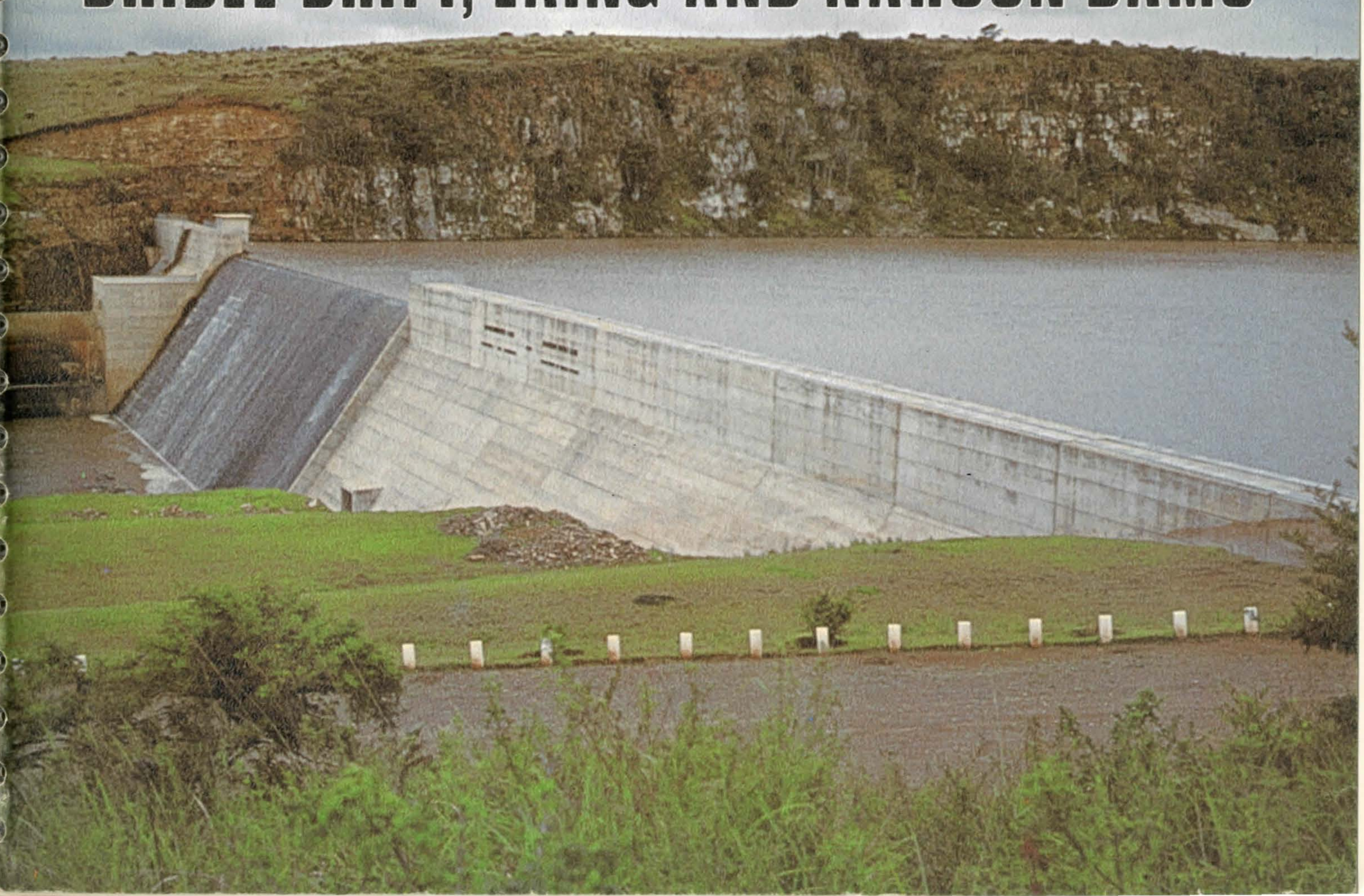
PHYSICO CHEMICAL LIMNOLOGY OF BRIDLE DRIFT, LAING AND NAHOON DAMS



PHYSICO-CHEMICAL LIMNOLOGY OF BRIDLE DRIFT, LAING AND NAHOON DAMS

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EAST LONDON MUNICIPALITY

PHYSICO-CHEMICAL LIMNOLOGY OF BRIDLE DRIFT, LAING AND NAHOON DAMS

M. Tow
National Institute for Water Research, Council for Scientific
and Industrial Research

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Water Research Commission
P.O. Box 824, Pretoria 0001, South Africa

National Institute for Water Research
Council for Scientific and Industrial Research
P.O. Box 395, Pretoria 0001, South Africa

Municipality of East London
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SAMEVATTING

'n Ondersoek is na die fisies-chemiese limnologie van Bridle Drift-, Laing- en Nahoondamme uitgevoer en die vernaamste eutrofikasiebronne kon geïdentifiseer word. Al drie die damme kan as warm monomikties geklassifiseer word. Daar is 'n suurstofonttrekking van hul hipolimnion in die somer en gedurende die afgelope paar jaar toenemende mineraal- en voedingstofkonsentrasies. Tydens die opname het die vernaamste voedingstofladings en toevloei tot Bridle Driftdam via die Buffelsrivier wat sy water hoofsaaklik van Laingdam aan sy bokant verkry, geskied. Die strome wat Mdantsane dreineer is gereeld deur rioolwater besmet wat verantwoordelik was vir een persent van die totale vloei terwyl die ortofosfaatfosfor en anorganiese nitraatbydraes nege en drie persent onderskeidelik was. Daar is gevind dat natuurlike prosesse 'n belangrike rol in die mineralisasie van Bridle Driftdam speel. Laingdam ontvang die meeste van sy vloei- en voedingstoflading van die Buffelsrivier. Die huishoudelike en industriële uitvloeiselbronne wat vir die eutrofiese stand van Laingdam verantwoordelik is, is in die opvanggebied van hierdie rivier geleë. Die Umlakalakastroom, 'n sytak van die Buffelsrivier, vervoer hoogs soutagtige en verkleurde tekstieluitvloeisel wat hoë nitraatladings bevat.

Alhoewel Nahoondam eutrofiese eienskappe vertoon met betrekking tot voedingstand, beladingsramings en die ontwikkeling van 'n anaërobiese hipolimnion, is sy minerale- en voedingstofladings hoofsaaklik van natuurlike bronne afkomstig. Tydens die opname is die watervlak as gevolg van konstruksie aan die wal verlaag en gevolglik was hidrologiese toestande ietwat ongewoon.

Die afwesigheid van ernstige alggroei in al drie die damme gedurende die opname kan moontlik toegeskryf word aan die hoë turbiditeit wat in die damme geheers het hoewel die moontlik inhiberende invloed van industriële uitvloeisels in Bridle Drift- en Laingdamme ook gedeeltelik daarvoor verantwoordelik kan wees.

SYNOPSIS

The physico-chemical limnology of Bridle Drift, Laing and Nahoon dams was investigated and the major sources of eutrophication were identified. All three impoundments can be classified as warm monomictic, display deoxygenation of the hypolimnion in summer and have in the past few years shown an increasing trend in mineral and nutrient concentrations. During the study the major nutrient loads and inflow into Bridle Drift Dam entered the impoundment via the Buffalo River, which derives its water mainly from Laing Dam, situated upstream. The streams draining Mdantsane were frequently contaminated with sewage and accounted for one per cent of the total flow, while the orthophosphate phosphorus and inorganic nitrogen contributions amounted to nine and three per cent respectively. Natural processes were found to be important in the mineralization of Bridle Drift Dam. Laing Dam receives the greater proportion of its flow and nutrient load from the Buffalo River. Sources of domestic and industrial effluent responsible for the eutrophic status of Laing Dam are situated in this river catchment. The Umlakalaka Stream, which is a tributary of the Buffalo River, carries textile effluent which is highly saline, grossly discoloured, and carries a high nitrogen load.

Nahoon Dam, although displaying eutrophic characteristics in terms of nutrient status, loading estimates and the development of an anaerobic hypolimnion, receives its mineral and nutrient loads predominantly from natural sources. During the study, the impoundment level was reduced due to construction activities on the dam wall and thus hydrological conditions were somewhat unusual.

The absence of severe algal blooms in all three impoundments during the study is thought to be largely due to the high turbidities prevalent in the impoundments, although in Bridle Drift and Laing dams it is possible that industrial effluents might also have inhibited algal growth.

ACKNOWLEDGEMENTS

During the course of this study, many people, too numerous to mention individually, gave generously of their time and assistance. To them, I express my sincere thanks. In particular, I wish to record my gratitude to the following:

Mr G.B. Keppie, Chief City Engineer; Mr R.E. Bartel, Chief Chemist; Mr R.B. Reed, past City Engineer and Mr G.P.K. Thornton, past Chief Chemist, for their advice, assistance and co-operation at all times; colleagues and friends in the City Engineer's Department and other institutions, for technical assistance and for providing valuable information; and a special word of thanks to Liz Coltman and Loanda Hein for invaluable assistance with the analyses and much appreciated encouragement; Professor D.F. Toerien and Mr R.D. Walmsley for their interest in the programme, sound advice and constructive criticism; Mr C.J. Alexander, for his contribution to the processing of data, and Mr M. Butty, for processing the hydrological data and for tabulating the results.

The co-operation of the East London City Council in making chemical and other records available is gratefully acknowledged. Laboratory work was carried out in the East London Municipal Laboratory and the boat used on Bridledrift Dam is the property of the East London Municipality.

I also acknowledge the Department of Water Affairs, Forestry and Environmental Conservation for supplying the hydrological data and for use of their boat at Nahoon Dam.

FOREWORD

Eutrophication can be both a natural and a man-made phenomenon, the latter having significant financial and health implications.

With due regard to the urban development within the catchment of the Buffalo River and its tributaries and to the discharge of industrial effluents in the upper catchment, the waters of both Laing and Bridle Drift dams are subject to enrichment. In contrast to some other South African catchments, the waters of the lower reaches of the Buffalo River tend to carry a heavy silt load which limits the depth of light penetration.

The waters of Laing and Bridle Drift dams in the Buffalo River and Nahoon Dam in a parallel catchment were consequently considered to be suitable for inclusion in a wider research programme aimed at understanding and alleviating the problems of eutrophication in South Africa in order to be able to exploit the available water resources to maximum benefit.

The study was financed by the Water Research Commission and was undertaken by the National Institute for Water Research in co-operation with the Municipality of East London.

This study is not only of great local value but it could also be of benefit to the wider community. As such it is a great privilege for the City Council and its officials to have been associated with this project and to have been able to give support where necessary to Senior Research Officer, M. Tow, who so ably undertook the demanding task of measuring, recording and analysing the immense amount of data necessary in formulating the conclusions to this study.

G.B. KEPPIE
Chief City Engineer
City of East London

CONTENTS

INTRODUCTION

The East London - King William's Town region of the eastern Cape, South Africa, with plentiful labour, harbour facilities, and a fair amount of urbanization and industrialization, is predicted to become a metropolitan area (Department of Planning and the Environment, 1975).

Water is presently supplied to this region from the Buffalo and Nahoon rivers. Together, these 2 rivers support a total population in the order of 500 000 (Water Research Commission, 1976). There are, in all, five major impoundments on these two rivers. They are, Maden, Rooikrantz, Laing and Bridle Drift dams on the Buffalo River and Nahoon Dam on the Nahoon River (Figure 1). There are two minor impoundments on the Buffalo River, Dunbar Lake, which is situated 10 km upstream of King William's Town, and Everitt Weir, in King William's Town.

The two largest impoundments on the Buffalo River, Bridle Drift and Laing dams, both have urbanized areas in their catchments. Mdantsane Township and the proposed Potsdam Township are situated in the Bridle Drift Dam catchment. The towns of King William's Town and Zwelitsha, as well as a textile factory and a tannery, lie in the Laing Dam catchment.

These urban and industrial developments in the respective catchments represent real or potential sources of plant nutrients, minerals and organic compounds, which may cause a deterioration in the water quality of the Buffalo River.

East London Municipality expressed concern regarding the future quality of the Buffalo River, particularly in Bridle Drift and Laing dams. More specifically, the possible influence of catchment activities on the trophic status of the dams and the appearance of algal blooms were causes for concern (Toerien and Walmsley, 1974).

Algal blooms were first reported in Laing Dam in 1975 and have occurred annually in Bridle Drift Dam since 1973. Nahoon Dam supported a bloom in 1976 (Toerien and Tow, 1976). A water hyacinth *Eichhornia crassipes* (Mart.) Solms infestation occurred in Bridle Drift Dam in 1973 and was successfully eradicated by physical removal (G.P.K. Thornton - personal communication).

The appearance of algal blooms in these impoundments indicates that they are either already eutrophied or in the process of becoming eutrophied. Preliminary calculations (Toerien and Tow, 1976) indicated that siltiness and resultant turbidity may be important factors regulating the severity of eutrophication. The presence of silt in Bridle Drift, Laing and Nahoon dams distinguishes them from other eutrophic impoundments in the Transvaal (Hartbeespoort, Roodeplaat and Rietvlei dams) on which some information on the trophic status is available (Toerien and Walmsley, 1974).

To assess the degree of eutrophication and the extent of algal growth in Bridle Drift, Laing and Nahoon dams, the National Institute for Water Research (NIWR) undertook, with the co-operation of the Municipality of East London, and under the auspices of the Water Research Commission (WRC), studies on these three impoundments. This investigation formed part of the 'Eutrophication of Rivers and Dams' programme, which aimed at providing guidelines for the prevention and control of eutrophication in South Africa.

This study is the first detailed investigation into the physico-chemical limnology of Bridle Drift, Laing and Nahoon dams.

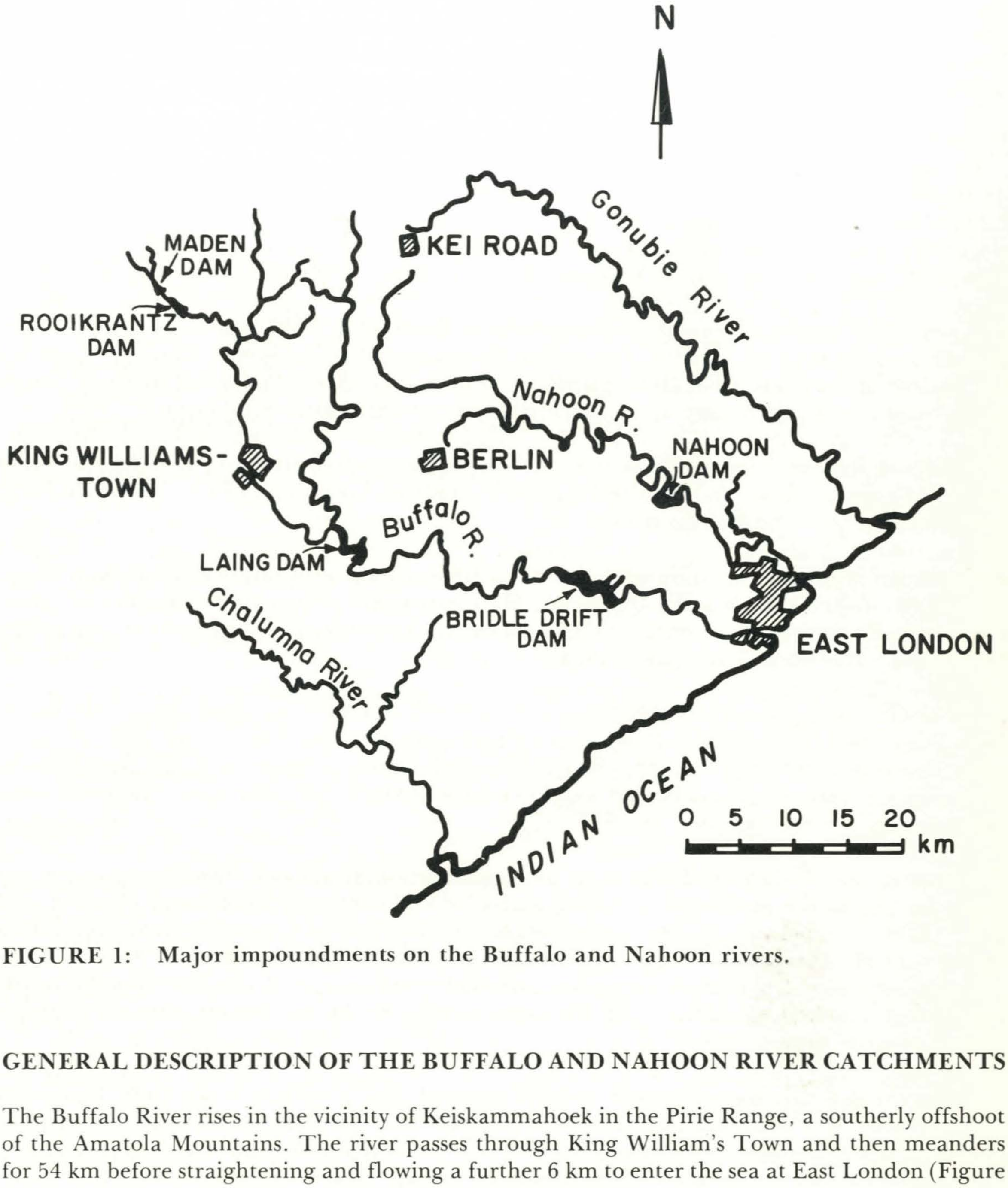

FIGURE 1: Major impoundments on the Buffalo and Nahoon rivers.

GENERAL DESCRIPTION OF THE BUFFALO AND NAHOON RIVER CATCHMENTS

The Buffalo River rises in the vicinity of Keiskammahoek in the Pirie Range, a southerly offshoot of the Amatola Mountains. The river passes through King William's Town and then meanders for 54 km before straightening and flowing a further 6 km to enter the sea at East London (Figure 1).

A feature which distinguishes the Buffalo River from the other rivers in the area is the fact that the Buffalo flows in a generally easterly direction, while the others flow at right angles to the coast in a south-easterly direction (Mountain, 1974). The river flows close to its southern watershed (Board, 1962), with the result that virtually no right bank tributaries exist. From source to mouth, the Buffalo River is 125 km long, the last 10 km of which are tidal. The total catchment area is in excess of 2 000 km^2.

The Nahoon River has its origin near to Kei Road and runs adjacent to the Buffalo River in a south-easterly direction for approximately 90 km before it reaches the sea just north of East London (Figure 1). The Nahoon River has a catchment area of 450 km^2 and is tidal for the last 5 km .

Geology

The dominant geological formations encountered in the two catchments are mainly of sedimentary rocks of the lower Beaufort Series of the Karroo System. Other geological formations which occur include sand and alluvium, dune rock, fixed dunes, tertiary marine limestone, silcrete, cretaceous limestone and Karroo dolerite (Mountain, 1974).

Topography

Topographically, the two river catchments can be divided into the following broad categories. An inner mountainous area, consisting of the Pirie mountains, which drops steeply to the plain below and a coastal belt, consisting of undulating lowlands which can be subdivided into an inner coastal belt and an outer coastal belt. The inner coastal belt ranges in altitude from approx imately 900 to 250 m . The slope increases sharply below 300 m . The narrow outer coastal belt decreases from 250 m to sea level and is approximately 10 km wide.

Vegetation

The vegetation of the catchments includes, according to Acocks (1975), the following types: Transitional Coastal Forest, Eastern Province Thornveld, Dohne Sourveld and Valley Bush. The vegetation types exhibit a distributional pattern which is related to the topography, namely, three vegetation belts approximately parallel with the coast.

The Transitional Coastal Forest belt is closest to the coast and being approximately 20 km wide, includes the outer coastal belt as described above. This is followed inland by a second belt, known as Eastern Province Thornveld, of which the inner margin is higher than 700 m . This, in turn, is followed by Dohne Sourveld, which is prominent in the north-western part of the Buffalo River catchment. This pattern is modified by Valley Bushveld, which is found in the larger river valleys. The natural vegetation has also been extensively modified by human activities.

Climate

The climate of the two catchments can, according to Schulze (1968), be described as temperate to warm and humid. A difference between the climatic conditions exists from the coast to the upper reaches of the catchments. Greater diurnal temperature fluctuations are experienced inland than at the coast, partly due to the presence of the warm Moçambique current off the south-east coast.

Winds generally blow parallel to the coast in a north-easterly and south-westerly direction, occasionally reaching gale force. Hot, dry 'berg' winds are sometimes experienced during late winter. These winds blow from inland at right angles to the coast.

The rainfall pattern shows a summer rainy season (Schulze, 1968) with a maximum in autumn (March) and a minimum in June. Mean annual rainfall can vary from over 1 525 mm in the Pirie Forests, to 500 to 625 mm in King William's Town, to 750 to 900 mm in East London. Rainfall is generally of a showery nature and thunderstorms occur fairly frequently. A number of intensive rainfall periods have been recorded, the last being in August 1970. During this downpour, which resulted in severe flooding, 150 mm was recorded in one hour and 300 mm over a 24-hour period (Pells *et al.*, 1972). It was as a result of these floods that the design criteria of certain dams in this region were reconsidered.

Underground water

The occurrence of underground water, in quality and quantity, is influenced by rainfall and geology. In general, waters from the sedimentary rocks of marine origin forming the lower Beaufort Series of the Karroo System are characterized by a high concentration of dissolved salts. These highly mineralized waters are of the chloride-sulphate type (Bond, 1946). These natural sources of water have been shown (Reed and Thornton, 1969) to contribute considerably to the mineralization of the Buffalo River.

BRIDLE DRIFT DAM

Bridle Drift Dam (32° 59′S; 27° 44′E), which is situated at an altitude of 147 m above sea level, is used as a potable water supply and serves as an important recreational centre. The catchment includes both cultivated and uncultivated land, as well as the densely populated Mdantsane Township. The Potsdam Development area is situated adjacent to, and directly west of Mdantsane and is also in the Bridle Drift catchment area. The catchment area below Laing Dam is approximately 256 km^2 while the total catchment has an area of 1 176 km^2.

Bridle Drift Dam, which is the property of the Municipality of East London, was completed in 1968 and is situated approximately 18 km west of East London. The purpose of constructing the dam was to regulate the flow in the lower reaches of the Buffalo River to augment the assured supply of water to East London (City of East London, 1968). Bridle Drift Dam now serves as a water supply for East London and its adjoining municipalities, Mdantsane and Potsdam. Recreational use of the dam includes yachting, motorboating, waterskiing and angling. In terms of Proclamation 459 (Province of the Cape of Good Hope) of 11 December 1973, Bridle Drift Dam Nature Reserve was established, and includes a section of the dam and certain adjoining areas. The extent of the reserve is indicated in Figure 2.

The crest of the Bridle Drift Dam was raised by approximately 2 m after the floods of August 1970. The severity of these floods can be estimated from a report that during a 48-hour period, the inflow into this impoundment amounted to 300 x 10^6 m^3, which is equivalent to about 4 times the mean annual runoff of the Buffalo River at this point (Pells *et al.*, 1972). The feasibility of a further raising of the dam to increase the net assured yield of the impoundment is under consideration. A 5 m raising, which is considered optimal, would result in an increase of 13 490 m^3/d in the net assured draft (Department of Water Affairs, 1976 — presently being updated).

The impact of urban and industrial development on the Buffalo River has been the subject of a number of investigations (Thornton *et al.*, 1967; Reed and Thornton, 1969; Water Research Commission, 1976). These investigations emphasized the need for rational consideration of effluent disposal and protection of water quality in the Buffalo River catchment.

Schutte and Bosman (1973) described Bridle Drift Dam as having a medium mineral quality and a low sodium content. Toerien and Walmsley (1974) noted that PO_4-P concentrations in Bridle Drift Dam were increasing and that this impoundment was already eutrophied to some extent. This observation was confirmed by a report that *Microcystis* blooms had appeared regularly since 1973 (Toerien and Tow, 1976).

The Buffalo River system, together with the Keiskamma and Nahoon catchments and the East London area, has been listed as a "Priority 1" area according to the "National Physical Development Plan" Planning Regions Code (Noble and Hemens, 1978). The priority research areas listed include the impact of urban and industrial development, eutrophication and chemical pollution.

Apart from the main inflow, the Buffalo River, Bridle Drift Dam has entering it, four streams which drain Mdantsane (Figure 2).

Table 1 shows the sizes of the catchment areas of the four streams.

TABLE 1. Catchment areas of the four streams draining Mdantsane

Stream	Catchment area km^2
Shangani	17,1
Sitotana	10,4
Tindelli	3,4
Umdanzani	8,6

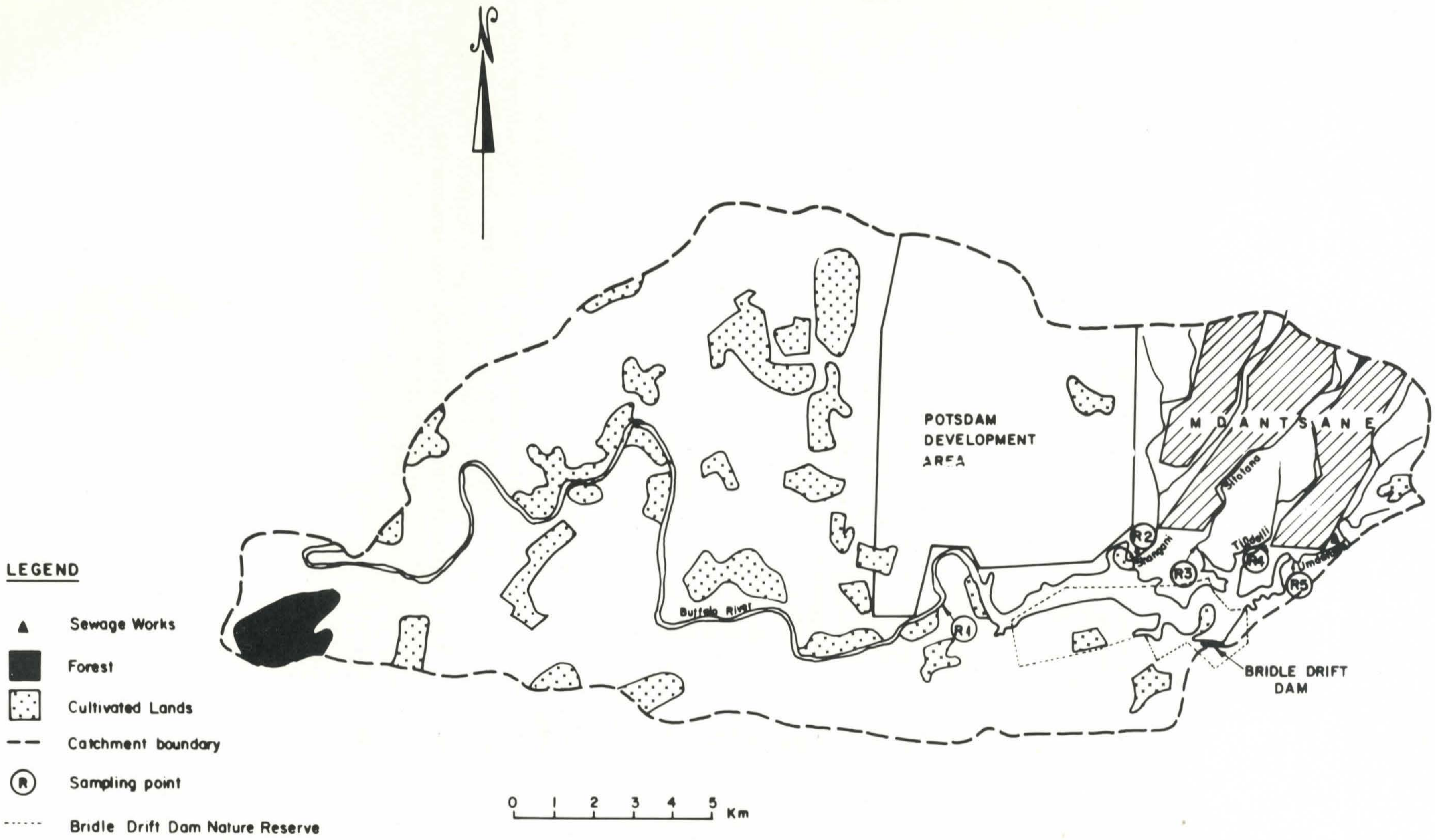

FIGURE 2: Map of Bridle Drift Dam catchment area below Laing Dam.

The Mdantsane Sewage Purification Works is located in the Umdanzani catchment on the banks of the Umdanzani approximately 2 km upstream from Bridle Drift Dam. The effluent from the works is discharged by means of a diversion weir, tunnel and pipeline to the Buffalo River downstream of Bridle Drift Dam below East London's water supply abstraction point.

Under dry weather conditions, the water in the streams is derived largely from underground water via natural springs which are abundant in this region (G.P.K. Thornton — personal communication).

The important morphometric features of the impoundment at full supply level are listed in Table 2, following Hutchinson (1957).

TABLE 2. Principal morphometric features of Bridle Drift Dam

Area (A) km^2	6,16
Volume (V) $x10^6$ m^3	76,0
Maximum depth (Zm) m	40,9
Mean depth ($\bar{z}$) m	12,3
Shoreline (L) km	44,0
Shoreline development (D_L)*	5,00
z : Zm**	0,30

* The shoreline development ratio (D_L), derived according to Hutchinson (1957), is regarded as a measure of the potential effect of the littoral processes of the lake. The value of 5,00 for Bridle Drift Dam is high compared with some other South African impoundments (Midmar 2,93; Buffelspoort 3,43 — R.D. Walmsley — personal communication). This value would suggest a strong littoral component, which is evident in the well-developed littoral macrophyte vegetation, particularly in the estuaries of the dam.

** The ratio of the mean to maximum depth ($\bar{z}$:Zm) describes the form of the dam basin. This ratio is greatest in lakes with flat bottoms. The majority of lakes have a ratio greater than 0,33 (Hutchinson, 1957). The value of 0,30 for Bridle Drift Dam may be accounted for by the presence of a localized deep valley, which is in excess of 40 m in the vicinity of the dam wall. This impoundment, although not large by South African standards, with respect to surface area and capacity (see Part VI) has a greater than average mean depth.

The bathymetry of Bridle Drift Dam is shown in Figure 3.

There is a deep valley which represents the course of the old river bed. This valley shows a number of steep banks formed by cliffs on the outer banks of the old river bed. The main basin behind the dam wall contains the deepest portion of the valley. This basin has a steeply edged east side and a gradually sloped west side. Apart from the old river bed, large portions of this dam are relatively shallow, especially towards the middle and upper reaches. There are four estuaries on the north side of the impoundment, into which the four streams flow.

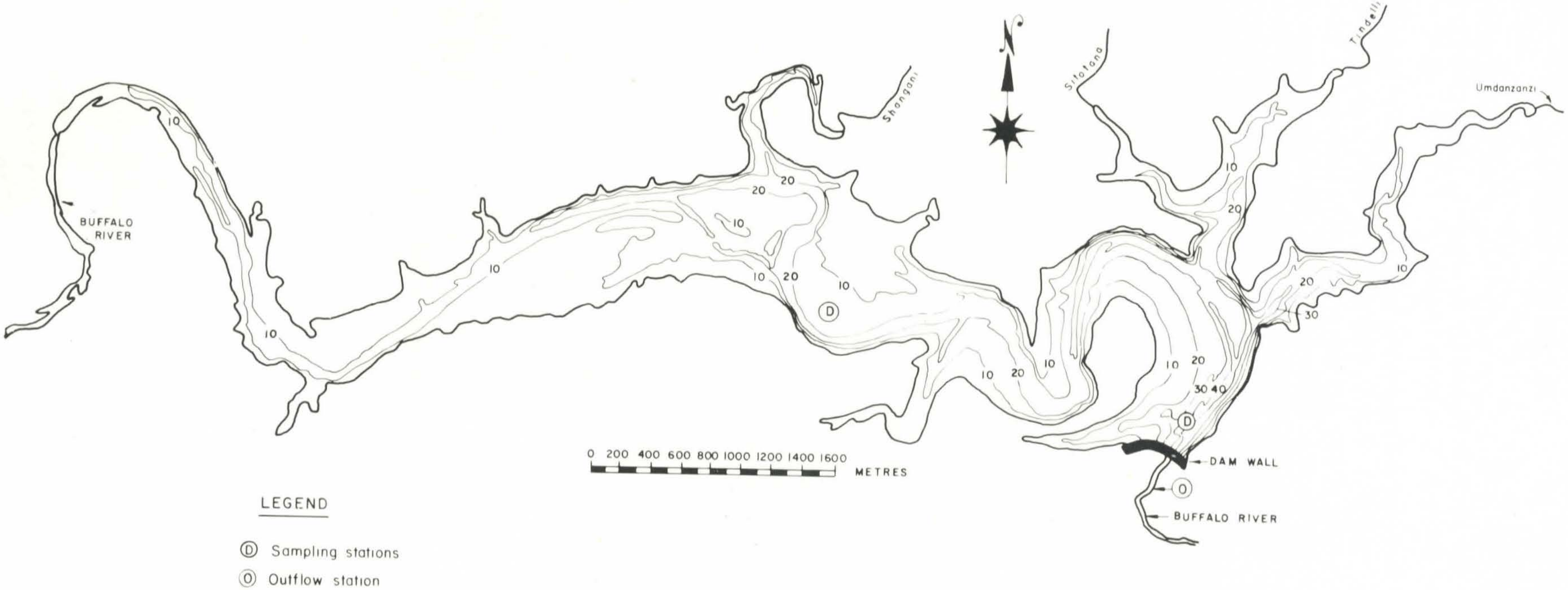

FIGURE 3: Bathymetric map of Bridle Drift Dam. Contours are in metres.

LAING DAM

Laing Dam (32° 58'S; 27° 30'E) is situated at an altitude of 310 m above sea level, and is the major source of water for the middle Buffalo catchment. The areas of supply include Zwelitsha, Berlin, Mount Coke Hospital, Qongqota location and Ciskei Transport Corporation Bus Depot.

Laing Dam, on the Buffalo River, is situated approximately 40 km west of East London and 14 km south-east of King William's Town. This water scheme was adopted by the East London Municipality in 1944 (City of East London, 1945) and completed in 1951. White Paper I — '75 made provision for the transfer of ownership of the impoundment from the East London Municipality to the Department of Water Affairs, Forestry and Environmental Conservation. The impoundment was constructed to regulate the flow in the Buffalo River for the purpose of supplying water to East London (Anon, 1976a).

The total catchment area of Laing Dam is 913 km^2 and includes the towns of King William's Town and Zwelitsha, cultivated and uncultivated lands and forests (Figure 4). The following point sources of nutrients, all of which ultimately discharge to the Buffalo River, the major inflow, can be recognized, a tannery, two sewage purification works and a textile factory. The other important inflow into Laing Dam is the Yellowwoods River, which has a catchment area of 197 km^2, and drains cultivated and uncultivated areas. The Breidbach Township is being established in the Yellowwoods River catchment. Apart from the Buffalo and Yellowwoods Rivers, there is a third inflow into Laing Dam, namely the Tshaba River (Figure 4). The flow in this river is highly irregular, and of little importance in relation to the other two inflows. The Tshaba River has not been included in this study.

Following the 1970 floods in the East London-King William's Town region, a reassessment of probable floods indicated that the spillway capacity of Laing Dam was inadequate and that the stability of the dam wall, under flood conditions, no longer complied with present-day standards (Anon, 1975). It is reported (Pells *et al.,* 1972), that during these floods the spillway capacity of this impoundment was exceeded by a factor of almost 2. The enlargement of the spillway capacity section and modifications to improve the safety of the dam commenced in 1975 (Anon, 1976b) and were completed in 1977.

Laing Dam has been the subject of a number of surveys with regard to water quality protection and rational water resources utilization in the Border Region (Thornton *et al.*, 1967; Reed and Thornton, 1969; Schutte and Bosman, 1973; Toerien and Tow, 1976; Water Research Commission, 1976; Department of Water Affairs, 1976). In a trophic status classification of 98 South African impoundments (Toerien *et al.*, 1975), Laing Dam, with an AGP of 70,1 mg/dm^3, was shown to be eutrophic (17th highest value out of 98 impoundments surveyed).

The main morphometric characteristics of this impoundment, at full supply level, are given in Table 3.

TABLE 3. Principal morphometric features of Laing Dam.

Area (A) km^2	2,11
Volume (V) x10^6 m^3	22,0
Maximum depth (Zm) m	37,5
Mean depth (z) m	10,4
Shoreline (L) km	22,8
Shoreline development (D_L)*	4,43
z:Zm**	0,28

* The value of 4,43 for D_L suggests a well-developed shoreline which can be expected from the sinuous shape of the impoundment.

** The ratio of mean depth to maximum depth indicates the deep nature of the bottom terrain as well as the extensive shore line.

The bathymetry of Laing Dam, shown in Figure 5, is simple. There is a valley which runs along the middle of the impcundment for some 5 km . The dam is consequently more than 30 m deep for approximately 1 500 m from the wall. Two islands are present in the upper reaches of the dam.

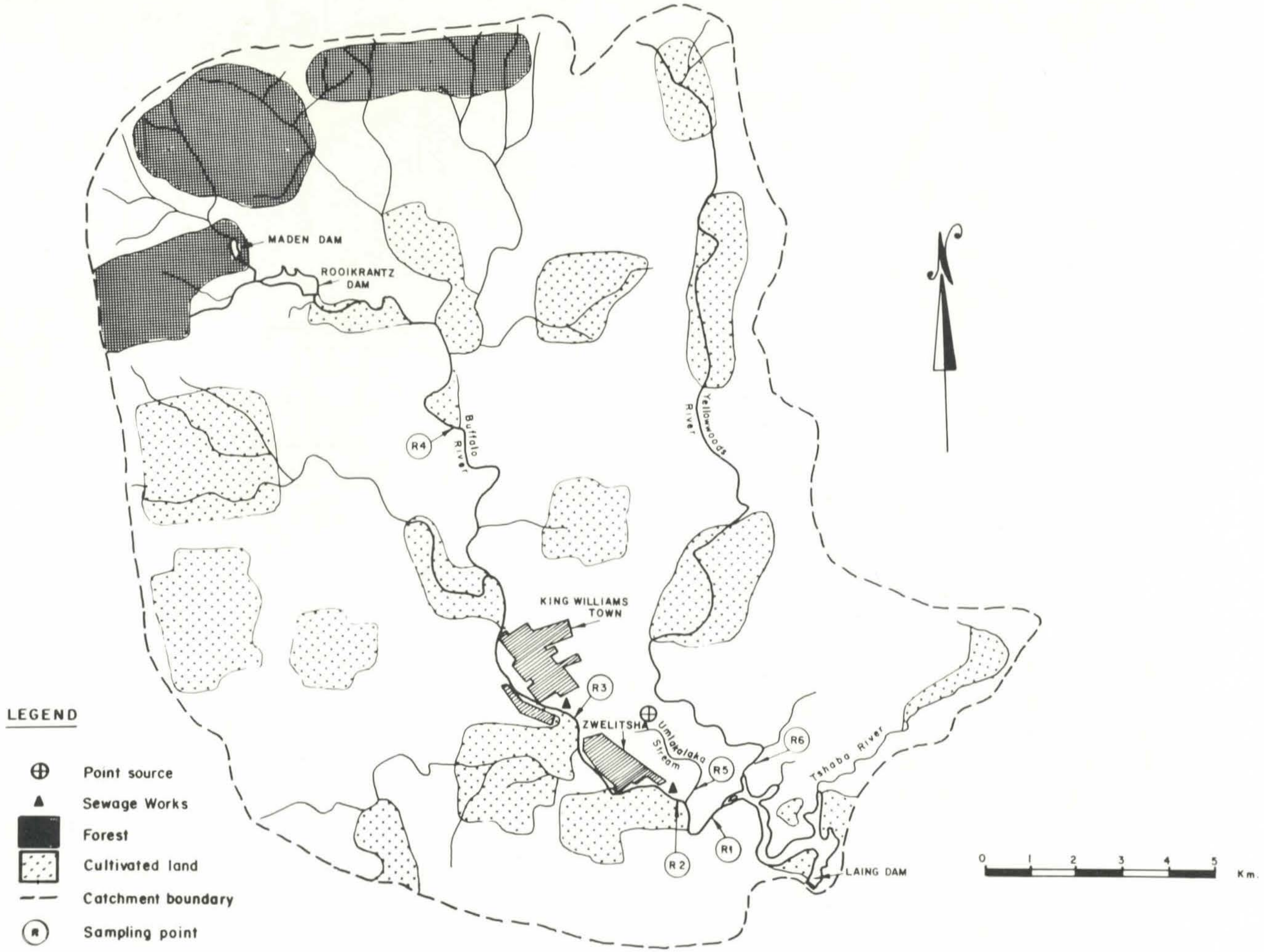

FIGURE 4: Map of Laing Dam catchment area.

FIGURE 5: Bathymetric map of Laing Dam. Contours are in metres.

NAHOON DAM

Nahoon Dam (32° 54'S; 27° 49'E) is situated at an altitude of 154 m above sea level. This impoundment is used as an urban and industrial water supply and for irrigation. The catchment area of the dam is 450 km^2 and is made up of both cultivated and uncultivated lands. The Berlin Sewage Purification Works is also situated in the Nahoon catchment. However, at the rate of development of Berlin during the study, the works were functioning well below full operational capacity and there was no significant outflow from the works to the Nahoon River.

Nahoon Dam is situated approximately 15 km north-west of East London and is the only impoundment on the Nahoon River. This dam is the property of the Department of Water Affairs, Forestry and Environmental Conservation and was completed in 1966. The original functions of the dam were to supply water to a local textile factory and to stabilize the water supply to irrigators downstream (White Paper C—'63). It is envisaged that in the future Nahoon Dam will also be used to augment supplies to Mdantsane and Potsdam.

There is a single inflow into the impoundment, namely the Nahoon River. The Rwantsa River, a tributary of the Nahoon River, was also sampled in this study. The Rwantsa has a catchment area of 53,7 km^2, and drains predominantly uncultivated areas (Figure 6).

In view of the expected future increase in demand for water in the East London-King William's Town complex, it was proposed (White Paper 0—'75) to raise the dam by 10,68 m, to the full potential at the site. The raising will increase the gross capacity from 5,9 x 10^6 m^3 to 22,1 x 10^6 m^3 and the water surface area at full supply level from 0,82 km^2 to 2,38 km^2 (White Paper 0—'75). Construction work commenced in 1975 and was completed in early 1979.

Hydrological calculations, subsequent to the proposals put forward in White Paper 0—'75, have indicated that a considerably greater quantity of water than originally estimated, is available at the dam. Thus a further raising is under consideration. It has been determined that on practical and economic considerations a further 3 m raising would be optimal (Department of Water Affairs, 1976).

In 1973, Schutte and Bosman (1973) described Nahoon Dam as having a low/medium mineral quality and a low sodium content. Toerien *et al.* (1975), indicated that Nahoon Dam exhibited a low trophic status. Schutte and Bosman (1973) showed that oxygen depletion occurred at the water-sediment interface. The importance of the Nahoon River in the Border Region was stressed in 1976 (Water Research Commission, 1976).

The major morphometric features of Nahoon Dam at full supply level before and after raising of the dam wall, are given in Table 4.

TABLE 4. Principal morphometric features of Nahoon Dam

	Before raising	After raising
Area (A) km^2	0,82	2,38
Volume (V) x 10^6 m^3	5,9	22,1
Maximum depth (Zm) m	18,4	29,1
Mean depth ($\bar{z}$) m	7,2	9,3
Shoreline (L) km	15,9	25,4
Shoreline development (D_L)*	5,95	4,64
$\bar{z}$:Zm**	0,39	0,32

* The D_L value of 4,95 is high and indicates a significant littoral component. This value is slightly decreased after the raising of the dam wall.

** The mean to maximum depth ratio is higher than the ratios encountered for both Bridle Drift and Laing dams. This value becomes reduced after raising.

The bathymetry of Nahoon Dam is shown in Figure 7.

There is a deep channel which runs along approximately the middle of the impoundment. The impoundment shows a number of steep slopes as well as gradual slopes. The mean depth of 7,2 m is within the range encountered in South African impoundments investigated by Walmsley and Butty (1979).

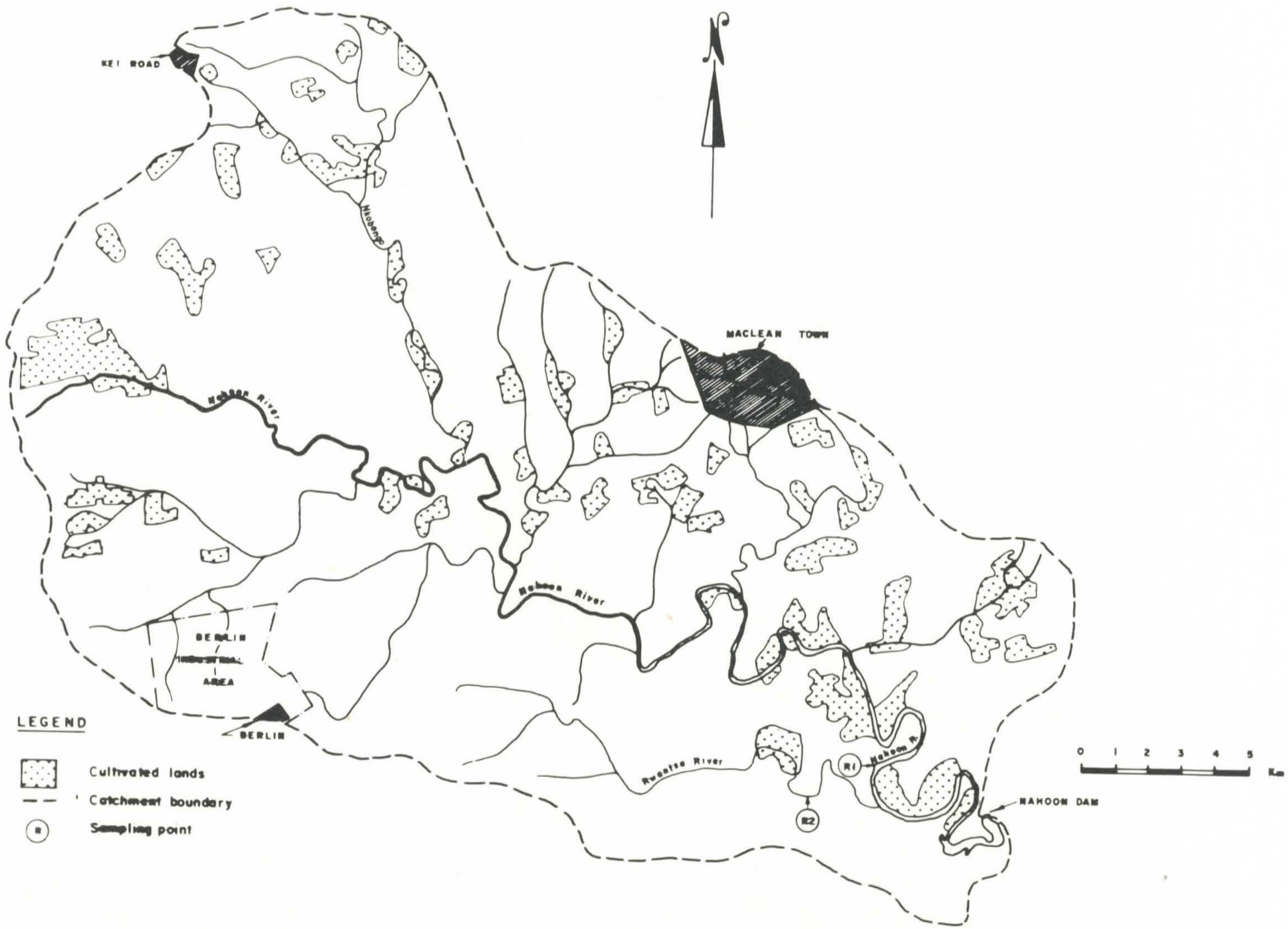

FIGURE 6: Map of Nahoon Dam catchment area.

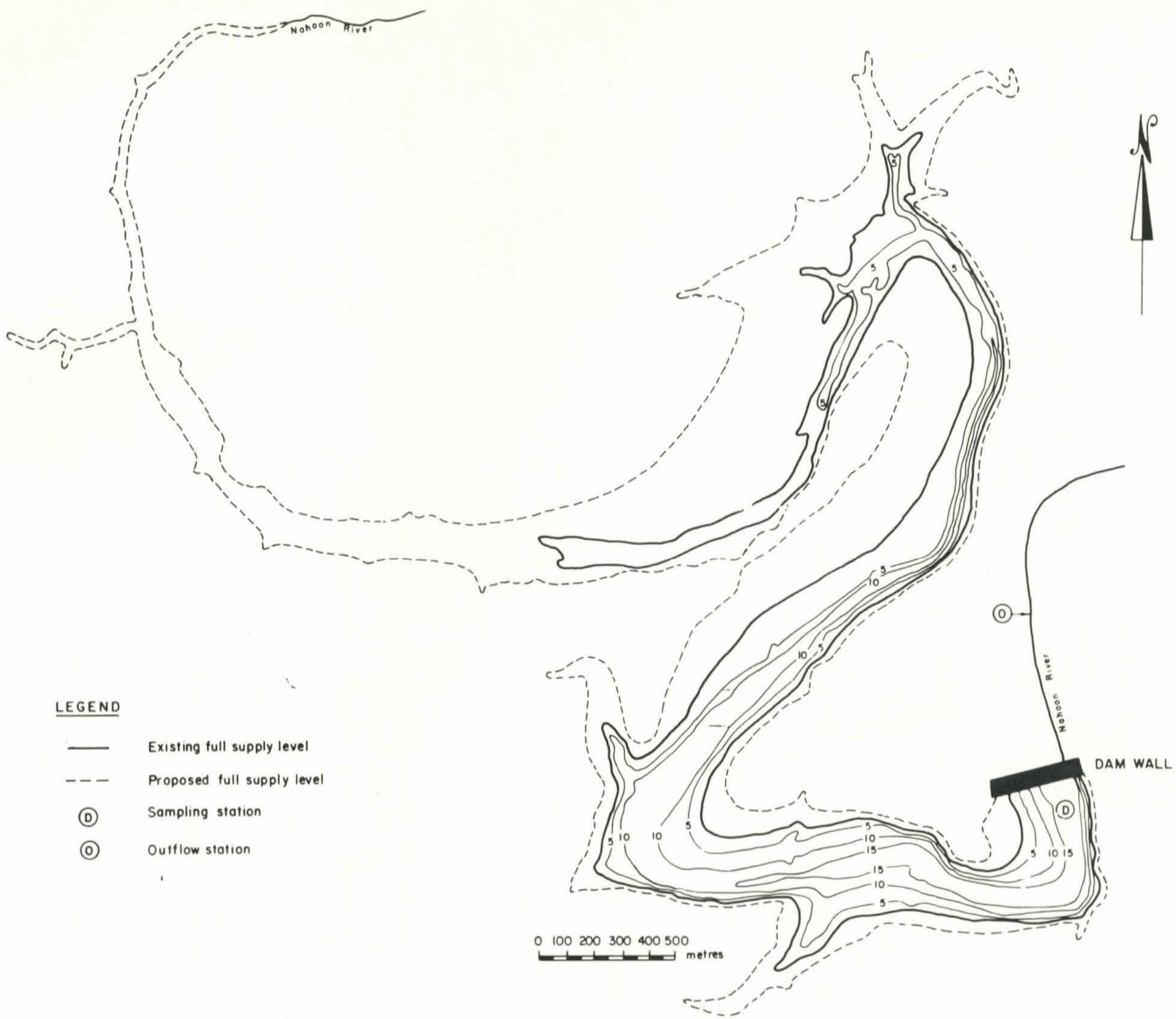

FIGURE 7: Bathymetric map of Nahoon Dam. Contours are in metres.

METHODS

Sampling points, periods and frequencies

Bridle Drift Dam

The sampling points are indicated in Figure 2.

Two dam stations were originally sampled, one in the middle reaches of the dam and the other near the dam wall. Sampling of the station in the middle reaches of the dam was discontinued in November 1977 as it was found to represent largely riverine conditions due to its position. Samples for the dam station near the wall were collected from 0,5 m , 18 m and 34 m . The sampling period extended from May 1976 to August 1978. Samples were collected at 2-weekly intervals. From November 1977 to August 1978 the inflowing streams were sampled weekly.

Laing Dam

The sampling points are indicated in Figure 4.

Two-weekly samples were collected from November 1977 to November 1978.

Samples from the dam station were collected from 0,5 m, 15 m and 27 m .

Nahoon Dam

The sampling points are indicated in Figure 6.

Samples from the dam station were collected at 0,5 m, 8 m and 15 m .

Samples were collected at 2-weekly intervals from May 1976 to September 1976, when sampling frequency was increased to weekly intervals till October 1977.

Sampling of the Rwantsa River commenced in September 1976 and ceased at the termination of the study.

Hydrological considerations

The following hydrological information has been used in assessing the loading characteristics of the study impoundments.

Bridle Drift Dam

Rainfall, evaporation, reservoir levels and outflow were calculated from records of Reservoir Gauging Station R2R03 (Department of Water Affairs, Forestry and Environmental Conservation). These records were also used to estimate the total inflow into the impoundment.

As the streams draining Mdantsane had on occasions been contaminated by sewage, it was felt necessary to monitor the flows of the four streams. In this regard, sharp crested weirs were constructed on the streams by East London Municipality, to measure flows under normal conditions. These weirs were constructed in July 1977.

Laing Dam

The rainfall, evaporation, reservoir levels and outflow have been estimated from records of Reservoir Gauging Station R2R01 (Department of Water Affairs, Forestry and Environmental Conservation).

Flow figures of the two major inflows, namely the Buffalo and Yellowwoods rivers, have also been estimated from Department of Water Affairs Forestry and Environmental Conservation data (River Gauging Stations RM210, RM211).

Nahoon Dam

As there are no river gauging stations on the Nahoon River, Reservoir Gauging Station R3R01 records have been used to determine the inflow as well as rainfall, evaporation, reservoir levels and outflow of Nahoon Dam. Catchment area size was used to estimate the contributions of the Rwantsa River to the impoundment.

Field procedures

Sampling

For each impoundment, samples were generally collected before 13h00 on any sampling day.

Samples were collected using a PVC Van Dorn water sampler and transported to the laboratory in polyethylene bottles. Bottom samples were collected 1 to 2 m above the sediments to ensure that the samples did not, as far as possible, contain sediment material.

Temperature (° C) and dissolved oxygen (mg/dm³)

Profiles were determined by use of a Delta Scientific Oxygen-Temperature Meter (Model 2110). The temperature probe was calibrated against a standard mercury thermometer. The dissolved oxygen probe was standardized against a chemical method, the azide modification of the Winkler Method (APHA, 1971), and found to record values differing in the region of 8% from values determined by the Winkler Method. The meter also showed greater instability at lower dissolved oxygen concentrations. For these reasons dissolved oxygen values below 0,5 mg/dm^3 are represented as anaerobic in the oxygen distribution figures.

Water transparency (m)

This was measured with a 20 cm diameter Secchi disc painted in black and white quadrants.

Laboratory procedures

Filtration

Samples were filtered for determinations of orthophosphate phosphorus, total phosphorus and Kjeldahl nitrogen. Due to the high silt content of the waters, filtration involved initial filtering through Sartorius glass fibre filters (Type SM 13430) and subsequent filtration through washed 0,45 μm Sartorius membrane filters (Type SM 11306).

pH

Determined electrometrically on a Taeuber and Corssen pH meter (Model 1000).

Turbidity (NTU)

Measured on a Hach turbidimeter (Model 2100A). Standards were calibrated against formazan.

Conductivity (mS/m at 20 °C)

Measured on a Wissenshaftlich Technische Werkstätten (WTW) conductivity meter.

Suspended solids (mg/dm^3)

Determined gravimetrically using Gooch crucibles packed with asbestos and dried at 180 °C for 2 hours.

Sodium (mg/dm^3)

Determined by atomic absorption spectrophotometry (Varian Techtron Model 1000)

Chloride (mg/dm^3)

The method employed is based on the precipitation of chloride as silver chloride by titrating with standard silver nitrate solution in the presence of potassium chromate.

Ammonium nitrogen (mg/dm^3 as N)

Determined by distillation with magnesium oxide and the subsequent nesslerization of the distillate.

Nitrite nitrogen (mg/dm^3 as N)

Measured through the formation of an azo dye produced by the reaction of sulphanilic acid with -naphthylamine hydrochloride. The nitrite concentration was determined spectrophotometrically against sodium nitrite standards.

Nitrate nitrogen (mg/dm^3 as N)

The determination of nitrate nitrogen involved the reduction of nitrate plus nitrite nitrogen to ammonia by Devarda's alloy. The ammonia, which was distilled over, was determined using Nessler's reagent. To obtain the nitrate nitrogen above, a separate determination of nitrite nitrogen was carried out (as described above), and the value found by difference.

Total nitrogen (mg/dm^3 as N)

This value was obtained by adding together the figures obtained on individual determinations of Kjeldahl nitrogen, nitrate nitrogen and nitrite nitrogen.

Kjeldahl nitrogen was measured by digestion with sulphuric acid, potassium sulphate and copper sulphate. The sample solution was distilled after being made strongly alkaline. The ammonia was determined by nesslerization. Determinations were carried out on filtered (dissolved) and unfiltered (total) samples.

Orthophosphate phosphorus (mg/dm^3 as P)

The principle of the method used involved the reaction of ammonium molybdate and potassium antimonyl tartrate in an acid medium with orthophosphates to form a heteropoly-phosphomolybdic acid. This compound was reduced to coloured molybdenum blue by ascorbic acid and was measured colorimetrically. Orthophosphate determinations were carried out on filtered samples.

Total phosphorus (mg/dm^3 as P)

Total phosphorus included dissolved and particulate phosphates. To release phosphates from combination, persulphate digestion was employed. Following digestion, the liberated orthophosphate was measured colorimetrically as described above. Determinations were carried out on filtered (dissolved) and unfiltered (total) samples.

Chemical Oxygen Demand (mg/dm³)

In the method used, the sample was reacted with boiling acid dichromate. The excess dichromate was then determined by titration with ferrous ammonium sulphate, giving a measure of total oxidizable material.

Chlorophyll a (µg/dm³)

One-litre samples were filtered through glass fibre filters which were placed in 95% methanol. Chlorophyll was extracted in the dark at 0°C to 4 °C for 18 to 24 hours. Chlorophyll a was quantitatively determined according to Talling and Driver (1963).

RESULTS

Bridle Drift Dam

Results of analyses and measurements are given in Tow (1979).

Hydrological characteristics

The hydrological characteristics of Bridle Drift Dam during the study period are shown in Figure 8. The water content of the impoundment remained at almost full supply level throughout the study period. The minimum monthly volume of 67,8 x 10^6 m^3 was recorded in September 1977. This represented 89% of the full supply capacity. The mean monthly volume during the study period was 73,8 x 10^6 m^3 (97% of full supply capacity). The mean surface area and mean maximum depth during the study period were 6,22 km^2 and 11,8 m respectively.

Inflow into the impoundment showed a seasonal pattern associated with rainfall. The largest inflows were recorded during October and November 1976 and December 1977. During December 1977 the inflow into Bridle Drift Dam amounted to 38,2 x 10^6 m^3. The total inflow into the impoundment from September 1977 to August 1978 was 134,0 x 10^6 m^3, of which the four streams draining Mdantsane contributed 1,1 x 10^6 m^3. This represented 0,84% of the total inflow. The flow in these streams was variable and could not always be correlated with rainfall. The mean annual contribution of the four streams during September 1977 to August 1978 was 0,28 x 10^6 m^3. The maximum annual flow (see Table 5) was recorded for the Sitotana Stream (0,47 x 10^6 m^3) and the minimum was recorded for the Umdanzani Stream (0,14 x 10^6 m^3).

The four streams draining Mdantsane drain 15% of the Bridle Drift Dam catchment area below Laing Dam.

TABLE 5. Total monthly flow figures (x 10^6 m^3) for the four streams draining Mdantsane from September 1977 to August 1978 (CV = coefficient of variation)

Month	Shangani	Sitotana	Tindelli	Umdanzani
0977	0,036	0,049	0,018	0,012
1077	0,042	0,033	0,012	0,008
1177	0,110	0,137	0,072	0,061
1277	0,012	0,027	0,008	0,005
0178	0,054	0,064	0,020	0,009
0278	0,014	0,021	0,006	0,007
0378	0,012	0,011	0,005	0,012
0478	0,019	0,028	0,007	0,006
0578	0,016	0,030	0,007	0,003
0678	0,017	0,021	0,005	0,006
0778	0,008	0,023	0,004	0,004
0878	0,016	0,027	0,004	0,003
Total	0,356	0,471	0,168	0,136
$\overline{x}$	0,030	0,039	0,014	0,011
CV%	98	86	136	141

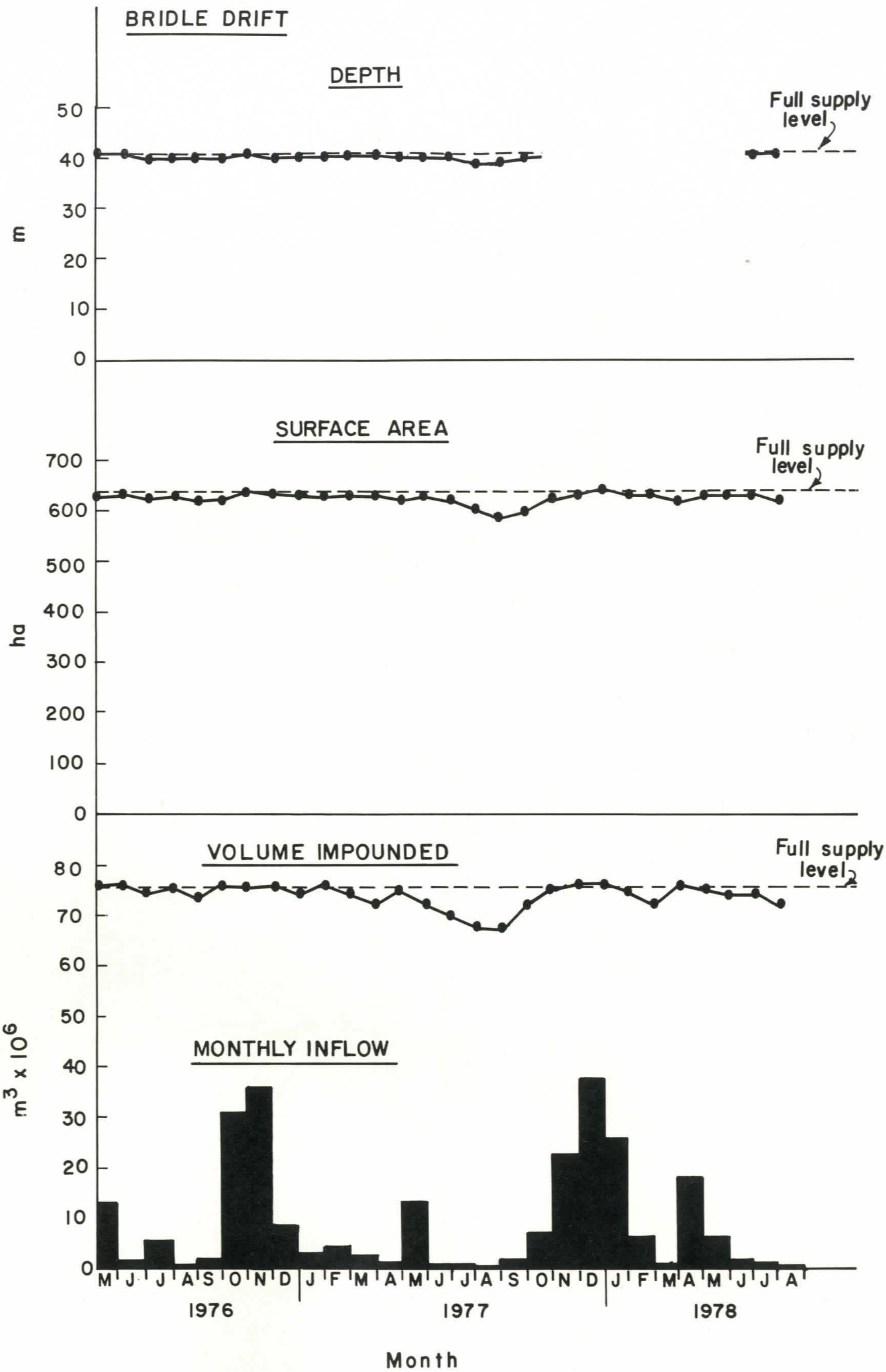

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FIGURE 8: **Maximum depth, surface area, water content and inflow volume (■) into Bridle Drift Dam during the study period.**

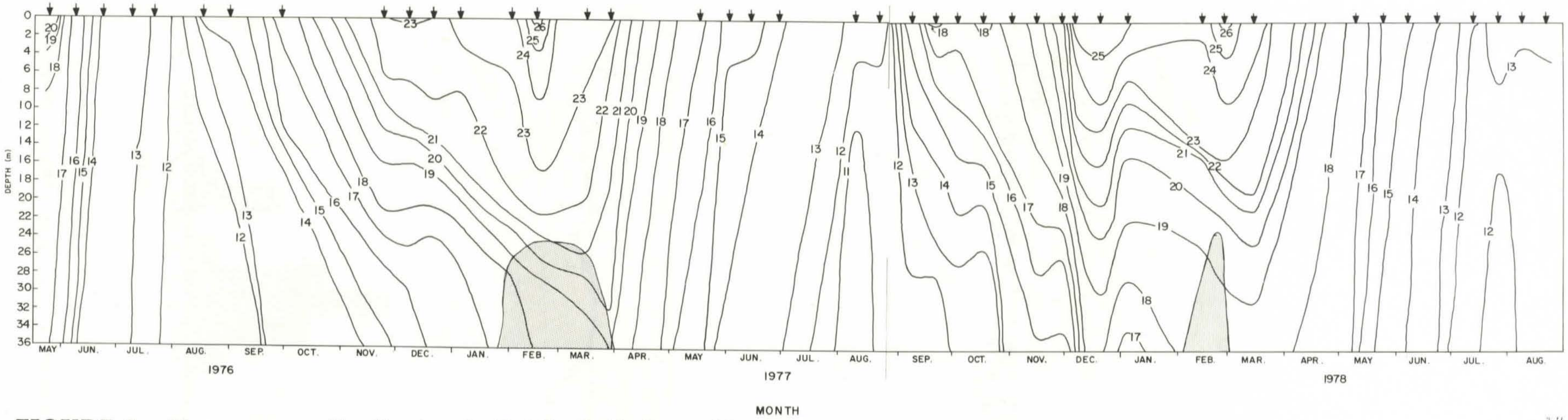

FIGURE 9: **Temperature distribution in Bridle Drift Dam (May 1976 — August 1978). Arrows indicate sampling dates, stippled areas represent anaerobic zones.**

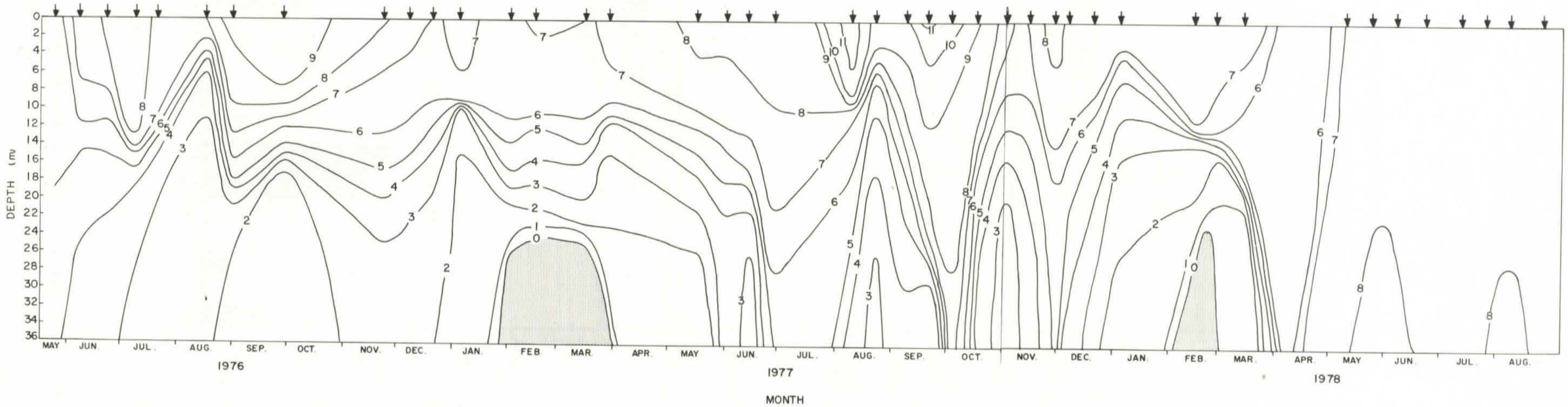

FIGURE 10: **Oxygen distribution in Bridle Drift Dam (May 1976 — August 1978). Arrows indicate sampling dates, stippled areas represent anaerobic zones.**

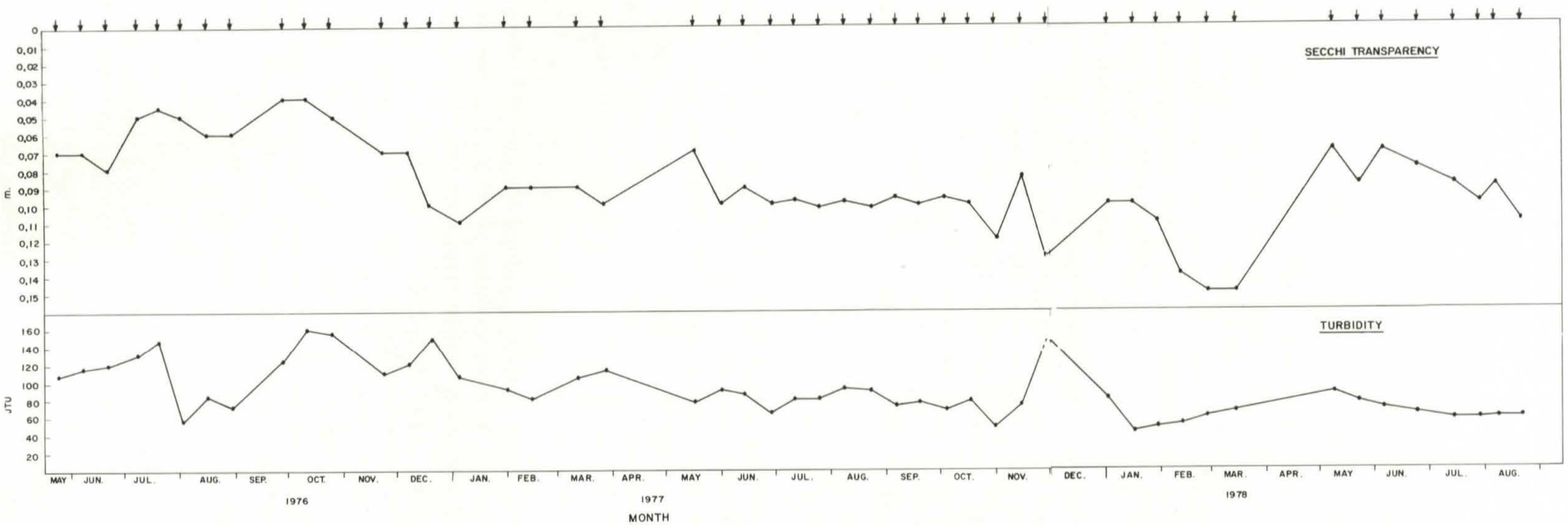

FIGURE 11: Secchi transparency (m) and turbidity (NTU) variation in the surface water of Bridle Drift Dam.

Thermal characteristics

At the commencement of the study in May 1976, a cooling of the water column was evident (Figure 9). The water column was isothermal from the end of May 1976 until early August 1976, when thermal stratification of the water column started. These conditions persisted until March 1977. A decrease in the water temperature resulted in circulation which lasted until August 1977. In September 1977 the water column developed stratification, but this was disrupted in December 1977 due to an increased inflow. Stratification redeveloped and persisted until March 1978. A temperature gradient of 8 °C through the water column was recorded in February 1977 and March 1978. Turnover occurred in April 1978 and circulation continued until the end of the study period in August 1978.

Oxygen characteristics

There was weak oxygen stratification in May 1977 (Figure 10). A well-defined oxycline was formed during July and August 1976. The depth of this oxycline varied between 3 and 18 m Stratified conditions persisted into the winter months of 1977 in spite of a cooling of the water. During February and March 1977, an anaerobic zone, with an upper boundary at 24 m, was formed. This zone represented approximately 10% of the full supply capacity of the impoundment. A dissolved oxygen gradient of 3 to 6 mg/dm^3 from surface to bottom was present throughout the winter months of 1977, despite the virtually isothermal conditions which were encountered during the same period. In September/October 1977 a re-oxygenation of the hypolimnion occurred through increased inflows. An oxygen deficit was noted in late October/November 1977, but this was again disrupted in December 1977, as a result of high inflows. Low oxygen levels were re-established by mid-December 1977. During February 1978 an anaerobic zone was formed at 23 m . This represented 10% of the full supply capacity. After overturn in March 1978, recirculation resulted in the re-oxygenation of the anaerobic zone. An orthograde oxygen distribution was present from April 1978 until the end of the study period in August 1978.

Water transparency and turbidity

The variations in water transparency and turbidity of the surface water during the study period are shown in Figure 11. Turbidity values generally increased during periods of high inflow, although there was no obvious seasonal pattern. The range over which Secchi depth varied was narrow (0,04 m - 0,15 m), and again no obvious seasonal pattern was evident. The maximum Secchi depth of 0,15 m was measured in February/March 1978 and the minimum depth of 0,04 m was recorded in October 1977 during a period of high inflow. The mean Secchi depth over the study period was 0,09 m.

The maximum, minimum and mean turbidity values for the inflowing, outflowing and impounded waters are given in Table 6. The mean value of 88 NTU recorded for the surface waters during the study period is indicative of a highly turbid system. The values recorded for the inflowing waters also indicated that by far the greatest amount of silt, as measured by turbidity, entered the impoundment via the Buffalo River. The mean values of turbidity of the streams draining Mdantsane ranged between 7 NTU (Umdanzani) and 20 NTU (Shangani). The mean value for the Buffalo River above Bridle Drift Dam was 85 NTU for the study period. The turbidity values recorded for the Buffalo River entering the impoundment and the impounded surface water indicate that little sedimentation or a high rate of resuspension occurred.

pH

The pH of the impounded waters varied between 7,1 and 8,1 during the study period. The median value was 7,6. For the bottom waters, a median pH value of 7,5 was recorded. Values were considerably higher at the surface than at the bottom during summer stratification. This gradient was greatly reduced or absent during winter circulation. The inflowing waters showed median values which ranged between 7,7 and 8,1. The median pH of the outflowing water was 7,9.

TABLE 6. A summary of physical and chemical characteristics of inflowing, outflowing and impounded waters of Bridle Drift Dam for May 1976 to August 1978 (CV = coefficient of variation; ND = not detected).

BRIDLE DRIFT DAM
24.5.76 - 22.8.78

PARAMETER	DAM STATION								BUFFALO				SHANGANI			
	TOP				BOTTOM											
	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.
Na	34	70	53	17	35	67	53	14	23	159	80	39	40	225	140	31
K	4,6	9,1	6,5	18	5,5	10,8	7,6	19	4,1	21,7	6,2	50				
Ca	11,1	20,9	14,4	18	11,5	19,5	14,6	13	9,3	42,2	22,0	40				
Mg	10,7	19,0	13,6	15	10,8	16,7	13,5	14	6,7	44,0	22,0	46				
SO_4	11,1	25,8	18,4	19	11,8	25,2	17,2	18	6,8	59,0	25,5	39				
Cl	44	86	68	14	48	78	67	13	36	280	112	48	66	406	227	36
Si																
Cond	26	45	37	14	26	44	37	13	12	111	53	38	30	152	96	29
Alk	57	86	73	11	58	85	72	10	21	170	105	35				
Tot - N	0,73	4,88	2,14	47	0,73	5,52	2,21	50	0,06	7,88	2,14	66	0,44	44,40	5,91	118
Dis - N	0,67	3,60	1,60	41	0,69	2,78	1,41	37	ND	6,81	1,52	73	0,48	30,80	4,40	119
NH_4-N	ND	0,27	0,05	134	ND	0,27	0,05	149	ND	6,08	0,19	437	ND	37,00	1,68	336
NO_3-N	0,44	2,88	1,06	39	0,18	2,52	1,02	42	ND	6,08	0,95	90	ND	6,32	2,37	79
NO_2-N	ND	0,05	0,003	324	ND	0,02	0	693	ND	0,08	0,01	220	ND	0,85	0,13	157
Tot P	0,20	5,40	0,85	90	0,16	9,28	1,27	115	0,15	3,28	0,90	80	0,18	9,60	1,85	116
Tot dis P	0,13	0,75	0,45	130	0,13	1,21	0,51	43	0,05	1,20	0,41	56	0,12	9,04	1,43	141
PO_4-P	ND	0,38	0,12	65	ND	0,52	0,10	111	ND	0,32	0,10	79	0,06	9,42	1,16	165
Fe																
Mn																
Temp	12,1	26,8	18,6	24	10,3	19,4	14,7	18	10,4	26,6	18,8	27	9,1	26,7	17	31
DO	5,5	11,5	8,1	15	0,1	8,7	3,4	77								
Tu	42	160	88	35	52	248	124	36	5	1100	85	178	1	282	20	250
pH	7,1	8,1	7,8	3	7,0	7,9	7,6	3	7,0	8,5	7,7	4	7,0	8,5	7,7	4
SS	8	85	53	34	54	301	159	41	9	2276	138	302	0	311	30	214

PARAMETER	SITOTANA				TINDELLI				UMDANZANI				OUTFLOW			
	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.
Na	39	500	230	31	39	325	142	37	22	254	146	29	35	75	52	16
K													5,7	12,3	7,7	18
Ca													9,9	28,6	14,4	18
Mg													9,8	20,0	13,4	15
SO_4													11,2	27,4	17,8	19
Cl	120	674	397	29	84	626	226	47	108	476	216	34	50	128	69	18
Si																
Cond	54	235	149	25	42	161	97	32	45	169	100	25	30	59	42	13
Alk													57	109	74	12
Tot - N	0,58	12,52	3,21	89	0,34	14,31	5,36	63	0,33	16,48	4,38	94	0,57	5,33	2,19	50
Dis - N	0,49	9,71	2,59	86	0,31	13,80	4,85	67	0,21	14,88	3,65	119	0,57	3,82	1,55	45
NH_4-N	ND	5,90	0,34	290	ND	9,84	1,21	198	ND	8,56	0,62	260	ND	0,38	0,07	133
NO_3-N	0,29	6,11	1,92	76	0,01	9,20	2,94	74	ND	11,56	2,46	106	0,56	2,48	1,05	39
NO_2-N	ND	0,50	0,06	215	ND	0,75	0,10	156	ND	2,30	0,14	258	ND	0,20	0,01	429
Tot P	0,15	2,90	0,86	75	0,44	9,96	2,37	98	1,55	9,70	4,21	55	0,17	5,40	1,11	78
Tot dis P	0,08	2,71	0,64	81	0,34	9,84	2,35	102	0,48	9,30	3,92	55	0,17	1,71	0,57	42
PO_4-P	0,03	2,71	0,37	135	0,08	9,52	1,86	123	0,24	8,95	3,31	57	0,03	0,53	0,14	56
Fe																
Mn																
Temp	9,4	27,2	17,9	28	6,9	28,4	17,4	34	7,3	26,6	17,7	34	12,6	22,0	17,1	17
DO																
Tu	0,4	168	12	281	0,4	162	9	280	0,4	100	7	255	40	300	120	39
pH	7,6	8,4	8,1	2	7,0	8,5	7,7	4	7,3	8,7	7,8	4	7,3	8,2	7,9	3
SS	0	188	16	203	0	65	9	127	0	101	11	172	6	232	107	50

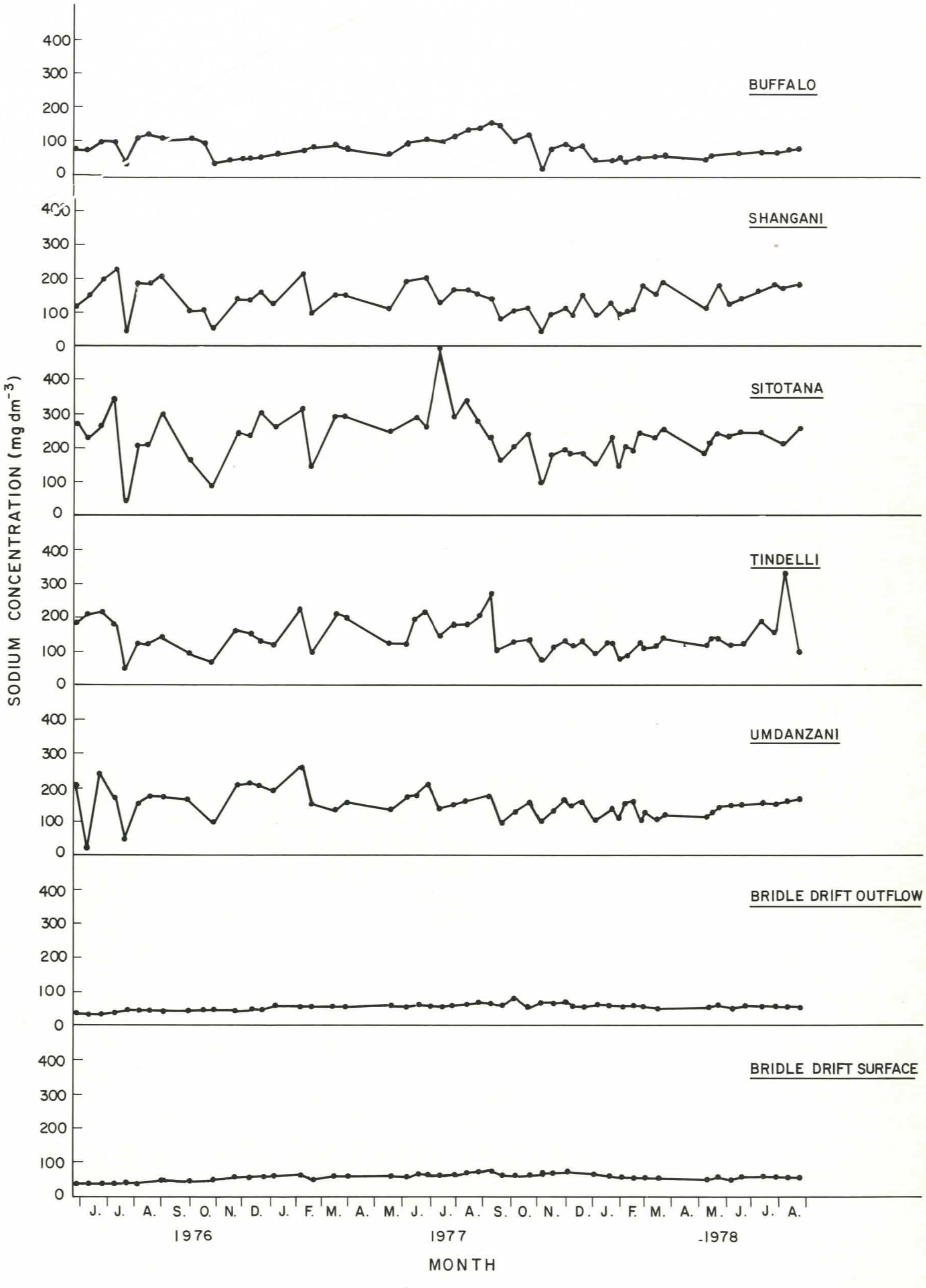

FIGURE 12: Variation in sodium concentrations in the inflowing, outflowing and surface waters of Bridle Drift Dam.

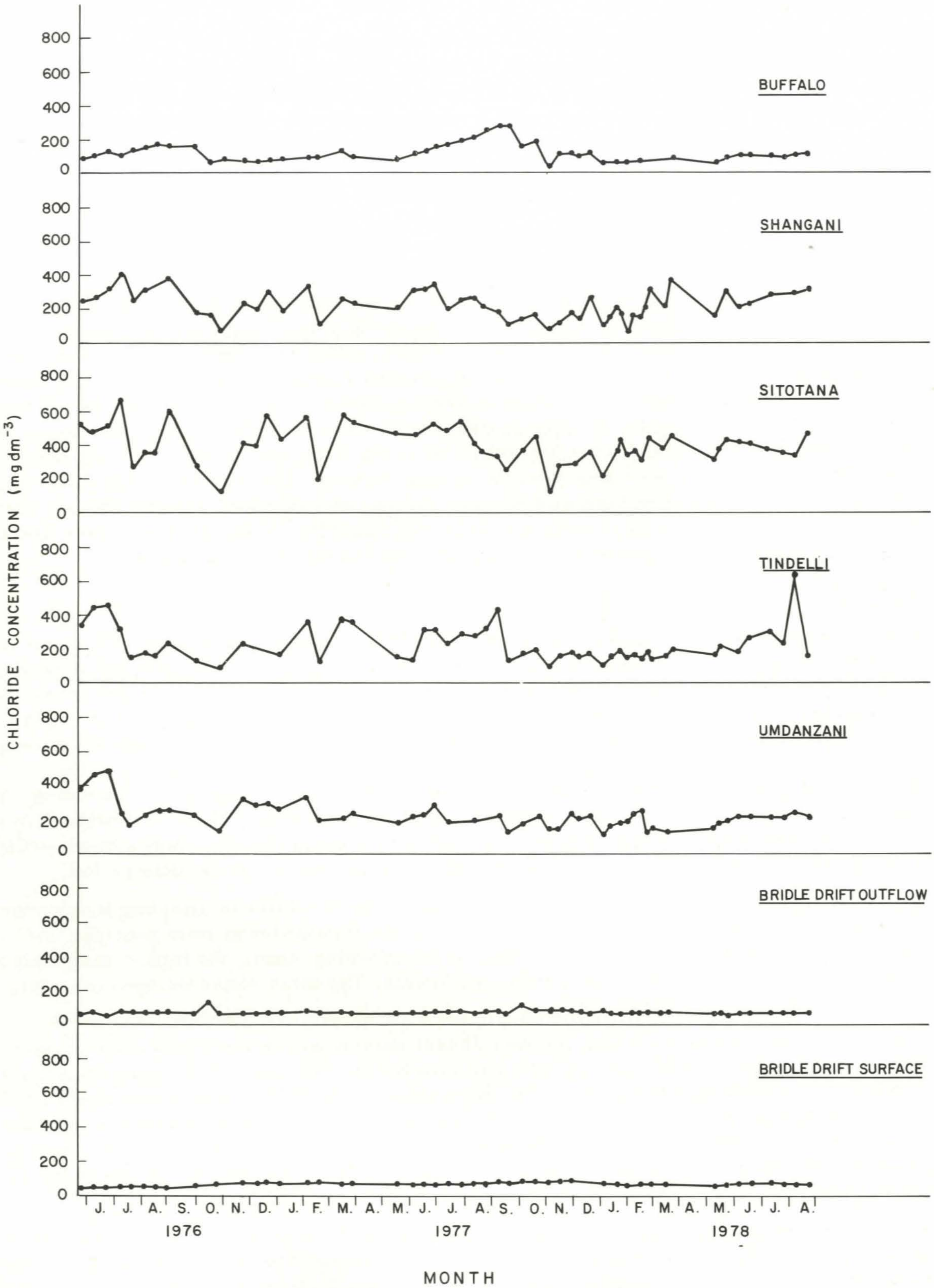

FIGURE 13: Variation in chloride concentrations in the inflowing, outflowing and surface waters of Bridle Drift Dam.

Conductivity

The mean conductivity for the study period for the surface water was 37 mS/m (Table 6), with a maximum of 45 mS/m and a minimum of 26 mS/m (Table 6). High mean conductivity values with wide variations were recorded for the inflowing rivers, in particular the four streams draining Mdantsane. Conductivity was generally lower during periods of high rainfall, indicating a diluting effect. The mean value for the Buffalo River above Bridle Drift Dam was 53 mS/m and 42 mS/m for the Buffalo River below the impoundment. Of the four streams draining Mdantsane, the lowest mean value was recorded for the Shangani (96 mS/m) and the highest for the Sitotana (149 mS/m).

Sodium and chloride

The variations in sodium and chloride concentrations in the inflowing, outflowing and impounded waters are shown in Figures 12 and 13. The variation in sodium and chloride content for all the stations show similar trends. For the impounded and outflowing waters, sodium and chloride levels were generally stable and little variation occurred during the study period. The mean sodium concentration in the surface water of the impoundment during the study period was 53 mg/dm^3 and the mean chloride concentration was 68 mg/dm^3 (Table 6). A greater degree of variation was recorded for the inflowing waters, particularly the four streams draining Mdantsane. The mean values for these streams ranged between 140 mg/dm^3 (Shangani) and 230 mg/dm^3 (Sitotana) for sodium and between 216 mg/dm^3 (Umdanzani) and 397 mg/dm^3 (Sitotana) for chloride. The mean sodium and chloride values for the Buffalo River above Bridle Drift Dam during the study period were 80 mg/dm^3 and 112 mg/dm^3 respectively.

Nitrogen

The variation in ammonia concentration in the inflowing, outflowing and surface waters of Bridle Drift Dam is shown in Figure 14. Concentrations which were not detected in the analytical method employed are indicated as zero in Figure 14. Levels were generally low, often below the detection limit, in the surface water as well as in the outflow. Apart from a value of 6,08 mg/dm^3 which was recorded in March 1978, the Buffalo River above Bridle Drift Dam generally showed low concentrations. A wider range of variation was observed in the streams draining Mdantsane. A number of peaks which were recorded were direct indications of organic contamination. A value of 37,0 mg/dm^3 was recorded for the Shangani in September 1977. The Buffalo River entering the impoundment had a mean value of 0,19 mg/dm^3 for the study period, while 0,05 mg/dm^3 was the mean concentration for the impounded waters for the same period.

The maximum, minimum and mean values for nitrite for the different sampling stations are given in Table 6. Nitrite nitrogen concentrations in the impoundment were generally low, a mean value of 0,003 mg/dm^3 being recorded. In the inflowing waters, the highest mean value (0,14 mg/dm^3) was recorded for the Umdanzani Stream. The mean nitrite nitrogen concentration for the outflow was 0,01 mg/dm^3.

Variations in nitrate concentrations for the different stations for the study period are shown in Figure 15. A mean value of 1,06 mg/dm^3 was recorded for the impounded waters (maximum 2,88 mg/dm^3, minimum 0,44 mg/dm^3). The mean value for the Buffalo River above Bridle Drift Dam was 0,95 mg/dm^3 for the study period. During the same period the mean values for the four streams draining Mdantsane ranged between 1,92 mg/dm^3 (Sitotana) and 2,94 mg/dm^3 (Tindelli). No clear seasonal pattern of concentration variation was evident in any of the inflowing streams.

The variation in total nitrogen concentration closely followed the variations observed for nitrate since nitrate was the dominant component of the total nitrogen. The mean total nitrogen value recorded for the impounded surface waters (Table 6) was 2,14 mg/dm^3 while the value for dissolved nitrogen was 1,60 mg/dm^3. Mean values for total and dissolved nitrogen for the Buffalo River above Bridle Drift Dam were 2,14 mg/dm^3 and 1,52 mg/dm^3 respectively. Total nitrogen values for the four streams draining Mdantsane ranged between 3,21 mg/dm^3 (Sitotana) and 5,91 mg/dm^3 (Shangani) and for dissolved nitrogen, between 2,59 mg/dm^3 (Sitotana) and 4,85 mg/dm^3 (Tindelli).

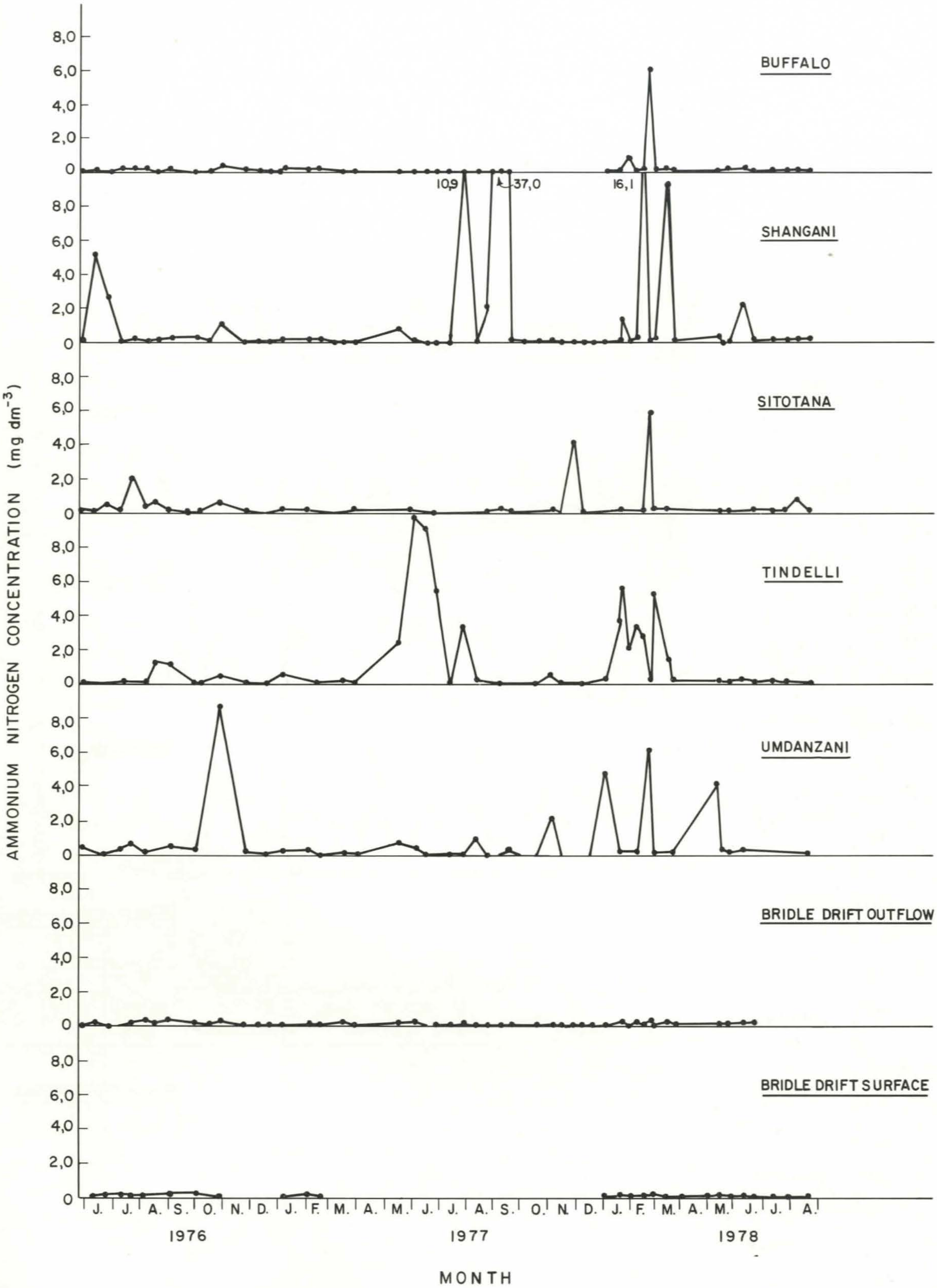

FIGURE 14: Variation in ammonium nitrogen concentrations in the inflowing, outflowing and surface waters of Bridle Drift Dam.

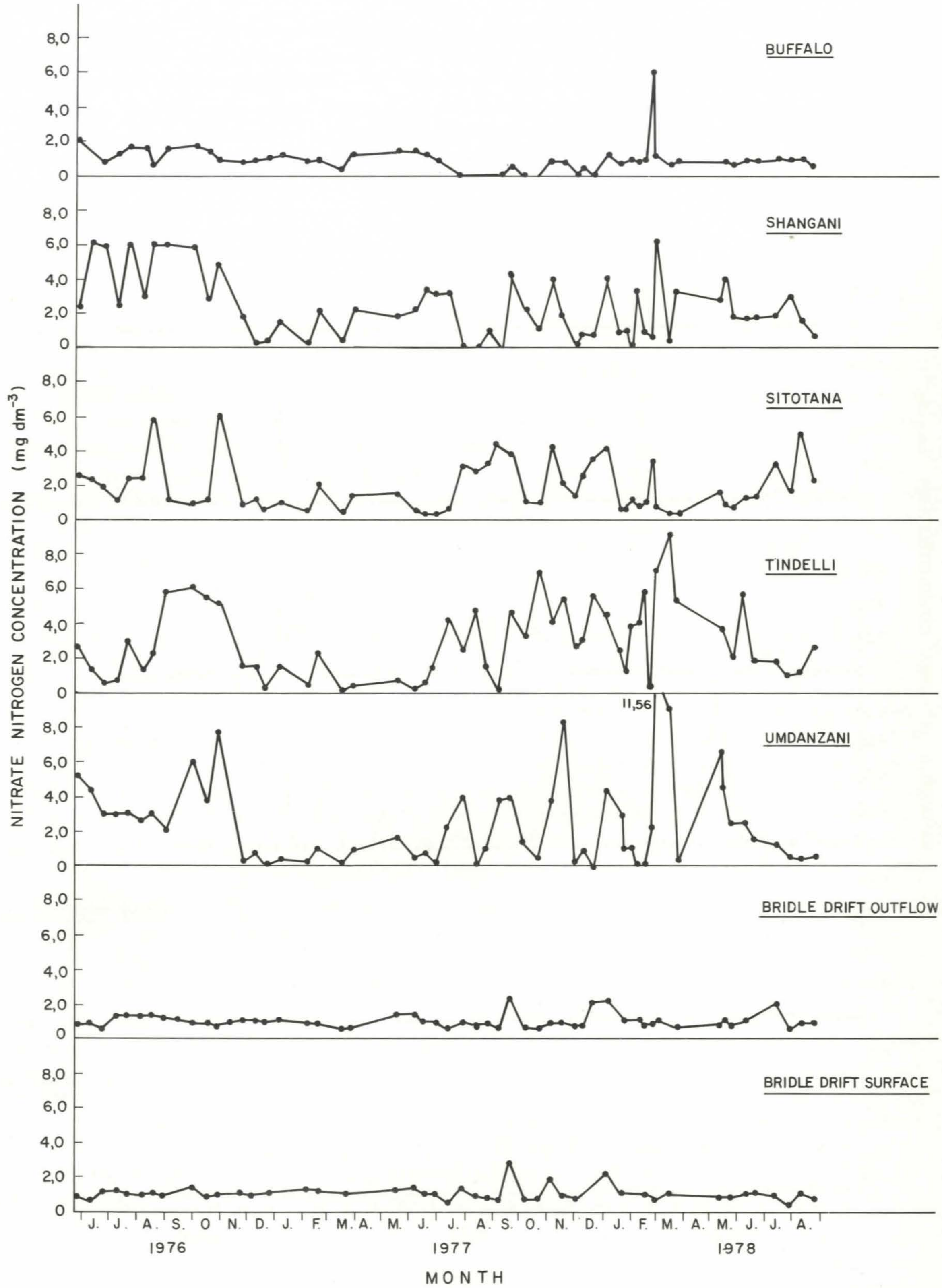

FIGURE 15: Variation in nitrate nitrogen concentrations in the inflowing, outflowing and surface waters of Bridle Drift Dam.

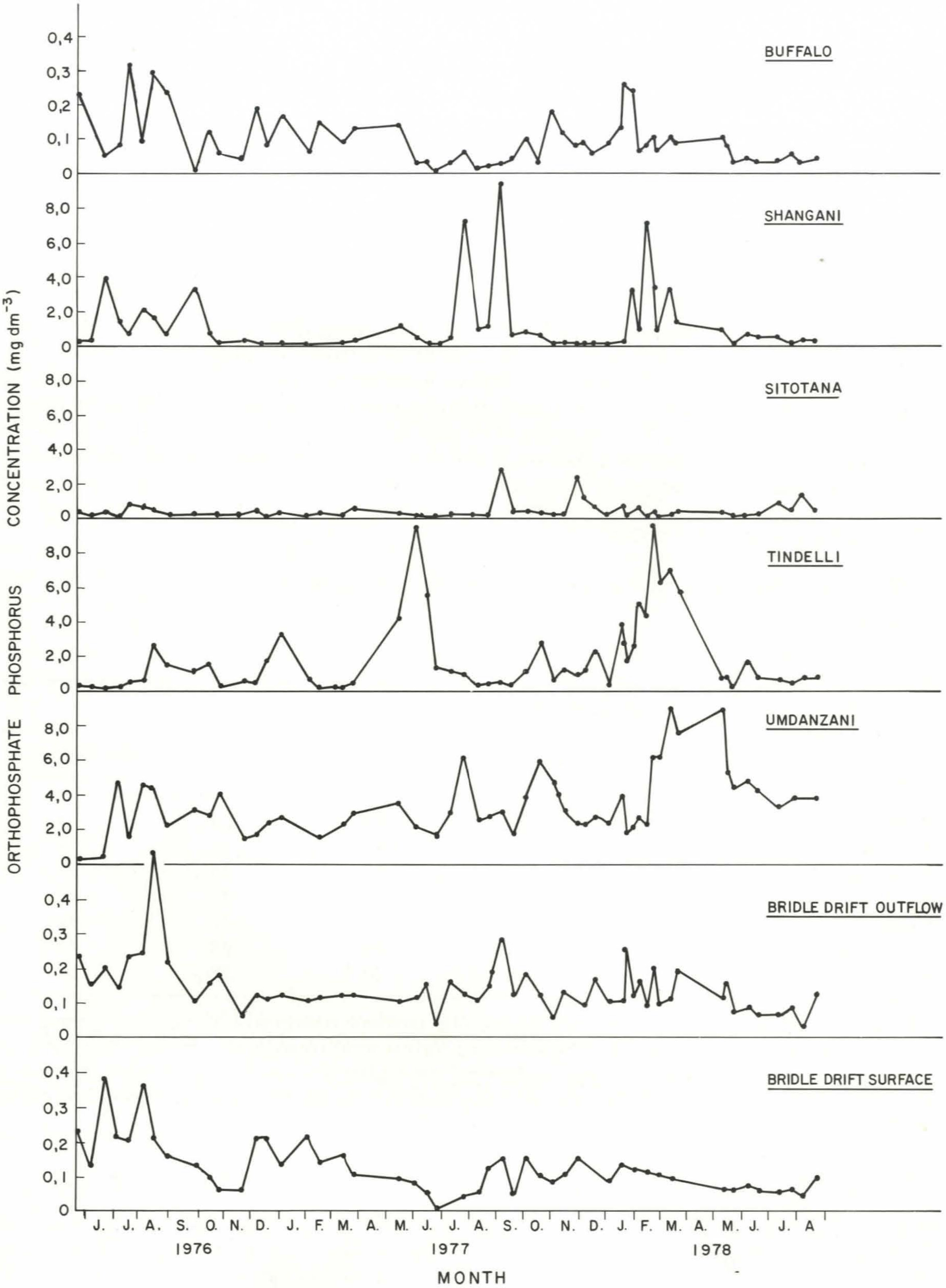

FIGURE 16: Variation in orthophosphate phosphorus concentrations in inflowing, outflowing and surface waters of Bridle Drift Dam.

Phosphorus

The variation in orthophosphate phosphorus concentrations in the inflowing, outflowing and impounded waters is presented in Figure 16. The phosphorus content of the impoundment was generally high, as indicated by the mean orthophosphate phosphorus concentration of 0,12 mg/dm^3 in the surface waters for the study period (Table 6). Of the four streams draining Mdantsane, the Sitotana Stream showed the lowest mean value (0,37 mg/dm^3). Mean concentrations of 1,16 mg/dm^3, 1,86 mg/dm^3 and 3,31 mg/dm^3 were recorded for Shangani, Tindelli and Umdanzani streams respectively. For the major inflow, the Buffalo River, a mean value of 0,10 mg/dm^3 was recorded. Many of the peaks which were recorded in the streams draining Mdantsane (Figure 16) could be directly associated with sewage contamination of the streams. Consistently high orthophosphate concentrations were recorded for the Umdanzani Stream.

From the total phosphorus values which were recorded during the study period, it can be seen that in the streams draining Mdantsane, the greatest proportion of phosphorus occurred in the dissolved form. This was not the case in the Buffalo River or the impounded waters, where a large proportion of the phosphorus was associated with the suspended material. The mean suspended solids content of the Buffalo River entering the impoundment was 138 mg/dm^3 (Table 6) and for the impounded surface water the value was 53 mg/dm^3. The mean suspended solids value for the four streams was 17 mg/dm^3.

Chemical oxygen demand (COD)

The minimum, maximum and mean values for COD are given in Table 7.

TABLE 7. Chemical oxygen demand (mg/dm^3) for inflowing, outflowing and impounded surface waters of Bridle Drift Dam from June 1977 to August 1978

Sampling station	Minimum	Maximum	Mean	Coefficient of variation %
Buffalo River	8	89	33	51
Shangani	12	241	36	110
Sitotana	13	59	26	45
Tindelli	9	92	32	61
Umdanzani	6	65	27	46
Buffalo River outflow	11	46	25	29
Bridle Drift surface	7	44	22	34

The mean COD values varied between 22 mg/dm^3 (surface water) and 36 mg/dm^3 (Shangani). The maximum values recorded for the inflowing waters were considerably higher than those for the impounded and outflowing water, indicating the higher quantities of oxidizable material in the inflows. The highest COD (241 mg/dm^3) was recorded for the Shangani Stream in September 1977.

Chlorophyll a

A low mean chlorophyll value of 0,15 $\mu g/dm^3$ was recorded for the study period (maximum 1,68;minimum often being undetected). *Microcystis* was present in the impoundment from March 1977 to May 1977. This alga was again observed in mid-October 1977 and prominent surface scums were intermittently present between November 1977 and March 1978. Large areas of the impoundment were covered by the alga. In January 1978 large scums of *Microcystis* were observed in the upper reaches of the impoundment and were probably growths which had been washed out of Laing Dam. A *Pandorina* bloom developed in the Umdanzani estuary at the beginning of August 1978 and was present for 3 to 4 weeks. Water hyacinth occurred in the impoundment in mid-March 1978.

Nutrient loading

The nutrient surface loading rates for Bridle Drift Dam, indicating the contributions from the various streams, are shown in Table 8.

The orthophosphate phosphorus surface loading rate for September 1977 to September 1978 was 2,43 $g.m^{-2}.a^{-1}$, of which 9% entered the impoundment via the four streams draining Mdantsane. This loading rate represented a total of 14,70 t of orthophosphate phosphorus which entered the impoundment. The total phosphorus surface loading rate was 18,72 $g.m^{-2}.a^{-1}$ whilst the inorganic nitrogen and the total nitrogen surface loading rates were 19,30 and 44,24 $g.m^{-2}.a^{-1}$ respectively. The large differences between the dissolved and total nitrogen phosphorus loads show that a large proportion of the nutrients which entered the impoundment was associated with suspended material in the inflowing waters.

TABLE 8. Nutrient loading rates and hydrological characteristics of Bridle Drift Dam from September 1977 to September 1978.

Surface loading rate ($g.m^{-2}.a^{-1}$)	PO_4-P	Dissolved P	Total P	Inorganic N	Dissolved N	Total N
Buffalo River	2,21	10,37	18,36	18,66	29,71	43,27
Shangani Stream	0,06	0,10	0,13	0,26	0,28	0,39
Sitotana Stream	0,04	0,05	0,07	0,17	0,22	0,28
Tindelli Stream	0,05	0,05	0,07	0,12	0,15	0,17
Umdanzani Stream	0,07	0,09	0,09	0,09	0,13	0,13
Total	2,43	10,66	18,72	19,30	30,49	44,24

Mean volume x 10^6 m^3	73,52
Mean area km^2	6,22
Mean depth m	11,8
Retention time a	0,56
Hydraulic load m/a	21,07

Laing Dam

Results of analyses and measurements are given in Tow (1979).

Hydrological characteristics

Apart from November 1977, the first month of the study period, the impoundment remained at full supply level (Figure 17). The largest inflows into the impoundment occurred during November and December 1977 and January 1978. During January 1978 the total inflow amounted to 16,7 x 10^6 m^3. An inflowing volume of 9,5 x 10^6 m^3 was recorded for April 1978. Apart from these periods the monthly inflow into the impoundment was generally low.

In terms of catchment area ratios, it has been estimated that the Yellowwoods River contributed between 25 and 30% of the total inflow into Laing Dam. On several occasions during the study period estimates were made of the flow rate of the Umlakalaka Stream, a tributary of the Buffalo River which drains lands irrigated with textile effluent. The flow rate was found to vary between approximately 2 200 m^3/d and 6 500 m^3/d .

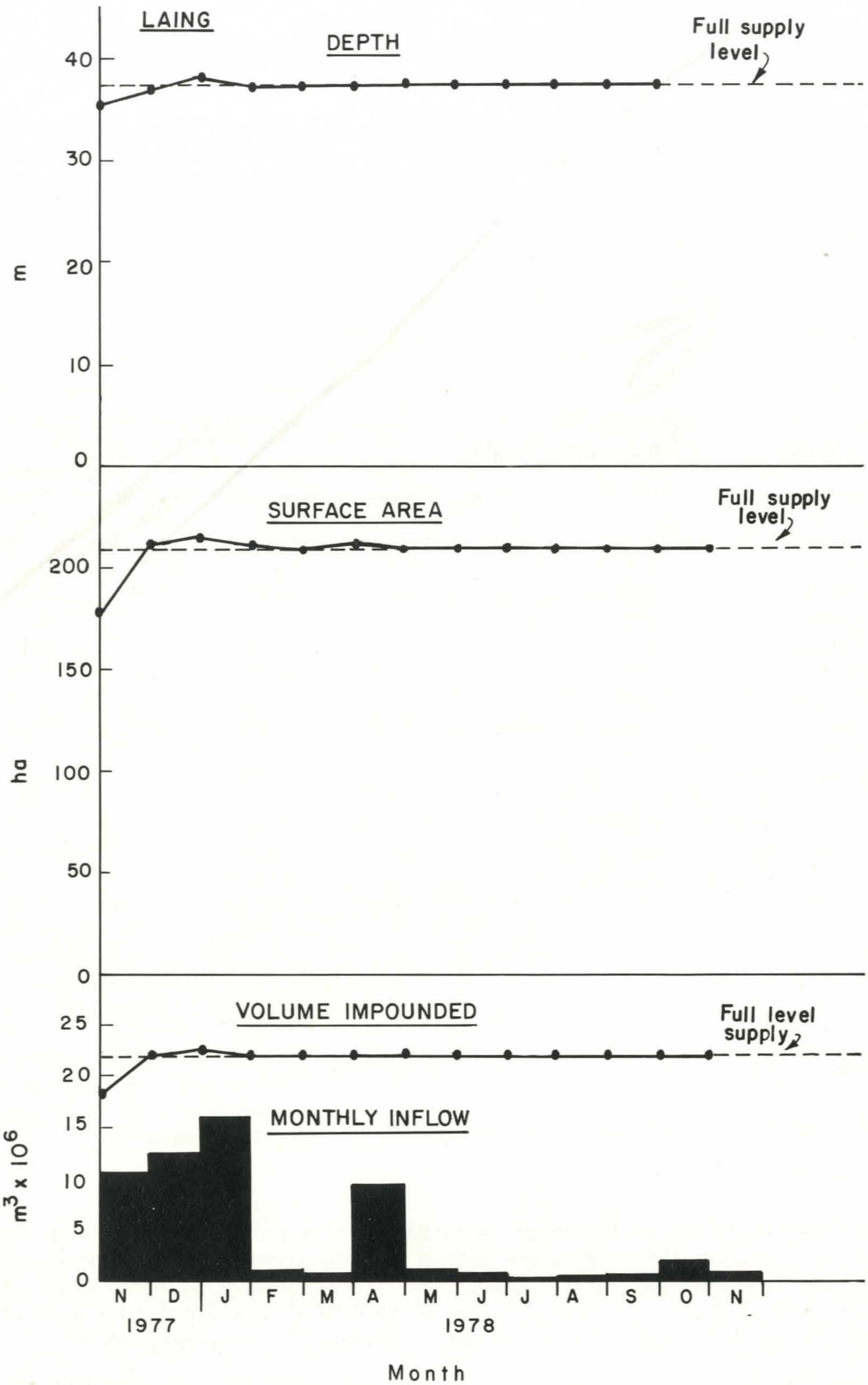

FIGURE 17: Maximum depth, surface area, water content and inflow volume (▬) into Laing Dam during the study period.

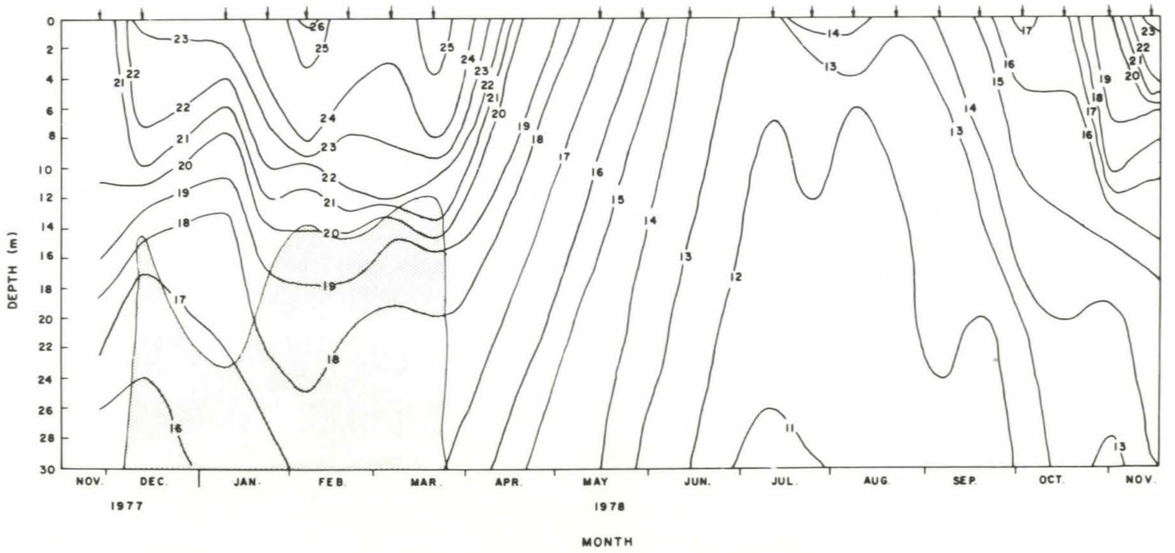

FIGURE 18: Temperature distribution in Laing Dam (November 1977 — November 1978).

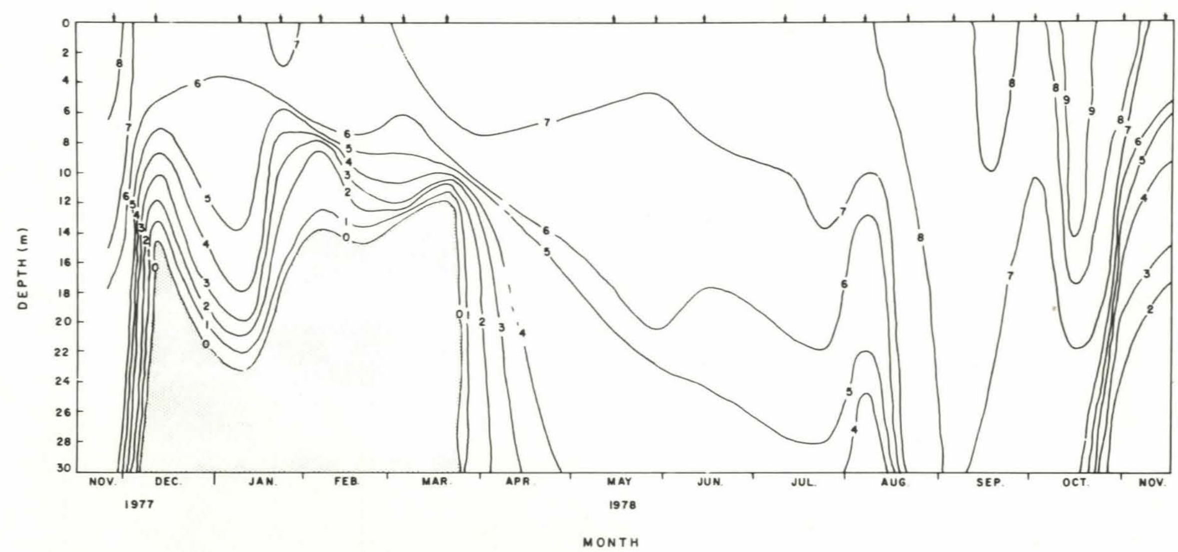

FIGURE 19: Oxygen distribution in Laing Dam (November 1977 — November 1978).

Thermal characteristics

The temperature distribution in the water column for the study period is shown in Figure 18. The water column was stratified at the commencement of the study in November 1977. These conditions persisted until the end of March 1978, when cooling of the water body resulted in overturn. During the winter months a temperature gradient of 1 °C to 4 °C between the surface and the bottom was always present. Stratification recurred in August/September 1978 and at the end of the study period in November 1978 a temperature gradient of 9 °C through the water column was present.

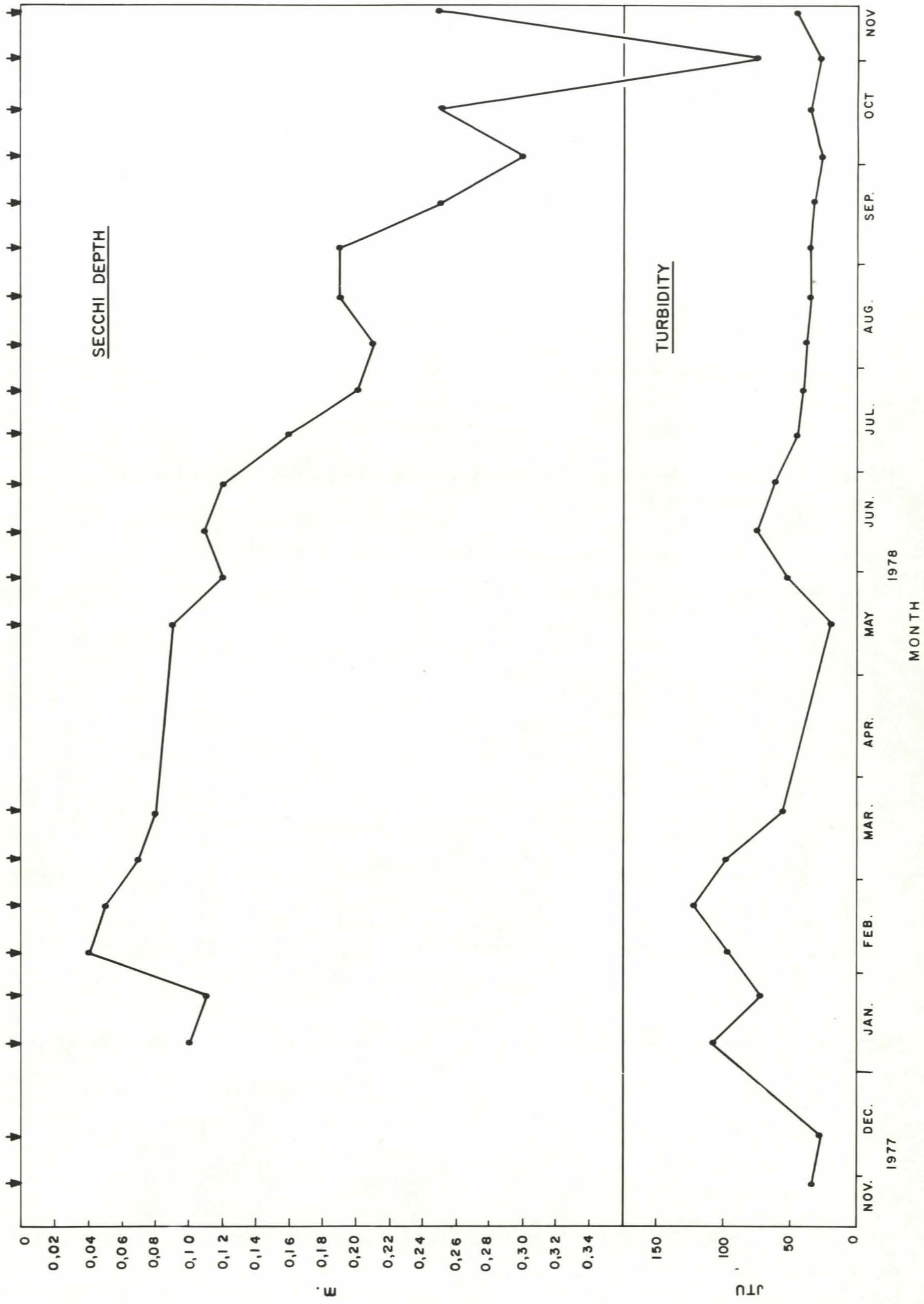

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FIGURE 20: Secchi transparency (m) and turbidity (NTU) variation in the surface waters of Laing Dam.

TABLE 9. A summary of physical and chemical characteristics of inflowing, outflowing and impounded waters of **Laing Dam from November 1977 to November 1978. (CV = coefficient of variation; ND = not detected).**

LAING DAM

PARAMETER	DAM STATION								BUFFALO RIVER (above King William's Town)				BUFFALO RIVER (above Zwelitsha)			
	TOP				BOTTOM											
	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.
Na	33	82	58	28	40	97	65	25	19	65	43	33	29	187	78	51
K																
Ca																
Mg																
SO_4																
Cl	40	102	73	29	42	108	78	24	30	88	60	31	34	174	98	44
Si																
Cond	21	62	42	29	31	69	47	24	14	50	36	36	21	89	56	42
Alk																
Tot - N	1,15	5,31	2,22	37	1,17	4,38	2,33	34	0,21	1,95	1,19	34	0,70	3,25	2,11	32
Dis - N	0,93	4,16	1,94	35	0,96	3,13	1,91	29	0,17	1,49	0,98	35	0,62	2,86	1,86	35
NH_4-N	ND	1,21	0,15	163	ND	1,59	0,21	173	ND	0,27	0,11	71	ND	0,23	0,11	70
NO_3-N	0,66	2,61	1,29	36	0,19	2,21	1,20	44	ND	0,98	0,57	56	0,37	2,21	1,31	44
NO_2-N	ND	0,02	0,001	351	ND	0,09	0,01	240	ND	0,06	0,02	118	ND	0,05	0,02	103
Tot P	0,40	2,56	1,05	52	0,51	2,23	1,19	38	0,10	1,36	0,55	74	0,09	1,76	0,70	74
Tot dis P	0,24	0,93	0,58	31	0,26	0,72	0,51	30	0,08	0,97	0,37	70	0,07	1,11	0,43	67
PO_4-P	0,06	0,31	0,16	42	0,06	0,27	0,15	44	0,02	0,18	0,06	72	0,02	0,41	0,09	96
Fe																
Mn																
Temp	12,8	26,9	19,0	25	10,8	17,5	14,0	18	10,3	24,4	18,3	27	10,5	25,5	18,9	26
DO	6,4	9,5	7,4	11	0,1	8,3	3,1	93								
Tu	19	122	53	55	35	95	58	32	1	100	26	120	1	100	32	112
pH	7,1	8,1	7,7	3	6,7	8,0	7,4	5	7,1	8,1	7,6	3	7,3	8,6	8,0	5
SS	5	90	33	76	16	160	66	66	0	81	18	113	0	106	32	112

PARAMETER	BUFFALO RIVER (below Zwelitsha)				UMLAKALAKA				BUFFALO RIVER				YELLOWWOODS RIVER				OUTFLOW			
	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.
Na	47	248	131	46	181	908	384	41	48	417	156	57	30	216	108	53	33	82	58	29
K																	4,5	7,2	5,6	15
Ca																	8,0	22,3	16,5	23
Mg																	8,1	16,6	12,6	23
SO_4																	11,3	28,2	21,5	26
Cl	64	356	161	48	44	182	101	30	60	324	164	45	44	368	168	56	38	106	73	30
Si																				
Cond	34	162	89	46	70	278	133	32	32	194	89	49	29	153	81	50	13	68	43	33
Alk																	38	103	77	21
Tot - N	2,06	16,94	9,37	46	7,20	50,10	16,34	61	1,97	10,83	5,70	49	0,69	3,45	1,76	40	1,11	3,97	2,25	27
Dis - N	1,77	15,51	7,75	51	1,08	39,30	12,36	63	1,65	9,72	4,61	49	0,55	2,78	1,35	43	0,89	2,47	1,83	25
NH_4-N	ND	12,84	4,43	76	ND	6,40	3,12	63	ND	4,52	1,02	125	ND	0,37	0,13	78	ND	1,25	0,15	165
NO_3-N	0,96	6,41	2,74	48	ND	23,30	1,35	365	0,94	5,74	2,80	51	ND	1,91	0,59	75	0,54	2,03	1,17	31
NO_2-N	ND	0,65	0,18	92	ND	0,25	0,04	204	ND	0,45	0,12	117	ND	0,50	0,06	239	ND	0,05	0,01	244
Tot P	1,72	9,92	5,43	46	1,75	6,44	4,14	35	0,71	6,36	2,89	41	0,18	2,60	0,97	81	0,52	3,00	1,13	61
Tot dis P	0,55	9,76	4,62	55	1,20	5,44	3,13	38	0,12	5,80	1,93	75	0,08	0,91	0,43	64	0,28	0,83	0,53	23
PO_4-P	0,28	9,40	3,47	67	0,08	4,66	1,87	70	0,08	3,30	1,35	71	0,01	0,26	0,09	79	0,02	0,23	0,12	52
Fe																				
Mn																				
Temp	11,2	26,6	19,7	25	9,8	24,4	18,0	27	10,9	26,6	19,0	28	10,6	26,2	18,8	28	12,1	24,8	18,9	22
DO																				
Tu	1	130	32	136	1	336	27	260	3	120	24	128	3	150	46	88	26	280	72	86
pH	6,9	8,7	7,6	5	7,4	9,5	8,2	7	7,1	9,0	7,7	5	7,2	8,6	8,0	5	7,7	8,8	8,1	4
SS	1	260	54	127	2	103	24	94	3	257	49	136	3	188	61	77	9	1784	157	238

Oxygen characteristics

The oxygen distribution in the water column for the study period is shown in Figure 19. A clinograde oxygen distribution was present from December 1977 until March 1978 when a decrease in water temperature resulted in overturn. During this period an extensive anaerobic zone whose upper layer varied between 12 and 23 m , was present. This zone represented between approximately 3 and 27% of the water capacity of the impoundment. Overturn resulted in the reoxygenation of the anaerobic hypolimnion. The winter temperature gradient caused an oxygen gradient to be present by preventing continuous circulation during the greater part of winter. The hypolimnetic waters showed signs of oxygen deficiency in October 1978 and a well-defined stratification pattern was again evident in November 1978.

Water transparency and turbidity

The mean Secchi depth for the study period was 0,17 m. The minimum depth of 0,04 m was recorded in February 1978, while the maximum of 0,45 m was recorded in November 1978. The water transparency showed a general increase from February 1978 until the end of the study period (Figure 20). This general trend was also seen in the variation in turbidity of the surface water through the study period. The mean turbidity of the impounded surface water was 53 NTU (Table 9). The impounded water was, on numerous occasions during the study period, distinctly discoloured by textile effluent discharged into the Umlakalaka Stream, a tributary of the Buffalo River.

The mean turbidity values of the Buffalo River entering Laing Dam and the Yellowwoods River for the study period were 24 NTU and 46 NTU respectively.

pH

The pH values of the impounded surface water varied between 7,1 and 8,1 and a median value of 7,6 was recorded. The bottom waters had a median pH of 7,3. During the study period, the Buffalo River above King William's Town had a median pH value of 7,6. After the river had passed through King William's Town, the pH value increased to 8,0. The river, below the point at which maturation pond effluent is discharged, had a median pH of 7,8. The median pH of the Buffalo River entering Laing Dam was 8,1, while the Yellowwoods River had a median pH of 7,9. The median pH of the Umlakalaka Stream was 8,5, with a maximum of 9,5 being recorded. The Buffalo River below Laing Dam had a median pH value of 8,3.

Conductivity

The mean conductivity of the impounded surface water was 42 mS/m for the study period (Table 9). A general increase in conductivity was observed in the Buffalo River from the sampling station above King William's Town (36 mS/m) to where the river enters Laing Dam. A mean conductivity value of 133 mS/m was recorded for the Umlakalaka Stream. The mean conductivity of the Yellowwoods River was 81 mS/m. As the water in the Buffalo River directly below Laing Dam was largely spillway overflow the mean conductivity (43 mS/m) was similar to that of the surface water in the impoundment.

Sodium and chloride

The variations in sodium and chloride concentrations in the inflowing, outflowing and impounded waters are shown in Figures 21 and 22. Mean values of 58 mg/dm^3 and 73 mg/dm^3 were recorded for the study period for sodium and chloride in the impounded surface waters (Table 9). In agreement with the conductivity values, there was a progressive increase in sodium and chloride from the Buffalo River above King William's Town to the Buffalo River as it enters Laing Dam. The mean sodium concentration increased from 43 mg/dm^3 to 156 mg/dm^3 and the mean chloride content increased from 60 mg/dm^3 to 164 mg/dm^3. A mean sodium content of 384 mg/dm^3 was recorded for the Umlakalaka Stream for the study period. A maximum level of 908 mg/dm^3 was recorded in October 1978 and a minimum level of 181 mg/dm^3 in January 1978, during a period of high rainfall. The mean chloride content of the Umlakalaka Stream was 101 mg/dm^3. The Yellowwoods River, which has no urban or industrial development in its catchment, had a mean sodium concentration of 108 mg/dm^3 and a mean chloride concentration of 168 mg/dm^3.

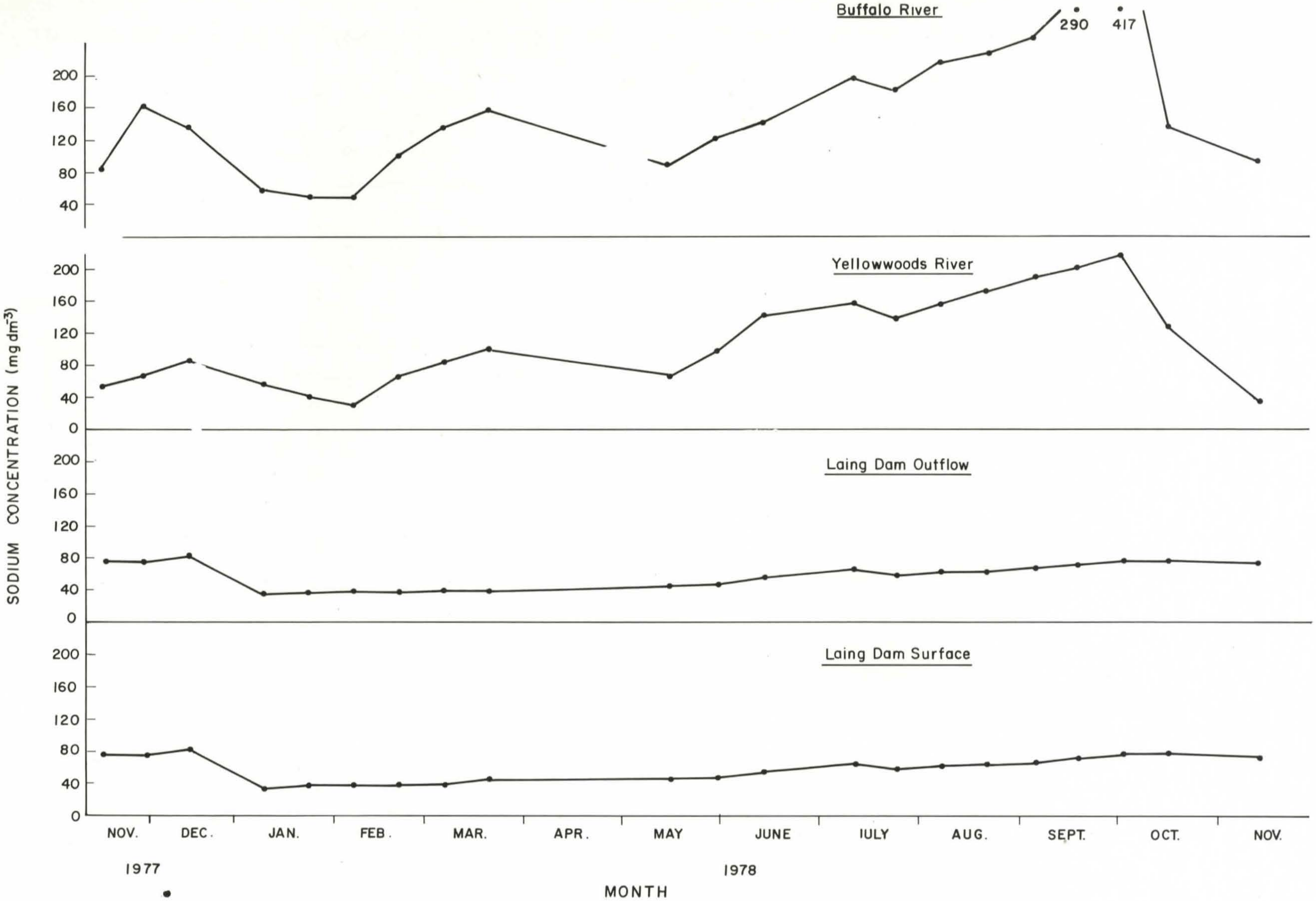

FIGURE 21: Variation in sodium concentrations in the inflowing, outflowing and impounded waters of Laing Dam.

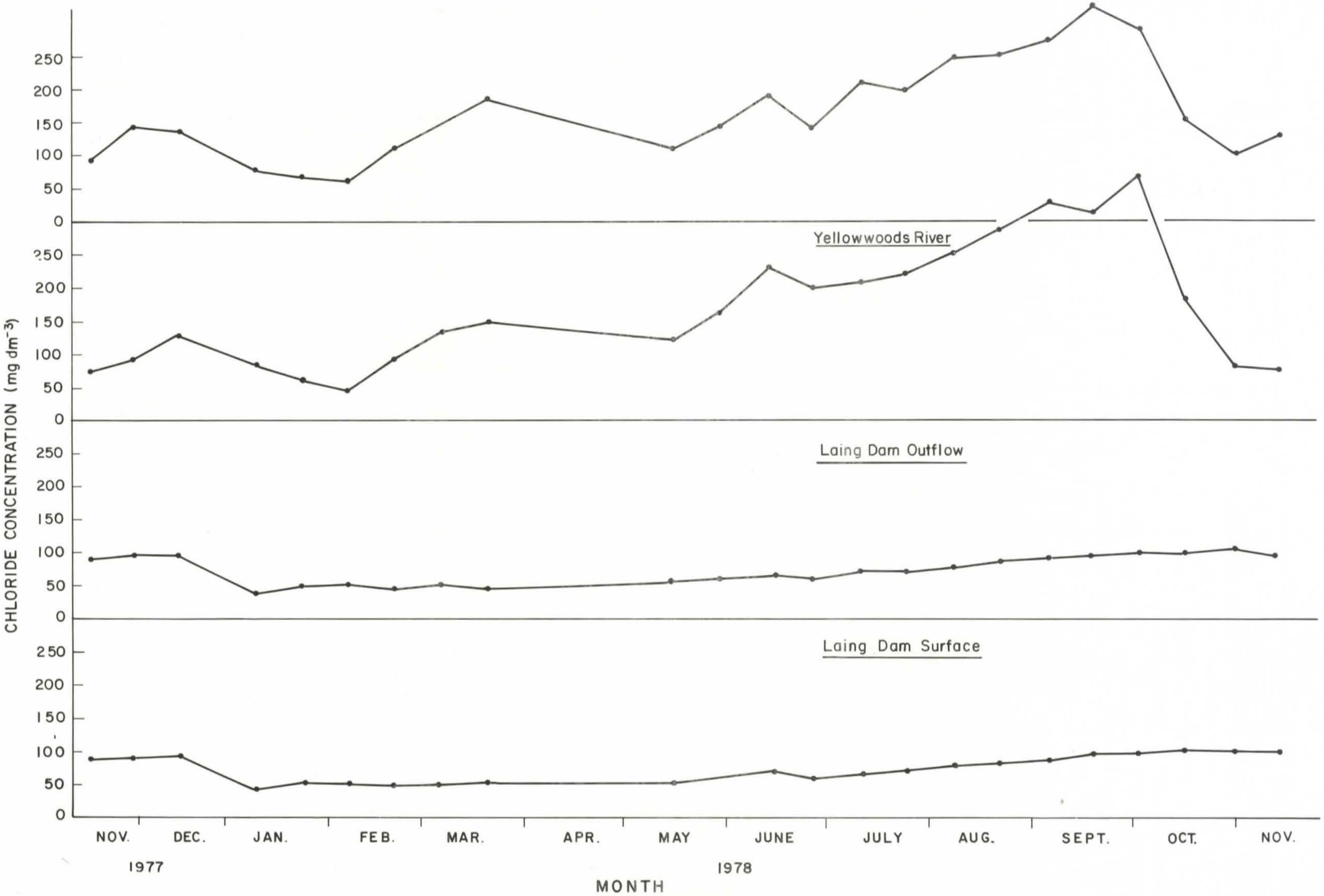

FIGURE 22: Variation in chloride concentrations in the inflowing, outflowing and impounded waters of Laing Dam.

Nitrogen

During the study period it was evident that large inputs of nitrogen were made to the Buffalo River through the discharge of maturation pond effluent from the Zwelitsha Sewage Purification Works. The mean total nitrogen concentration increased from 2,11 mg/dm^3 above the outfall to 9,37 mg/dm^3 below the outfall; dissolved nitrogen from 1,86 mg/dm^3 to 7,75 mg/dm^3; ammonium nitrogen from 0,11 mg/dm^3 to 4,43 mg/dm^3, and nitrate nitrogen from 1,31 mg/dm^3 to 2,74 mg/dm^3 (Table 9). The mean total nitrogen concentration in the Umlakalaka Stream during the study period was 16,34 mg/dm^3, of which 12,36 mg/dm^3 occurred in the dissolved form. The mean ammonium nitrogen concentration for this stream was 3,12 mg/dm^3 and the mean nitrate nitrogen concentration was 1,35 mg/dm^3. Of the two inflows into Laing Dam, considerably higher nitrogen levels were observed in the Buffalo River. The Buffalo River entering the impoundment had a mean total nitrogen level of 5,70 mg/dm^3 while for Yellowwoods River the value was 1,76 mg/dm^3. The mean ammonium nitrogen values for the Buffalo and Yellowwoods rivers were 1,02 mg/dm^3 and 0,13 mg/dm^3 respectively and the corresponding values for nitrate nitrogen were 2,80 mg/dm^3 and 0,59 mg/dm^3. The variations in ammonium nitrogen and nitrate nitrogen concentrations in the inflowing, outflowing and impounded waters are shown in Figures 23 and 24. There was a noticeable increase in ammonia, and to a lesser extent in nitrate, in the Buffalo River in the latter half of the study period. Ammonium nitrogen concentration reached a peak of 4,52 mg/dm^3 in October 1978 but had been considerably reduced by the end of the study period, most likely by the increased inflows. The mean nitrate and ammonium nitrogen concentrations in the impounded surface waters were 1,29 mg/dm^3 and 0,15 mg/dm^3 respectively.

Phosphorus

As with other parameters measured, the phosphorus concentration in the Buffalo River increased from above King William's Town to its point of entry into Laing Dam, the most significant increase occurring below the township of Zwelitsha. The mean total phosphorus concentration increased from 0,70 mg/dm^3 above Zwelitsha to 5,43 mg/dm^3 below Zwelitsha, while orthophosphate phosphorus increased from 0,09 mg/dm^3 to 3,47 mg/dm^3 (Table 9). The ratio of mean total dissolved phosphorus to mean total phosphorus increased from 0,61 to 0,85, indicating a large input of dissolved phosphorus. The Umlakalaka Stream had a mean total phosphorus concentration of 4,14 mg/dm^3 and an orthophosphate phosphorus concentration of 1,87 mg/dm^3. The Buffalo and Yellowwoods rivers had mean total phosphorus concentrations of 2,89 mg/dm^3 and 0,97 mg/dm^3 respectively and orthophosphate phosphorus concentrations of 1,35 mg/dm^3 and 0,09 mg/dm^3 respectively. Variation in orthophosphate phosphorus concentrations in the inflowing, outflowing and impounded waters is shown in Figure 25. The mean orthophosphate phosphorus concentration in the impounded water was 0,16 mg/dm^3. No seasonal variation pattern was observed for the study year.

Chemical oxygen demand

The minimum, maximum and mean values for chemical oxygen demand (COD) are given in Table 10.

A general increase in COD was noted in the Buffalo River from above King William's Town to where it enters Laing Dam (from 19 mg/dm^3 to 49 mg/dm^3). For the Yellowwoods River, a mean COD value of 34 mg/dm^3 was recorded. The Umlakalaka Stream had a high mean value of 294 mg/dm^3, indicating a high content of chemically oxidizable material. A maximum of 451 mg/dm^3 was recorded in October 1978, and a minimum of 18 mg/dm^3 in February 1978. A mean COD value of 25 mg/dm^3 was recorded for the impounded surface water and 28 mg/dm^3 for the Buffalo River below Laing Dam.

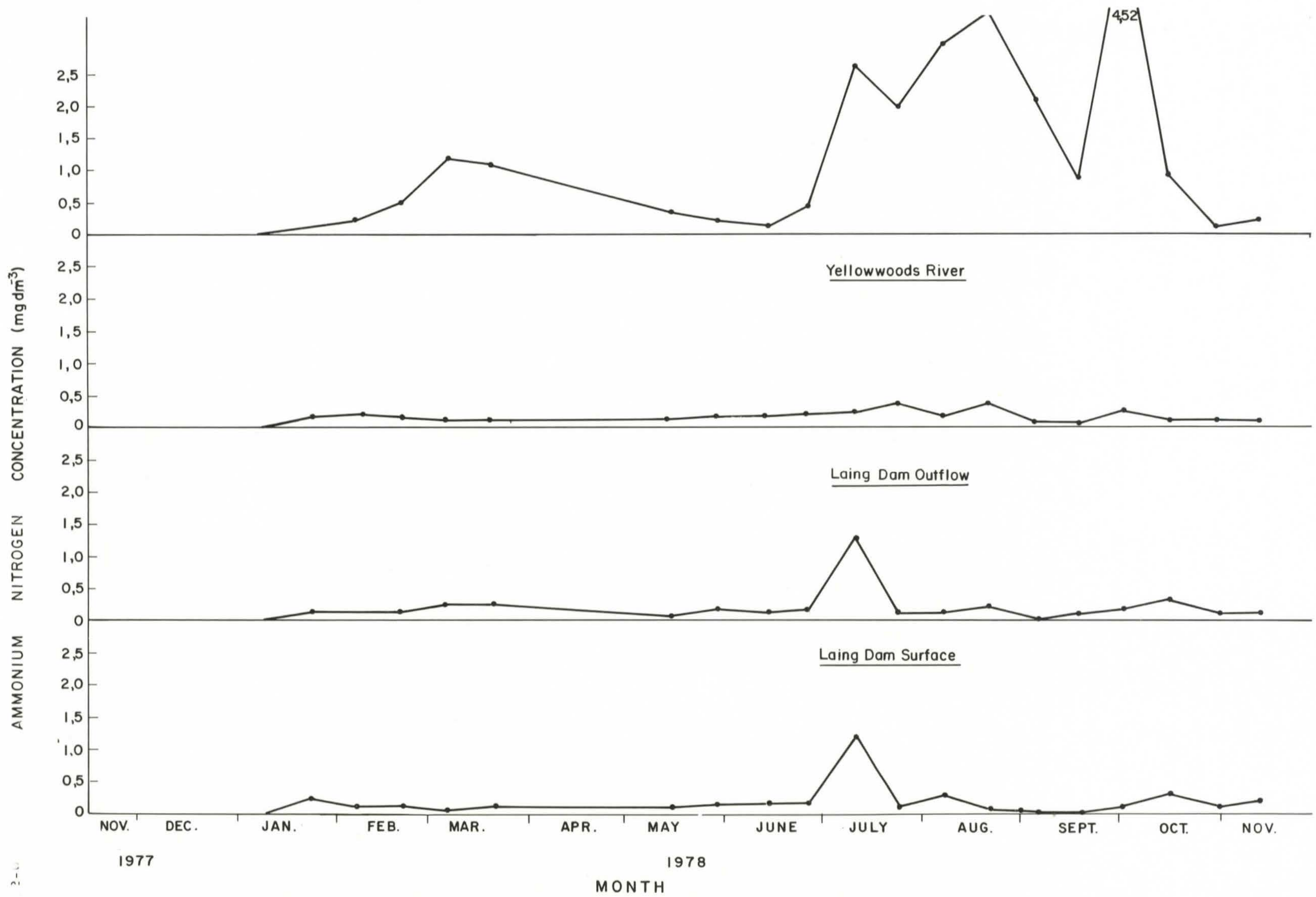

FIGURE 23: Variation in ammonium nitrogen concentrations in the inflowing, outflowing and surface waters of Laing Dam.

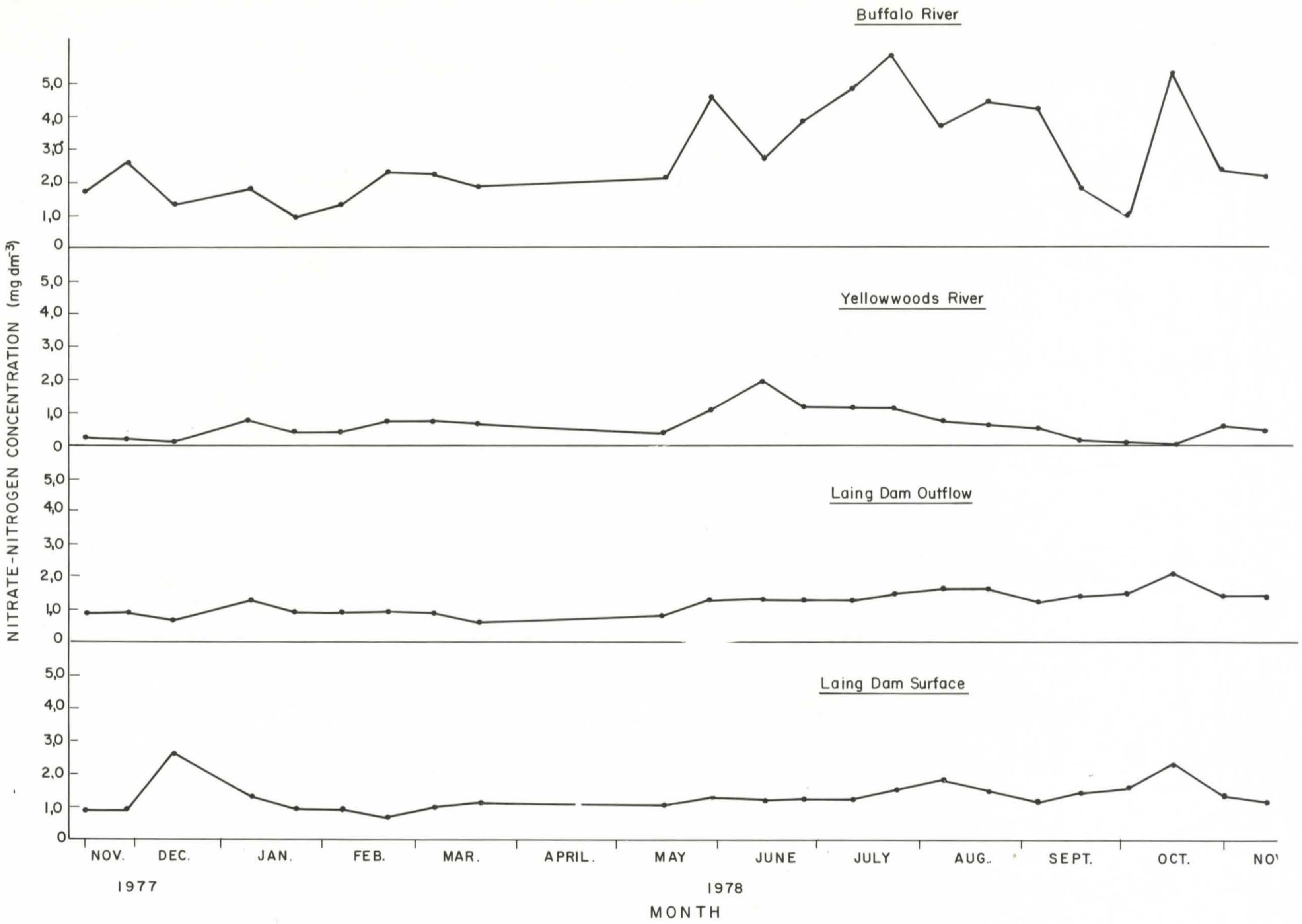

FIGURE 24: Variation in nitrate nitrogen concentrations in the inflowing, outflowing and surface waters of Laing Dam.

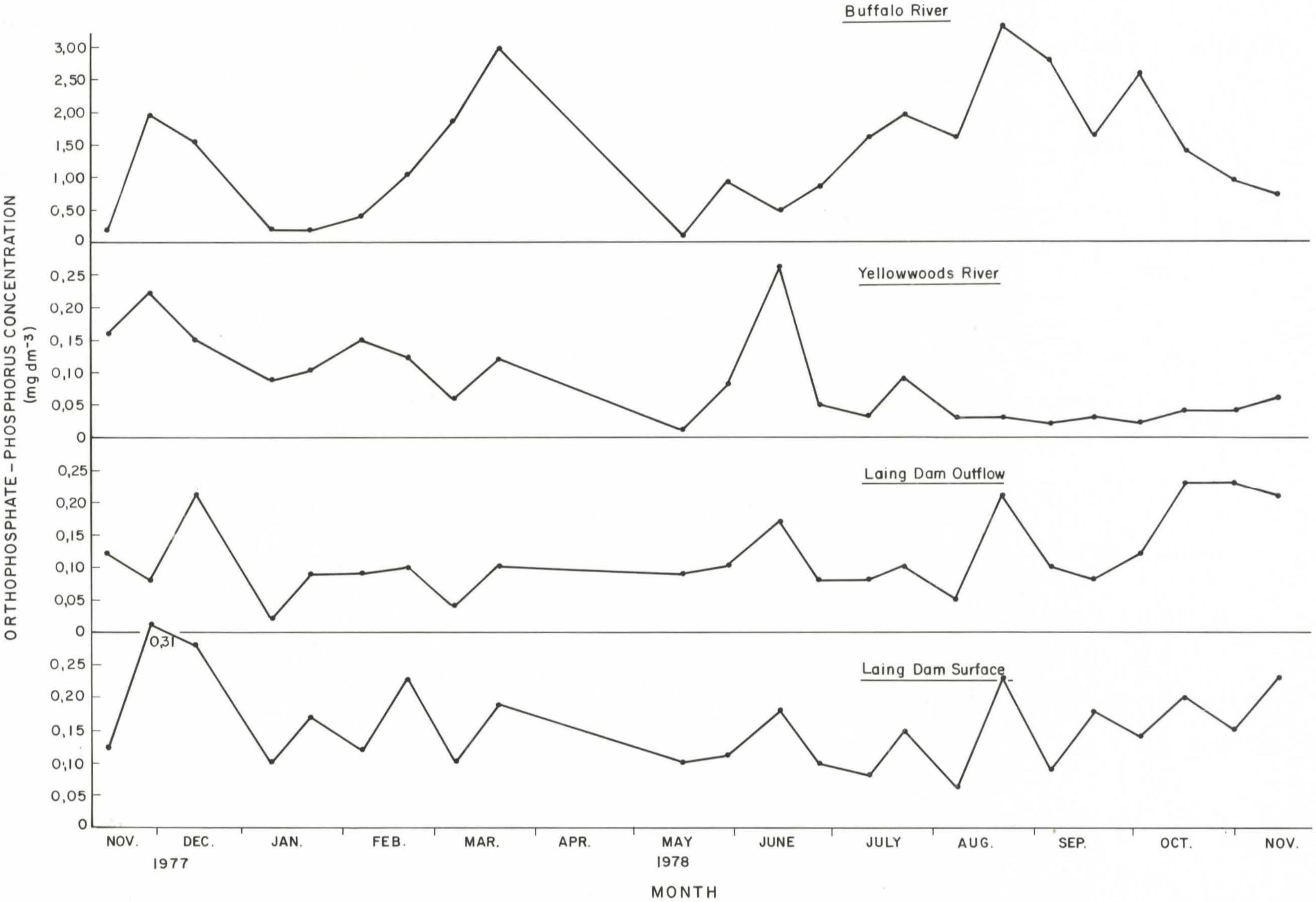

FIGURE 25: Variation in the orthophosphate phosphorus concentrations in the inflowing, outflowing and surface waters of Laing Dam.

TABLE 10. Chemical oxygen demand (mg/dm^3) for inflowing, outflowing and impounded surface waters of Laing Dam from November 1977 to November 1978.

Sampling station	Minimum	Maximum	Mean	Coefficient of variation %
Buffalo River above King William's Town	2	49	19	58
Buffalo River below King Williams's Town	4	69	24	64
Buffalo River below Zwelitsha	17	111	36	55
Umlakalaka Stream	18	451	294	30
Buffalo River above Laing Dam	4	110	49	47
Yellowwoods River	17	52	34	32
Buffalo River below Laing Dam	15	101	28	60
Laing Dam surface	14	74	25	48

Chlorophyll a

The chlorophyll a concentration in the impoundment throughout the study period was extremely low, often below the limit of detection. The mean value for the study period was 0,16 ug/dm^3. A maximum value of 2,22 $\mu g/dm^3$ was recorded in February 1978.

Microcystis growths appeared in the impoundment in late December 1977, but were washed out by high inflows which occurred during that period. Thereafter this alga did not reappear.

Nutrient loading

The major portion of nutrients entered Laing Dam via the Buffalo River during the study period (Table 11).

TABLE 11. Nutrient loading rates and hydrological characteristics of Laing Dam during the study period.

Surface loading rate ($g.m^{-2}.a^{-1}$)	PO_4-P	Dissolved P	Total P	Inorganic N	Dissolved N	Total N
Buffalo River	13,26	20,51	27,34	34,16	46,76	52,20
Yellowwoods River	0,56	3,65	6,60	3,39	8,09	11,41
Total	13,82	24,16	33,94	37,55	54,85	63,61

Mean volume x 10^6 m^3	21,91
Mean area km^2	2,14
Mean depth m	10,2
Retention time a	0,42
Hydraulic load m/a	24,29

The total orthophosphate phosphorus surface loading rate was 13,82 $g.m^{-2}.a^{-1}$, of which 13,26 $g.m^{-2}.a^{-1}$ or 96% of the total, entered the impoundment via the Buffalo River. This represented 31,57 t of phosphorus which entered the impoundment as orthophosphate phosphorus. The inorganic nitrogen surface loading rate was 37,55 $g.m^{-2}.a^{-1}$ of which 9% entered via the Yellowwoods River. The loading estimates reveal that 80,89 t of nitrogen entered the impoundment as inorganic nitrogen.

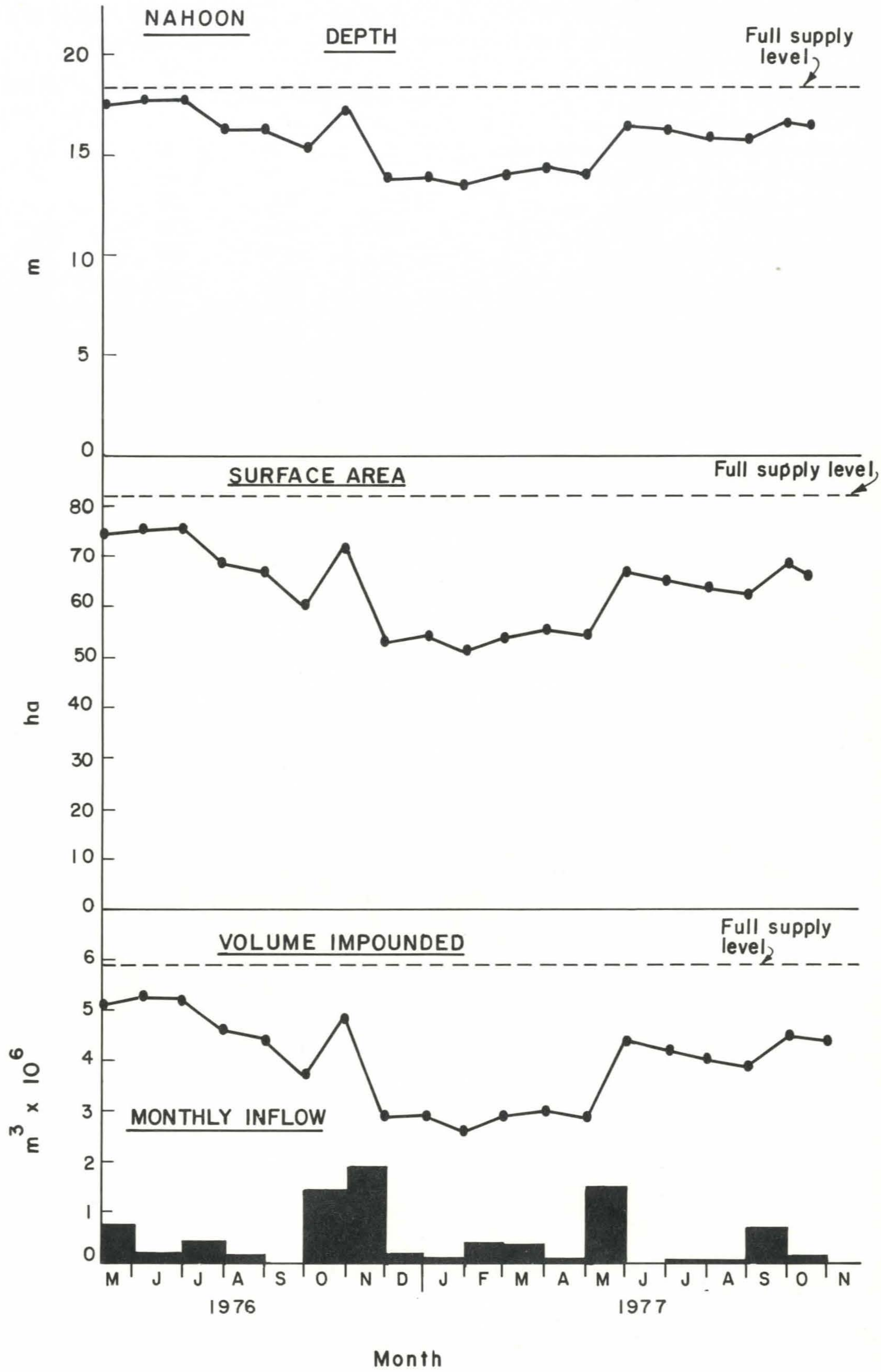

FIGURE 26: Maximum depth, surface area, water content and inflow volume (m) into Nahoon Dam during the study period.

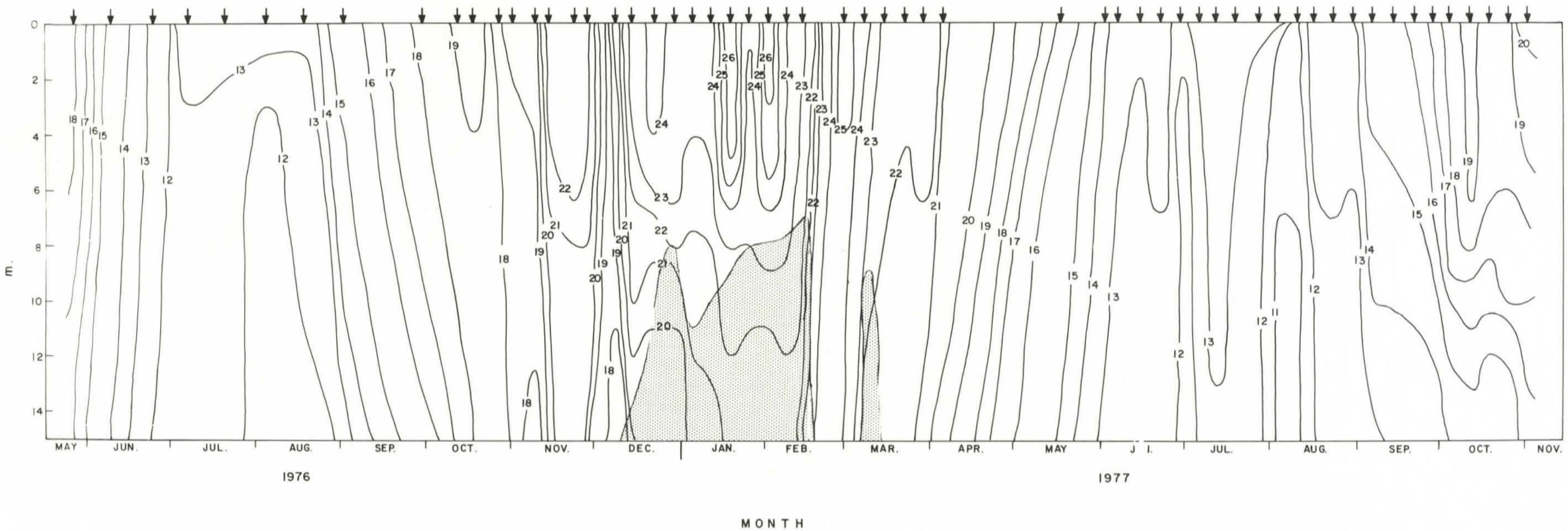

FIGURE 27: Temperature distribution in Nahoon Dam (May 1976 — November 1977).

Nahoon Dam

Results of analyses and measurements are given in Tow (1979).

Hydrological characteristics

Throughout the study period the volume of impounded water varied, but remained below the full supply level (Figure 26). The mean monthly volume during the study period was 4,0 x 10^6 m^3 (67,8% of full supply capacity). A minimum volume of 2,8 x 10^6 m^3 was recorded in January 1977 (47,5% of full supply capacity). The reduced volume in the impoundment can be accounted for firstly by the low inflow into the impoundment during the study period, and secondly, by the necessity for keeping the water at a reduced 'safe' level in view of construction activities on the dam wall. The values for maximum depth and surface area showed fluctuations corresponding to the variation in water content. The mean depth during the study period (May 1976 — November 1977) was 6,2 m and the mean surface area was 0,63 km^2. The highest inflows were recorded during October and November 1976 and May 1977 (Figure 26).

In terms of its catchment area size, the Rwantsa River has been estimated to contribute 12% of the total flow of the Nahoon River.

Thermal characteristics

At the commencement of the study in May 1976, the water column was approximately isothermal (Figure 27). A gradual increase in the water temperature was observed from late August 1976 and signs of stratification were evident in November 1976. This trend was briefly disrupted in early December 1976, after which the water body became restratified until mid-February 1977. Throughout the period of stratification, the thermocline was indistinct. This may possibly be attributed to the unstable nature of the water column. From February 1977, the water temperature decreased gradually until July/August 1977 when warming of the water body occurred. Stratification was observed from late September 1977 and at the end of the study in November 1977, the water column was again distinctly stratified.

Oxygen characteristics

An approximately orthograde oxygen distribution was present in the impoundment at the beginning of the study (Figure 28). An oxygen gradient developed in August 1976 and stratified conditions persisted until February 1977. As a result of the oxygen deficit which developed in the hypolimnion in November 1977 and from December 1977 to February 1978, an anaerobic zone was formed. The upper limit of this zone varied in depth between 7 and 11 m . This represented between 17 and 50% of the water volume during the study period. From late February 1977 to April 1977, great variability in the oxygen distribution pattern was observed. During this time dissolved oxygen concentrations were generally below 5 mg/dm^3. During the winter months of 1977, an oxygen gradient was always present. The water column showed signs of oxygen stratification in September 1977, and at the end of the study in November 1977 the impoundment was clearly stratified and there was an oxygen deficit in the water near the sediment.

Water transparency and turbidity

The variations in water transparency and turbidity of the impounded surface waters are shown in Figure 29. In the first half of the study (May 1976 - January 1977), the water transparency remained relatively stable, apart from fluctuations recorded during periods of high inflow during October and November 1976. During these two months, light penetration increased to 0,60 m . Corresponding fluctuations were recorded for turbidity. In the first half of the study period, water transparency values were generally less than 0,20 m . A general increase in water transparency occurred from February 1977 and a maximum value of 1,78 m was recorded in September 1978. The mean Secchi depth for the study period was 0,52 m and themean turbidty value was 42 NTU. A minimum turbidity value of 3 NTU was measured in September 1977 while a maximum of 240 NTU was recorded in November 1976.

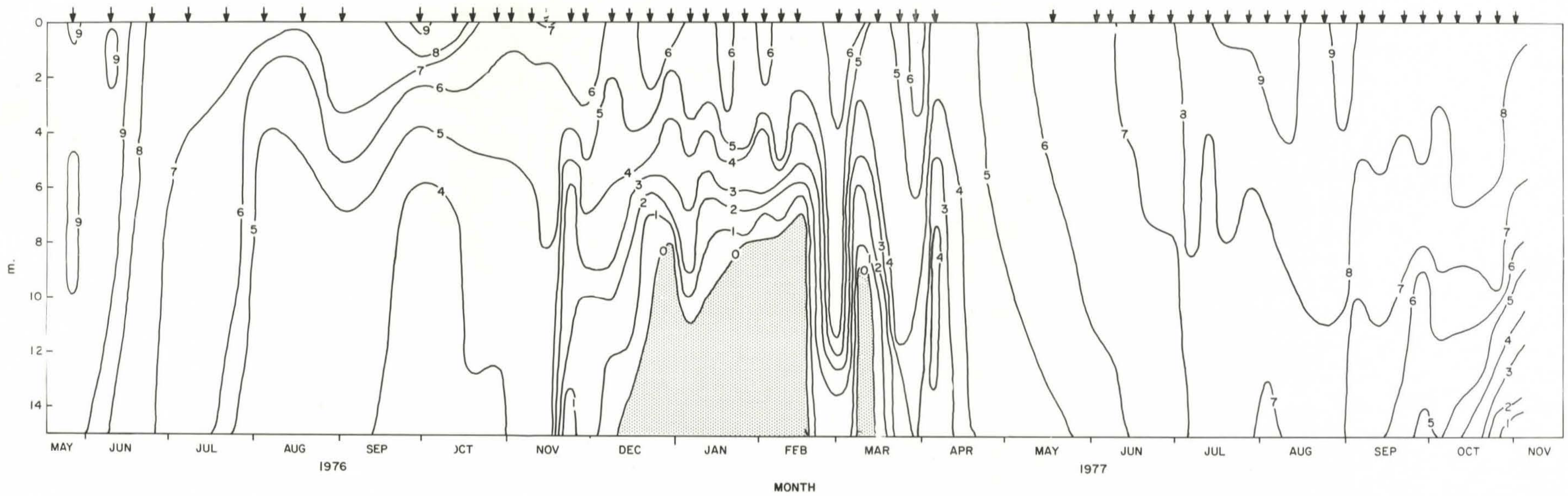

FIGURE 28: Oxygen distribution in Nahoon Dam (May 1976 — November 1977).

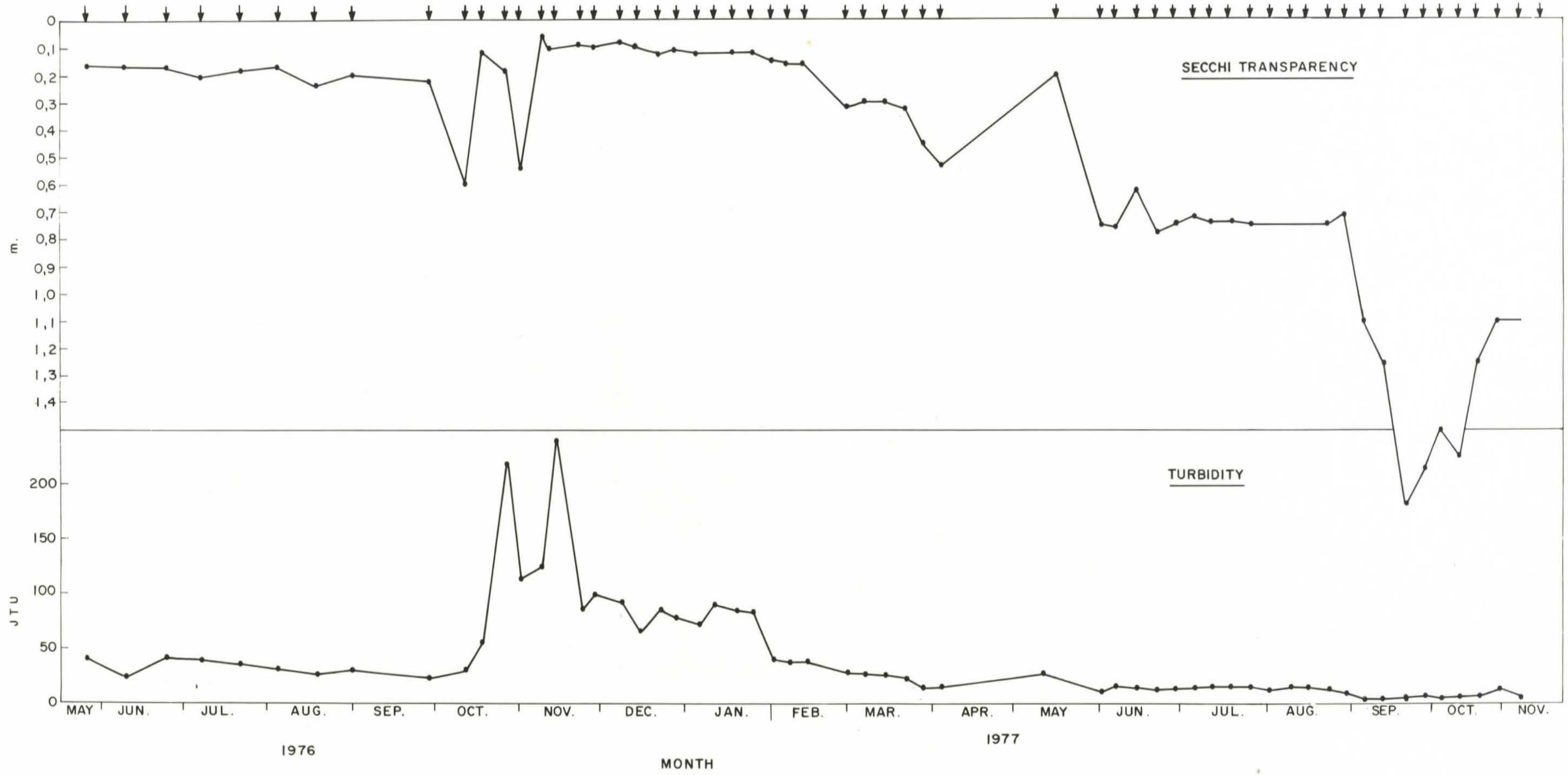

FIGURE 29: Secchi transparency (m) and turbidity (NTU) variation in the surface waters of Nahoon Dam.

TABLE 12. A summary of physical and chemical characteristics of inflowing, outflowing and impounded waters of Nahoon Dam from May 1976 to November 1977. (CV = coefficient of variation; ND = not detected)

NAHOON DAM
26.5.76 - 1.11.77

PARAMETER	DAM STATION								RWANTSA				NAHOON				OUTFLOW			
	TOP				BOTTOM															
	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.	MIN	MAX	MEAN	C.V.
Na	38	105	81	19	24	99	79	20	34	306	147	49	38	250	163	29	36	190	82	25
K																				
Ca																				
Mg																				
SO_4																				
Cl	51	268	124	26	29	202	116	27	43	386	201	48	51	578	260	36	48	322	122	133
Si																				
Cond	25	82	61	19	14	92	57	23	22	177	93	44	28	158	101	29	23	126	60	26
Alk																				
Tot - N	0,03	6,25	1,62	67	0,15	6,09	1,69	66	ND	2,75	1,02	70	ND	3,84	1,27	68	ND	4,49	1,37	66
Dis - N	0,03	2,94	1,18	63	0,15	3,05	1,00	60	ND	2,35	0,75	82	ND	3,94	0,84	84	ND	2,77	0,95	63
NH_4-N	ND	1,42	0,05	402	ND	1,60	0,10	248	ND	0,19	0,03	186	ND	1,42	0,05	352	ND	1,34	0,07	343
NO_3-N	0,03	1,34	0,65	50	0,15	1,44	0,57	55	ND	1,12	0,31	89	ND	2,23	0,49	83	ND	3,06	0,61	79
NO_2-N	ND	0,05	0,01	189	ND	0,05	0,01	181	ND	0,05	0,01	198	ND	0,05	0,004	218	ND	0,07	0,004	279
Tot P	0,10	1,37	0,48	59	0,12	1,50	0,61	55	0,10	1,08	0,54	52	0,15	1,20	0,47	56	0,10	1,27	0,54	56
Tot dis P	0,10	0,90	0,34	58	0,09	1,04	0,37	55	0,10	0,75	0,31	54	0,09	0,68	0,31	56	0,09	0,93	0,37	58
PO_4-P	ND	0,26	0,07	98	ND	0,29	0,09	87	ND	0,28	0,07	88	ND	0,23	0,08	86	ND	0,34	0,08	97
Fe																				
Mn																				
Temp	12,0	26,7	18,5	24	11,5	24,2	16,0	24	12,0	26,8	18,9	22	12,7	26,8	19,1	23	12,4	28,2	18,6	23
DO	4,9	9,7	7,3	19	0	9,1	3,9	71												
Tu	3	240	42	114	4	978	95	173	2	170	36	118	2	198	29	157	3	780	66	189
pH	7,2	8,2	7,9	3	7,1	9,1	7,6	35	7,6	8,5	8,0	3	7,2	8,4	8,0	4	7,2	8,5	7,9	4
SS	0	314	27	168	1	1804	152	207	0	283	45	134	3	329	34	154	0	843	53	221

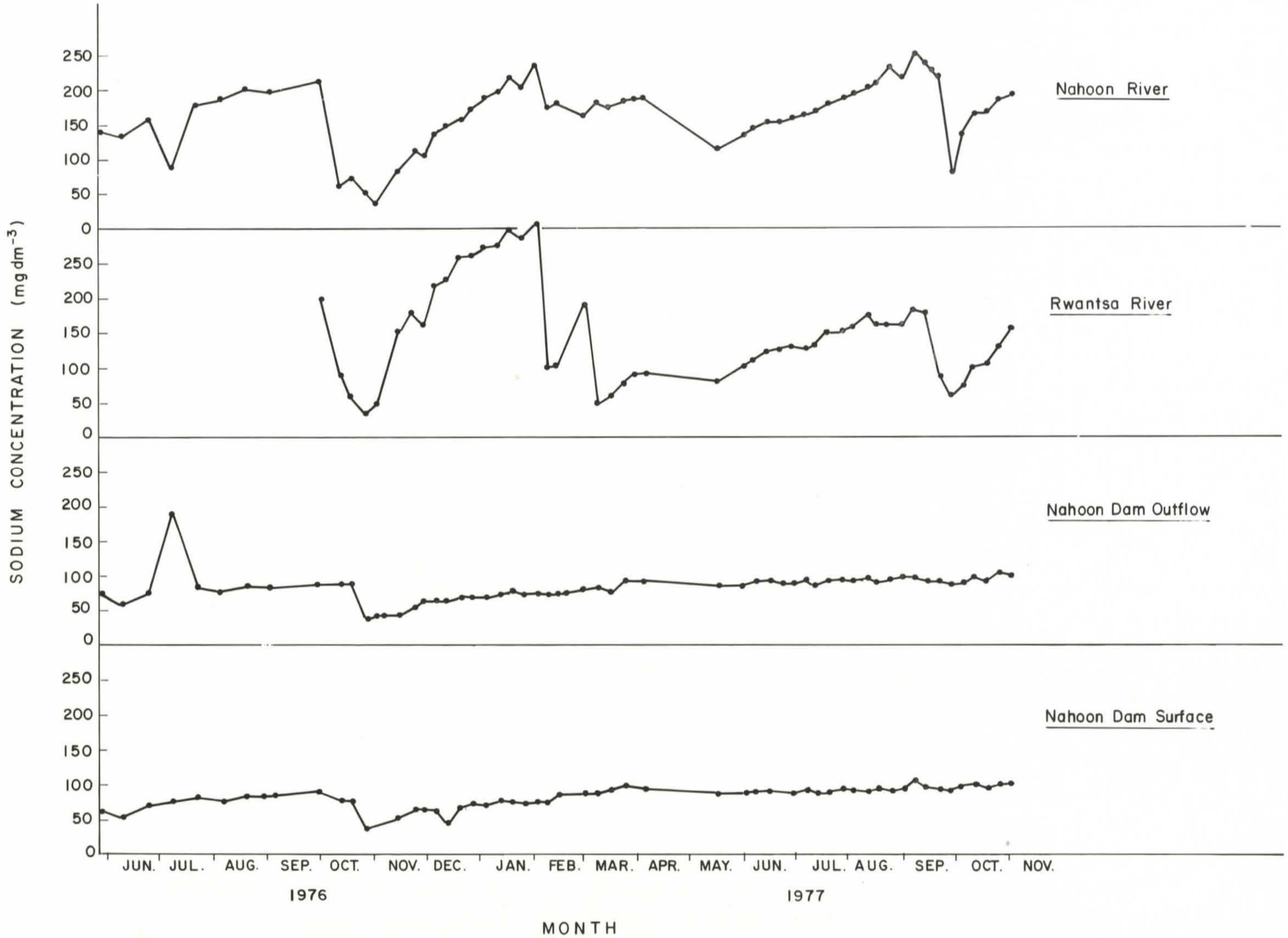

FIGURE 30: Variation in sodium concentrations in the inflowing, outflowing and surface waters of Nahoon Dam.

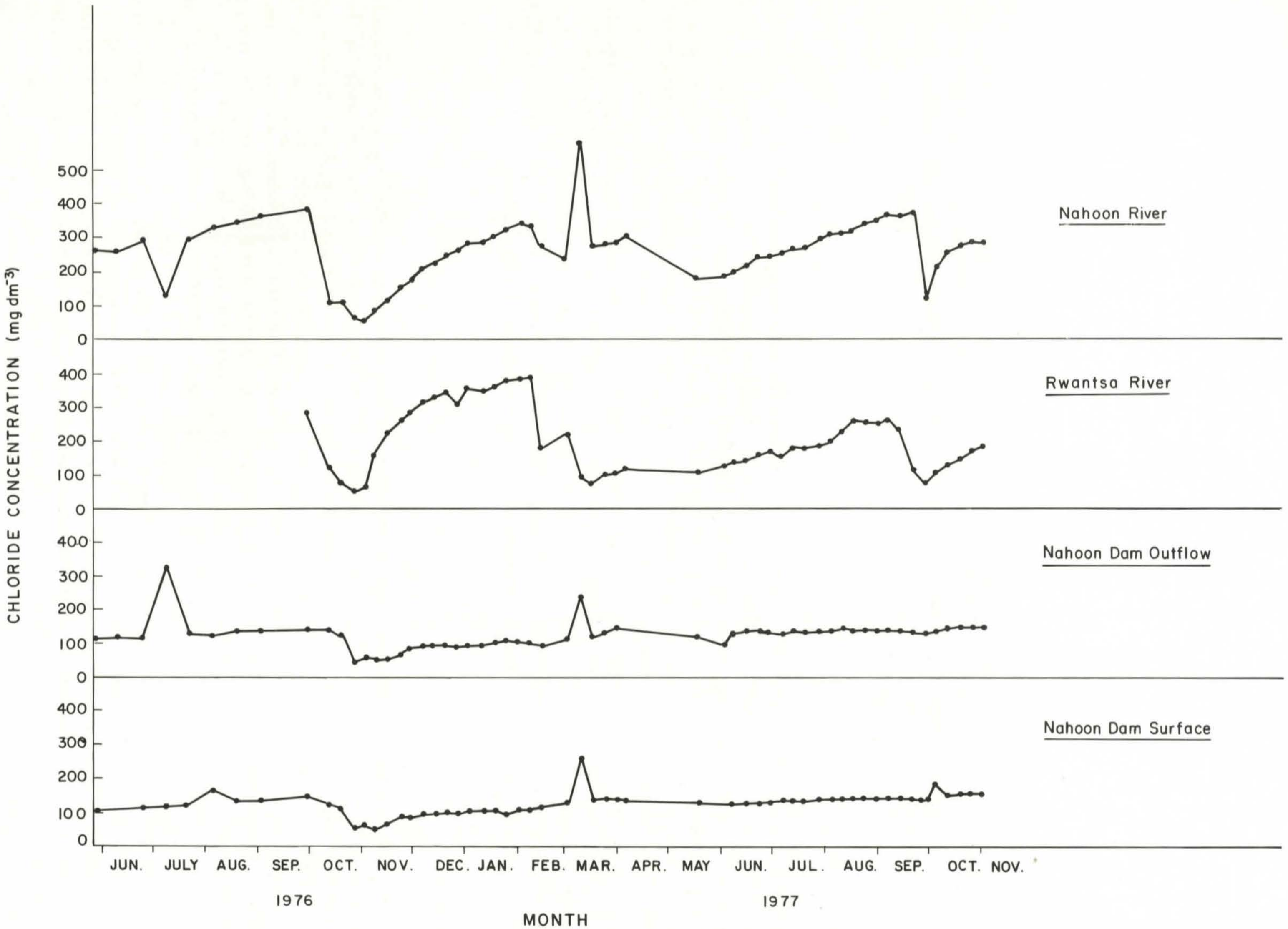

FIGURE 31: Variation in chloride concentrations in the inflowing, outflowing and surface waters of Nahoon Dam.

pH

The median pH of the impounded surface water for the study period was 7,7 while a median pH value of 8,1 was recorded for the bottom waters (Table 12). A greater variation was observed in the pH values of the bottom waters (7,1 – 9,1) than in the surface waters (7,2 – 8,2). The median pH of the Nahoon River entering Nahoon Dam was 7,8 while the Rwantsa River had a median pH of 8,1. For the outflow, a median pH value of 7,9 was recorded.

Conductivity

A mean conductivity of 61 mS/m was recorded for the impounded surface water (Table 12). The minimum value (25 mS/m) was measured in October 1976, after a period of high rainfall and the maximum (82 mS/m) in August 1977. The Nahoon River had a mean conductivity of 101 mS/m and for the Rwantsa River, 93 mS/m was recorded. The mean conductivity of the outflow for the study period was 60 mS/m.

Sodium and chloride

The variations in sodium and chloride concentrations in the inflowing, outflowing and impounded surface waters are shown in Figures 30 and 31. Similar variations were recorded for both sodium and chloride during the study period. Decreases in sodium and chloride concentrations were recorded in the inflowing waters generally during periods of high rainfall. The sodium and chloride concentrations in the surface waters were 81 mg/dm^3 and 124 mg/dm^3 respectively (Table 12), and were generally constant throughout the study period. The mean sodium and chloride concentrations in the Nahoon River were 163 mg/dm^3 and 260 mg/dm^3 respectively. The levels in the Rwantsa River were slightly lower, 147 mg/dm^3 for sodium and 201 mg/dm^3 for chloride. The sodium and chloride content of the inflowing waters were reflected in the conductivity values which were recorded. The Nahoon River below Nahoon Dam had a mean sodium concentration of 82 mg/dm^3 and a mean chloride concentration of 122 mg/dm^3.

Nitrogen

The variation in ammonium nitrogen concentrations in the inflowing, outflowing and impounded surface waters is shown in Figure 32. Ammonium nitrogen was often undetectable by the method of analysis employed. These values are indicated as zero in Figure 32. Apart from high values which were recorded during July and August 1976, ammonium nitrogen concentrations at all the sampling stations were generally below 0,10 mg/dm^3. The mean ammonium nitrogen concentration for the impounded surface water during the study period was 0,05 mg/dm^3. The mean concentrations for the Nahoon River entering the impoundment and the Rwantsa River were 0,05 mg/dm^3 and 0,03 mg/dm^3 respectively. Nitrite nitrogen concentrations at all the sampling stations were most often undetectable. The highest mean value of 0,01 mg/dm^3 was recorded for the impounded water and for the Rwantsa River (Table 12). A mean value 0,004 mg/dm^3 was recorded for the Nahoon River. The variation in the nitrate nitrogen concentrations in the inflowing, outflowing and impounded surface waters is shown in Figure 33. During the study period, the variations showed no apparent seasonal trends. The surface waters showed a mean concentration of 0,65 mg/dm^3. The mean values for the Nahoon and Rwantsa rivers were 0,49 mg/dm^3 and 0,31 mg/dm^3 respectively, and 0,61 mg/dm^3 was recorded for the outflowing waters. The mean total nitrogen concentration in the surface waters was 1,62 mg/dm^3 during the study period. Of this, 73% occurred in the dissolved form. The mean total nitrogen values for the inflowing waters were 1,27 mg/dm^3 (Nahoon) and 1,02 mg/dm^3 (Rwantsa) (Table 12). The outflow had a mean total nitrogen concentration of 1,37 mg/dm^3.

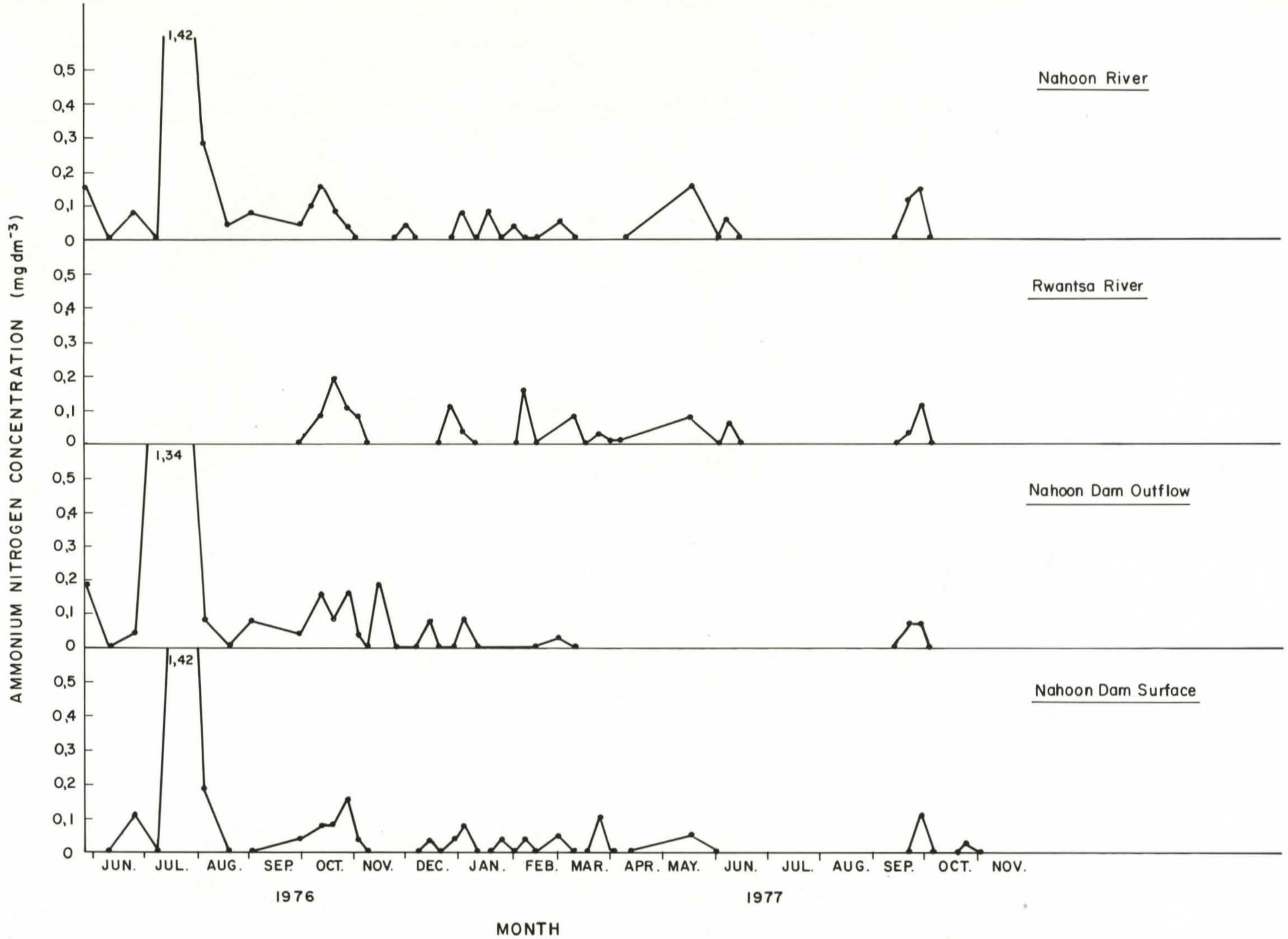

FIGURE 32: Variation in ammonium nitrogen concentrations in the inflowing, outflowing and surface waters of Nahoon Dam.

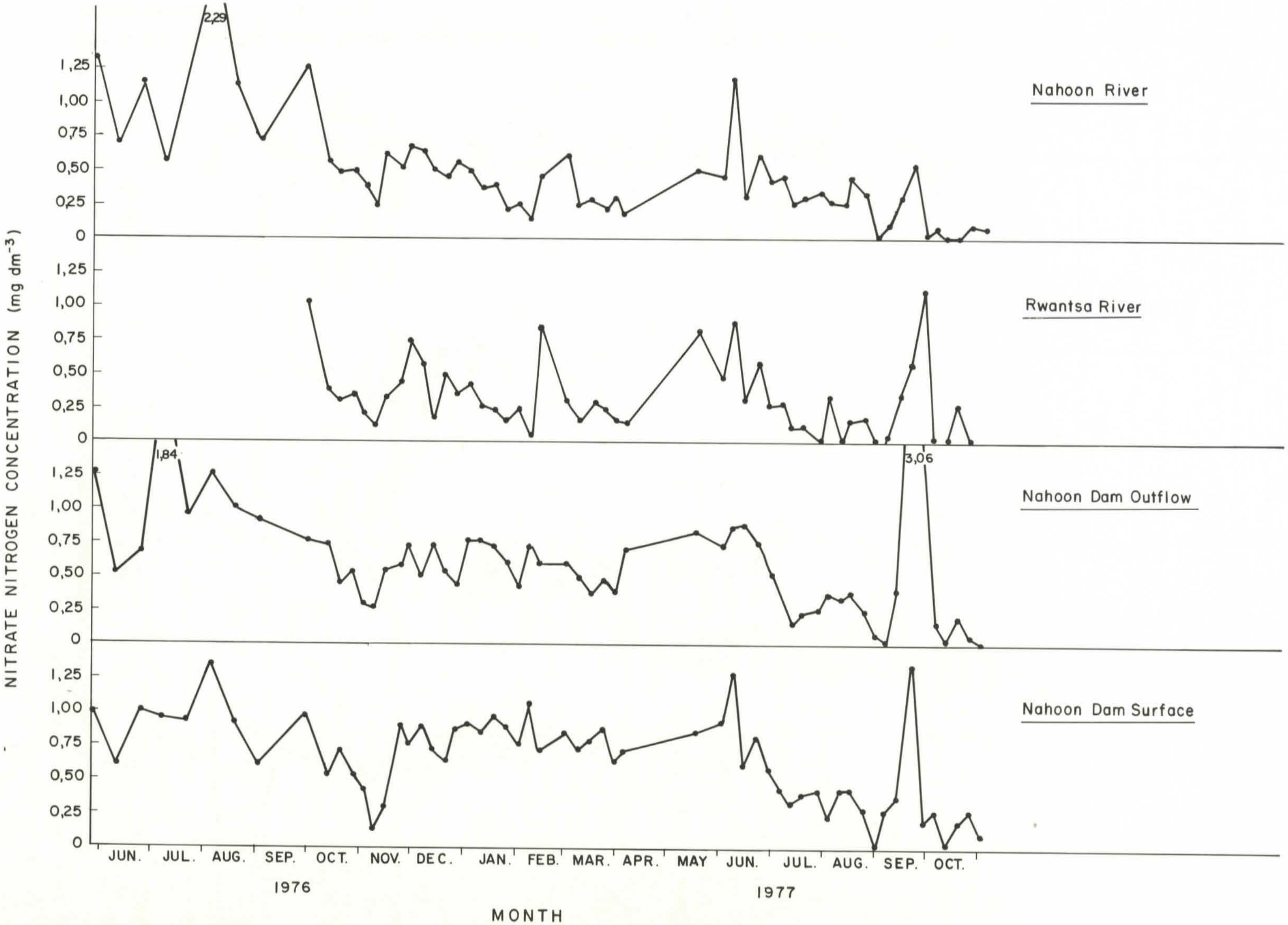

FIGURE 33: Variation in nitrate nitrogen concentrations in the inflowing, outflowing and surface waters of Nahoon Dam.

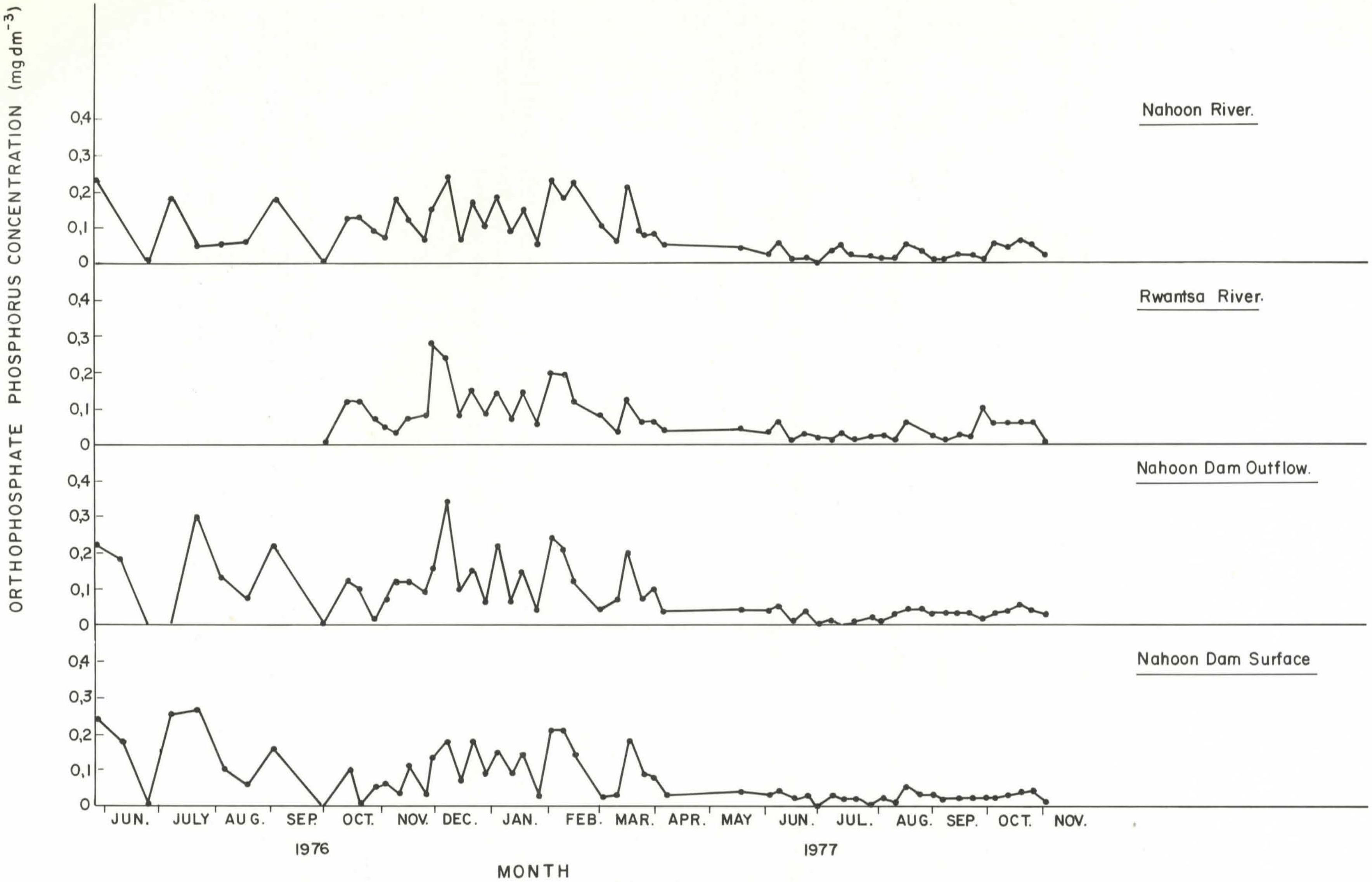

FIGURE 34: Variation in orthophosphate phosphorus concentrations in the inflowing, outflowing and surface waters of Nahoon Dam.

Phosphorus

The variation in orthophosphate phosphorus concentrations in the inflowing, outflowing and impounded surface waters is shown in Figure 34. From May 1976 until March 1977, concentrations at all the sampling stations showed considerable variation but remained generally below 0,20 mg/dm^3. From April 1977 until the end of the study in November 1977 there was a noticeable decrease in orthophosphate phosphorus concentrations at all the sampling stations. During this period, values were below 0,10 mg/dm^3. The reason for this decrease is not known but may be associated with the reduction in turbidity (Figure 29). The mean orthophosphate phosphorus concentrations for the impounded surface waters was 0,07 mg/dm^3 during the study period (Table 12). The Nahoon and Rwantsa rivers had mean concentrations of 0,07 mg/dm^3 and 0,08 mg/dm^3 respectively. The total phosphorus concentration in the surface waters varied between 0,10 mg/dm^3 and 1,37 mg/dm^3, and a mean value of 0,48 mg/dm^3 was recorded. The mean total phosphorus value for the Nahoon River was 0,47 mg/dm^3 and for the Rwantsa River, 0,54 mg/dm^3.

Chemical Oxygen Demand

The chemical oxygen demand values for June 1977 to the end of the study in November 1977 are given in Table 13.

TABLE 13. Chemical oxygen demand (mg/dm^3) for inflowing, outflowing and impounded surface waters of Nahoon Dam from June 1977 to November 1977.

Sampling station	Minimum	Maximum	Mean	Coefficient of variation %
Nahoon River	13	44	21	34
Rwantsa River	13	44	25	30
Nahoon River below Nahoon Dam	11	31	19	22
Nahoon Dam surface	11	27	20	21

The mean chemical oxygen demand values for June 1977 to November 1977 varied between 19 mg/dm^3 (Nahoon River below Nahoon Dam) and 25 mg/dm^3 (Rwantsa River). A maximum value of 44 mg/dm^3 was recorded for both inflowing rivers which were sampled.

Chlorophyll a

A mean chlorophyll a concentration of 0,67 μg/dm^3 was recorded for the study period. The maximum value of 8,60 μg/dm^3 was recorded in March 1977, a period during which *Microcystis* was present in the impoundment. Chlorophyll a was not detectable for most of the study period.

Microcystis was frequently present from January 1977 until April 1977. The alga was generally localized at the surface and often formed scums along the shores of the dam.

Nutrient loading

Nutrient loading estimates for the last year of the study period are given in Table 14.

TABLE 14. Nutrient loading rates and hydrological characteristics of Nahoon Dam from November 1976 to November 1977.

Surface loading rate ($g.m^{-2}.a^{-1}$)	PO_4-P	Dissolved P	Total P	Inorganic N	Dissolved N	Total N
Nahoon River	0,77	2,78	5,03	4,28	11,89	14,50

Mean volume x 10^6 m^3	3,62
Mean area km^2	0,60
Mean depth m	6,0
Retention time a	2,43
Hydraulic load m/a	2,47

The mean volume from November 1976 until November 1977 amounted to 61% of the full supply capacity. The retention time of 2,43 years reflects the low inflow during this period. An orthophosphate phosphorus loading rate of 0,77 $g.m^{-2}.a^{-1}$ was recorded, whilst the total phosphorus surface loading rate amounted to 5,03 $g.m^{-2}.a^{-1}$. The total nitrogen surface loading rate was 14,50 $g.m^{-2}.a^{-1}$, of which 4,28 $g.m^{-2}.a^{-1}$ entered the impoundment in the form of inorganic nitrogen. These surface loading rates represent 0,50 t of orthophosphate phosphorus and 5,93 t of total phosphorus which entered the impoundment from November 1976 to November 1977. During the same period, 4,28 t of inorganic introgen and 14,50 t of total nitrogen entered the impoundment.

DISCUSSION

Bridle Drift Dam

Bridle Drift Dam is a warm monomictic impoundment which is highly turbid, and, despite a high nutrient status, shows a low algal standing crop.

Between September 1977 and September 1978, approximately 99% of the flow into the impoundment entered via the Buffalo River. The total annual inflow for this period was 2% higher than the average mean annual inflow for September 1969 to September 1978. The retention time was 0,88 years, which indicates that the water in the impoundment was replaced approximately 1,14 times during this period. The highest inflows to the impoundment were recorded during the summer months October to January. The annual inflows of the four streams draining Mdantsane varied between 0,14 x 10^6 m^3 (Umdanzani) and 0,47 x 10^6 m^3 (Sitotana).

In order to assess the variability of the chemical nature and flow patterns of the four streams draining Mdantsane, a continuous sampling programme was undertaken in January/February 1978 (results given in Tow, 1979). The results indicated that considerable variation occurred both between the different streams on the same day and within the same stream on different days. The variations in the chemical nature of each stream were largely associated with changes in rates of flow. Variations which occurred within each stream during normal dry weather conditions are thought to be due to natural processes and are considered normal. A decrease in flow was generally accompanied by an increase in conductivity. This is compatible with the abundance of natural springs in this region which have been classified as highly mineralized, and of the chloride-sulphate type (Bond, 1946). Under natural dry weather conditions, the determinands measured in these streams remained generally stable. Large increases in nutrient concentrations were directly attributed to sewage contamination.

Overturn in the impoundment occurred in late March, followed by approximately isothermal conditions which persisted until August. Stratification in summer did not produce a distinct epilimnion and hypolimnion separated by a well-defined thermocline. Schutte and Bosman (1973), in 1972 noted a tendency toward the formation of thermocline at 15 m . The dissolved oxygen distribution pattern showed that in the winter months of 1976 and 1977, a significant oxygen gradient existed despite winter circulation. During the summer months (February and March) of the study period, the hypolimnion became anaerobic. Schutte and Bosman (1973) reported that in February 1972, bottom waters were low in dissolved oxygen.

The mean turbidity value of 88 NTU indicates an increase since 1975 (Toerien and Tow, 1976). The extremely high turbidity of this impoundment is, in part, due to the high incoming silt loads. Based on a mean suspended solids concentration of 133 mg/dm^3 and an inflowing volume of 132,83 x 10^6 m^3, approximately 17 666 t of suspended solids entered this impoundment via the Buffalo River during September 1977 to September 1978. Of this load, 8 580 t was exported from the impoundment via the spillway and dam outlet. This represents a net retention of 9 086 t suspended material in the impoundment. The ability of the soils of the Beaufort series, which are prevalent in the Buffalo River catchment, to remain in suspension, may also be a contributing factor to the highly turbid nature of this impoundment (G.P.K. Thornton — personal communication). According to Reed and Thornton (1969), high silt loads may be attributed to poor farming methods, over-grazing of lands and lack of erosion control.

The high sodium and chloride concentrations encountered in the impoundment and in the inflowing waters, particularly the four streams draining Mdantsane, are consistent with the characteristic highly mineralized natural water of this region. Under dry weather conditions, natural spring water contributed to a large proportion of the inflowing water, particularly in the smaller streams and this accounts for the mean sodium and chloride values in the inflow being higher than the mean values in the impounded waters. During periods of high rainfall, sodium and chloride values in the inflowing waters were considerably reduced. Reed and Thornton (1969) drew attention to the importance of natural geological contributions to the mineral load carried by the Buffalo River. After the floods of August 1970, the sodium concentration in the impoundment decreased from 59 mg/dm^3 to 13 mg/dm^3 while chlorides decreased from 89 mg/dm^3 to 27 mg/dm^3. A gradual increase in both sodium and chloride was later recorded and by 1975, the sodium concentration in the impounded surface water had risen to 67 mg/dm^3 and chloride values had reached 92 mg/dm^3. The mean values recorded for the study period (1976—1978) were 53 mg/dm^3 and 68 mg/dm^3 for sodium and chloride respectively. This represents a decrease in the mineral content of the impounded water during the study period, possibly due to the higher inflows recorded during this study.

Nitrogen and phosphorus, the two elements consistently implicated in eutrophication, occurred at mean concentrations of 2,14 mg/dm^3 total nitrogen and 0,85 mg/dm^3 total phosphorus. The mean concentration of orthophosphate phosphorus for the study period was 0,12 mg/dm^3. Since the 1970 floods there has been a general increase in the orthophosphate level of the impounded water (Toerien and Walmsley, 1974). Mean annual inorganic introgen concentrations in Bridle Drift Dam showed a gradual decline from 1,35 mg/dm^3 after the floods in 1970, to 0,55 mg/dm^3 in 1975. A mean inorganic nitrogen value of 1,13 mg/dm^3 was recorded for the study, representing a considerable increase since 1975 (Toerien and Tow, 1976).

The total nitrogen and total phosphorus values encountered in the impoundment are comparable to other highly eutrophied impoundments in southern Africa (Scott *et al.,* 1977). From September 1977 to September 1978, the four streams draining Mdantsane contributed only 0,84% of the total flow into the impoundment. They contributed 3% of the inorganic nitrogen load and 9% of the orthophosphate phosphorus load into the impoundment. Of concern is the frequency of sewage contamination of the streams, as indicated by results of analyses. These occurrences resulted in a deterioration of the chemical nature of the streams, discoloration, foaming, odour and a general aesthetic detraction. Steps must be taken to prevent future recurrences of this nature. Chemical data obtained during the study also indicated that the diversion weir over the Umdanzani Stream did not always operate at maximum efficiency, with the result that sewage effluent was regularly discharged into the impoundment. This accounted for the high mean orthophosphate phosphorus concentration (3,31 mg/dm^3) recorded in the Umdanzani Stream for the study period. The possibility of raising the weir to prevent effluent from reaching the Umdanzani Stream should be considered.

The total phosphorus surface loading rate into the impoundment was 18,72 $g.m^{-2}.a^{-1}$ for the period September 1977 to September 1978, of which 98% was contributed by the Buffalo River. The total nitrogen surface loading rate for the same period amounted to 44,24 $g.m^{-2}.a^{-1}$. On the basis of these values and the values obtained for dissolved nitrogen and dissolved phosphorus, the system can be considered to be nitrogen-limited. It is noteworthy that during the study period, little nitrogen or phosphorus was retained by the impoundment. Of the total phosphorus which entered the impoundment only 1% was retained and of the total nitrogen which entered, 12% was retained. In assessing the nutrient loads into the impoundment it must be borne in mind that the accuracy of the estimates is to an extent, limited by the precision of the flow measurements and the adequacy of the sampling frequency.

Microcystis appeared in the impoundment from March 1977 to May 1977 and from October 1977 to April 1978. This alga formed prominent scums intermittently between November 1977 and March 1978, and during December 1977 and January 1978 large areas of the impoundment were covered by the floating alga. Apart from an aesthetic detraction, *Microcystis* did not directly affect water treatment processes during the study (R.E. Bartel — personal communication). However, at various times during the study, blocking of sand filters occurred and there has been an increase in chemical doses necessary for effective flocculation. At this stage, the exact causes of these problems are not known.

In August 1978, a bloom of *Pandorina* occurred in the impoundment. This alga, which has been reported to cause taste and odour problems (Palmer, 1962), appeared to originate in the Umdanzani estuary, but it was also observed in the upper reaches of the dam. The bloom persisted for approximately 3 to 4 weeks. Prescott (1962) noted that *Pandorina* occurs frequently in waters which are rich in nitrogenous matter.

In March 1978, water hyacinth was present in patches in the Shangani estuary, where a previous infestation occurred in 1973. These plants were physically removed and did not reappear during the study.

In terms of its nutrient status and the development of an anaerobic hypolimnion during summer stratification, Bridle Drift Dam can be classified as being eutrophic. It is, however, clear that the impoundment did not reach its full potential with regard to algal growth and in this regard, can be considered as oligotrophic. It appears likely that the high turbidity in the impoundment, which showed no seasonal variation, played an important, moderating role in suppressing algal growth. By limiting light penetration, the depth of the photic zone is also limited. The role of silt in binding nutrients, in particular by phosphorus adsorption, must also be of significance in an impoundment as turbid as Bridle Drift Dam. In this way, phosphorus is not available for algal growth and the potential of the impoundment to develop severe eutrophication problems in terms of phytoplankton productivity is not realized. It should be borne in mind that while no major problems were encountered during the study with regard to algal blooms, should physical conditions become favourable (such as a reduction in turbidity due to low inflows), severe blooms of *Microcystis* can be expected.

Laing Dam

Of the two major inflows into Laing Dam, the Buffalo and Yellowwoods rivers, the Buffalo River accounts for approximately 70% of the total inflow. However, in terms of nutrient loads, the Buffalo River contribution is far higher, indicative of the greater degree of urbanization and industrialization in this catchment.

From November 1977 to November 1978, the total inflow into the impoundment amounted to 56,77 x 10^6 m^3 while the outflow amounted to 53,40 x 10^6 m^3. The mean monthly volume represented 99,6% of the full supply capacity and the retention time of 0,41 years indicates that the water in the impoundment was replaced approximately 2,44 times during the study. The highest inflows were recorded in November and December 1977 and January 1978. The inflow during these three months amounted to 73% of the total annual inflow. The estimated flow rate of the Umlakalaka Stream varied between 2 160 m^3/d and 6 480 m^3/d . Consequently, at a con servative estimate of 4 000 m^3/d, the Umlakalaka Stream accounted for approximately 1,46 x 10^6 m^3 of the water entering Laing Dam, or 4% of the flow of the Buffalo River.

Laing Dam is a warm monomictic impoundment. Overturn occurred in late March, followed by a period of circulation. During this period, a temperature and dissolved oxygen gradient was always present. Stratification occurred in September and during summer stratification, no distinct thermocline was evident. Oxygen distribution showed a well-defined oxycline. During stratification an extensive anaerobic hypolimnion developed, accounting for 27% of the water capacity of the impoundment in March 1978. Schutte and Bosman (1973) also recorded no oxygen in the hypolimnion in the summer of 1968/69.

The turbidity of Laing Dam has varied considerably over the past 15 years (Toerien and Tow, 1976). Values of over 300 NTU were recorded after the August 1970 floods. A mean annual turbidity value of 33 NTU was recorded in 1975. During this period of reduced turbidity the first major outbreak of algal blooms was reported. A mean turbidity value of 53 NTU was recorded during the study period, and the mean Secchi depth was 0,17 m . Based on 8 readings taken during 1968 to 1970, Schutte and Bosman (1973) recorded a mean light transparency value of 0,10 m . The suspended solids carried into the impoundment during the study period amounted to 3 249 t of which 1 285 t originated from the Yellowwoods River. On several occasions during the study, the impounded waters were discoloured by industrial effluent in the waters from the Umlakalaka Stream. Considering that the Umlakalaka Stream contributed less that 3% of the total inflow into the impoundment, this indicates the extent to which this stream was discoloured. The mean suspended solids concentration of the Umlakalaka Stream during the study period was 24 mg/dm^3.

Since 1950, there has been a general increase in the mineralization of the impoundment (Toerien and Tow, 1976). The mean values of 58 mg/dm^3 for sodium and 73 mg/dm^3 for chlorides indicate the extent of mineralization of the impoundment. A general increase in sodium and chloride concentrations was observed in the Buffalo River from a point above King William's Town to the point where it enters Laing Dam. This observation confirms the findings of Thornton *et al.,* (1967). Since there is no significant urban or industrial development in the Buffalo River catchment above King William's Town, the mineralization of the Buffalo River up to King William's Town must be due to natural processes. The increased mineral content of the river after it had passed through King William's Town is thought to be partly due to leaching from an area irrigated with tannery and sewage effluent. A further marked increase in the mineral content was observed in the Buffalo River after it had received maturation pond effluent from Zwelitsha Sewage Works. The mean sodium concentration of the Umlakalaka Stream during the study period was 384 mg/dm^3.

Based on an estimated annual inflow of 1,46 x 10^6 m^3, the Umlakalaka Stream contributed 561 t of sodium into Laing Dam. The high mean sodium and chloride concentrations in the Yellowwoods River, of which the catchment is at present undeveloped, confirm the observations of Reed and Thornton (1969) that natural processes are important in the mineralization of the Buffalo River. The general increase in minerals in the impoundment and thus also in the outflowing waters, means that Bridle Drift Dam, which is sited downstream of Laing Dam, will become more mineralized. This trend is confirmed by values recorded in this study. It must be mentioned that the catchment area between Laing and Bridle Drift dams is also partly responsible for the increasing sodium and chloride values of the Buffalo River entering Bridle Drift Dam.

Estimates of nutrient loading have indicated that in this regard, Laing Dam is comparable to other eutrophic South African systems (Walmsley *et al.,* 1978). The orthophosphate phosphorus surface loading rate of 13,82 $g.m^{-2}.a^{-1}$, of which the Buffalo River contributed 96%, represented an orthophosphate phosphorus load of 31,57 t . The inorganic nitrogen surface loading rate was 37,55 $g.m^{-2}.a^{-1}$, of which the Buffalo River contributed 92%. The two major sources of nutrients in the Buffalo River during the study were the Zwelitsha Sewage Works and a textile factory. Large increases in all the nutrients monitored in the Buffalo River were associated with the discharge of maturation pond effluent. Nutrients in the maturation pond effluent occurred predominantly in the dissolved form. Particularly high total nitrogen values were recorded in the Umlakalaka Stream. The mean total nitrogen value for the study period was 16,34 mg/dm^3. Of the total nitrogen load (63,16 t) which entered the impoundment, 23,86 t, or 38%, originated in the Umlakalaka Stream. The dissolved nitrogen: dissolved phosphorus ratio is of the order 2:1 indicating that in terms of algal productivity, the system is nitrogen-limited. This observation is not in keeping with the observation of Toerien *et al.* (1976) that the impoundment is phosphorus-limited.

Microcystis growths were observed in the impoundment during the latter half of December 1977. However, the presence of this alga was short-lived, as it was washed out of the impoundment at the end of December 1977, and did not reappear during the rest of the study. The growths were subsequently noted in the upper reaches of Bridle Drift Dam. A low mean chlorophyll value of 0,17 $\mu g/dm^3$ was recorded for the study period.

In terms of its nutrient status and the presence of an extensive anaerobic zone during summer, Laing Dam can be classified as eutrophic. The limited algal growth in the impoundment may be attributed to the highly turbid conditions. Reduction of the photic zone limited the algal response to the very high nutrient loading rates. Possible inhibitory effects of textile wastes on algal growth cannot be discounted, but at this stage there is little information in this regard.

Laing Dam has the potential to develop severe problems in terms of algal growth and steps must be taken to improve the quality of the Buffalo River. It is clear that a large contribution of nutrients is made to the Buffalo River via maturation pond effluent which is discharged from the Zwelitsha Sewage Works. The works were designed for an average dry weather flow of 2,6 x 10^6 m^3/d (Water Research Commission, 1976). With the development of Breidbach

Township, there is a possibility of sewage from this settlement being treated at Zwelitsha Sewage Works. Although no final decisions have been reached, it appears certain that the additional effluent will ultimately be discharged into Laing Dam. This would further increase the nutrient level of the impoundment. Another significant source of nutrients and minerals is the Umlakalaka Stream. The textile factory situated in the Umlakalaka catchment disposes of highly saline effluent by means of evaporation ponds, the remainder of the effluent being irrigated. In view of the chemical data obtained during the study, the gross discoloration and frequent foaming observed, it appears that this method of treatment is not effective. It is imperative that steps be taken to improve the efficiency of the manner of disposal of the factory wastes.

Nahoon Dam

During the study period, this impoundment experienced unusual hydrological events in the form of low inflows and a reduced water level. The retention time for the period November 1976 to November 1977 was 2,43 years, indicating that the impounded waters were replaced approximately 0,41 times. The mean monthly volume of 3,61 x 10^6 m^3 represented 61% of the full supply capacity. The inflowing waters did not show any seasonal pattern related to rainfall. Major inflows were recorded during October and November 1976 and during May 1977. The total inflow during November 1976 to November 1977 amounted to 5,31 x 10^6 m^3, while the total outflow amounted to 1,49 x 10^6 m^3. The mean annual inflow from September 1968 to August 1977 was 27,74 x 10^6 m^3.

Nahoon Dam is a warm monomictic impoundment. Thermal stratification (November 1976 — February 1977) did not produce a well-defined thermocline. Overturn occurred in February 1977 and was followed by a winter circulation pattern. An oxygen gradient was present during both winters (July — October) of the study period. Schutte and Bosman (1973) noted oxygen depletion at the water/sediment interface in the summer of 1968/1969. In the present study, an extensive anaerobic zone was formed during summer stratification. This zone represented 50% of the impounded water during February 1977.

The mean turbidity of the impounded surface waters was 42 NTU during the study period and a mean Secchi depth of 0,51 m was recorded. During November 1976 to November 1977, it has been estimated that 181 t of suspended solids entered the impoundment via the Nahoon River, of which 79 t was exported. The net gain of suspended solids to the impoundment was 102 t . A considerable increase in light penetration was observed during the second half of the study period (from May 1977). This was probably brought about by silt sedimentation due to the low inflows during this period.

The extent of mineralization of the waters of Nahoon Dam is indicated by the high sodium and chloride values and the mean conductivity of 61 mS/m for the impounded surface waters. The Nahoon River had mean sodium and chloride concentrations of 163 mg/dm^3 and 160 mg/dm^3 respectively. As the Nahoon River catchment is undeveloped, these high values indicate the importance of mineralization through natural processes.

The nutrient status of the impoundment during the study period was similar to that of the inflow. Using the Wilcoxon Matched-pairs Signed Ranks 2-tailed P Test, the Rwantsa River, a tributary of the Nahoon River, was shown to be statistically similar to the Nahoon River during the study period. The only parameter found to be significantly different ($p < 0,05$) was nitrate-nitrogen being more concentrated in the Nahoon River. The reason for this difference is not known.

Loading estimates for Nahoon Dam indicate that this impoundment is not highly eutrophied when compared with certain other South African systems (Walmsley *et al.,* 1978). The orthophosphate phosphorus surface loading rate of 0,77 $g.m^{-2}.a^{-1}$ represented the import of 0,50 t of orthophosphate phosphorus of which 0,10 t was exported. The inorganic nitrogen loading rate was 4,28 $g.m^{-2}.a^{-1}$ (2,58 t), of which 1,67 t was exported.

Microcystis growths appeared in the impoundment during the summer of 1976/77, and apart from forming aesthetically displeasing scums, did not present any major problems. The mean chlorophyll a value for the study period was 0,67 $\mu g/dm^3$.

In terms of its nutrient status, loading rates and the development of an anaerobic hypolimnion in summer, Nahoon Dam can be classified as mesotrophic, tending to eutrophic. As with the two other turbid impoundments considered in this study, it appears that the role of high turbidities in moderating phytoplankton production is considerable. In terms of algal productivity, Nahoon Dam can be considered as oligotrophic. Since there is at present little or no development in the Nahoon catchment, the nutrients which enter the impoundment must arise from natural sources. Future development of the Berlin industrial complex would result in an increase in the mineral and nutrient content of the Nahoon River and also Nahoon Dam. In this regard, strict control will have to be maintained in the catchment to protect the quality of the water in the impoundment.

CONCLUSIONS

Bridle Drift Dam

(a) Bridle Drift Dam is a turbid impoundment which has a high nutrient and mineral status and a low algal standing crop, probably due to the high turbidity.
(b) The impoundment showed a monomictic thermal cycle and was stratified during summer, during which an anaerobic hypolimnion developed.
(c) The major portion of the total inflow and major nutrient loads entered the impoundment via the Buffalo River, which is derived largely from Laing Dam.
(d) There was evidence of frequent sewage contamination of the streams draining Mdantsane and results indicated that sewage works effluent was frequently present in the Umdanzani Stream.
(e) During the study the four streams draining Mdantsane accounted for less than 1% of the total inflow, while contributing 9% of the orthophosphate phosphorus and 3% of the inorganic nitrogen loads.
(f) Natural processes are important in the mineralization of Bridle Drift Dam.
(g) Results confirm the long-term upward trend of nutrient and mineral concentrations in the impoundment.

Laing Dam

(a) The impoundment displayed stratification during the summer months and can be described as warm monomictic.
(b) Laing Dam can be described as eutrophic in terms of nutrient status, nutrient loading and the presence of an extensive anaerobic hypolimnion in summer, although the impoundment is oligotrophic in terms of algal productivity.
(c) The major inflow into Laing Dam is the Buffalo River which also carries the greater portion of nutrients and minerals.
(d) A progressive deterioration in the water quality of the Buffalo River was evident from the upper reaches above King William's Town to where the Buffalo River enters Laing Dam.
(e) A large input of nutrients to the Buffalo River is derived from the maturation pond effluent from Zwelitsha Sewage Purification Works.
(f) There has been a general increasing trend in nutrient and mineral content of Laing Dam. These increases also affect Bridle Drift Dam.
(g) The waters of the Umlakalaka Stream are highly saline, grossly discoloured and carry extremely high nitrogen loads.
(h) The absence of severe algal blooms is thought to be largely associated with the high turbidity although the possible inhibitory effect of textile effluent cannot be discounted.

Nahoon Dam

(a) Nahoon Dam is a warm monomictic impoundment which experienced abnormal hydrological events during the study period.
(b) In terms of its nutrient status, loading estimates and the presence of an anaerobic hypolimnion, Nahoon Dam can be classified as mesotrophic-eutrophic, but is oligotrophic in terms of algal productivity.
(c) The minerals and nutrients which entered the impoundment were derived predominantly from natural sources.
(d) The impoundment did not reach its full potential with regard to algal growth, possibly due to the moderating effect of the high turbidities.

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