys the living organisms that inhabit them and hence reduces the self-purifying powers of the waters, makes streams unfit for most uses, and requires surface waters to be extensively treated, which is not always possible, before they are suitable for use. Thus extensive pollution from coal mines entails considerable expenditure on the part of all water users if its direct and indirect effects are to be combatted while attempts at devising and applying measures to reduce the pollution increase the operating costs of the mines themselves.

The drainage waters from coal mines vary widely in appearance from almost colourless to deep orange-red. They contain the sulphates of ferrous and ferric iron, aluminium, calcium, magnesium and usually sodium in solution, though the relative proportions of these vary greatly from case to case. They precipitate iron compounds such as ferric hydroxide and basic ferric sulphate on standing and invariably show a low pH value (down to pH 2 or less). However, numerous analyses have indicated that fresh samples of mine waters do not contain free acid, the low pH values arising from the hydrolysis of dissolved salts. It is only when the precipitation of iron compounds commences that free sulphuric acid is generated, and since this precipitation does not occur below pH 3.0 - 3.5 (depending on the concentration) it follows that a mine water with a pH below this level does not contain free acid whilst one with a higher pH might.

It has been established (5, 6) that the source of the acidic substances is the iron sulphide present in the coal measures. This occurs as crystalline pyrite, FeS_2, or its grey polymorph marcasite, both of which are often found in coal seams as finely divided particles which constitute the principal source of the inorganic sulphur of coal. Pyrite can also occur in coal in the form of larger aggregates or concretions. In addition it occurs as finely divided black material in the strata adjacent to coal seams and in partings. Since the rock above and below the seam as well as a small portion of the top and bottom coal are left in place when the coal is mined, their pyrite content constitutes a lasting source of acidic material.

The precise mechanism of the formation of the acidic substances is not known (13) but it has been established that the overall process is the oxidation of pyrite in the presence of air and water to ferrous and ferric sulphates, with or without free sulphuric acid as an intermediate product. Since the aqueous solution of the reaction products does not contain free acid, it is evident that any sulphuric acid formed must rapidly react with other materials, becoming neutralized to form salts which may or may not show an acidic reaction in solution.

Bacteria may play a part in the oxidation of pyritic material. Various autotrophic bacteria have been isolated from mine waters, but as yet, there is no clarity as to the part they play in the oxidation process(13).

It is obvious that water must reach and dissolve the oxidation products underground before the mine can discharge mineralized and acidic drainage. This water may be underground water in the strict sense, i.e. the mine may intersect an aquifer or water-bearing stratum, or it may be surface water that is moving downwards by percolation through cracks or fissures in the overburden. Therefore it is clear that the drainage water from a mine will not be acidic if the water entering the mine does not come into contact with the oxidation products. Equally well, it will not be acidic if precipitation and neutralization reactions are completed underground before the effluent reaches the surface.

There is thus one major difference between acidic mine drainage and other kinds of industrial effluents. As long as there is oxidizable material underground exposed to air and water, acidic substances will be produced and will continue to be produced almost indefinitely. Consequently pollution of surface waters does not cease when mining operations are discontinued. Mines that have been abandoned for decades are still producing drainage which, if not actually acidic, which in many cases it is, is none the less loaded with dangerously high concentrations of dissolved salts. Thus in every case the amount of pollution material discharged from coal mines in a particular region increases progressively from the time mining is first commenced.

The oxidation processes are natural phenomena which must commence as soon as mining operations provide the correct conditions for them, and as long as there are coal mines there will continue to be some discharge of mineralized effluents. No blame for this can be attached to those controlling any mine. However, it should be possible to control the disposal of the acidic waters coming from mine workings and hence to minimize the effects likely to be produced in nearby streams.

From studies of many mine drainages sampled regularly for periods of a year or more, Braley (5) arrived at the following conclusions:

(a) The composition of the drainage from a given mine is characteristic of that particular mine;

(b) the composition (i.e. the ratios of the concentrations of the various solutes) remains almost constant at all times;

(c) the flow varies seasonally in the same way as the flow of surface streams;

(d) there is a tendency for the concentrations to rise during the season of low flow.

Since spoil dumps also contain pyritic material, precisely the same oxidation processes occur within them. Acidic oxidation products become leached out by percolating rain water and ultimately find their way into any nearby stream.

The analyses of some effluents from mines and dumps in the Tugela Basin are given in Table 41. These illustrate the wide range of chemical composition of such effluents, but they all have one feature in common - an enormously high concentration of sulphate.

TABLE 41

Analyses of streams and effluents from Natal coal mines

Source	pH value	TDS ppm	Total acidity as ppm $CaCO_3$	Total alkalimity as ppm $CaCO_3$	Total Fe, ppm	Al, ppm	Ca, ppm	Mg, ppm	Na, ppm	K, ppm	SO_4, ppm	Cl, ppm	SiO_2, ppm
Hattingspruit mine (abandoned)	3.7	3 800	191	-	33.0	0.7	492	319	203	16.3	2 890	3.9	50
Bannockburn mine (abandoned)	5.5	1 490	412	-	31.0	Nil	62	12	568	7.3	770	20.0	20
Effluent streams from Natal Navigation Colliery (A	8.7	2 400	-	903	Nil	Nil	12	22	815	6.5	960	13.1	27
(B	8.5	2 330	-	968	0.1	Nil	30	21	819	7.1	820	14.0	27
(C	8.9	1 400	-	759	Nil	Nil	8	14	542	2.8	356	13.2	9
(D	8.2	2 280	-	430	Nil	Nil	141	82	481	12.7	1 280	13.2	23
(E	8.1	1 530	-	220	Nil	Nil	176	144	114	3.1	935	6.3	15
Droogeplaats mine dump (abandoned)	2.8	14 500	10 700	-	1 355	5.5	364	526	224	1.8	12 050	4.1	-
Colliery dump (active) in the Ingagane catchment	5.6	2 110	54	-	0.2	1.4	290	79	116	7.3	1 590	11.5	22
Colliery pump effluents (Ingagane catchment)) A	3.5	4 365	314	-	214	20	482	309	202	11.3	3 080	6.9	40
) B	6.3	9 000	588	-	570	40	479	975	158	28.3	6 700	16.4	40
Newcastle Colliery (abandoned)	3.3	3 000	750	-	34	25	311	157	33	5.3	2 380	4.0	40

According to the findings of overseas workers, when acidic mine drainage discharges into a surface stream the first process that occurs is the rapid oxidation of the ferrous iron to the ferric state. Iron compounds thereby become precipitated to form a characteristic red to yellow deposit on the stream bed. This oxidation, which is augmented by the oxidizing activities of such bacteria as Ferrobacillus ferrooxidans and F. sulphooxidans that have invariably been isolated from such streams (5), occurs far more rapidly than the corresponding purely chemical process. Since the conversion of ferrous to ferric iron requires oxygen, the dissolved oxygen content of the stream is usually reduced. The deposition of iron compounds does not change the total acidity of the water, however, although it often results in a decrease in the pH.

At this stage the lowered oxygen content of the water, its low pH value and the blanketing of the bed with iron deposits destroy the living organisms in the stream so that the self-purifying powers it could exert upon effluents of other kinds that may enter it are impaired. The stream thus becomes useless as a receiving stream for sewage and similar wastes.

If the stream runs over chemically inert soils and rocks, it will remain acidic even though it has been purged of most of its iron. On the other hand, if alkaline substances in the rocks and soils counteract the acidity, the stream will come to a normal, almost neutral condition and life will eventually return to the water. But even if the acidity is neutralized in this way the stream will still carry high concentrations of calcium, magnesium and other sulphates, so that it will show an abnormally large TDS and a very high total hardness and sulphate content. Its water will be useless for most domestic, agricultural and industrial purposes and the treatment of highly sulphated water is a difficult and usually an uneconomic process.

2. THE NATAL COALFIELDS

The following notes have been compiled from several sources (2, 3, 10, 11, 12, 26).

The principal Natal coal deposits are contained in the coal measures of the Middle Ecca series of the Karoo system. The strata are made up of sediments of every degree of coarseness from conglomerates to shales, with a predominance of sandstones and grits. Over considerable areas beds of iron ore are in places intercalated with these rocks. The coalbearing beds are mostly disposed horizontally, or almost so, and in many places are intruded by dykes and sheets of dolerite. The coal has a characteristically banded appearance and its sulphur content is rather high, often exceeding 2 per cent, mainly combined with iron in the form of pyrite and marcasite but also partly in organic combination.

There is evidence that coal was used in ancient times in South Africa, for old slag heaps near ancient workings in Zululand have been found to contain coal. There is no doubt either that the Bantu used coal more recently for smelting metals. However, although the existence of coal in Natal was known to Europeans by about 1840 and a few early workings were established, no serious investigation of the coal resources was made until 1880, when F.W. North was invited by the Natal Government to undertake a survey. By 1888 a number of coal mining companies were formed, operating mainly in the vicinity of Dundee and Newcastle, some of which are still in existence although the original mines have now been abandoned.

In 1889 seven mines were operating in Natal, but since then development has proceeded steadily and today over thirty mines are being worked in the Province. The annual coal output has risen progressively, and since 1950 it has exceeded five million short tons.

The three coalfields usually recognized in Natal, as shown in Figure 23, are:

(a) The Klip River Coalfield

This comprises an area that stretches north from Ladysmith as far as the Incandu river at Newcastle and eastward beyond Dundee as far as the Buffalo river. The principal town of the area is Dundee, around which the original collieries were situated, although the greatest activity is now centred in the area south of Newcastle. Many of the now abondoned mines in this coalfield ceased production not because of exhaustion of the coal but either because broken ground and coal of very low volatile content was encountered or because they were unable to compete economically with newer mines.

The general configuration of the country is that of an elevated plateau (average altitude 4000 ft), crossed midway from west to east by a spur of the Drakensberg, the Biggarsberg mountains. The abundance of intrusive dykes and sills of Karoo dolerite leads to the presence of prominent flattish and round-topped hills. The area is drained by the Buffalo and Sundays rivers and their tributaries.

The intrusion of dolerite throughout this coalfield has resulted in an exceedingly complex geological structure. Much of the coal has become metamorphosed, and this has resulted in the occlusion of large quantities of gas so that many of the mines are fiery. The high sulphur content of some of the coal (as much as 4 per cent, mainly in the form of finely divided pyrite) has also given rise to trouble from spontaneous combustion.

The mines are deep, and their workings may be anything from 90 to 700 ft below the surface.

(b) The Vryheid Coalfield

This comprises the area east of Vryheid and is bounded on the north by the Pivaans river. It is drained by the Pivaans, Black Umfolozi and White Umfolozi rivers and their tributaries, i.e. not by streams of the Tugela system.

The coal deposits are not continuous but are scattered over a large stretch of country and represent the remnants of a once continuous field which has been dissected by streams. The workable areas lie in isolated mountains in which the coal seams are situated several hundred feet above the level of the surrounding country. Hence adit workings prevail throughout. Although intrusions of dolerite have burnt the coal over considerable areas and rendered it commercially useless, fiery conditions are rarely encountered in the mines.

Coal was worked as early as 1898 at several places in the district, but owing to poor communications the output was small. The rate of development increased after 1908, however, when a railway was built from Vryheid to Hlobane, and again after 1912 when mining was commenced at Schaapkopjie and a coking plant was erected there.

(c) The Utrecht Coalfield

This extends from near Newcastle to Paulpietersburg and northwards to the Transvaal border. It is virtually an extension of and closely resembles the Vryheid Coalfield, but although it is possibly the largest coalfield in Natal it has been little developed, apparently owing to its inaccessibility and poor communications. It is drained by the Pongola river, its tributary the Pivaans and their smaller streams, as well as by the Buffalo and Blood rivers and their tributaries which are streams of the Tugela system.

In addition, there are extensive coal-bearing areas in Zululand, but there are largely unexplored. Most of the coals there lie in the Lower Beaufort beds. A colliery was started at Somkele about 1915 but was early abandoned because the coal proved to be anthracitic and very dirty.

3. POLLUTION IN RIVERS OF THE COALFIELDS

During the course of the Tugela survey, fairly detailed investigations were made of the Umzinyatshana river catchment near Dundee, the lower Ingagane river catchment and the Sundays river catchment. Only some of the results obtained are given in this report, the more detailed results having been published elsewhere (17). Similar studies have also been made in the Dorps river catchment near Utrecht and in the upper portions of the Black and White Umfolozi rivers in a region to the south-east of Vryheid.

These investigations (15, 17, 20, 22) have fully demonstrated the consequences of pollution by drainage from coal mines in Natal. Near the point of entry of acidic mine drainage water or of drainage from spoil dumps, iron deposits are found on the stream bed, the pH may be anything below about 4.0 and virtually no living organisms are present, although iron bacteria of filamentous form can usually be seen. During the summer rainy season the ferruginous bottom sediments become scoured out by floods so that no permanent accumulation occurs and the region of precipitation moves up and downstream according to the flow. Below this region the water is virtually free from iron but is still acidic. Within a few miles, however, the acidity of the water becomes neutralized owing to the fact that the Natal Coalfields mainly lie in regions where Ecca rocks build the land surface, the overlying soils contain numerous calcareous concretions (11) while the surface waters normally show relatively high pH values, from 8.0 to 8.5.

The detailed studies made it quite clear that wherever there is a coal mine, either active or disused, streams in the vicinity are liable to be polluted. Indeed, this was found to be so reliable an indication of the presence of a coal mine in the neighbourhood that, over and over again during the field studies, mineralized water, detected in the field by measurement of the electrical conductivity, when traced back to its origin always led to some source of mine or dump drainage.

The variation between different mines is so great, however, that it is not possible to predict quantitatively the extent of the effect of a given mine upon nearby streams.

Where the streams are small, that is with a flow of 2 cusecs or less, as in the Umzinyatshana and Wasbank rivers, the pollution may reach alarming proportions, but where they are larger i.e. with a flow of 10 cusecs or more, the effects are less marked, as in the Sundays river, or even slight as in the Ingagane. This, of course, is only to be expected since it is a consequence of dilution. It is because of this that the major Tugela and Buffalo rivers, although they ultimately receive a large proportion of the total drainage from the Natal Coalfields, do not show appreciable signs of pollution from this source; these rivers rise in regions well away from mines and have already attained a considerable size before they reach the mining areas.

In the rainy season the effects of this form of pollution are not so pronounced because, although during that period the load of dissolved material coming from mines in any area appears to increase from twice to four times its dry season value, normal stream flows increase much more. There were indications that immediately after rain, especially after the first spring rains, the streams of the coalfields carry truly enormous loads of dissolved materials, owing to the leaching of soluble substances that accumulated in dumps and on the catchment surface during the preceding dry spell. Unfortunately, it was not possible to investigate this matter in any detail.

4. POLLUTION ABATEMENT

Drainage from the coalfields clearly constitutes a major source of stream pollution in Natal.

There is no known means of preventing this type of pollution, although it could be kept to a minimum if working mines would adopt a suitable code of practice or policy of 'good housekeeping'. It is certain that the drainage water will have less opportunity to take up soluble puritic axidation products if it is removed from a mine by the shortest and most rapid route. In America it has been possible to eliminate acidic drainage completely from opencast mining operations by such means (5). Similarly mine dumps would give rise to less objectionable drainage if they were so constructed that water could drain from them easily and rapidly. The drainage from abandoned mines, however, must remain very difficult to control, one factor here being the legal problem of with whom responsibility for these mines rests.

Once mine drainage water has reached the surface, there is very little that can be done in the way of treating it. Lagooning is of little benefit apart from the possibility it affords of controlling the final discharge so as to match its flow to that of the local stream. Treatment with lime certainly destroys acidity and precipitates iron, but it is a costly business requiring constant supervision and would need to be continued indefinitely after a mine had been abandoned. In any case it would never succeed in reducing the sulphate content of the final effluent.

Perhaps the only satisfactory way of dealing with the problem in Natal would be through a regional water conservation scheme involving keeping certain streams free from all pollution of this nature and diverting drainage from mines by canals or pipelines into other streams which would become recognized as drainage channels rather than as sources of water. Such a scheme would require very careful and detailed planning in full co-operation with all water users in each catchment and with proper attention paid to possible future developments in the area concerned.

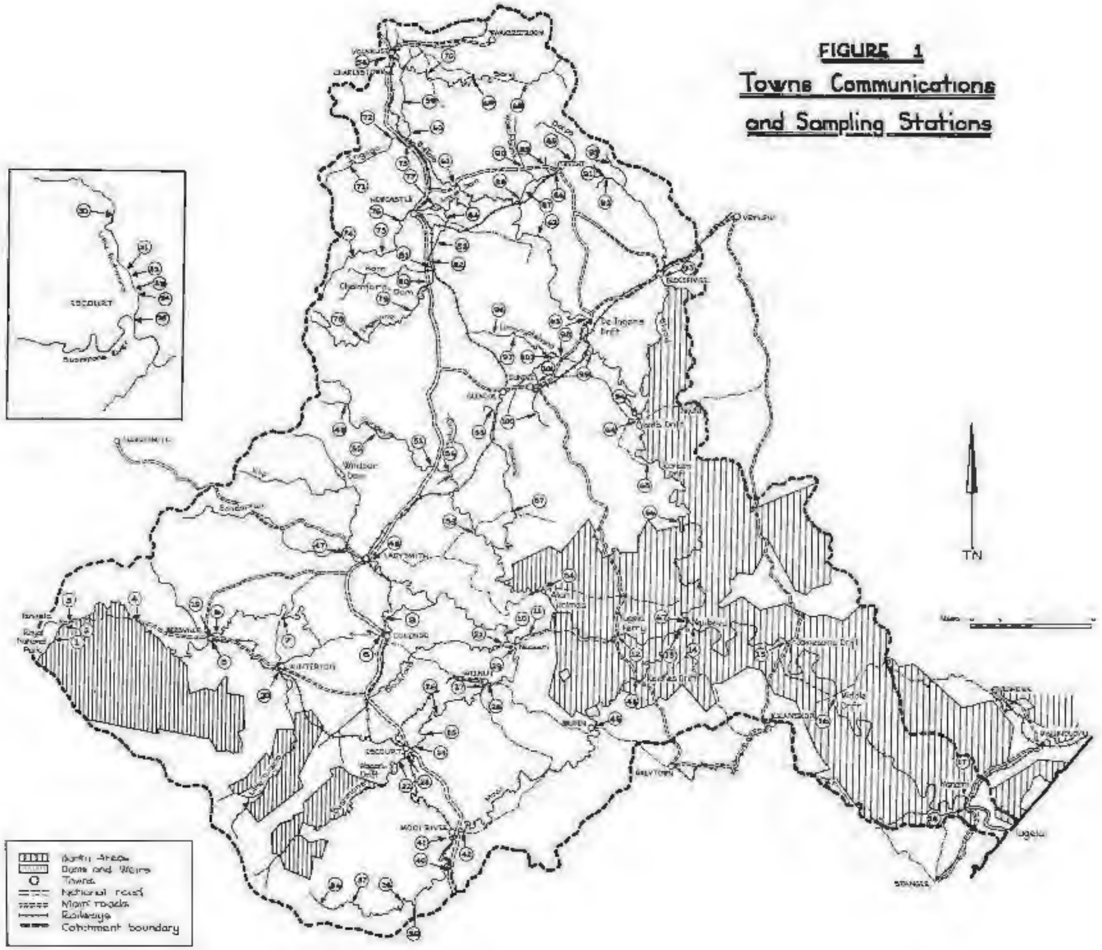
It was mentioned above that the pollutional effects of mine drainage are cumulative, becoming more pronounced as more mines are opened and more coal dug. To date, the output of coal from Natal has reached a cumulative total of over 250 million short tons since mining began in the late nineteenth century, and it is increasing at the rate of over 5 million short tons per year (the present annual output). If this rate of increase in maintained it is clear that in about 40 years time pollution due to mine drainage in Natal will be double what it is at present, and if coal output increases further this doubling may be attained in only 20 years. Therefore, it may confidently be predicted that by that time most small streams and rivers of the Natal Coalfields will be extensively polluted and that major rivers will be showing appreciable pollution.

The serious nature of such a situation is sufficiently evident as not to need emphasis. In fact, some of the mines themselves are already experiencing difficulty in obtaining additional good quality water for their own needs, since all the streams in their immediate neighbourhood are polluted.

The time available is all too short for a regional water conservation scheme to be properly planned and implemented.

FIGURE 1

Towns Communications and Sampling Stations



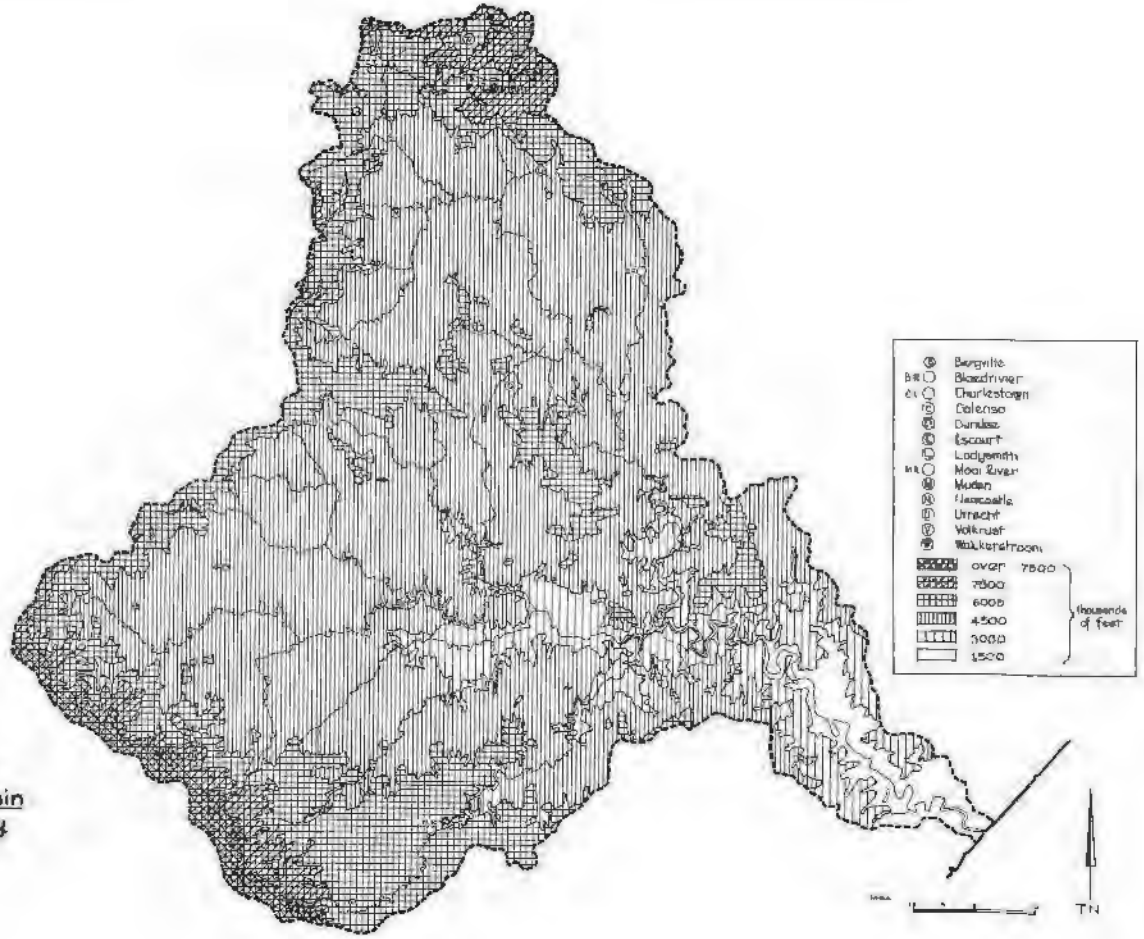


FIGURE 2

Tugela Basin Topography

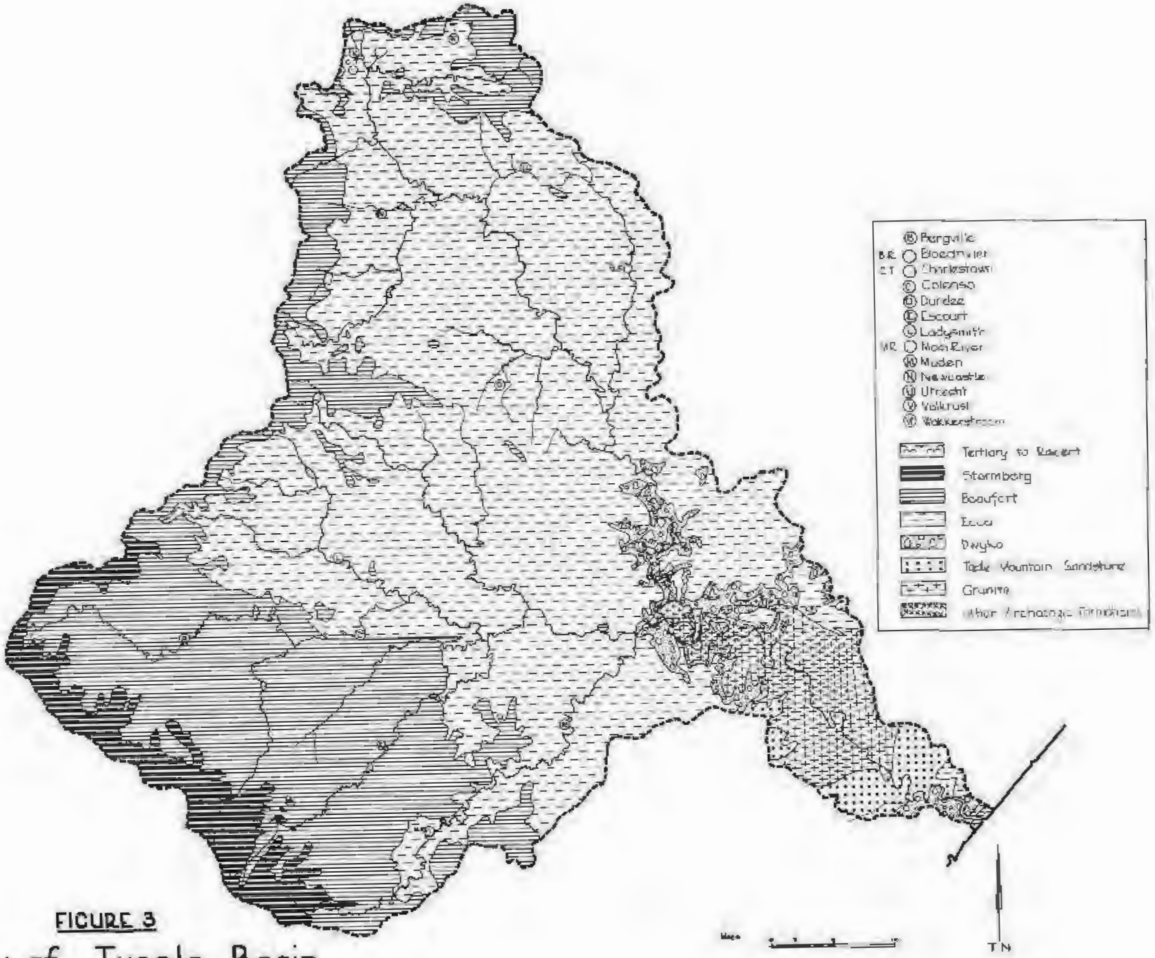


FIGURE 3
Geology of Tugela Basin

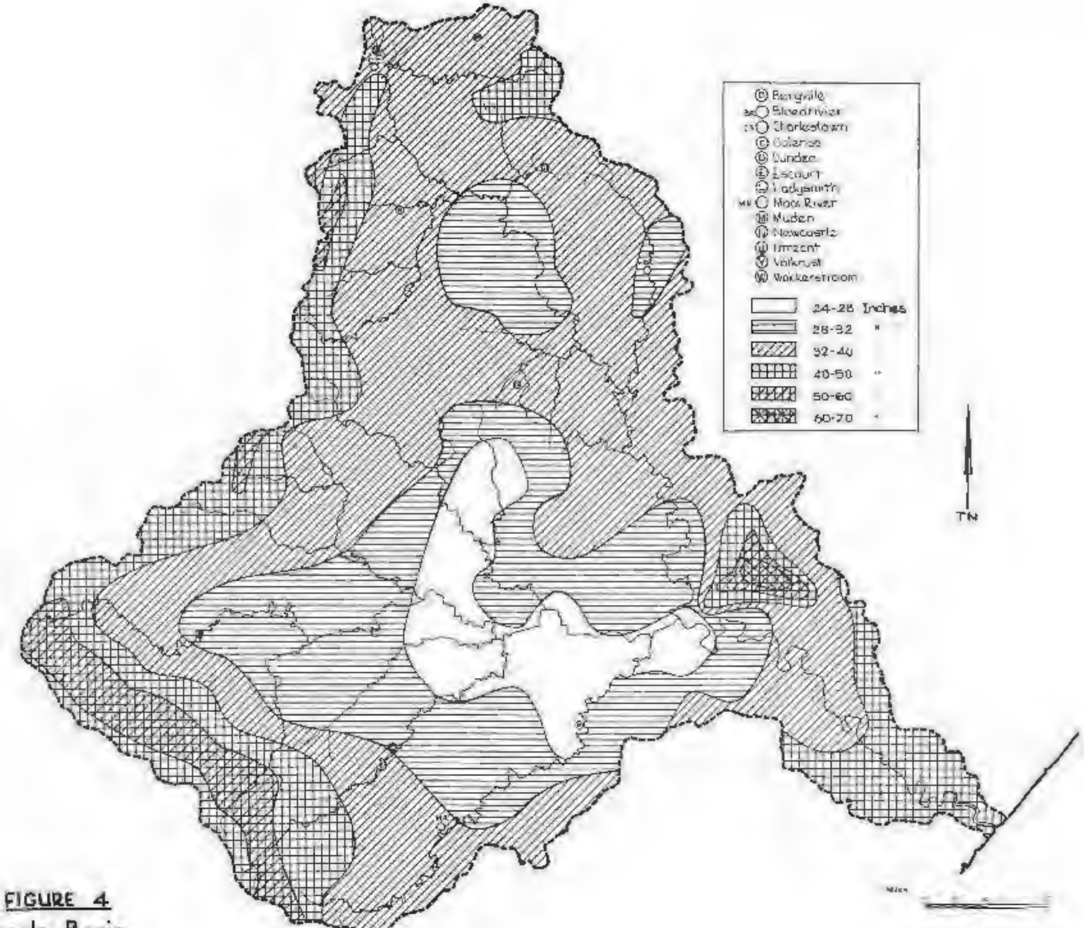


FIGURE 4
Tugela Basin
Rainfall

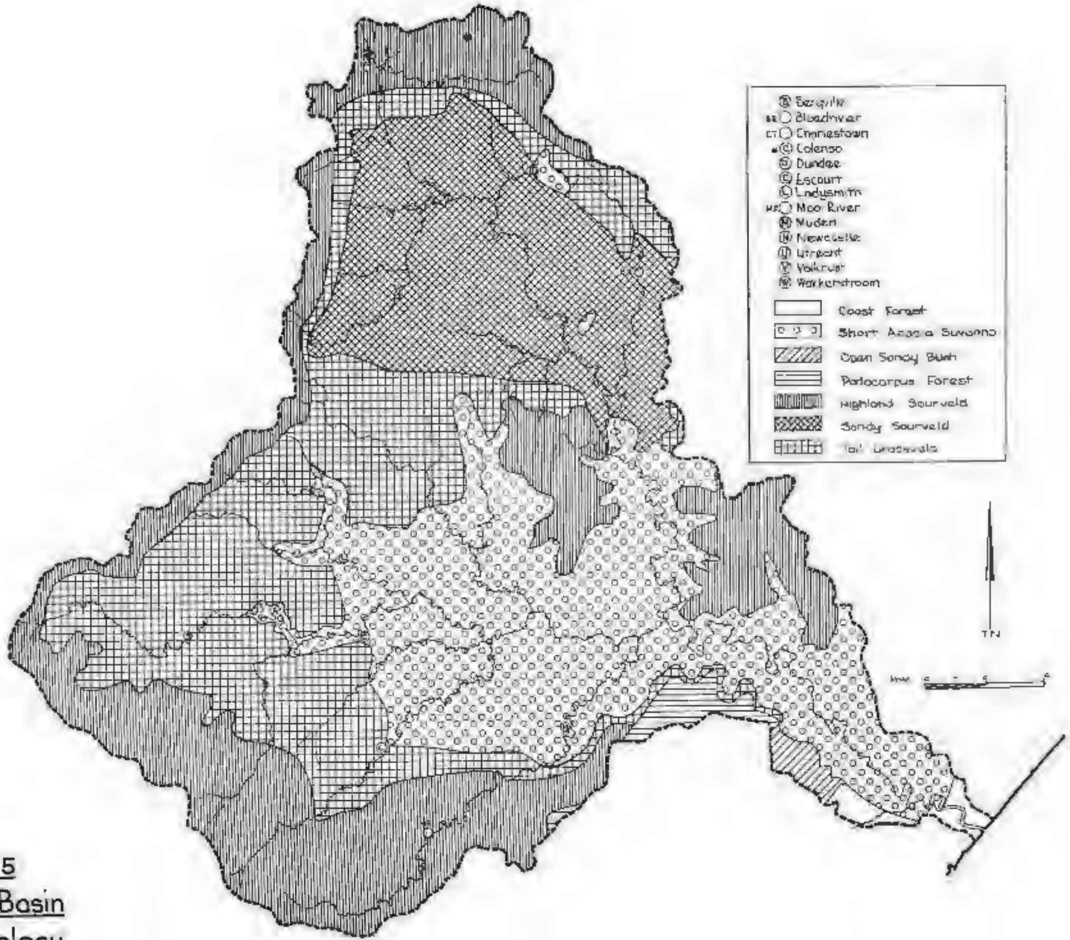
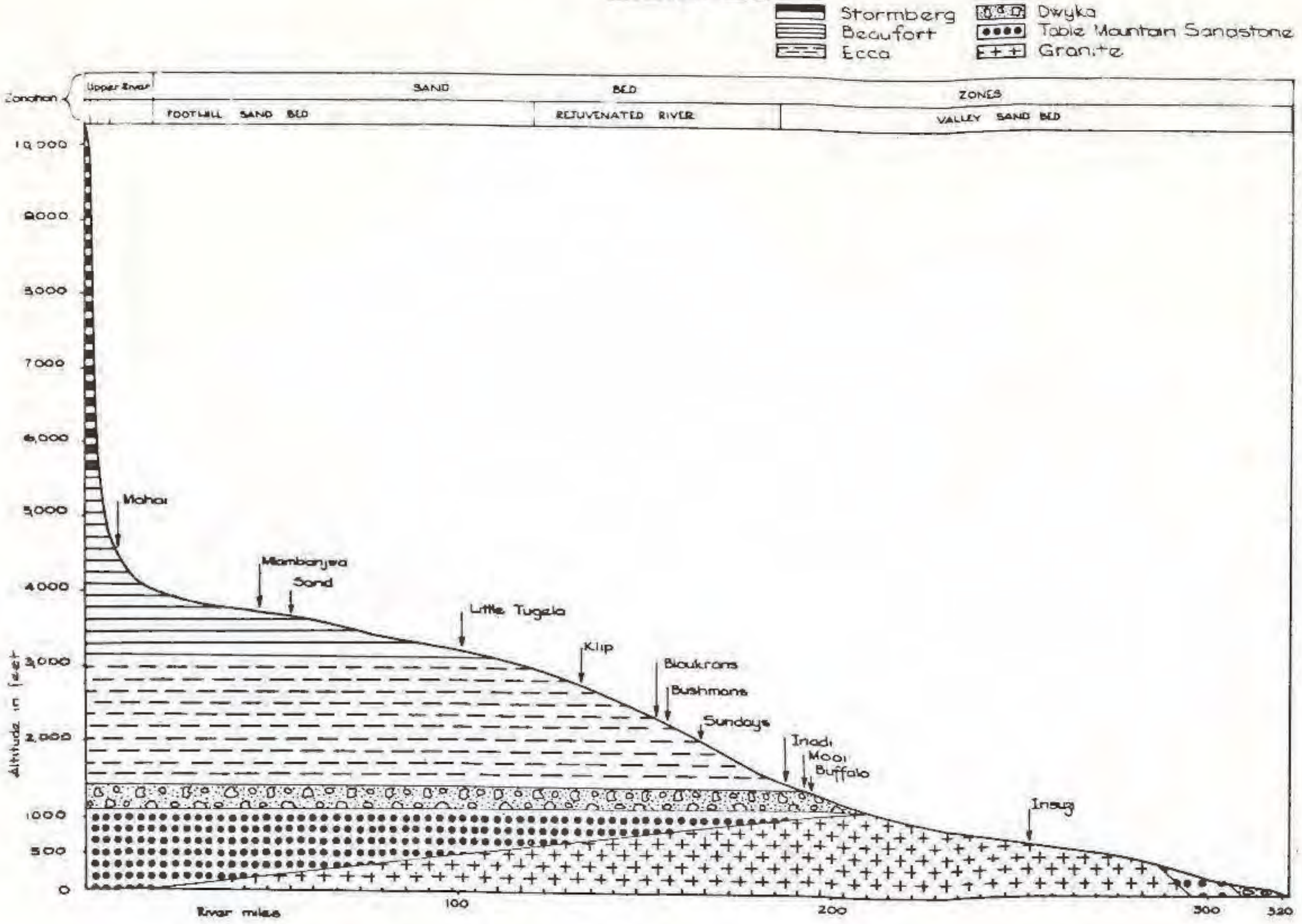
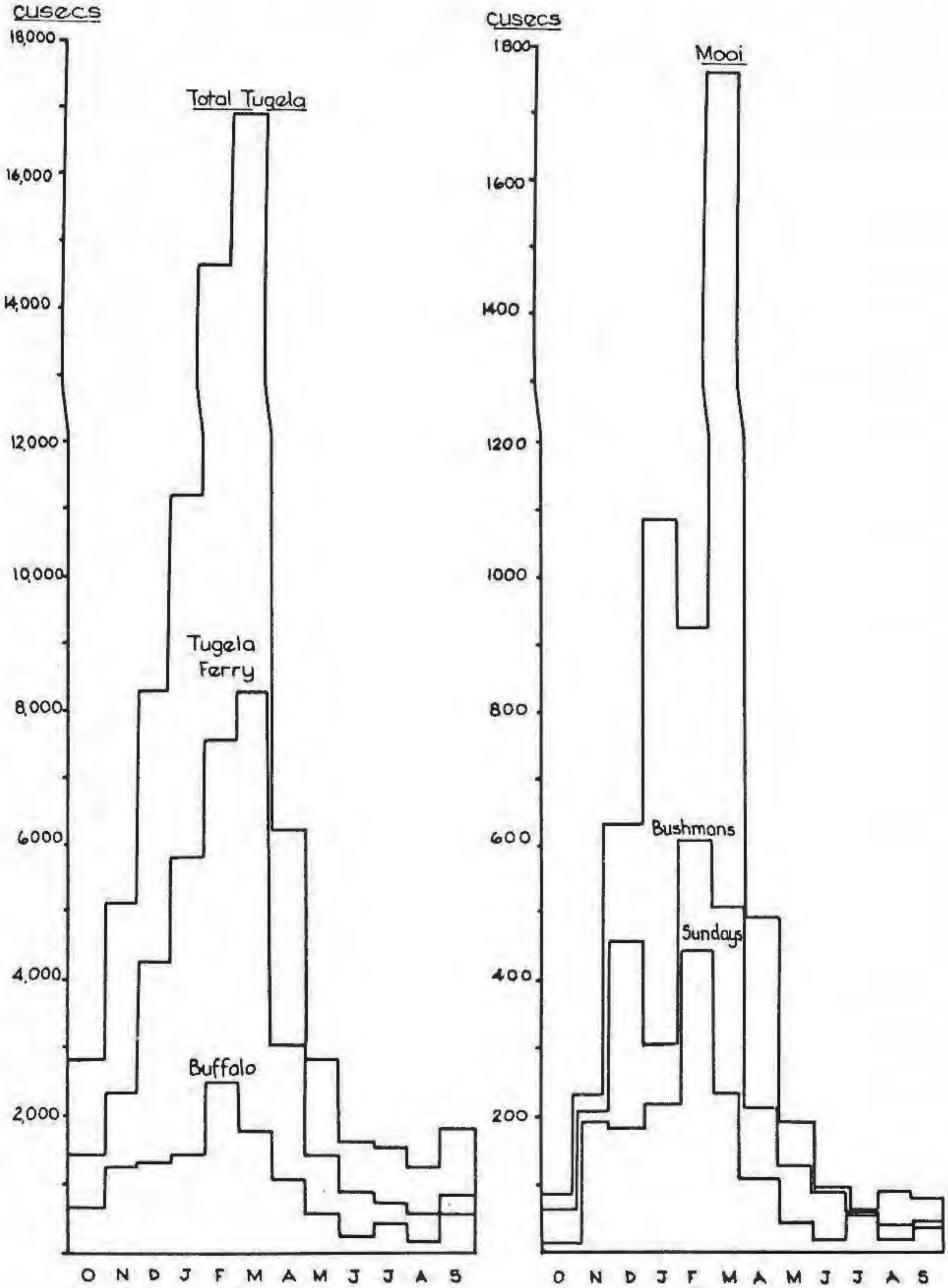


FIGURE 5
Tugela Basin
Agro-Ecology.
From Acocks (1)

FIGURE 6



Profile of Tugela River



(a) (b)

FIGURE 7

Flow Histograms

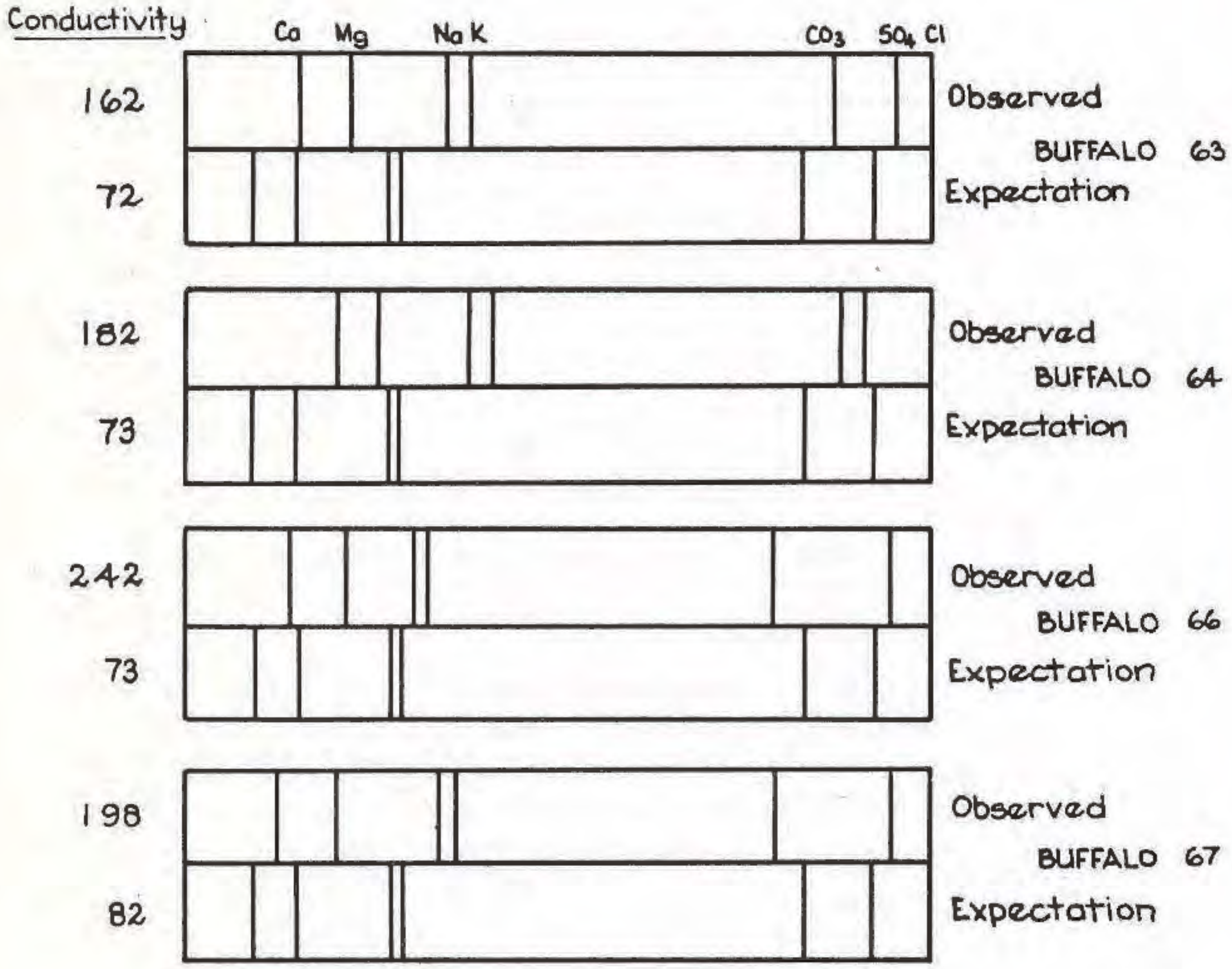


FIGURE 8

Water Composition in the Buffalo river

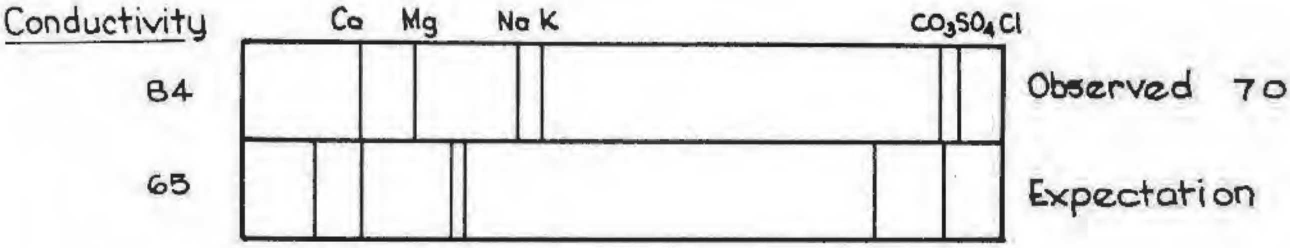


FIGURE 9

Water Composition in the Slang river

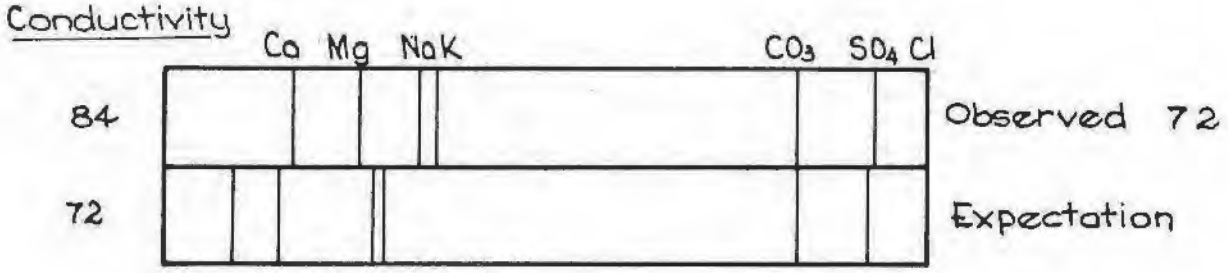


FIGURE 10

Water Composition in the Ingogo river

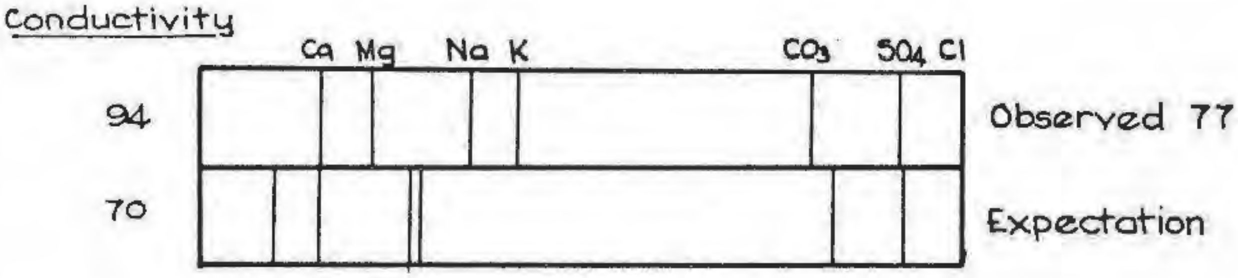


FIGURE 11

Water Composition in the Incandu river

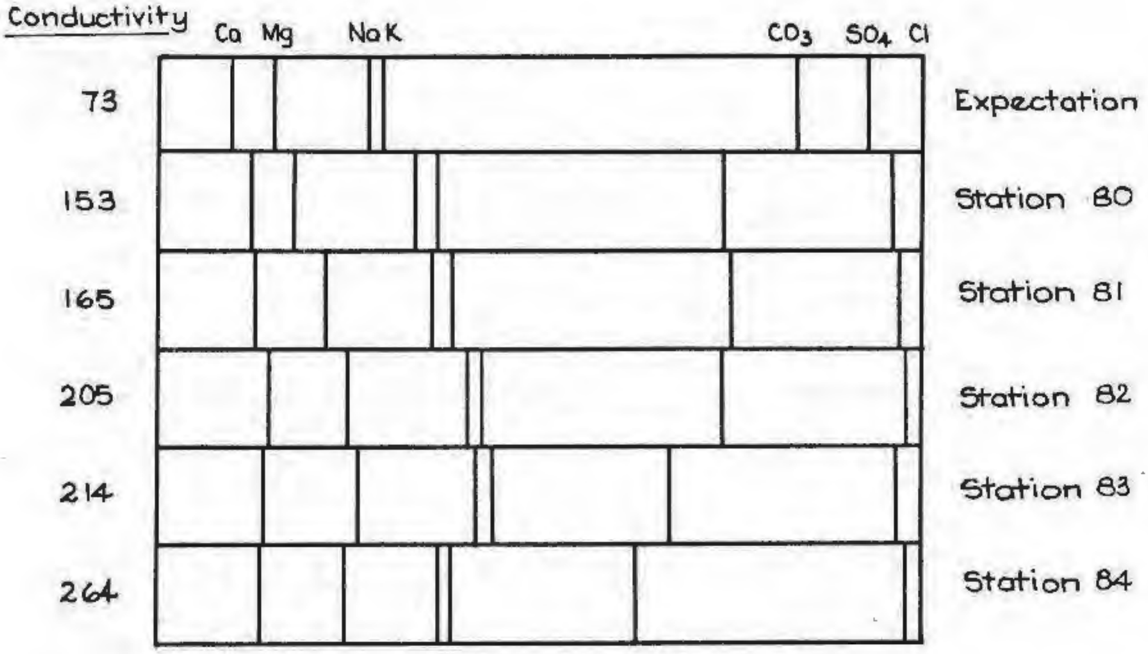


FIGURE 12

Water Compositio in the Ingagane river

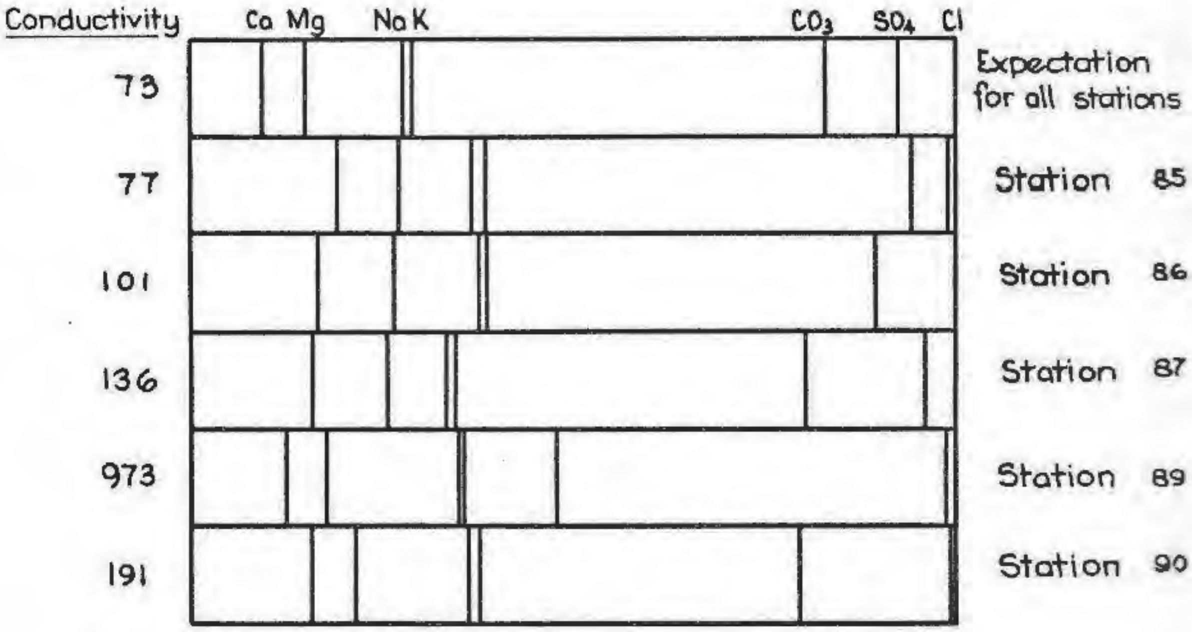


FIGURE 13

Water Composition in the Dorps river

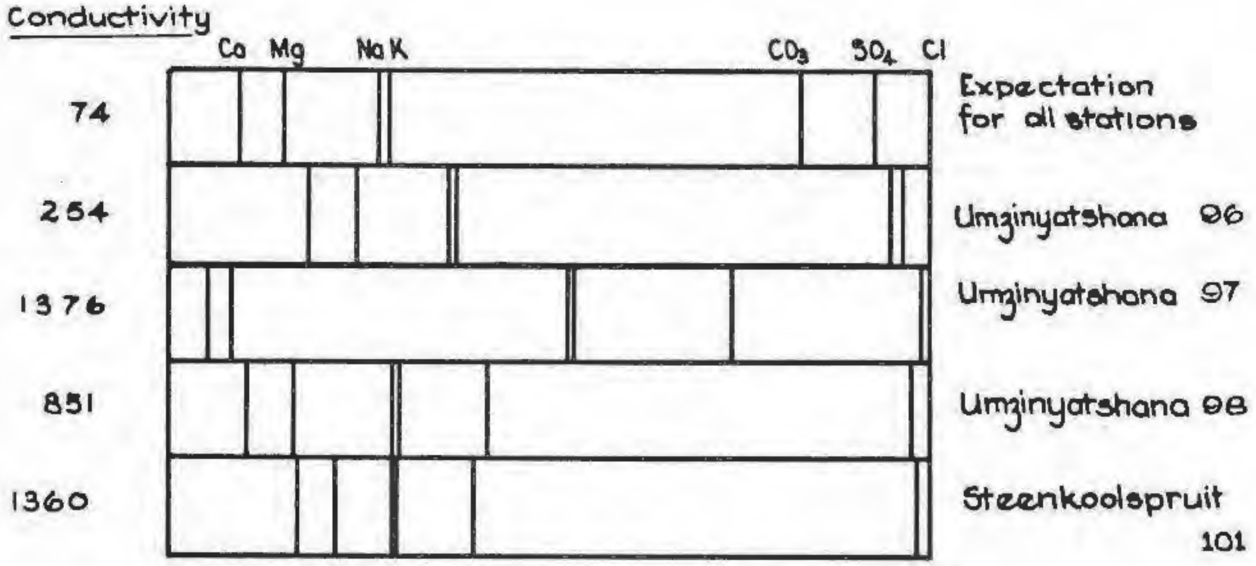


FIGURE 14

Water Composition in the Umzinyatshana river

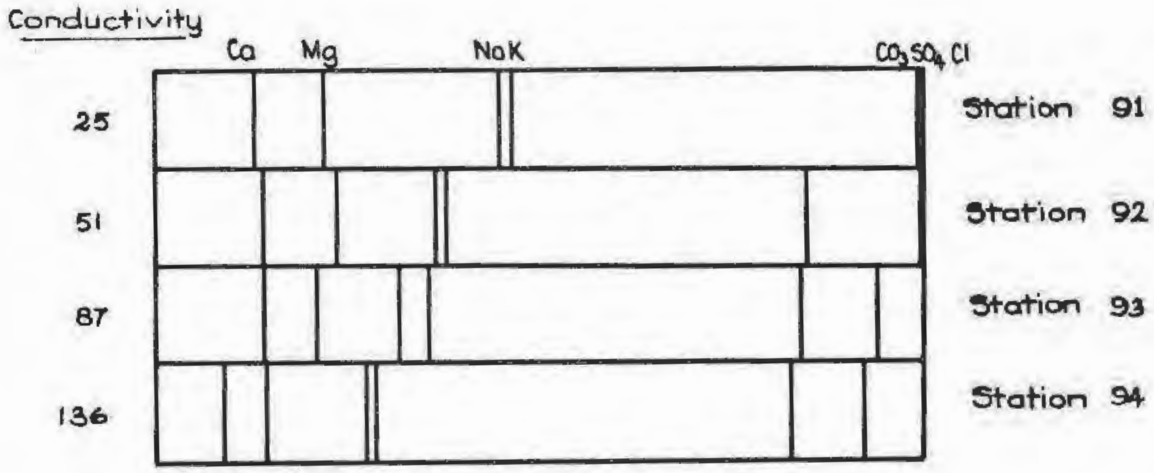


FIGURE 15

Water Composition in the Blood river

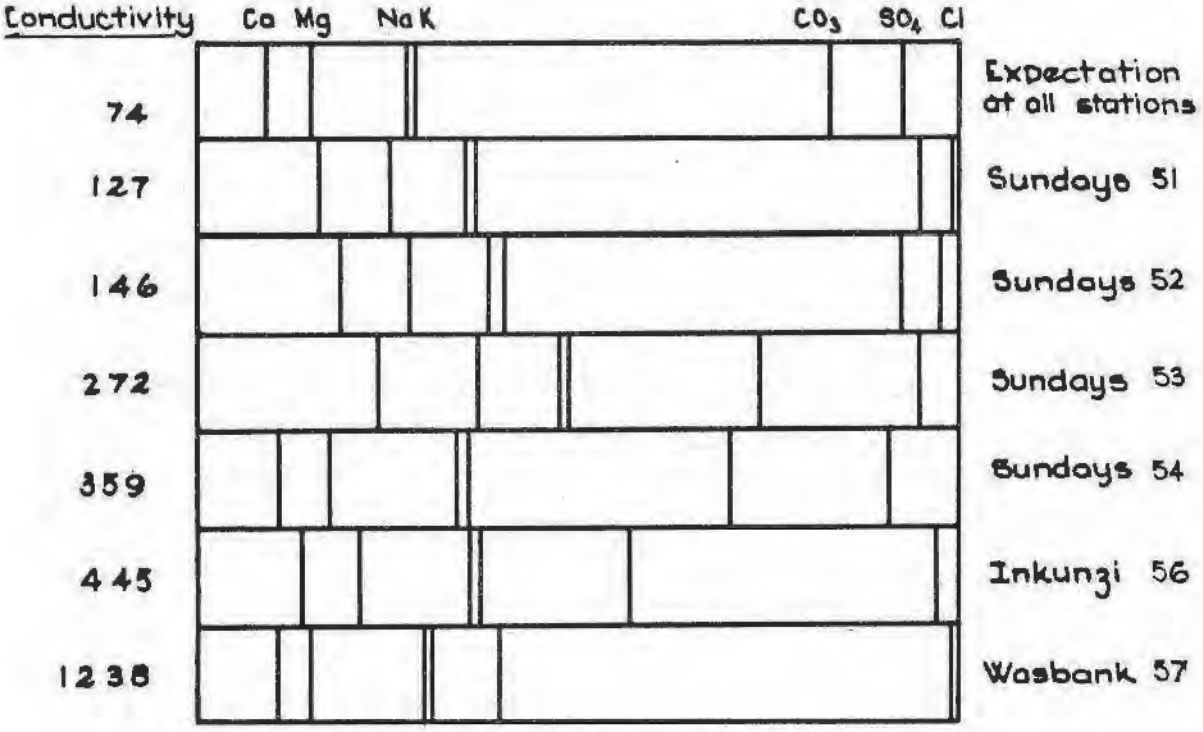


FIGURE 16

Water Composition in the Sundays river

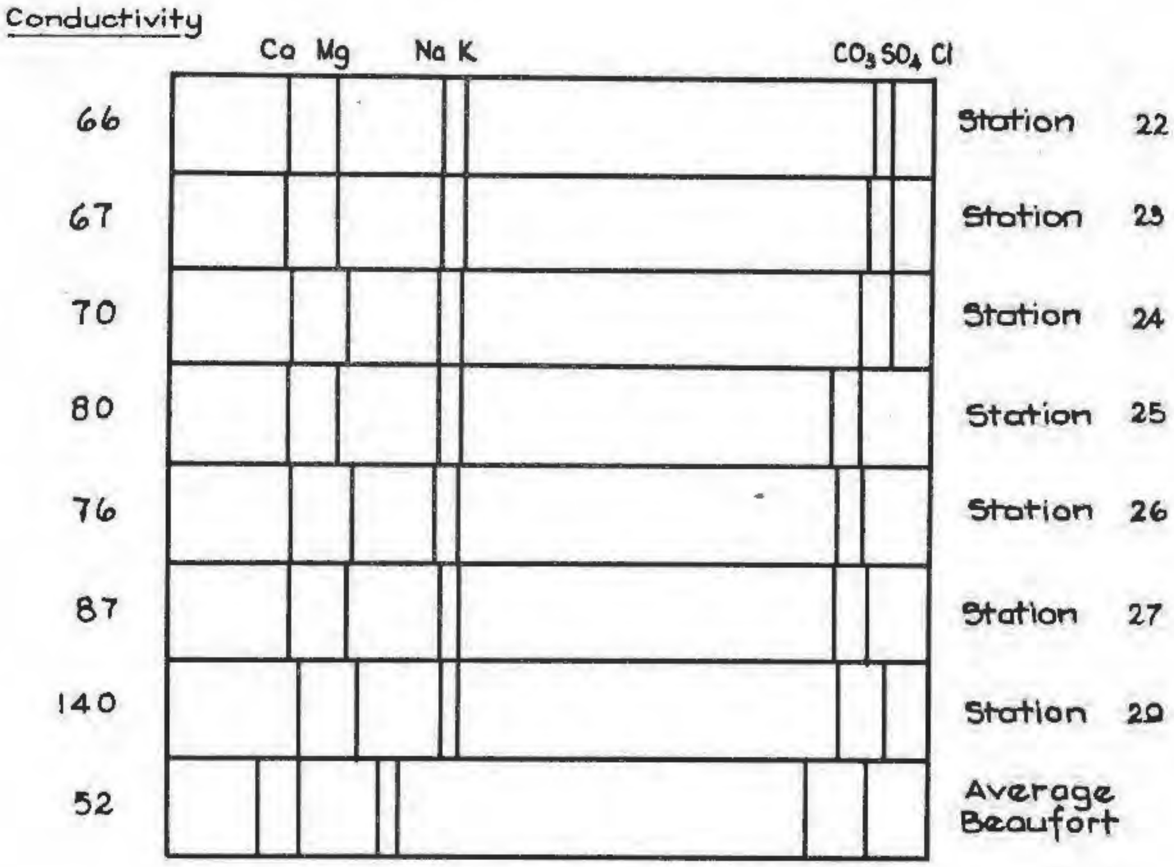


FIGURE 17

Water Composition in the Bushmans river

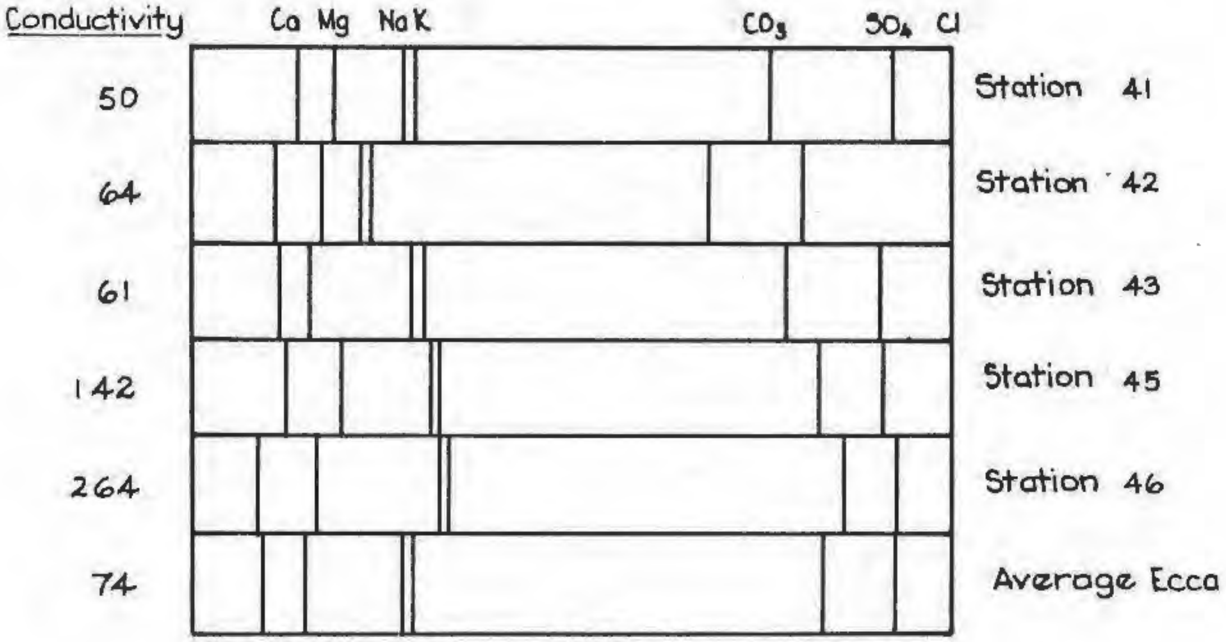


FIGURE 18

Water Composition in the Mooi river

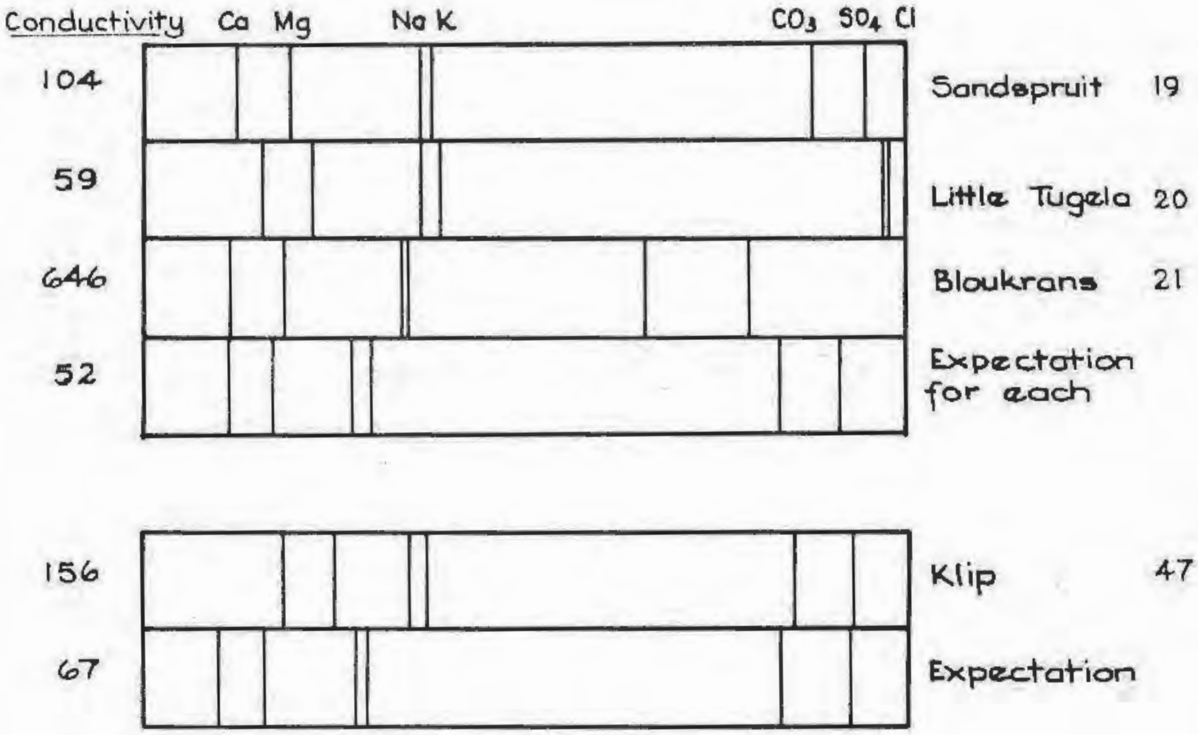


FIGURE 19

Water Composition in the minor Tributaries

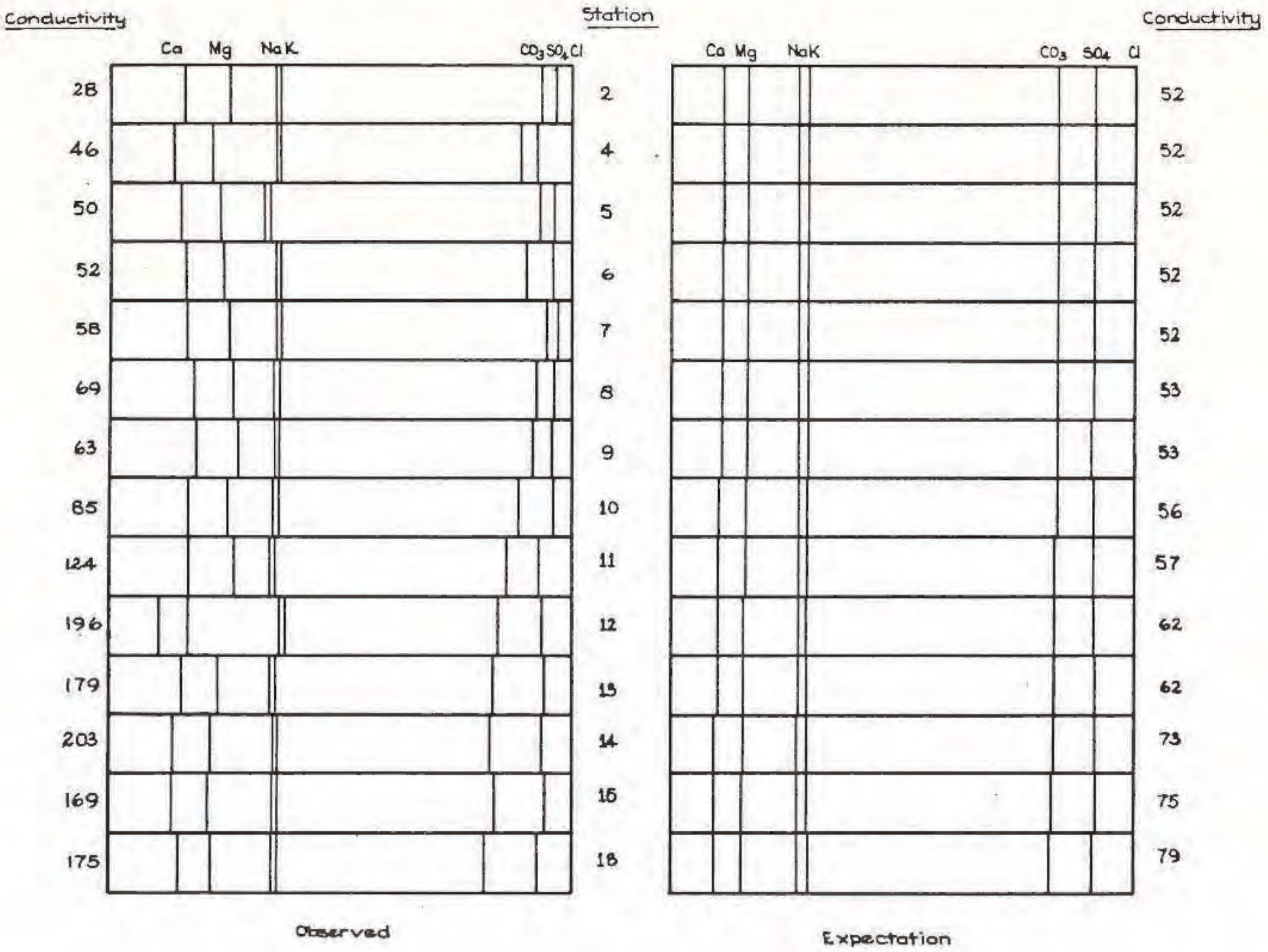


FIGURE 20

Water Composition in the main Tugela river

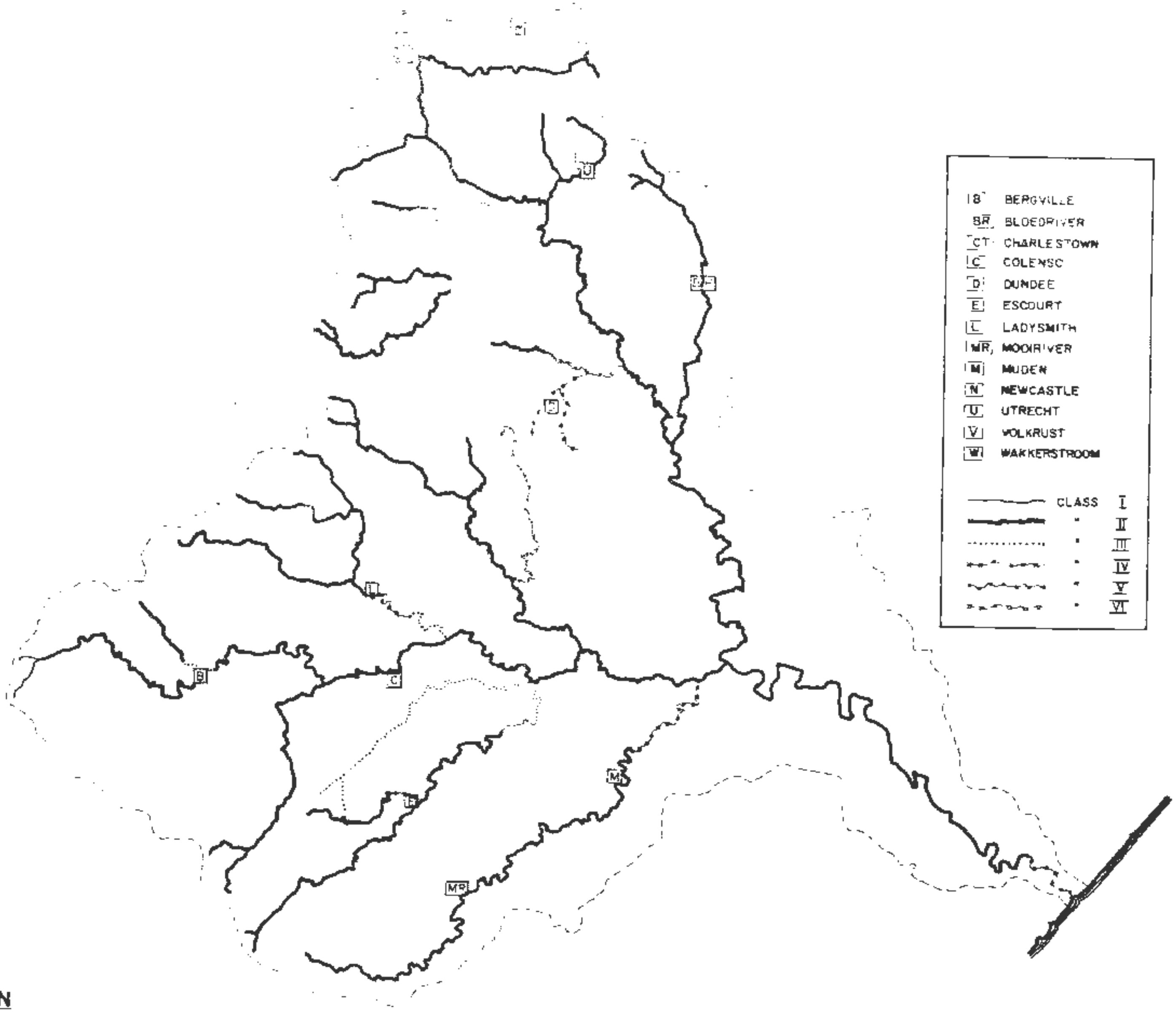


FIGURE 21
TUGELA BASIN
Existing Water Quality.

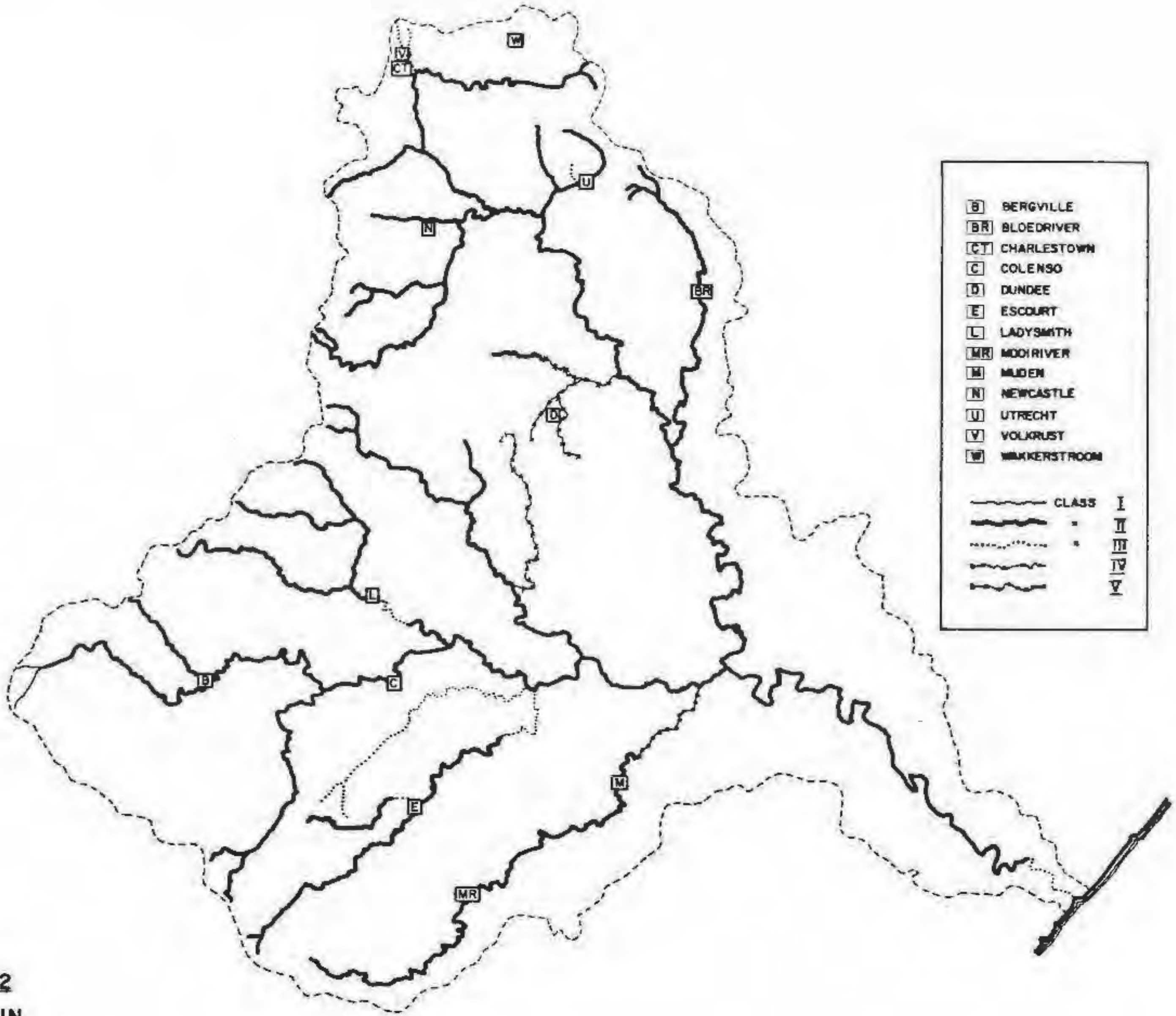


FIGURE 22

TUGELA BASIN

Possible Improved Water Quality.

FIGURE 23

Sketch Map of Northern Natal Coalfields