The Swartkops Estuary

Proceedings of a symposium held on 14 and 15 September 1987 at the University of Port Elizabeth

D Baird, J F K Marais and A P Martin (Editors)

Symposium held under the aegis of the South African National Committee for Oceanographic Research (SANCOR)

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ABSTRACT

KEYWORDS: Swartkops estuary, physical characteristics, sedimentological characteristics, geological characteristics, pollution status, botanical research, ecological research, land use planning, urban development, river floods, ichthyofauna, birds.

The Swartkops estuary has been an object of study for many years and research results obtained during the past 30 years were considered at a symposium in 1987. This report documents the proceedings of this symposium as well as conclusions and recommendations of delegates on problems facing the estuary and the formulation of a cohesive and comprehensive management plan for the estuary.

UITTREKSEL

Die Swartkops-getyrivier word reeds vir baie jare bestudeer en navorsingsresultate wat gedurende die afgelope 30 jaar verkry is, is by 'n simposium in 1987 oorweeg. Hierdie verslag dokumenteer die verrigtinge asook aanbevelings van afgevaardigdes oor probleme met betrekking tot die getyrivier en die formulering van 'n samehangende en alomvattende bestuursbeleid vir die getyrivier.

ACKNOWLEDGEMENTS

The symposium was organized on behalf of the Estuarine Committee of the South African National Committee for Oceanographic Research, and hosted by the University of Port Elizabeth. We thank both organizations for their financial support to have made this symposium possible, and the University of Port Elizabeth for providing the necessary facilities.

We are also grateful to all authors and participants for their contributions.

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INTRODUCTION

The Estuarine Committee of SANCOR has during its meeting in September 1986 suggested that a symposium on the Swartkops estuary in 1987 would be the ideal opportunity for the presentation of research results obtained during the past 30 years and to discuss these in relation to the future of this ecosystem.

The Swartkops estuary forms an integral part of Port Elizabeth and surrounding areas; it is a valuable recreational and ecological asset and is also, due to its geographical position in a rapidly expanding urban area, subjected to influences and effects of various developments. The philosophy on conserving the estuary as a viable ecological entity is deeply imbedded in the thinking of organizations such as the City Engineer's Department of the City of Port Elizabeth, the Zwartkops Trust, the Department of Nature Conservation of the CPA, the Department of Environment Affairs and Fisheries, the University of Port Elizabeth, the Port Elizabeth Museum and the people that live along its banks.

The Swartkops estuary has been an object of study for many years and some of these results were recently documented in a CSIR Research Report (Baird *et al.* 1985). Ecologists and other scientists have from time to time provided the City Engineer's Department and other organizations with (hopefully) useful advice in its formulation of short- and longterm development plans for the estuary but to date no in depth attempt has been made to integrate the results of research with future development and management of the ecosystem.

The main objectives of the symposium were therefore:

(i) to present reviews and results of research conducted during the past two decades;

(ii) to address management related problems in the estuary and the contribution ecological research can make towards solving them;

(iii) to integrate research results with socio-economic, conservation and other relevant issues into an advisory management plan for the Swartkops estuary.

The symposium was held on 14 and 15 September 1987 at the University of Port Elizabeth and was attended by approximately 80 delegates from a large number of institutions and organizations in South Africa. This report presents the proceedings of that symposium and contains four research review papers, five papers addressing specific socio-economic and ecological aspects and a final one which summarizes ideas expressed by delegates on the problems facing the estuary and the formulation of a general management plan for the estuary.

Several of the papers in this report refer to regional and local features of the Swartkops river and estuary. To prevent too many duplications of the same figure, three figures are inserted in this introductory chapter as Figure 1 (regional features of the Swartkops river), Figure 2 (local features of the Swartkops river and estuary) and Figure 3 (detailed features of the Swartkops estuary).

Figure 1. *Regional features of the Swartkops River.*

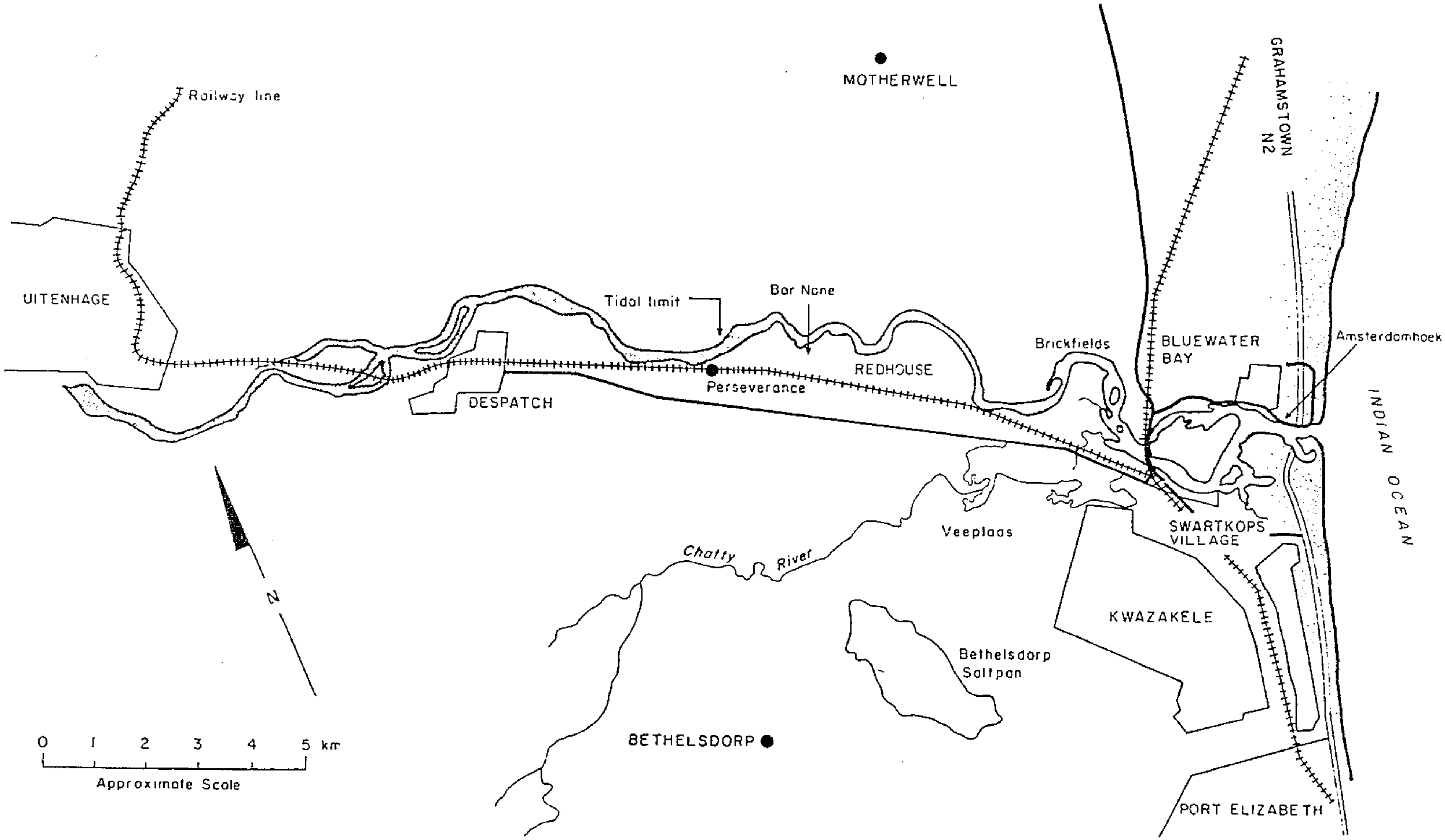

Figure 2. *Local features of the Swartkops River and estuary.*

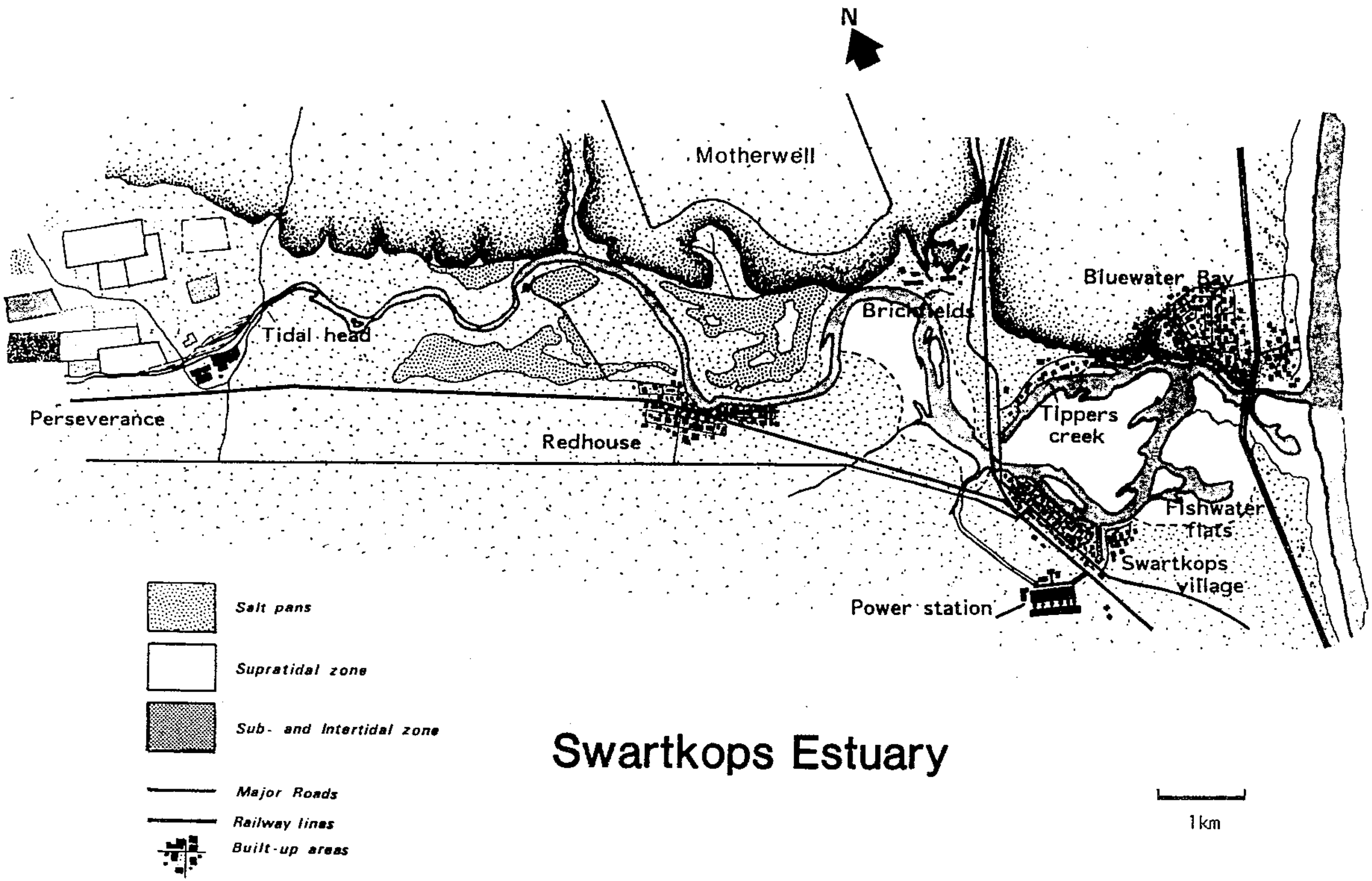

Figure 3. *Detailed features of the Swartkops estuary.*

RESOLUTIONS AND RECOMMENDATIONS

At the end of the symposium, a number of resolutions and recommendations were formulated with a view to the long-term management needs of the Swartkops estuarine system.

It was agreed that sharper focus needs to be placed on steps which can be taken to promote:

(i) effective co-ordination of the activities of the various authorities in the whole catchment area;

(ii) the creation of an objective scientific/socio-economic advisory body;

(iii) the compilation of a cohesive and comprehensive management (and conservation) plan for the catchment area and estuary;

(iv) co-ordination and integration of such a management plan with national coastal zone management objectives;

(v) educational and consultation mechanisms for all user communities (i.e. black, coloured and white);

(vi) access to technological management tools such as:
- hydrodynamic models
- water quality models
- sediment transport models
- monitoring of ecological components;

(vii) real ability to enforce the management and conservation policies agreed to.

The importance of the latter point cannot be over-emphasized. Unless one authority takes responsibility for the overall co-ordination of management and conservation of the Swartkops system, it will not be possible to realize recommendations (i) - (vii) above. Since the symposium was held, executive responsibility for coastal zone management in the Cape Province was devolved from the Department of Environment Affairs to the provincial Chief Directorate of Nature and Environmental Conservation. It is this latter body which is most suited for taking on the responsibility for the overall co-ordination of management and conservation action.

THE SWARTKOPS ESTUARY: PHYSICAL DESCRIPTION AND HISTORY

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INTRODUCTION

The Swartkops estuary, 8 km north of Port Elizabeth, has a tidal prism of about 3 x $10^6 m^3$. The estuary is predominantly sandy and has wide intertidal and supratidal areas in the lower estuary, whereas the muddier upper estuary has steep banks.

The earliest Quaternary deposits of the Swartkops consist of a tidal inlet sequence dating back to the Eemian interglacial. After the Flandrian transgression mid-Holocene estuarine deposits were accumulated and these were dominated by river floods and by flood-dominant tides. The modern estuary has actively meandering channels and is incised into older terraces.

This paper reviews the physical, sedimentological and geological characteristics, as well as the geological history of the Swartkops estuary. Aspects such as the accumulation and removal of sediment, the migration patterns of the downstream channel and the influence of man on these processes are also discussed. Figures 1, 2 and 3 on pages 3, 4 and 5 refer to the various localities mentioned in the text.

PHYSICAL DESCRIPTION

The Swartkops estuary lies in the metropolitan area eight km north of the Port Elizabeth city centre. Industrial and residential areas of the city lie adjacent to both banks of the estuary. The sedimentary behaviour of the estuary has been described by Reddering and Esterhuysen (1981).

The valley of the Swartkops estuary is incised chiefly into (Early) Cretaceous mudstone and sandstone units of the Lower Sundays River Formation. The estuary occupies the northern margin of the valley so that the northern valley slope is steep whereas that to the south is comparatively gentle. This phenomenon is common in many rivers and estuaries of the eastern Cape and has not been satisfactorily explained. The steepness of the slope to the north of the Swartkops estuary is further accentuated by the capping of well-cemented calcareous sandstones of the Tertiary Alexandria Formation overlying sediments of the Uitenhage Group. Because the Alexandria Formation resists erosion it leads to undercutting by the river/estuary which thereby creates a steep northern slope.

The Swartkops estuary has a permanently open tidal inlet which connects it to Algoa Bay. The estuary is in a mature state of development, that is, the channels of the estuary are maintained to allow river floods to reach the sea (Reddering 1988). Sediment that accumulates during periods between river floods is subsequently scoured out of the estuary during floods. Most of the estuarine sand is derived from the adjacent beach and enters during flood tides, accumulating primarily on large sand bars (flood-tidal deltas) in the lower estuary. The estuary meanders along its entire reach of just over 14 km and it has a tidal prism of about 2.9 x $10^6 m^3$ (high tide capacity - 5.1 x $10^6 m^3$, low tide capacity - 2.2 x $10^6 m^3$). The tidal head lies at a causeway near Perseverance.

The lower estuary has a low relief with wide supratidal flats (salt-marshes), covering 2.4 km^2, and fairly extensive intertidal flats covering 1.6 km^2. The sub-aerial flats to the south of the estuary consist of Holocene terraces of the estuary (see below). The low relief of the estuary extends to the Brickfields from where there is a sudden change from a low relief to fairly high relief with steep channel banks extending up-estuary to the tidal head. There are two reasons for this increased relief. Firstly, levees are developed in the upper estuary, particularly in the Redhouse area. Levees are sub-aerial, elongate sand bars which develop during river floods on the edges of the main channels where sediment is deposited at the zones of flow separation developed there. Deposition on levees is aided by vegetation that is established on the river banks. Secondly, the mud content of the sediment is highest in these upper regions of the estuary resulting in stable steep banks.

Sediment in the estuary consists of three main mineralogical groups. The predominant sediment type is sand consisting largely of quartz. The subordinate sand fraction consists of skeletal carbonate material which is mainly derived from the sea, although some is produced locally by estuarine molluscs and crustaceans, and limited volumes are derived from the calcareous fossiliferous units of the Alexandria and lower Sundays River Formations. Most of the sand is fine-grained (0.125-0.25 mm) to medium-grained (0.25-0.5 mm). Medium-grained sand is found mainly in the lower estuary where tidal currents winnow the finer-grained fraction. In the middle and upper estuary the sand is mostly fine-grained. The carbonate content of the sand is controlled by two factors. The coarser-grained fraction of the sand that enters the estuary from the sea through the tidal inlet consists largely of $CaCO_3$. The finer-grained fraction is more quartz-rich. The finer-grained fraction of the sediment that moves up the estuary under the influence of the flood tides contains less carbonate sand, which because it is fine-grained is more easily dissolved in the estuarine water, which is corrosive to $CaCO_3$ (Olaussen 1980). As the finer-grained sand is winnowed from the sand the coarser-grained remainder in the lower estuary is enriched with carbonate.

The other common mineral constituent in the estuary is a group of clays. Clay-rich mud is found in those areas of the estuary where effective mud-trapping mechanisms operate. These traps are by far the most common on the saltmarshes where the vegetation creates a very efficient boundary layer that captures mud near the bed. Mud is also found in areas where tidal circulation is severely restricted. Although mud occurs fairly extensively at the surface our coring programme in the supratidal areas indicates that the mud in the lower estuary is seldom thicker than 0.5 m so that it largely forms a superficial veneer that overlies predominantly sandy sediment. This concentration of mud is largely the result of natural movement of mud onto the supratidal flats (Postma 1967) and the efficient trapping of mud by the saltmarsh vegetation.

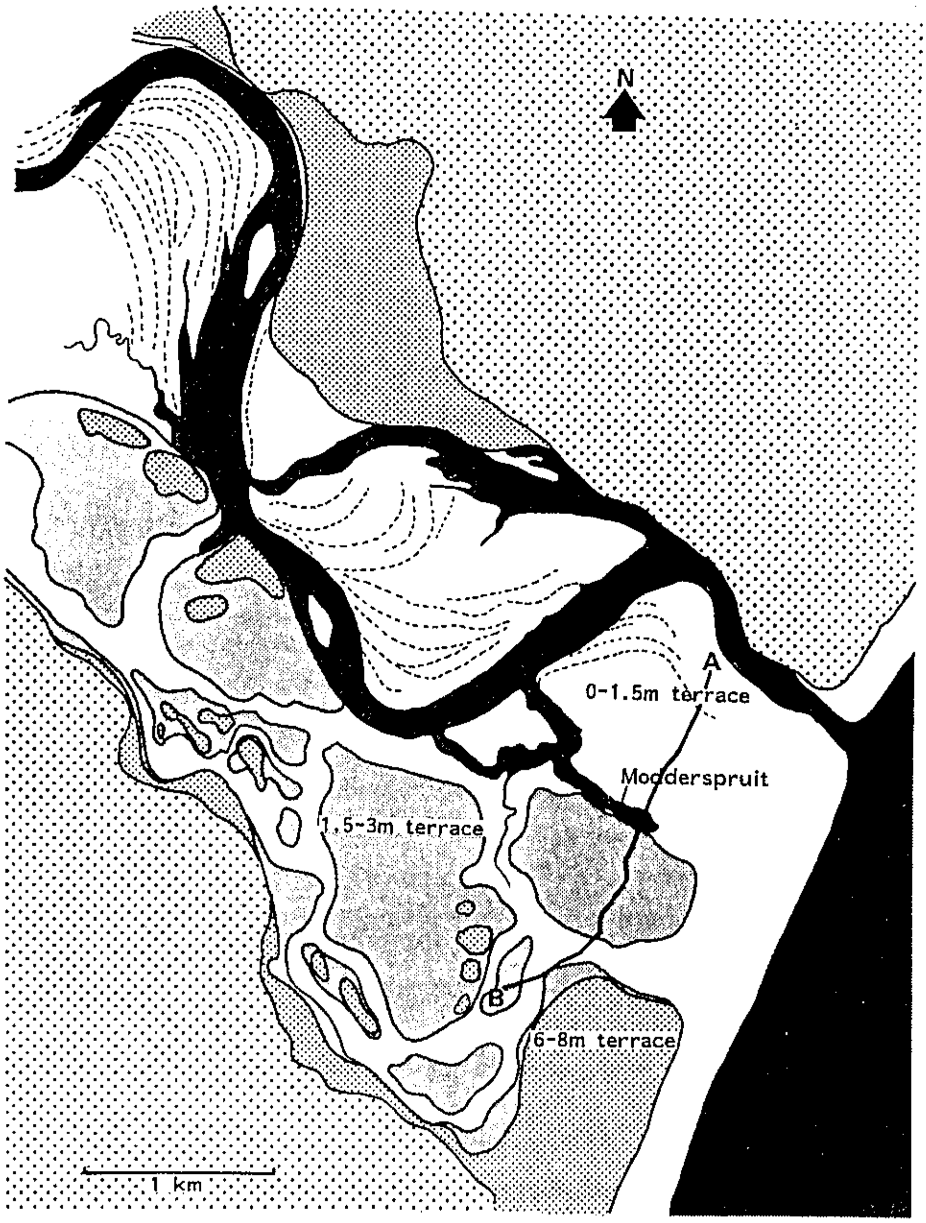
Sediment is derived from two main areas. The first is the beach adjacent to the estuary. Marine-derived sediment preferentially enters the estuary under flood-tidal conditions whereas less sediment leaves the estuary during the ebbing tide. The sediment deposited in this way accumulates on the flood-tidal deltas and causes the channels of the lower estuary to shoal. Marine-derived sediment has penetrated as far as 5.5 km up-estuary from the tidal inlet and forms a 2.5 km long transition zone with the land-derived sediment in the channel. Up-estuary of the Brickfields sediment in the estuary is derived from the land, mostly from the river catchment basin, but some sediment also enters the estuary by hill-wash off the local slopes. Although some established mud deposits are present in the upper estuary the generally low content of mud in the sediment of the Swartkops estuary is surprising - the Uitenhage Group which underlies a significant part of the catchment basin contains a large number of shale units which weather to mud.

HISTORICAL DEVELOPMENT

Quaternary deposits older than those associated with the modern system fall into two age groups. The oldest deposits underlie a 7 m terrace. An age of about 30 000 BP has been obtained, based on shell material from this deposit (C^{14} analysis; Pta-4332), but this is a minimum age as sea level is known to have been considerably lower at that time. The level of the terrace corresponds well with other 6-8 m terraces along the southern and eastern Cape coast which are generally assigned an Eemian (120 000 BP) age (Butzer and Helgren 1972, Hendey and Cooke 1985) or to an even earlier interglacial event (Hendey and Volman 1986).

Based on this correlation the sediment underlying the Swartkops 7 m terrace is provisionally assigned an Eemian age and the deposit is thought to represent an approach channel to the tidal inlet of the palaeo-Swartkops estuary. The second age group is represented by the deposits underlying Holocene terraces that occur at elevations 1.5 m and 3 m above sea level.

The Eemian terrace 2.5 km south of the present tidal inlet (Fig. 4) consists of an old approach channel to the tidal inlet that was aligned parallel to the coast for a considerable distance. Evidence for the deposits representing this channel type is based on the characteristic sedimentary structures, their attitude and association with the burrow traces of *Echinocardium cordatum*. *Callianassa kraussi* burrows at a higher level in the deposit indicate gradual abandonment of the channel by the main tidal currents. Final abandonment is indicated by accumulations of muddy sediment and *in situ* shells of burrowing estuarine bivalves (*Anodontia edentula*, *Loripes clausus*, *Dosinia hepatica*) near the top of the preserved sequence. Oxygen-isotope studies presently underway may indicate the age of this ancient estuary.



Quaternary terraces

Figure 4. *Quaternary terraces surrounding the lower Swartkops estuary. Line A-B is the vibracore profile section across Fishwater Flats.*

Holocene deposits (5 140 to 3 980 BP, C^{14} analyses; Pta-4463 and Pta-4464) underlie the terrace at Fishwater Flats. Sea level at this stage is considered to have lain between 1.5 m and 3 m above the present (Reddering in press-b). Although it has not been possible to determine accurately the sea level when these Holocene deposits were accumulated, the general level indicates a height of 1.5 m rather than the 3 m level. Information obtained from vibracores sampled in a north-south line across the Holocene terrace indicates a distinct facies change at Modderspruit. To the south of this tidal creek the sand underlying the terrace consists of lenticular units containing thin layers of mud and lag gravels consisting of estuarine shell material (dated at 5 100 to 4 000 BP). Many of the estuarine bivalve shells are articulated but are not in the burrowing attitude - this indicates that the bivalves were removed from the sediment by a river flood, transported while still alive and deposited as part of the shell gravel. These large sand lenses represent estuarine deposits which were dominated by river floods so that the dominant structure is fluvial in origin but the sediment contains skeletal remains of molluscs that originate from within the estuary. A facies change at the southern bank of Modderspruit indicates an erosional feature and the younger, predominantly sandy sediment underlying the terrace to the north of Modderspruit contains carbonate fragments of coralline algae which indicate a marine source for the sediment. Cross-bedding indicates that this sediment was accumulated on a flood-tidal delta. This sediment is by inference younger than that to the south of the facies change at Modderspruit and should be confirmed by C^{14} dates which are being determined. The abandoned channel forming Modderspruit would have formed a logical continuation of the meander at Tippers Creek which shows an interrupted meander pattern at its western end. This indicates that the Swartkops inlet at the time lay about 1 km to the south of its present locality. The position of the shoreline during the mid-Holocene could not be determined.

A provisional reconstruction of the history of the Swartkops estuary can be done using the available data. The 8 m terrace represents an estuary that was considerably larger than the present estuary. The channel at the inlet then exceeded 8 m water depth, compared with the present depth of only 3-4 m. Conflicting reconstructions on the palaeoclimate at the time appear from the fossil record because species from present warmer and colder climatic zones co-existed in the deposits. The last glacial episode started about 100 000 BP, after the Eemian interglacial and sea level fell by about 120 m (Dingle and Rogers 1972) so that the lower Swartkops valley was deeply incised by the river and estuarine terrace deposits of Eemian age were abandoned. The river valley formed during the Last Glacial was subsequently drowned during the Flandrian Transgression. When the sea reached roughly its present level the valley was again occupied by an estuary. Sea level stabilized about 6 000 BP (Yates *et al*. 1986) at a level 3 m above the present and subsequently dropped to a level 1.5 m above the present sea level. The estuaries which developed terraces at these levels during the mid-Holocene were partially incised into the older ?Eemian estuarine deposits. The deposits underlying the Holocene terraces indicate that river floods occurred frequently in the estuary at the time. Sea level dropped to its present level about 4 000 - 3 000 BP (Reddering in press-b) at which time the modern estuary established itself by incision into the mid-Holocene terraces.

SEDIMENTATION RESULTING FROM HUMAN INFLUENCE (Fig. 5)

The extent to which artificially increased sedimentation is occurring in the Swartkops estuary is limited to isolated areas. Most of the sediment-related problems occur where natural sedimentation phenomena conflict with man's waterside endeavours. Restrictions to free tidal movement do not constitute an environmental threat and are only noticeable in the channel section between the railway bridge and the Brickfields where extensive sand shoals are present. Most of the effects of sedimentation originate during river floods.

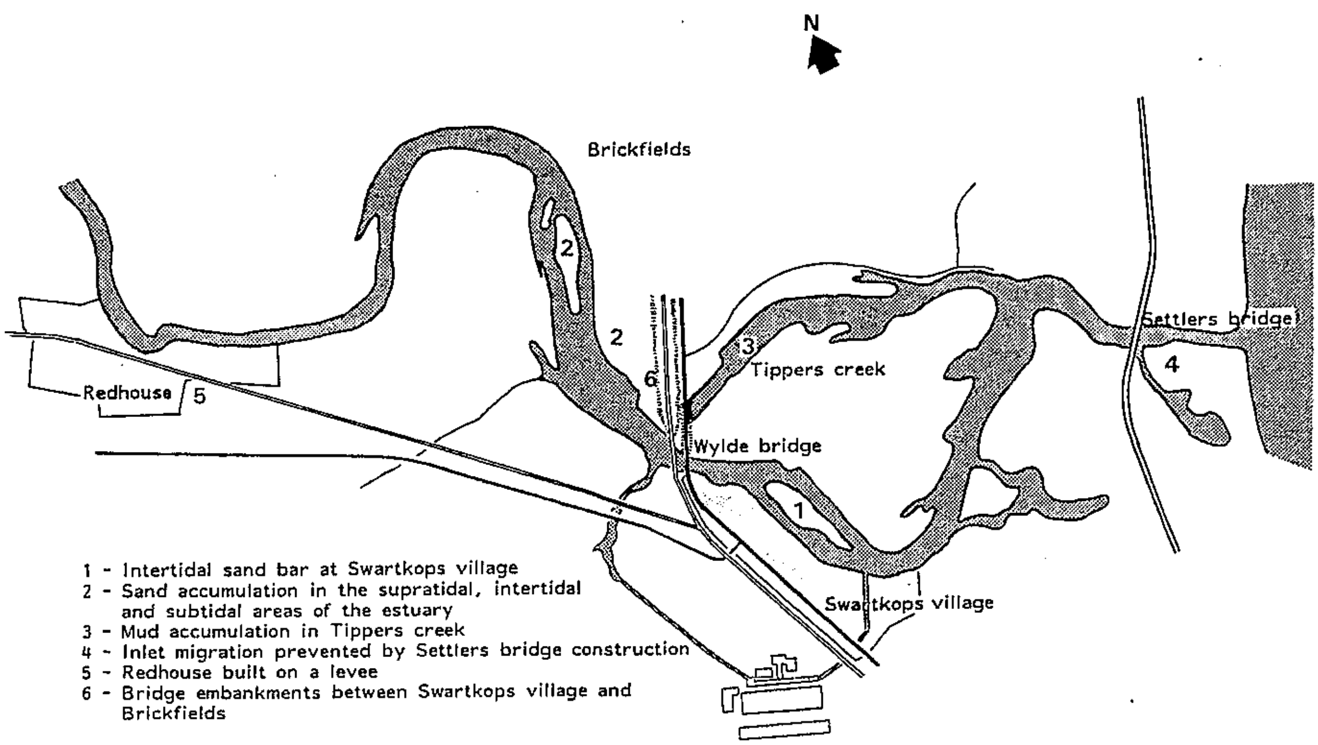


Figure 5. *Areas where artificial sedimentation patterns are influenced by human interaction.*

Redhouse is built on a levee which is a river bank higher than the adjacent floodplain that accumulates during very high discharge floods and will naturally be inundated during floods. Whether living in such a locality is acceptable is a trade-off between the aesthetic nature of a waterside home and the acceptability of periodic flooding and the concomitant damage.

Construction on various parts of the floodplain for industrial and residential purposes constitutes a similar trade-off. Every time that a river flood passes through the Swartkops estuary there is some flood damage. People do not move away so that the chance of being flooded appears to be an acceptable risk. However, the floodplain fulfills an essential function during drainage of the river system and the estuary, so that further encroachment should be discouraged.

The bridge embankments are an appreciable constriction during severe river floods. There is a significantly different water level upstream compared with downstream sides of the bridge system at Swartkops village during such floods. The water level upstream of the bridge is higher than would naturally have been the case. At the same time a cell of flow separation is formed in the water dammed up behind the railway embankment so that sediment accumulates there. This raises the surface of the saltmarshes in that area which could become of environmental concern if the level of the salt flats were to be raised above spring high tide level, as they would then cease to function as saltmarshes. It would also appear as if the channel between the bridges and the Brickfields is similarly influenced by the cell of flow separation because this is the only sector of the estuary where shoals are not efficiently removed by river floods.

In addition to the cell of flow separation floods also cause water to jet through the narrow channel underneath the bridges only to decelerate rapidly as the channel widens downstream (Esterhuysen and Rust 1987). The sand bar opposite Swartkops village initially formed a short distance downstream of the bridge where the flood current decelerates after passing under the bridge. Over the past 80 years floods have led to erosion of the upstream end of this intertidal sand bar and deposition of sediment on its downstream end resulting in downstream migration of the sand bar. This has had two noticeable effects. What was open water in front of the Zwartkops Yacht Club at the turn of the century is now occupied by a sand shoal which causes unfavourable boating conditions at that locality, particularly at low tide. Secondly, the downstream section of the sand bar has now migrated towards the southern bank up to the intake for cooling water of the power station so that this may require management. It is probable that the rapid lateral migration (2,6 m y^{-1}) towards the southeast of the channel between Swartkops village and Amsterdamhoek is aided by the jetting effect of the flood water after having passed underneath the bridge.

The southern embankment of the Settlers bridge near the Swartkops tidal inlet seems to prevent any southward migration of the inlet channel so that it no longer has the tendency to periodically lie parallel to the coast for a few hundred metres before the seaward end of the channel is directed towards the sea. Such a channel, formed prior to the construction of the bridge, created the Blue Hole to the south of the present inlet before both ends of the channel were blocked.

CONCLUSION

Patterns of sediment movement in the Swartkops estuary have remained largely unaffected by human influences. If the undesirable shoals that do occur in the estuary were to be dredged it must be accepted that the improvement will be temporary because natural processes will cause shoals to return in time.

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THE SWARTKOPS ESTUARY: POLLUTION STATUS

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INTRODUCTION

The Swartkops estuary is situated about 15 km north of Port Elizabeth harbour, at 33°52'S and 25°38'E. It is tidal for 16 km from the mouth, the tidal limit being fixed by a causeway across the Swartkops River. The main catchment of the Swartkops River Estuary is the Groot Winterhoek Mountains to the west of Uitenhage and is approximately 1 342 km^2 in area. The Swartkops and Elands Rivers are the prime contributors of freshwater to the head of the estuary, with a smaller contribution coming from the Chatty River, directly into the lower reaches of the estuary (see Fig. 1, p. 3).

Exchange of water with the sea takes place via the estuary mouth just below Amsterdamhoek. Although it is the fresh water that maintains the estuarine character of the system, the regular exchange of seawater is the main flushing mechanism for the estuary. These features are shown in Table 1, where the 'average' replacement time for the estuary is shown to be twenty-five hours. Expressed in another way, on average approximately one-half of the total volume of the estuary is exchanged on each tidal cycle. However, this fact is a bit misleading, as the estuary is not completely mixed during each tidal cycle. As a result more frequent exchange occurs near to the mouth of the estuary, whereas waters at the head of the estuary take longer to be replaced.

Table 1
Hydrology of the Swartkops Estuary

a)	Tidal length	16.4 km
b)	Average depth at HWOST	3 m
c)	Spring tides	
	Volume at HWOST	5.1×10^6 m^3
	Tidal prism	2.9×10^6 m^3
	% exchange per tide	57
d)	Average river flow per tidal cycle (i.e. 12.38 hr)	2×10^4 m^3

Based on the nature (i.e. rapidity) of exchange of water with the sea, the estuary can be conveniently subdivided into three zones; the lower estuary (mouth to old road bridge across estuary) where almost complete exchange of water with the sea occurs on each tide, the middle estuary (old road bridge to Brickfields) where marine exchange is less pronounced, and the upper estuary (Brickfields to tidal reach) where marine exchange is least. This division clearly matches the distribution of surface sediments in the estuary (Fig. 6) where sediments of marine origin are found near the mouth, sediments of fluvial origin are found at the head, with a transition zone between these two (CSIR 1986).

DISCHARGES INTO THE SWARTKOPS, AND THEIR MANAGEMENT

There are no direct discharges of industrial or municipal effluent into the Swartkops Estuary itself. However, a number of these enter the Swartkops River above the tidal reach. These are from:

(i) sewage works - Uitenhage - 8×10^6 l/day;
(ii) sewage works - Kwanobuhle - 3×10^6 l/day;
and (iii) sewage works - Despatch - 3×10^6 l/day.

Each of these discharges are required to meet the General Standards as laid down by the Department of Water Affairs. Other possible sources of pollution include the two wool processing plants adjacent to the river, and a tannery at Uitenhage. The Uitenhage Tannery treats its effluents in solar evaporation ponds situated in deep clay soil, from which there are no indications of seepage. Similarly, Perseverance Wool Pullery also has an effective evaporation pond system. The wool washery above Uitenhage could present a problem. Its ponds are situated within the river channel in sand, where seepage as well as overflow during floods can occur.

No single comprehensive study on contamination of the estuary has been undertaken, but an examination of existing data and comparing with established Water Quality Criteria for Coastal Waters (Lusher 1984) for the parameters; nutrients, microbiological parameters, trace elements, persistent chlorinated hydrocarbons, petroleum hydrocarbons, and temperature elevation, does allow for a reasonable assessment of the "state of health" of the estuary to be undertaken.

CRITERIA ASSESSMENT

Nutrients

The concentrations of nutrients in water - particularly nitrogen and phosphorus - are an important indication of the presence of enriched discharges which can occur from sewage works, run-off from farmland,

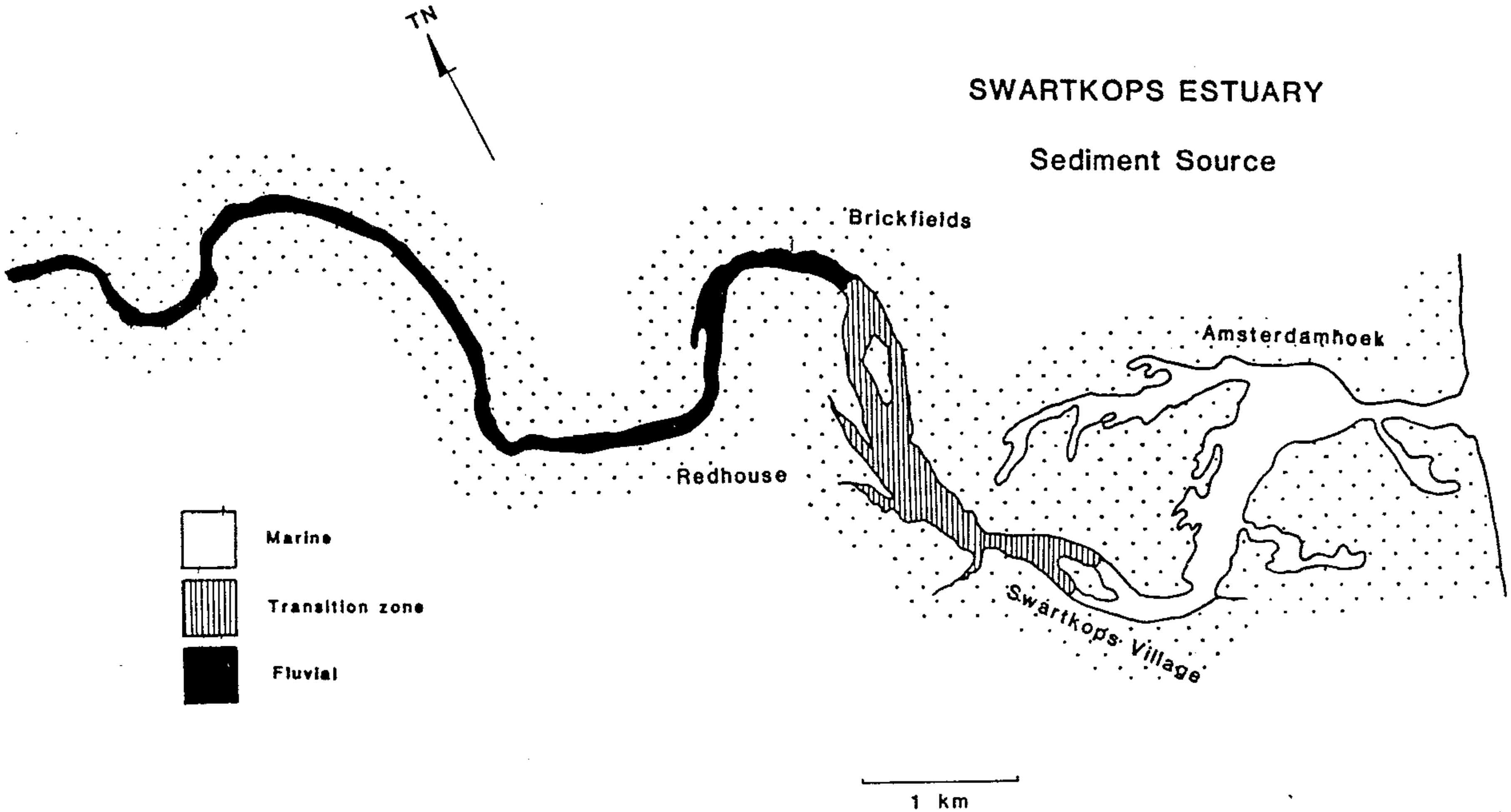

Figure 6. *Sediment source and characteristics of the Swartkops estuary.*

industrial discharges and stormwater. An excess of these nutrients will result in a nuisance growth of algae or other aquatic plants, which then can cause a reduction in dissolved oxygen levels.

The two most comprehensive studies on nutrient levels in the Swartkops are those by Emmerson (1985) and Thompson *et al.* (1986) in which all previous nutrient data are summarized. These two studies show the same general trends, which are:

(i) mean nutrient levels in the Swartkops estuary are greater than those in Algoa Bay;

(ii) nutrient levels decrease from the head to the mouth of the estuary;

(iii) nitrogen levels in particular, are dramatically increased after rainfall events.

In absolute terms, nutrient levels are low. By comparison, they are equivalent to those found in the relatively unpolluted Bashee River, and are far lower than those found in the Buffalo River, or even the Sundays River Estuary.

These absolute levels are insufficient for nuisance plant growth to occur within the estuary, and any management plan for the estuary should strongly support the maintenance of these low levels.

Microbiological Parameters

The presence of sewage derived wastes in receiving waters are conventionally detected by determining the presence of *E. coli* bacteria, or by determining the less specific indicator 'faecal coliform'. These bacteria are only indicators of sewage, as they are mainly derived from the digestive tract of warm blooded animals and do not themselves cause infection. Nonetheless, the presence of *E. coli* and faecal coliform bacteria still represents the most convenient means of rapidly evaluating sewage related contamination in water.

For the Swartkops River, most of the available data is reported as *E. coli*. Results reported by Emmerson (1985), Thompson *et al.* (1986) and Thompson (unpublished data) are the most complete that are available, and are summarized in Table 2 for five sites in the Swartkops. These can then be compared with recommended maximum levels for faecal coliform bacteria for the recreational use of estuaries as given in Water Quality Criteria for the South African coastal zone (Lusher 1984); this is done in Table 3.

From these results it is obvious that while sites 3 and 4 (Brickworks and Redhouse, respectively) are acceptable in terms of WQC, the Blue Hole and Swartkops fall slightly below the acceptable standard. The

TABLE 2

***E. coli* levels in the Swartkops Estuary, August 1980 to June 1986**

Date	Site 1	Site 2	Site 3	Site 4	Site 5
1980					
August	0	30	56	10	700
September	210	107	180	13	800
November	70	61	80	26	329
1981					
February	32	190	198	500	1 170
March	2	2	6	6	70
April	5 500	500	200	200	459
April	–	1 150	–	–	–
May	20	90	120	43	90
May	0	146	8	7	10
August	24	30	20	11	120
August	2 300	72 000	750	250	2 430
November	40	60	140	290	2 790
SUMMER 1980	29	63	71	165	872
WINTER 1981	1 083	1 163	723	417	721
1985					
April	23	1 740	140	31	41
May	34	19	11	5	20
June	0	0	43	2	21
July	0	26	17	6	6
August	8	13	11	24	61
September	–	3	6	6	15
October	29	110	150	17	2
November	75	700	600	586	1 500
December	0	20	170	38	250
1986					
January	6	4	8	70	86
February	0	10	10	10	10
March	0	0	23	56	0
April	1	20	16	23	50
May	20	22	44	6	32
June	10	760	190	60	28

– = No sample taken

Key:
Site 1 = Blue Hole
Site 2 = Swartkops Village
Site 3 = Brickworks
Site 4 = Redhouse
Site 5 = Perseverance

site at Perseverance exceeds the acceptable limit. Since this is situated below the major pollution source (Kwanobuhle) and at a part of the estuary where the tidal influence and therefore the purification effect, is least felt, these findings are understandable, but give some cause for concern, as this area is well used for a variety of recreational purposes especially in the warm summer months.

Table 3
***E. coli* levels in the Swartkops Estuary expressed as per cent values within defined ranges**

Range	Blue Hole	Swartkops Village	Brick-works	Red-house	Perse-verance
E. coli <100/100 ml	85	60	59	76	59
E. coli <400/100 ml	89	77	97	90	69
E. coli <2000/100 ml	93	97	100	100	91

WQC requirements for recreational purposes : Faecal coliform bacteria (Lusher 1984)

50 % of values not to exceed 100/100 ml
90 % of values not to exceed 400/100 ml
and 99 % of values not to exceed 2000/100 ml

Note : *E. coli* is a more specific term than 'faecal coliforms'; consequently *E. coli* levels will always be less or equal to total faecal coliform levels.

Emmerson (1985) concluded that *E. coli* levels correlated with river flow especially in the upper reaches. These results were confirmed in 1985/86 (Thompson *et al.* 1986), while unpublished data (G A Thompson) indicate that one further upper estuarine site and the site of a storm-water outlet pipe in the middle reaches also fall short of the WQC recommendations. There is a need therefore for regular bacteriological monitoring at selected sites along the estuary, preference being given to the upper reaches of the estuary, particularly during the spring and summer months, as well as at Swartkops (where aquaculture takes place) and the stormwater run-off canal from Motherwell. The seasonal incidence of pathogenic vibrio species including *V. cholerae* 01 El Tor (causative agent of cholera) in the estuary has also been shown (Thompson *et al.* 1986). The regular monitoring for bacteria such as *V. cholerae* 01 and non 01, *V. parahaemolyticus* and *V. alginolyticus* may be impractical at this stage, but an awareness is required that all these potentially pathogenic bacteria have estuaries as a natural habitat, and that *E. coli*, faecal coliforms or coliforms are only convenient indicators of bacterial pollution in recreational waters.

Trace Metals

The occurrence of elevated levels of trace metals especially in sediments is a good indication of man-induced pollution. However, significant natural variations in metal sediment levels do occur due to the differences in chemical composition of host rocks; consequently these natural variations need to be known and catered for.

A detailed study of the distribution of metals in water, surface sediment and in sediment cores was undertaken by Watling and Watling (1982). Sixteen elements were determined in samples collected along the estuary. Of interest here are particularly the levels of the more toxic metals, copper, lead, zinc and mercury. Metal levels in the mouth area are low, and considered to be natural, or background. Metal levels were higher in the upper reaches of the estuary, but only by at most a factor of 3. These higher levels occur where the sediment is of fluvial origin, confirming the normal association found between metal levels and the smaller clay size fraction of sediments. No levels recorded in the estuary can be considered cause for concern.

Persistent Chlorinated Hydrocarbons

The occurrence of persistent chlorinated hydrocarbons has been measured in fish from the Swartkops estuary, collected between 1981 and 1984 (De Kock 1984). Considerable variation occurred both within, and among the species sampled. Comparisons were made with recommended levels for residues in foodstuffs, particularly fish, and of the 53 samples collected, one spotted grunter exceeded the 1.0 µg g recommendation for t-DDT, while the PCB recommended level of 0.5 µg g was exceeded by two eagle rays, three spotted grunters, and two skipjacks.

These levels can be considered typical of a moderately industrialized area. They are not sufficiently high to warrant concern for the health of humans consuming these fish, but, in the absence of direct discharges into the area, indicate a contribution from the surrounding areas, either by run-off, contained in river flow, or in precipitation.

Petroleum Hydrocarbons

Any oil pollution of the Swartkops is restricted to incidental (and indirect) pollution from the use of powerboats, run-off after rain, and atmospheric fallout from the surrounding industrial areas. The

Swartkops estuary has never been exposed to a major oil spill. One very brief study of hydrocarbon levels in Swartkops estuary waters has shown low but detectable levels of the water soluble fraction of oil (Hilmer and Bate 1987), this being derived presumably from one of the sources mentioned above.

Temperature elevation

Seawater extracted from the estuary is used for cooling at the Swartkops electricity generating station, situated 4 km up from the estuary mouth. Cooling water requirements vary from 100 to 11 100 m^3 per minute, depending on power demand. Water is chlorinated at the intake with sodium hypochlorite to produce a residual chlorine level at discharge not exceeding 0.5 ppm. Temperature increase in the water ranges between 5 and 10 °C, with a mean around 7 °C.

Water temperatures rapidly approach ambient after mixing in the estuary, and at distances less than 500 m from the discharge point into the estuary, a temperature elevation of an average of only 2.2 °C is observed.

There is no doubt that the chlorination of intake waters plus the thermal shock and mechanical damage that occurs, causes mass mortality of particularly planktonic organisms contained in the cooling water intake. However these factors appear to be at worst, a minor contributing factor to the low species diversity of marine phytoplankton recorded in the estuary, with natural causes being the most important (Perissonotto & Wooldridge 1987).

CONCLUSIONS

The preceding analysis would indicate that the Swartkops estuary is indeed in remarkably good health, this fact mainly related to the very large exchange of water taking place with the sea on each tidal cycle and the absence of major discharges into the estuary. The evidence of periodic contamination associated particularly with rainfall, would, under normal situations prompt regulatory authorities to take the necessary remedial action. However, these are not normal times, and there are massive changes occurring in the catchment of the Swartkops river and estuary - these changes being primarily the development of two major townships (Kwanobuhle - southwest of Uitenhage, and Motherwell - on the northwest escarpment adjacent to the estuary).

Other township developments (McNaughton and Langa) as well as the establishment of squatters adjacent to all these sites is also happening.

It is estimated that by the year 2000, there will be more than one million people living within the catchment of the Swartkops. The discharge of treated sewage, and particularly run-off from areas where waterborne sewage is neither installed nor operating properly, will provide a substantial increase in load to the river and estuary.

The estuary represents a major resource for the community. The maintenance of the quality of the estuary can only be achieved by influencing planning and land use in the catchment to control the nutrient and bacterial load to the estuary, particularly via the major stormwater canals. The estuary will not be able to assimilate any significant load of industrial material.

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A SYNTHESIS OF RECENT BOTANICAL RESEARCH IN THE SWARTKOPS ESTUARY

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INTRODUCTION

A list of the main botanical research conducted in the Swartkops estuary is given in Table 1. Much of the work has been of a purely descriptive nature (e.g. species lists) and only since the beginning of this decade has the emphasis shifted towards ecological and physiological research aimed at gaining information on the role of plants in the system. This review will concentrate on these latter studies which provide some information useful to future management strategies. The results presented here supplement, and in some cases supercede, the information given in Baird *et al.* (1986).

Table 1.
Botanical research that has been carried out in the Swartkops estuary.

Aspect	Reference
Seaweeds	Pocock 1955
Macrophytes	Macnae 1957 Jacot Guillarmod 1974 Pierce 1983 Talbot and Bate 1987
Nitrogen fixation	Talbot 1982, Talbot *et al.* (in press)
Identification of diatoms	Cholnoky 1960 Giffen 1963 Mason and Marais 1975 James 1982
Identification of nanoplankton	Glen 1980
Epibenthic algal production	Dye 1978
Phytoplankton production	Hilmer 1984
Phytoplankton - bacterioplankton interactions	Hilmer 1984
Oil pollution	Hilmer and Bate 1983, 1987 Bate and Crafford 1985 Grierson *et al.* in prep

MACROPHYTES

The macrophytic vegetation of the Swartkops estuary has been studied with the major aim of evaluating its role as carbon and nitrogen fixer. In addition, the role of plants as nursery habitats and sediment stabilizers have been briefly considered.

The three studies considered here are those on *Spartina maritima* Curtis (Fernald) (Pierce 1983), *Zostera capensis* Setchell (Talbot and Bate 1987) and nitrogen fixation (Talbot 1982, Talbot *et al.* in press).

Spartina maritima

Spartina maritima is by far the most conspicuous and abundant macrophyte in the Swartkops estuary, covering 82 of the 363 ha of intertidal marsh.

It is understandable, therefore, that this species has received the larger share of botanical attention. This is justifiable in light of reports from European and American scientists of extremely high productivity rates for local *Spartina* species, which have been shown to equal even the most productive terrestrial plant species.

The first aspect of Pierce's (1983) work speculated on the status of *S. maritima* as an exotic in the Swartkops estuary. Circumstantial evidence appears to indicate that this marsh grass was introduced to the Cape and is an aggressive invader which has out-competed indigenous plants of prime importance to local communities, the most obvious being the seagrass *Zostera capensis*. Pierce has warned that the extension of *S. maritima* into the Zosteretum would limit the scouring action of strong floods and in addition enhance silt accumulation.

The major thrust of this study was to quantify the role of *S.maritima* as a carbon producer to the estuary. A method had to be designed to account for the continuous growth, and absence of seasonal die-back, peculiar to *S. maritima*, and involved detailed measurements of shoot and leaf growth and community structures.

The most significant finding concerned the low productivity of *S. maritima*. With a production:biomass ratio of only 1.1, it compared unfavourably with the values of 4.6 for *S. alterniflora* (Hopkinson *et al.* 1978) and 6.7 for *S. patens* (Hardisky and Reimold 1977). Still, compared to the other macrophytes of the Swartkops, *S. maritima* is an important contributor of carbon. The net aerial production was calculated at 523 - 680 g dry mass.$m^{-2}.yr^{-1}$, most of it coming from the leaves. Of this, 62 per cent is rapidly broken down to detritus. How much of this then becomes available to the estuary is unknown, but it is likely to be a small fraction. This, according to the estimates of Baird *et al.* (1987), yields *c.* 115 tons $POC.yr^{-1}$, with all the other macrophytes producing a mere 1.2 tons $POC.yr^{-1}$, or 1 per cent of the *S. maritima* production. This ratio is probably unrealistically high since *S. maritima* only constitutes 50 per cent of the total aerial distribution of marsh vegetation.

Zostera capensis

Seagrasses form extensive meadows in many marine habitats. In South African estuaries their distribution is far more restricted. Yet they have been shown to form an integral component of many estuarine and coastal lagoons where they play a number of important ecological roles. This includes the production of carbon and the fixation of new nitrogen, the role of nursery habitats for a number of associated faunal species and the role of sediment stabilization.

Z. capensis appears to be unique in that it is highly susceptible to environmental pressures. Much of the attention has, therefore, centered around the dynamics of the population (Talbot and Bate 1987).

Thorough surveys of seagrass beds during the winter and summer of 1981 indicated the presence of a thriving community with up to 16 ha or 10 per cent of the estuarine mudflats covered by *Z. capensis*. A significant but small difference was observed between the winter and summer surveys of 1981 and this was ascribed to a recovery of above-ground components from flood damage. Productivity was estimated to be 2.1×10^7 $gC.yr^{-1}$.

Of the biomass, 28 per cent was contributed by epiphytes, consisting of unicellular algae as well as filamentous forms of red algae. The importance of this contribution is stressed since, unlike the host plant, epiphytes serve as a direct, available source of carbon and nutrients to the associated fauna. Further, it has been postulated that the smothering effect of dense epiphytic covering stimulates the production of new leaf tissue and subsequent abscission of old leaves.

A subsequent survey of the estuary in late 1984 indicated a complete disappearance of the entire *Z. capensis* population from the estuary. Re-colonization of the estuary was only apparent in August 1988 where a total of 0.6 ha or 4 per cent of the 1981 population size had returned. This re-colonization was restricted to the immediate mouth region.

From aerial photographs taken in 1949, 1967, 1976 and 1978 it was possible to show that despite distinct changes in the distribution of beds within the estuary and in the total estuarine biomass, the population showed no major overall changes during the period 1949 to 1978.

Amidst these scales of temporal variability, the task of ascertaining the influence of anthropogenic disturbances on the *Z. capensis* beds of the estuary appears problematic. Such disturbances cannot be gauged by merely monitoring changes in biomass and distribution, and will, instead, require a far greater understanding of its autecology.

It is unfortunate that no sampling of relevant environmental conditions had been carried out during the die-back period of 1981-1984. Flood damage, siltation, eutrophication and grazing are amongst some of the causal factors shown to be responsible for the die-back of seagrass ecosystems in other parts of the world. In the two East London estuaries, the Kwelera and the Nahoon, as well as the Sundays estuary, sedimentary perturbations linked to flood action appear to have been the responsible factors in the disappearance of *Z. Capensis* beds.

It is also unfortunate that there have been no follow-up studies on the fate of the fauna that had been associated with the *Z. capensis* beds prior to the die-back. Although we are in a position of quantifying the loss of C and N fixing potential, we have no idea of the repercussions on the associated fauna.

Macrophytes are not as stable as first indications had led us to believe. Disturbances, both natural and anthropogenic, may directly affect the biomass and productivity of the macrophytic vegetation within the estuary or may alter the competitive advantage of certain species. Our studies have clearly highlighted the dynamic nature of the marsh vegetation and the need to move away from intensive but short-term studies. It is only on those short-time scales that the estuary is in some degree of equilibrium. At monthly or yearly time scales, only non equilibrium models can adequately describe the dynamics of the vegetation. In this respect a number of key questions remain unanswered:

* Is *Z. capensis* likely to recover to previous levels of productivity and aerial distribution, or will *S. maritima* extend further into the Zosteretum habitat?

* What are the likely sedimentary implications of the *Z. capensis* die-back?

* Can anything be done, or in fact, should anything be done to redress the above situation, such as transplanting operations?

Nitrogen fixation

Biological fixation of inert dinitrogen by free-living micro-organisms has been shown to be an important source of new nitrogen to temperate salt marshes in Europe and the USA. The contribution of nitrogen fixation to the nitrogen budget of the Swartkops estuary, or any other South African estuary for that matter, had never been established.

More currently, with the finding that the Swartkops estuary is an exporter of nitrogen to Algoa Bay, this biological function has gained significance.

A study of the spatial patterns of nitrogen fixation across a number of environmental gradients in the estuary indicated, firstly that all sites, except for the water column, have high potential for nitrogen fixation (Talbot 1982). Secondly, a number of environmental factors such as carbon and moisture content of the soil, sediment type and interstitial nitrogen levels seriously affect the biological fixation of nitrogen (Talbot *et al.* in press). The influence of pollution and other man-related activities has not yet been investigated, but it is likely that changes in vegetation type and nitrogen inputs would have the greatest effects.

By far the major contributor of fixed nitrogen is the *S. maritima* community which by itself contributes more than 60 per cent of the total estuarine fixation (Table 2). Other species such as *Triglochin bulbosum* have higher rates of fixation but are not as important because of their more restricted aerial distribution. Yet, for those particular plants the process of nitrogen fixation is expected to provide them with all their nitrogen requirements as evidenced by their year-round dark green colour, even at times when other halophytes show clear indications of chlorosis. Over 90 per cent of all salt marsh nitrogen fixing activity comes from the surface sediments, highlighting the importance of cyanobacteria.

There is a strong seasonal pattern with a clear summer maximum and winter minimum. Nitrogen fixation responded directly to the decreasing light and temperature conditions during autumn. With the onset of summer, however, there was a lag of six weeks before the nitrogen fixers responded to the warmer conditions.

Using the spatio-temporal information it was possible to calculate that on an annual basis 11.4 tons N is fixed by the estuarine diazotrophs.

We conclude from this work, therefore, that the biological fixation of N, while of substantial importance to the N requirement of individual marsh populations, does not account for the exportation of N to Algoa Bay. The export status of the Swartkops estuary is difficult to explain from the work carried out thus far. N is not being replenished within the system in large enough quantities to account for even 10 per cent of the annual export value. It remains to be shown whether the exported 120 tons of particulate organic N (Baird *et al.* 1987) comes from pollution sources, fluvial, or sediment reworking within the estuary.

It is also highly likely that exchange of N across the estuary mouth is not a process in equilibrium, so that the estuary may oscillate from being an exporter to an importer of nitrogen on time scales greater than a year.

Table 2

The combined nitrogen fixation (acetylene reduction activity, ARA) and percentage contribution of each community along a marsh transect.

Community	ARA (moles ethylene.ha^{-1}.day^{-1}) A	B	C	Total	Total ARA for area in estuary covered by community	% contribution
Water column	-	-	-	0.00	0.00	0.0
Sublittoral	0.02	1.53	-	1.56	220.66	3.6
Mud bank	0.02	1.56	-	1.58	284.15	4.6
Zostera capensis	0.80	9.68	0.16	10.64	152.79	2.5
Spartina maritima	40.41	6.16	0.86	47.43	3904.91	63.2
Triglochin bulbosum	118.59	3.83	0.25	122.67	182.78	2.9
Sarcocornia perenne	22.29	1.44	0.27	24.00	1340.40	21.7
Chenolea diffusa	0.38	0.25	2.59	3.22	89.90	1.5

A = surface sediment, B = rhizosphere, C = phyllosphere

PHYTOPLANKTON PRODUCTION

Phytoplankton primary production has been studied in three different size fractions (>12 µm, 12-3 µm and 3-0.2 µm, which for the purpose of this study are referred to as the micro-, nano- and picoplankton) with the aim of determining magnitudes, distribution and controlling factors (Hilmer 1984). In order to compare the marine mouth area with an area of the estuary influenced by freshwater inflow, study sites were established at Amsterdamhoek and at Redhouse. During the course of this study in 1983 a major flood occurred and its effects on the physical and chemical aspects relating to phytoplankton productivity will be discussed further on.

Production in the Swartkops estuary is mainly due to the microplankton, which usually contribute more than 60 per cent of the total production. Compared to other South African estuaries, the Swartkops occupies an intermediate position (Table 3). Annual production was estimated at 93.3 $gC.m^{-2}$ and 2.98 x 10^{8} $gC.yr^{-1}$ (298 tons) for the total estuary. This is comparable to the Wassaw Sound estuary and the turbid Bristol Channel (Table 3). These are low values compared to the Long Island estuaries, such as the Peconic Bay and Great South Bay estuaries. For instance, in the Great South Bay estuary, the eelgrass *Zostera marina* was estimated to produce 1.55 x 10^{10} $gC.yr^{-1}$ and its epiphytes 0.34 x 10^{10} $gC.yr^{-1}$. Of the total phytomass, the phytoplankton therefore contributed 85 per cent, Zostera 14 per cent and the epiphytes 1 per cent (Lively *et al.* 1983).

Table 3.

A comparison of the phytoplankton primary production in the Swartkops estuary with estuaries elsewhere

South African estuaries	Production	
	$mgC.m^{-3}.hr^{-1}$	$mgC.m^{-3}.day^{-1}$
Swartkops	13.9 - 24.1	38.4 - 66.6
Fafa lagoon (Grindley 1981)	0.3 - 7.5	
Swartvlei (Robarts 1976)	5.0 - 13.1	
Richards Bay lagoon (Grindley 1981)		100.0 - 320.0
Langebaan lagoon (Henry *et al.* 1977)		121.5 - 885.3
Other estuaries		$mgC.m^{-2}.yr^{-1}$
Swartkops		93.2
Wassaw Sound (Turner *et al.* 1979)		90.0
Bristol Channel (Joint & Pomroy 1981)		6.8 - 164.9
Peconic Bay (Bruno *et al.* 1980)		191 - 213
Great South Bay (Lively *et al.* 1983)		450

A similar comparison can be made for the Swartkops estuary, which in addition also supports *S. maritima*. Using a carbon to dry mass ratio of 0.41 (Pierce 1983), *S. maritima* can be calculated to produce 2.02 x 10^8 $gC.yr^{-1}$. *Z. capensis*, at the time before its disappearance from the estuary, was calculated by Talbot to produce 2.1 x 10^7 $gC.yr^{-1}$.

Thus of a total phytomass production of 5.21 x 10^8 $gC.yr^{-1}$, the phytoplankton contribute 57.2 per cent, *S. maritima* 38.8 per cent and *Z. capensis* 4 per cent. *Z. capensis* is therefore not an important primary producer in comparison to the other two and its disappearance would have little impact on the carbon provided by the primary producers.

The effect of flooding on phytoplankton production

Flooding resulted in marked short-term increases in primary production (Fig. 7) as a result of increased chlorophyll levels at the two study sites. A look at the physical and chemical variables measured in association with this study will help to gain some insight into the causal factors.

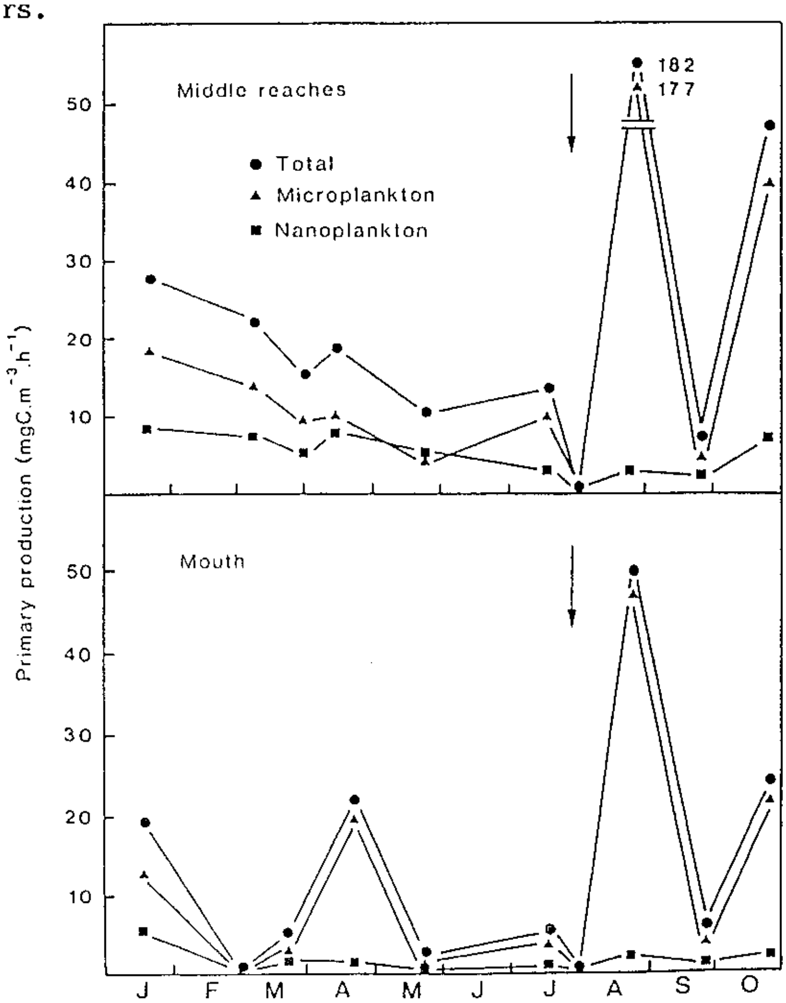

Figure 7. *Phytoplankton production in different size fractions showing the marked increase in production after flooding (arrow). The low picoplankton production has been excluded for clarity.*

The flood, quite obviously, introduced fresh water throughout the estuary (Fig. 8). Recovery to pre-flood salinity levels at the mouth was evident after two months, while in the middle reaches salinity levels remained low.

Light attenuation in the middle reaches increased greatly, while at the mouth the increase was less pronounced (Fig. 8).

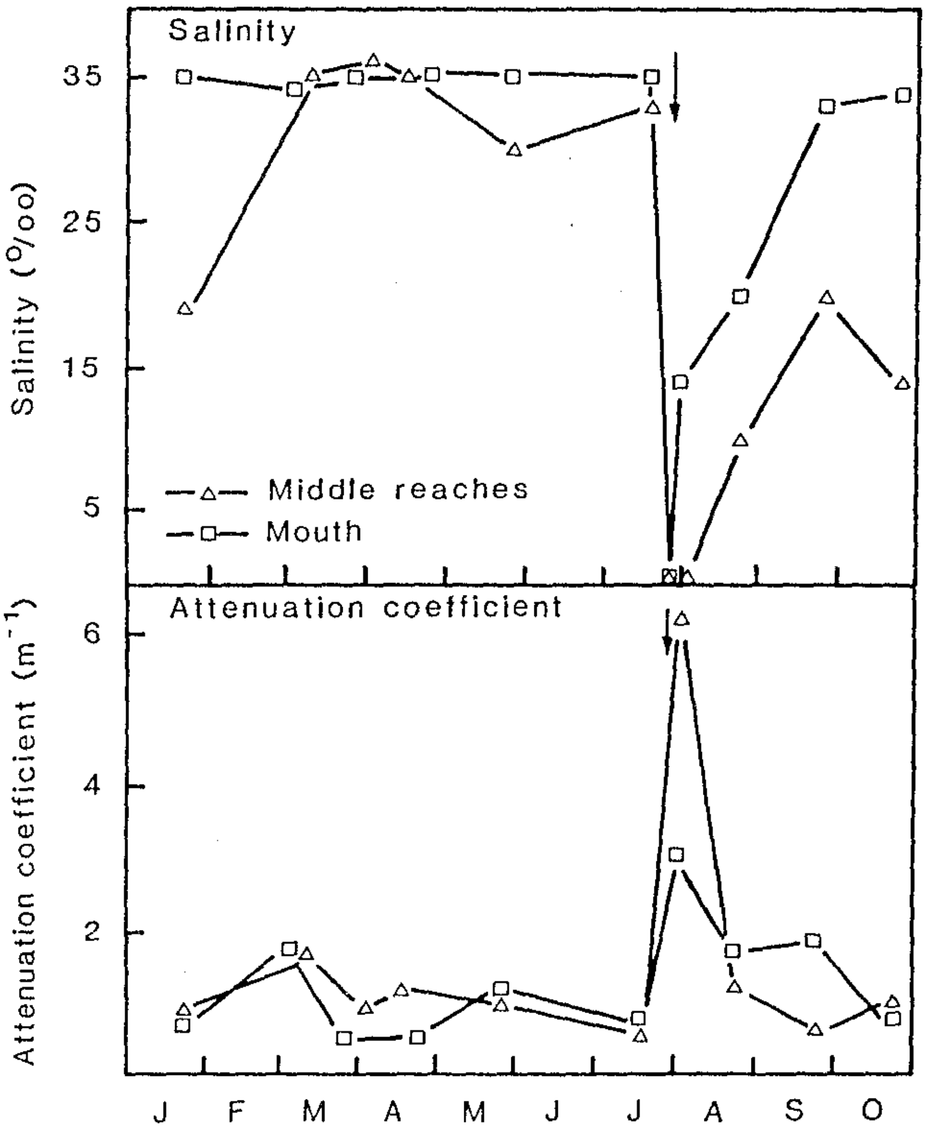

Figure 8. *The effect of flooding (arrow) on salinity and light attenuation in the estuary.*

A large amount of suspended material was introduced into the middle reaches by the flood, the majority being organic material (Fig. 9). Two months later, with the decrease in freshwater input, the particle load was back to pre-flood levels. At the mouth the total suspended matter showed three distinct peaks during the ten month period, with no peak associated directly with the flood event.

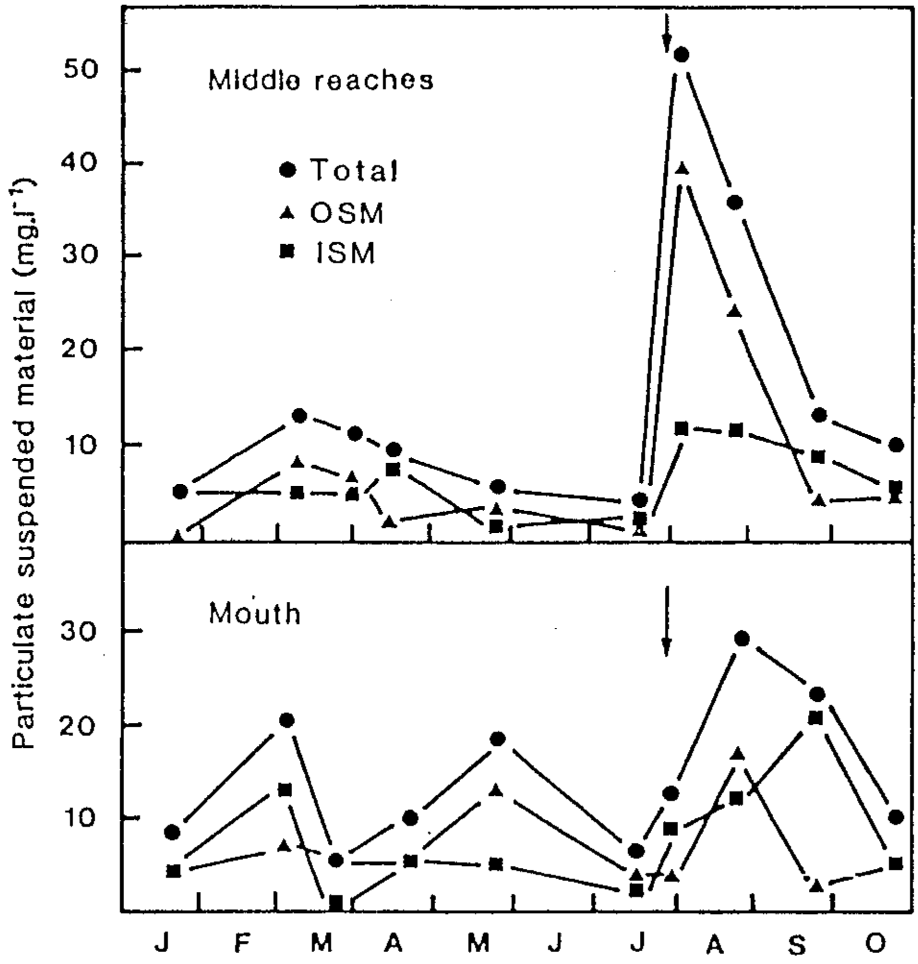

Figure 9. *Fluctuations in the total, organic (OSM) and inorganic (ISM) suspended material load before and after flooding (arrow).*

The fact that the patterns of the suspended particle load at the two stations differed quite markedly, with peak values near the mouth often much larger than corresponding values upriver, indicates that the sources are different. The saltmarsh lying between the two stations seems to be the most likely source of organic and inorganic suspended material in the mouth area, with release patterns possibly depending on the tide. The fluvial sediment load during this study was not high and did not increase greatly after flooding, thus it would contribute little to the inorganic suspended material at the mouth.

A stepwise regression revealed that in the middle reaches, organic suspended material contributed 75.8 per cent to the variation in the attenuation coefficient. At the mouth inorganic suspended material contributed 79.8 per cent, and organic suspended material 13.7 per cent, to the variation in the attenuation coefficient.

All forms of nitrogen displayed peaks immediately after the flood (Fig. 10), while phosphate levels at Redhouse showed a sharp decrease. In all cases, nutrient levels were higher at Redhouse than at the mouth.

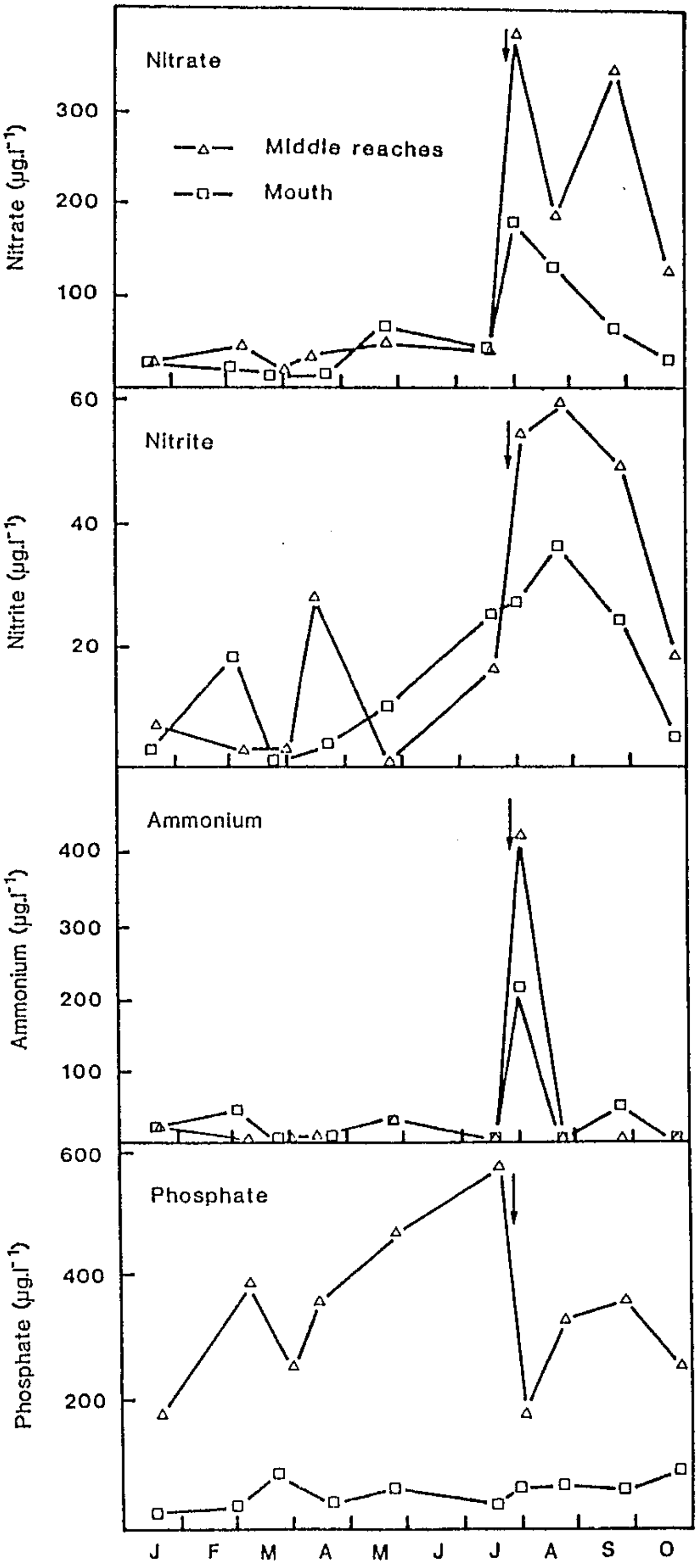

Figure 10. *Changes in nutrient concentrations caused by flooding (arrow).*

The impact of the flood may appear predictable i.e. introducing freshwater throughout the system, raising the particle load thus decreasing the submarine irradiance, and increasing the nutrient levels. However, some noteworthy aspects have come to light. The disturbance caused by the flood lasted almost two months. After this period most variables measured reflected values corresponding to pre-flood conditions. The middle and lower regions of the estuary displayed quite differing responses.

Based on these results, the following sequence of events may be reconstructed as taking place as a result of flooding: The flood introduces freshwater phytoplankton species throughout the estuary which remain active for a period after the flood while the salinity is still low and light penetration has returned to normal levels. They raise the level of organic suspended material and probably rapidly utilize the high nitrogen levels, resulting in a bloom of freshwater phytoplankton. The period of low salinity is longer upriver, and nitrogen levels are higher, therefore there is a greater increase in production here than near the mouth. As the high nitrogen concentrations are depleted and salinity increases, the bloom decays and production values decrease as estuarine species become more dominant. This may be an over simplification of the situation as other factors are certain to be involved.

Floods are not uncommon in the Swartkops and result in large short-term increases in primary production in the estuary. At present we do not know of what importance this phenomenon is to the system as a whole, but it may supply ample carbon needed by the consumers immediately after such a catastrophic event.

OIL POLLUTION

Work on oil pollution has centered around the effects of the water soluble fraction of crude and refined oils on phytoplankton productivity, as it is in this form that uptake is facilitated into the algal cells (Hilmer and Bate 1983, 1987, Bate and Crafford 1985, Grierson *et al.* in prep). Concern was levelled at the possible adverse effects of incidental pollution, such as road run-off from bridges covered with sump oil from passing vehicles, and also the exhaust emissions from outboard motors on ski boats.

Investigations on species isolated from the Swartkops involved testing the effects of various crude and refined oils, such as Qatar crude oil, petrol and diesel engine sump oil, outboard motor exhaust emissions and actual road run-off. Results on the ageing of the oils, lethal dose experiments and recovery experiments, show that the effects of the oils are highly variable and species specific. Road run-off had no effect on phytoplankton photosynthesis, while crude oil was found to be less toxic than refined oil. Of the refined oils tested, petrol engine sump oil was the most toxic, while outboard motor exhaust emissions were capable of reducing photosynthesis in certain species. Reductions in photosynthesis caused by the water soluble fraction of oils do not involve the chloroplast. Interference seems to be restricted to energy-yielding processes in the mitochondria, but this does not appear to involve membrane damage. This implies that, although monitored chlorophyll levels in an estuary may show no change, the ecology of a system may be affected by changes in species composition, the results of which on the consumer level are not known at present. However, as the concentrations of the WSF used in these experiments would seldom be encountered under natural conditions, and as pollution resulting from sump oil could occur only under exceptional circumstances, we feel that the implications of these findings are not a cause for concern in the context of present hydrocarbon levels in the estuary. Intensified industrialization and recreational use of the estuary, exceeding that at present found at the Swartkops estuary, would require in-depth studies into sources and concentrations of hydrocarbons in the field.

FUTURE WORK

Although a fair amount of work has been done in recent years, there are still many areas of the floristic community associated with the Swartkops estuary that we know very little about. These include:

* The primary production and ecophysiology of:

  (i) The terrestrial plant communities of the whole catchment area;
  (ii) The fringing plant species along the banks;
  (iii) The epiphytic algae;
  (iv) The benthic algae, (including those on exposed substrates), whose habitat extent is unknown, and which may equal, or even exceed, the importance of the phytoplankton.

* The role of bacteria in the system.

The brief studies by Dye (1978) on epibenthic production and by Hilmer (1984) on the bacterioplankton interactions have only touched upon some of these aspects. Until these fields have been studied in detail, there will be great gaps in our knowledge regarding the state of the estuary, the role of primary producers, and in any model attempting to describe the functioning of the system.

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SYNTHESIS OF ECOLOGICAL RESEARCH IN THE SWARTKOPS ESTUARY

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INTRODUCTION

The Swartkops estuary has been the subject of many studies over the past twenty years. The majority of these were on the living plants and animals occurring in the estuary, but more recently, geological, sedimentological and water quality related aspects have received attention as discussed by Reddering and Esterhuysen (1987) and Lord and Thompson (1987).

Historically, the first ecological study of the Swartkops estuary was carried out by F.W. Fitz Simons in 1916 on the fisheries resources of the Swartkops estuary. His findings were published by the government marine biologist J.D.F. Gilchrist in 1918. Other studies were those of Pocock (1955) who gave an account of the seaweeds in the estuary, and a comprehensive, qualitative review of the plants and animals occurring in the estuary by MacNae (1957a and b). In 1971 the City Engineer of Port Elizabeth commissioned an environmental study of the Swartkops river basin as a prerequisite to the preparation of a development plan for the area. A series of reports were subsequently prepared by Hill, Kaplan, Scott and Partners, a firm of consulting engineers, and included a volume on the ecology of the estuary based on information available at that time. Baird *et al.* (1986) published a report in which more recent information on virtually all aspects of the abiotic and biotic characteristics of the estuary was documented.

In addition to these studies a large number of research projects have been conducted on the ecology of the estuary. The purpose of this paper is to review the current status of knowledge on ecologically related aspects of the Swartkops estuary. To give some structure to the review the estuary is examined from an ecosystems point of view in which the various biotic constituants are identified, estimates of biomass given for each and their interactions quantitatively assessed as flows between them. The functioning of the estuary as an importer or exporter of materials is briefly discussed and, finally, gaps in knowledge are identified.

BIOMASS AND PRODUCTIVITY OF BIOTIC COMMUNITIES

Phytoplankton and macrophytes

Phytoplankton primary production is reviewed by Hilmer *et al.* (1987). Hilmer (1984) has concluded that microplankton (> 12 µm) were the dominant producers accounting for between 68 and 77 per cent of the phytoplankton primary production, while nanoplankton (3-12 µm) and picoplankton (0,2-3 µm) contributed the remaining. Annual phytoplankton production was estimated at 93.3 g m^{-2} and 2,98 x 10^{8} g C y^{-1} for the entire estuary (Hilmer *et al.* 1987). Biomass values vary seasonally but I have calculated an annual mean biomass value of approximately 3,73 g m^{-2} at an annual turnover rate (P/B ratio) of 25.

Eel grass, *Zostera capensis*, has virtually disappeared from the estuary (Talbot and Bate 1987). The standing crop (above and below ground) prior to its disappearance fluctuated seasonally with a mean annual value of about 19,2 g C m^{-2}. The production of *Z. capensis* was estimated at approximately 148 g C $m^{-2}y^{-1}$ or 20,4 x 10^{-6} g C y^{-1} for the entire estuary. *Z. capensis* has yet to re-establish itself in the Swartkops estuary and biomass and production values are at present extremely low.

The dominant halophyte on the 166 ha of saltmarsh, *Spartina maritima* (rice grass) has a standing crop value of 273 g C m^{-2} and an annual production in the order of 301 g C $m^{-2}y^{-1}$ or about 2,47 x 10^{8} g C y^{-1} for the entire estuary (Pierce 1983, Hilmer and Bate unpublished manuscript).

Pierce (1979) calculated the contribution of *S. maritima* detritus to estuarine waters to be in the order of about 3,0 g C m^{-2} at equinoctial tides. This export value is lower at spring tide and probably minimal during neap tides. Assuming that approximately 60 per cent of Pierce's estimate is exported during spring tides about 46,8 g C $m^{-2}y^{-1}$ of *Spartina* detritus is washed into the estuary.

Hilmer and Bate (unpublished manuscript) estimated the total phytomass production of the Swartkops estuary to be in the order of 5,65 x 10^{8} g C y^{-1} with phytoplankton contributing 52,7 per cent, *Spartina* 43,7 per cent and *Zostera* about 3,6 per cent. Standing stocks and production estimates of benthic and epibenthic algae have not yet been investigated.

Bacteria, microflagellates and microzooplankton

The abundance of free living bacteria in the Swartkops estuary has been estimated by Hilmer and Bate (unpublished manuscript) to be in the order of 10^{4} cells ml^{-1}. Assuming a carbon content of 10^{-14} g C per cell (Gerlach 1978) and a mean water collumn depth of 2,5 m a standing stock of 0,0003 g C m^{-2} has been calculated, which is very low compared to other estuarine systems. Hilmer and Bate (unpublished manuscript) further suggested that heterotrophic bacterial uptake amounts to only 0,7 per cent (or 0,65 g C $m^{-2}y^{-1}$) of photosynthetically produced dissolved carbon. Assuming a carbon efficiency of 50 per cent (Ducklow 1983, Joint and Williams 1985) and a rate of uptake of 0,65 g m^{-2} y^{-1}, bacterial production is estimated at about 0,33 g C $m^{-2}y^{-1}$, and the amount respired at about 0,30 g C $m^{-2}y^{-1}$ (Azam *et al.* 1983). The mean standing stock of DOC in the Swartkops estuary is about 5 g C m^{-2} and a very small fraction (about 13 %) of DOC is thus utilized by bacteria.

No information exists at present on the abundance and productivity of water collumn heterotrophic microflagellates (in the 2-20 µm in diameter) and microzooplankton (20-30 µm in diameter). It would nevertheless appear, that due to the relatively low abundance and production of free living bacteria, the biomasses and production of these groups would also be low. Consequently, the microbial loop, identified in many other aquatic ecosystems (Azam *et al.* 1983, Ducklow 1983, Baird and Ulanowicz in press), appears to be of little importance in the Swartkops estuary. This aspect of the ecology is however, poorly understood and needs further investigation.

Meiofauna production has been estimated by Dye *et al.* (1978) to be in the order of 61,0 g C $m^{-2}y^{-1}$ in the muddy and sandy areas of the estuary. This community has a mean standing crop of about 0,6 g C m^{-2} (Dye and Furstenberg 1978) and consume about 5 g C m^{-2} of sediment bacteria annually. Results from the work of Dye (1978) would indicate that meiofauna are more abundant and their production higher on the exposed sand flats of the estuary than in non-vegetated, intertidal muddy areas bordering the saltmarshes. Meiofauna, and in particular nematodes, occur in high numbers in the saltmarshes where they are mainly associated with the roots of halophytes such as *Spartina, Trichlochia* and *Chenolea*. The standing crop is about 14 g C m^{-2}, yielding an annual production of 112 g C $m^{-2}y^{-1}$ assuming an annual P/B ratio of eight. The fate of this production is unknown as no known predators of nematodes exist in the salt marsh sediments. Most of this carbon is assumed to remain in the sediment and reabsorbed within the saltmarsh system (J.P. Furstenberg unpublished data). For the purpose of this paper, meiofauna biomass and production from the different areas were combined (see Fig. 11).

Sediment bacteria in the intertidal area have a biomass of about 4 g C m^{-2} and a total annual production of 742 g C m^{-2} (Dye *et al.* 1978). Approximately 27 per cent of the bacterial production is consumed by detritivores and meiofauna. Epibenthic algal production was calculated by Dye (1978) to be in the order of 85 g C $m^{-2}y^{-1}$.

Macrofauna

The benthic invertebrate macrofauna community has received considerable attention during the past ten years and several publications emanated

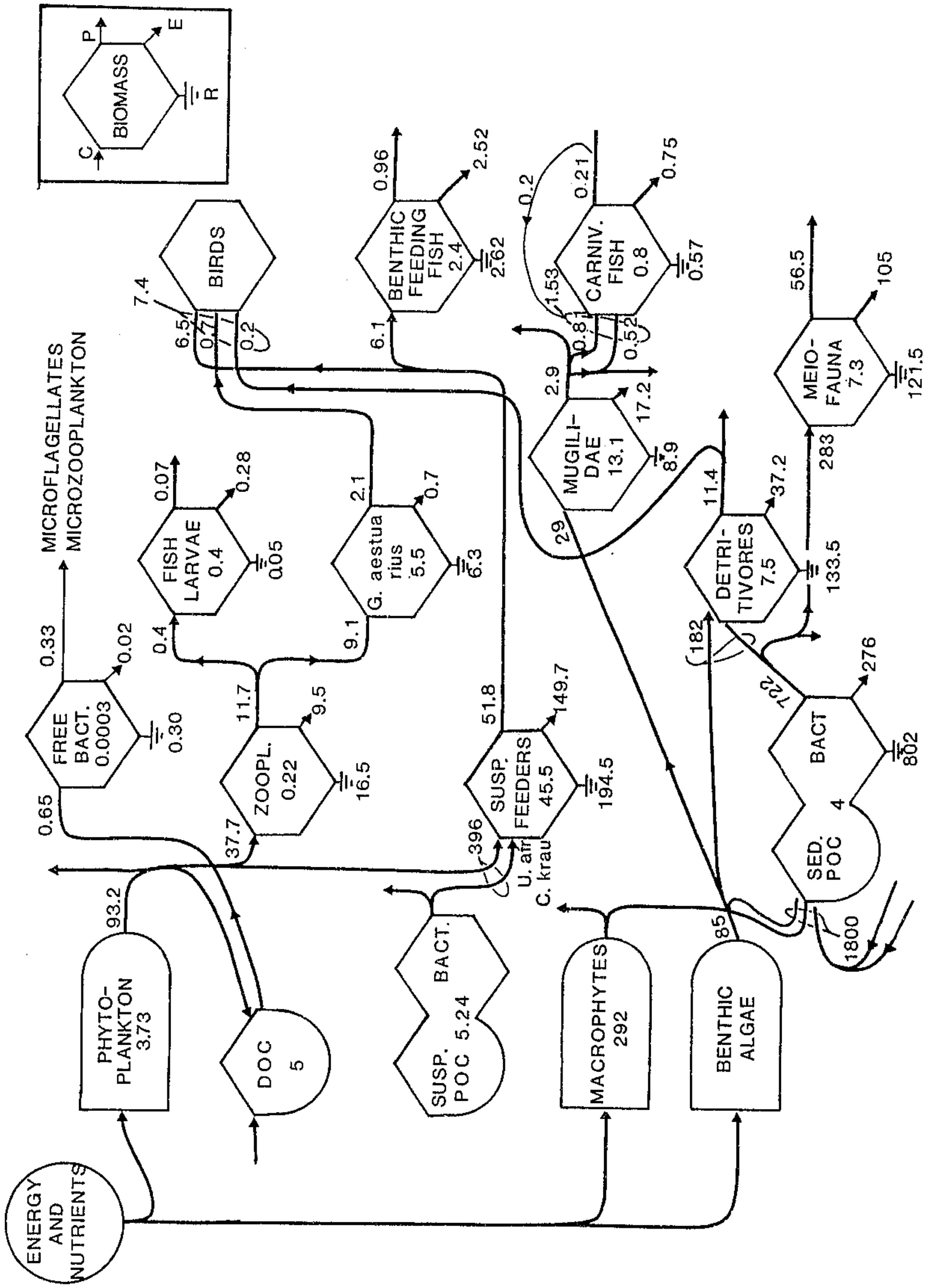

Figure 11. *An energy flow network of the Swartkops estuary. Biomass values (within each compartment) is given in g C m^{-2} and flows (between compartments) in g C m^{-2}y^{-1}.*

from these studies. Hanekom *et al.* (1988) conducted an extensive quantitative study on sub and intertidal distribution of macrobenthos colonizing the soft substrate of the estuary. Thereby species were recorded and of these only ten species occurred in relatively high densities and biomass. The mud prawn, *Upogebia africana*, appeared to be the most dominant macrobenthic species inhabiting the soft substrate in the non-marshland regions of the estuary. It constituted 82 per cent of the total standing biomass and had approximately seven times the numbers and biomass of the next most important species, namely the sand prawn, *Callianassa kraussi*.

The largest *U. africana* populations were found in the muddy intertidal areas of the lower reaches. Numbers decreased rapidly in the subtidal areas of the main channel where strong currents (up to 55 cm sec^{-1}) during spring tides had left a coarse sediment (MD = 2,4) with a low subsieve content (*c.* 2,14 %), apparently unsuitable for colonization by *U. africana*. Studies on the energetics of most of the major species populations have been done and their role in the feeding ecology of predators assessed.

The total standing biomass of the macrobenthic community was estimated by Hanekom *et al.* (1988) to be in the order of 23,52 x 10^3 kg C. Of this, 78 per cent was concentrated in the intertidal areas, the rest occurred subtidally. *U. africana* and *C. kraussi* comprised 82 per cent (or 19,29 x 10^3 kg C) and 11 per cent (or 2,59 x 10^3 kg C) respectively of the total community.

U. africana were found primarily in the muddy intertidal areas of the lower reaches while *C. kraussi* occurred in the sand flats of the intertidal areas of the mouth region and in inter and subtidally in the upper reaches. The communities of these two species overlapped slightly in the middle reaches where a fairly large bivalve community, comprising mainly of three bivalva mollusc species namely *Solen corneus, Dosinia hepatica* and *Macoma litoralis*, occurred.

The middle reaches thus appeared to be a transition zone, as none of the above groups dominated in abundance or biomass there. The substrate type and competition for space would appear to be the factors limiting the spatial distribution of the various species populations.

The biomass productivity and energetics of most of the invertebrate species have been determined and this information is given in Table 1.

The fauna of the saltmarshes in the Swartkops estuary have also been studied. This community is low in diversity but has a relatively high productivity. The dominant species consist of two crab species *Sesarma catenata* and *Cleistostoma edwardsii*, both detritivores. A hydrobiid

TABLE 1

Biomass (g C m^{-2}), production, respiration and excretion (g C $m^{-2}y^{-1}$) of the major invertebrate macrobenthic communities, meiofauna and sediment micro-organs in the Swartkops estuary

Species Community	Biomas	Consumption	Production	Respiration	Excretion
SUSPENSION FEEDERS					
Upogebia africana	23,2	182,7	23,0	92,1	67,6
Solen capensis	10,5	102,0	15,6	44,1	42,3
Solen corneus	0,8	6,6	1,0	3,5	2,1
Macoma litoralis	0,2	2,0	0,3	0,9	0,8
Aalpheus crassimanus	0,8	4,8	0,8	2,8	1,2
Dosinea hepatica	0,5	2,0	0,3	1,5	0,2
Callianassa kraussi	9,5	95,9	10,8	49,6	35,5
TOTAL	45,5	396,0	51,8	194,5	149,7
DETRITIVORES					
Cleistostoma algoense	1,3	9,0	1,5	4,2	3,3
Cleistostoma edwardsii	2,0	4,1	0,6	1,9	1,6
Sesarma catenata	4,2	169,0	9,3	127,4	32,3
TOTAL	7,5	182,1	11,4	133,5	37,2
GRAZERS					
Assiminea bifaciata	3,1	20,2	3,5	9,2	7,5
MEIOFAUNA	7,3	283,0	56,5	121,5	105,0
Sediment bacteria and other microorganisms in sediment	4,0	1 800,0	722,0	802,0	276,0

mollusc, *Assiminea bifasciata*, occurs in high densities and obtains its energy mainly from grazing on benthic diatoms. The saltmarsh community is spatially separated from the sand and mudflat communities and also utilize a different foodsource than the benthos of the sand and mud flats.

Zooplankton

The zooplankton community consists predominantly of copepods and mysids and their seasonal and temporal distribution and abundance were examined by Wooldridge (1979). An annual mean biomass of 0,22 g C m^{-2} was calculated from his data. Applying appropriate P/B and P/R ratios to these two groups an annual production of 11,7 g C m^{-2} and respiration of 16,5 g C m^{-2} were estimated and assuming an assimilation efficiency of 75 per cent, consumption was calculated at 37,7 g C $m^{-2}y^{-1}$. Their diet consists mainly of phytoplankton and suspended detritus. Zooplankton are in turn consumed by fish larvae and other small fish species; about 80 per cent of their production is consumed by these predators.

Fish community

Ichthyoplankton

A total of seventeen larval fish species have been recorded in the Swartkops estuary. Larval fish were most abundant during the summer months, although most species were present throughout the year. The ichthyofauna was dominated by larvae of the fam. Gobiidae (59 %) and the estuarine round herring, *Gilchristella aestuarius* (31 %). The diversity of larvae, calculated on a seasonal basis using the Shannon-Weaver index of diversity, were low throughout the year (see Melville-Smith 1978 and Melville-Smith and Baird 1980). Most larvae feed predominantly on zooplankton, mainly copepods, phytoplankton and free living protozoans.

The mean number of larvae fluctuated between a low value of 0,028 larvae m^{-3} to a high value during summer of 24,728 larvae m^{-3}. The mean number calculated over a period of 25 months is 1,820 ($\pm$ 4,896) larvae m^{-3} and the mean biomass was estimated to be in the order of 0,364 g C m^{-3}. The annual energy intake was calculated as 0,4 g C $m^{-2}y^{-1}$, respiration at 0,05, egesta at 0,28 and production (or growth) at 0,07 g C $m^{-3}y^{-1}$. The behaviour of fish larvae in response to water currents in estuaries has been investigated by Melville-Smith *et al.* 1981).

Juvenile and adult fish communities

The fish community of the Swartkops estuary has received a considerable amount of attention and a large number of publications have emanated from these studies (e.g. Marais 1975, Winter 1979, Marais and Baird 1980a and b, Beckley 1983, Marais 1984, Mason and Marais 1975).

These studies investigated, *inter alia*, patterns of seasonal abundance and diversity, feeding ecology, energetics and angling. The biggest remaining problem, however, is some quantitative assessments of the various populations. Only the works of Talbot (1982) and Talbot and Baird (1985) shed some light on the density and quantitative role of the estuarine round herring, *Gilchristella aestuarius* in the Swartkops estuary. Consequently, it is not possible at this stage to provide a reliable assessment as to the magnitude of energy produced in the estuary shunted to the fish community. Beckley (1983) also investigated the association of ichthyofauna with eelgrass (*Zostera capensis*) and concluded that *Zostera* beds were found to form an integral and important part of the nursery function of the estuary. *Zostera* beds have, however, disappeared completely from the estuary since her studies and a reassessment of the situation is clearly needed. Hanekom and Baird (1984) have found that only two species namely *Monodactylus falciformes* (Cape moony) and *Rhabdosargus holubi* (Cape stumpnose) occurred in higher numbers in the *Zostera* than in the non-*Zostera* regions of the Kromme estuary. They have also shown when comparing numbers, species richness and diversity no significant differences ($P<0,05$) could be detected between samples from the two regions. They have concluded, by comparing their findings with other workers, submerged macrophytes, such as *Zostera* beds, indeed provide essential shelter for smaller fish from predators, but that the importance of this shelter may be reduced with increasing turbidity.

The majority of the fish species found in the estuary are temporary residents. Some species use the estuary as a nursery area and are present during their larval and juvenile stages only. Others migrate into the estuary to feed, and leave the estuary again. Only a few species complete their life cycle from egg to adult in the estuary and these are members of the fam. Gobiidae and the estuarine round herring *Gilchristella aestuarius*. Sea-catfish (*Tachysurus feliceps*) use the mouth and middle reaches of the estuary for breeding.

The feeding relations of some of the more important species were investigated by Talbot and Baird (1985), Mason and Marais (1975) and Marais (1984). The most abundant group of fish in the estuary, the fam. Mugilidae, feeds predominantly on benthic diatoms and sediment detritus (Mason and Marais 1975). The estuarine round herring, *G. aestuarius*, the most abundant single species in the estuary, feeds mainly on zooplankton. Benthic feeding fish species such as *Pomadasys commersonni* (spotted grunter) and *T. feliceps* (sea-catfish) feed mainly on *U. africana* and *C. kraussi* (the mud and sand prawn respectively). Carnivorous fish, such as *Argyrosomus hololepidotus* (kob), *Lichia amia*, (leervis), *Elops machnata* (ten pounder), *Pomatomus saltatrix* (elf), *Platycephalus indicus* (bartail flathead) feed predominantly on *G. aestuarius* and juveniles of the Mugilidae (Marais 1984).

Estimates of biomass (in g C m^{-2}), rates of consumption, production, respiration and egestion (in g C $m^{-2}y^{-1}$) were made for the species mentioned above and summarized in Table 2. Results indicate that although the biomass of the Mugilidae is about twice that of *G. aestuarius*, the production of the round herring is only slightly less than that of the Mugilidae. They are consumed in about equal proportions by carnivorous fish. Both these groups occupy rather key positions in the food web despite the fact that they obtain their food energy from different sources; the round herring via the classical grazing food chain and the Mugilidae via sediment bacteria and benthic diatoms (see Fig. 11).

TABLE 2
Biomass (g C m^{-2}) and energetics (g C $m^{-2}y^{-1}$) of the most abundant fish species in the Swartkops estuary

	B	C	P	R	E
Gilchristella aestuarius	5,5 5,5	9,1 9,1	2,1 2,1	6,3 6,3	0,7 0,7
Mugilidae	13,1	29,0	2,9	8,9	17,2
BENTHIC FEEDERS					
Pomadasys saltatrix	1,9	4,8	0,76	2,12	1,92
T. feliceps	0,5 2,4	1,3 6,1	0,2 0,96	0,5 2,62	0,6 2,52
CARNIVORES					
A. hololepidotus	0,5	1,1	0,15	0,37	0,58
L. amia	0,2	0,43	0,06	0,20	0,17
E. machnata	0,006 0,8	- 1,53	- 0,21	- 0,57	- 0,75
FISH LARVAE	0,4	0,4	0,07	0,05	0,28

The bird community in the Swartkops estuary consists generally of 35 species of which only four are responsible for over 75 per cent of the total avian annual energy requirement of 70,6 x 10^5 g C. These species are the kelp gull, *Larus dominicanus*, the grey plover, *Pluvialis squatarola*, the whimbrel, *Numerius phaeopus* and the common tern, *Sterna hirundo*. Birds take 88 per cent of their energy requirements from the intertidal areas, 9 per cent from the subtidal areas and 3 per cent from the salt marshes. It would appear that birds depend heavily on a single prey species namely *U. africana* for most of their energy requirements. The feeding patterns of the avian predators are closely related to the behaviour of their prey and recent studies show that *U. africana* are available as prey to birds only when they come to the surface of the substrate. Birds remove collectively 5,3 g C $m^{-2}y^{-1}$ of the production of *U. africana*, 0,3 g C $m^{-2}y^{-1}$ from the saltmarshes (mainly crabs *S. catenata*, *C. edwardsii* and the hydrobiid snail, *A. bifasciata*) and 0,04 g C $m^{-2}y^{-1}$ of the round herring, *G. aestuarius* (A.P. Martin pers.com.)

Energy flow pathways and key species

The general pathways of energy flow in the Swartkops estuary are shown in Figure 11. The standing crop of each component is given in g C m^{-2} and the rates of flow between compartments are given in g C $m^{-2}y^{-1}$. Species are grouped together according to their main mode of feeding.

The food web dynamics of the Swartkops estuary are typified by two major energy flow path ways, namely by a grazing and a detritus route. Approximately 37 per cent of the total system productivity is channelled through the grazing chain and 63 per cent follows the detritus pathway.

Water collumn productivity, mainly phytoplankton and suspended detritus (and associated bacteria) is consumed by zooplankton and invertebrate suspension feeders which is in turn preyed upon by fish larvae and smaller fish species (e.g. *G. aestuarius*). *G. aestuarius* are preyed upon by birds and carnivorous fish, while benthic feeding fish and birds consume suspension feeding invertebrates. About 40 per cent of the production of *G. aestuarius* is passed on to their predators and approximately 23 per cent of the suspension feeders (mainly *U. africana*) production is consumed by birds.

It is important to note the key positions occupied by *G. aestuarius* and *U. africana* in the food web. *G. aestuaries*, one of the few resident fish species in the estuary forge a strong link between zooplankton and bird and fish predators, and about 58 per cent of its annual production is utilized by predators. The mudprawn appears to be the major prey species of the diverse avifauna and a number of fish species also feed on it. Furthermore, *U. africana* contribute approximately 45 per cent to the total benthic invertebrate production which emphasizes the importance of this species in the ecosystem. Since this species is also subjected to exploitation as bait by anglers, its preservation, and consequently the status of intertidal mudbanks, must receive serious consideration.

The detritus food web consists mainly of saltmarsh invertebrates and meiofauna. Despite the relatively high production of saltmarsh fauna, the diversity of this community is very low while only a small fraction (*c.* 2 %) of its production is utilized by predators.

Import-export function of the estuary

Considerable attention has recently been given to the exchange of material (e.g. inorganic nutrients, particulate and dissolved carbon) between estuaries and near-shore environments in attempts to establish the sink or source characteristics of estuaries (see for example Valiela *et al.* 1978, Nixon 1980, Chrzanowski *et al.* 1982, 1983, Dame *et al.* 1986). Most of these studies were undertaken in saltmarsh systems and the direction and magnitude of transport of materials suggested some variability. Odum (1980) proposed the hypothesis that estuarine systems produce more material than can be utilized within the estuarine system and that excess production is exported to the coastal sea where it may contribute to near-shore productivity. This "outwelling" hypothesis was tested in the Swartkops estuary over a period of four years by direct measurements of the fluxes of water, dissolved inorganic nutrients and suspended particular material over a cross section in the mouth of the estuary. Water volume fluxes were calculated by means of a one-dimensional hydrodynamic model (Huizinga 1984).

The results of this study are given by Baird *et al.* (1987a and b) which would indicate a net annual export of suspended particulate material in the order of 5306 (SE = 1771) metric tonnes. Inorganic nutrient (e.g. NH_4, NO_3, PO_4) and dissolved organic carbon (DOC) fluxes show greater variability but a general trend of export has been determined with the exception of phosphates for these constituents. The results from these studies are now being prepared for publication.

The role of saltmarshes in estuarine ecosystems as an exporter of organic material and inorganic nutrients have been investigated by many workers, particularly in the USA. The rates of exchange of these materials have yet to be quantified in the Swartkops estuary but a CSIR funded project to examine the role of marshes is now in progress. Its contribution to the total system activity appears at present to be mainly the export of organic material in the form of invertebrate feaces and *Spartina* detritus. Excreta amounts to about 37 g C $m^{-2}y^{-1}$ while results from Pierce (1979) show an annual export of *Spartina* detritus to estuarine water to be in the order of 46,8 g C $m^{-2}y^{-1}$.

As a food source for animal predators and in terms of organic detritus, salt marshes may not play such an important role in the dynamics of the Swartkops estuary.

In many aquatic ecosystems, including estuaries, attempts have been made to assess the magnitude of energy shunted into the microbial loop. That is, the productivity of free living bacteria, micro flagellates (2-20 µm) microzooplankton (20-200 µm). Very little information on this aspect exists at present for the Swartkops estuary.

Another major gap in our knowledge is a quantitative assessment of fish species in the estuary. Until such time the relative importance of especially the larger carnivorous fish and their impact on prey species will remain difficult to understand.

Future research should entail, in addition to the two aspects mentioned above:

(i) a refinement of the seasonal dynamics of the system;

(ii) the magniture and quality of river and airborne substances (such as particulate and dissolved material) brought into the estuary by riverflow, wind, stormwater canals, etc;

(iii) a refinement of the energy flow network into more compartments, i.e. the subdivision of for example suspension feeders, the fish community. Once this has been done the network can then be analysed for the magnitude of recycling, overall systems throughput analysis, total systems activity, and an assessment of the "stress level" of the estuary.

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LAND USE PLANNING IN THE GREATER ALGOA BAY METROPOLITAN AREA WITH SPECIAL REFERENCE TO THE SWARTKOPS ESTUARY

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The future of the Swartkops Estuary is very much in the hands of the local authorities which administer the Port Elizabeth/Uitenhage metropolitan area and the surrounding rural area which falls within the Swartkops River catchment area. These local authorities are responsible for land use planning in their areas. They are advised by their town planning and engineering personnel on matters relating to the planning and development of their areas including the conservation of the natural environment.

This paper is written from the point of view of the town planner and the engineer. Its purpose is to explain the role of the local authorities in the urbanization process, the problems that the local authorities face with regard to the conservation of the Swartkops Estuary and the manner in which these problems are being tackled. I intend to conclude with some thoughts on issues that I believe this symposium will need to address in order that an effective management system may be developed for the Swartkops River catchment area - one that will ensure the protection of the Swartkops Estuary for posterity.

The Municipalities of Port Elizabeth, Despatch and Uitenhage, as well as the Black City Councils of Ibhayi and Kwanobuhle and those parts of the Algoa Regional Services Council which were formerly administered by the Winterhoek and Dias Divisional Councils, are all local authority areas located within the Swartkops River catchment area. Town planning is the responsibility of these individual local authorities.

The five urban local authorities and the Algoa Bay Regional Services Council, either on an individual basis or jointly through the body responsible for the coordination of land use planning at Metropolitan level, i.e. the Greater Algoa Bay Planning Authority, have the responsibility for controlling and directing the process of urbanization in the Greater Algoa Bay Metropolitan area. They are required to formulate plans, policies and strategies for the future development of their areas and they achieve their planning objectives through the day to day control of development

The local authorities are responsible for urban planning at all levels. They are guided only by the broad provisions of the Greater Algoa Bay Guide Plan which is prepared (with planning input from the local authorities) and approved by Government under the provisions of the Physical Planning Act No. 88 of 1967.

As planning authorities responsible for urban planning, the local authorities have a legal (as well as a moral) responsibility for the protection and conservation of both the natural and man-made environments. The importance of environmental protection in the planning process is underscored by the fact that the Land Use Planning Ordinance No. 15 of 1985 specifically provides that in the preparation, amendment, withdrawal or review of structure plans, regard shall be had to the preservation of the natural and developed environment and steps taken in this connection shall be specified. That is to say, every structure plan prepared by a local authority is required by law to contain an explanation of the measures that are required to be implemented for the purpose of protecting the environment.

The protection of environmentally sensitive areas, the conservation of unique ecosystems and the general lessening of the impact of development on the environment are therefore amongst the more important goals of land use planning.

In the case of the Greater Algoa Bay Metropolitan area it has long been recognized that the most important environmental issue that needs to be addressed in the planning of the metropolitan area is the need to conserve the Swartkops Estuary. The significance of the Swartkops Estuary as an ecological entity and its importance in the overall coastal ecosystem is fully appreciated by the planning authorities. Its protection and conservation for posterity is one of the primary objectives of planning at metropolitan level.

Of concern to town planners is the effect of urbanization in the catchment area on the estuarine ecosystem. Planners are concerned that the adverse effects of development may not be immediately apparent but could pose a long-term threat to the estuary. The planners need to know what effect planning decisions today will have on the estuary in the future. Town planners and, indeed, anyone concerned with the conservation of the natural environment appreciate that as much as this conservation is for the benefit of the present generation, it is more important that we see it as our obligation to the generation that has yet to be born.

These are the issues facing the town planners in the formulation of land use proposals for the Greater Algoa Bay Metropolitan Structure Plan which is at present in the course of preparation. The Metropolitan Structure Plan will, when it is complete, be submitted to the Guide Plan Committee in terms of section 6A of the Physical Planning Act for acceptance and approval as a Guide plan. The purpose of this plan will be to lay down guidelines for the future development of the metropolitan area and one of its most important elements will be a land use strategy as policy aimed at conserving the Swartkops Estuary.

The vulnerability of the Swartkops Estuary to the damaging effects of urbanization in the catchment area becomes evident when the following facts are considered:

1. The Swartkops River catchment, measuring ± 1 370 km², contains almost the entire municipal areas of Uitenhage and Despatch, as well as the Black local authority areas of Ibhayi and Kwanobuhle, and at least one half of the Port Elizabeth municipal area. Roughly 30 per cent of the catchment area has potential for urban development. The Greater Algoa Bay Guide Plan prepared in 1979 by the then Department of Environmental Planning and Energy predicts that by the year 2000 some 1 224 000 persons will be living in the metropolitan area (the Greater Algoa Bay Planning Authority's population projection is ± 1 300 000 by the year 2010). It is estimated that of this population, some 80 per cent, or roughly one million persons, will be living and working in the Swartkops River Catchment area - an area that eventually drains into Algoa Bay through the Swartkops Estuary.

Not only is the Swartkops River catchment area likely to contain the greatest part of the metropolitan population, but it is also the area where there will be greatest diversity of urban uses and where urban growth will be the most rapid. It is within this area where high density housing for low-income groups will continue to be developed and where industrial expansion will continue to take place.

This massive and fairly rapid urbanization of the lower catchment area is bound to have a significant effect on stormwater run-off and flood levels in the Swartkops River. It is this urbanization on an immense scale, coupled with the fact that the upper half of the catchment area includes the Groot Winterhoek range, a region known for the severity of its storms and floods, that causes concern for the safety of both lives and property in flood prone areas and the future of the Swartkops Estuary as a healthy, viable ecosystem.

Moreover, much of the future development, particularly in the form of high density residential development, will take place on the northern side of the Swartkops valley. This will necessitate further road and rail crossings of the flood plains below the tidal reach. Plans are already well advanced for the construction of a major arterial, the Bramlin- Markman arterial, to link Motherwell with Port Elizabeth. As the urban population increases on the northern side of the Swartkops River Valley it can be anticipated that further communication linkages across the valley will be required.

While each proposal for the road or rail crossing of the inner valley will by law require an environmental impact assessment, it is the long-term cumulative effect of these crossings that cause the planners concern, rather than the immediate impact of the individual crossings.

2. The multiplicity of authorities responsible for land use planning and development control in the Swartkops River catchment area, which includes the Department of Mineral and Energy Affairs as the authority responsible for the control of mineral exploitation in the area, militates against the formulation and implementation of an overall management strategy for the catchment area aimed at flood control and the conservation of the estuary.

The Greater Algoa Bay Planning Authority, although having responsibility for the coordination of planning in the metropolitan area, is unable to take on the responsibility for the implementation of environmental conservation measures in the river catchment area because:

(i) it has no legal responsibility for development control and is not empowered to interfere with the development control decisions of the individual local authorities, and

(ii) it is obliged to ensure an equitable distribution of resources and development opportunities amongst the local authorities and cannot therefore formulate urban policies which, however necessary they may be from the point of view of protecting the environment, are detrimental to the economic growth and prosperity of individual local authorities.

3. The Swartkops River bed, almost in its entirety from the tidal reach to the foothills of the Groot Winterhoek range, together with the beds of its major tributaries, the Elands and Chatty Rivers, a total river length of some 30 km, is the source of high quality building sand, stone and gravel. For the most part these rivers flow through private properties, the owners of which are only too well aware of the commercial value of this resource and have little hesitation in exploiting it. While quarrying and sandwinning is controlled by the Department of Mineral and Energy Affairs in terms of the Physical Planning Act, this control is mainly from the point of view of the proper utilization of the country's mineral resources rather than environmental conservation. It can be expected that with the ever increasing demand for building material the exploitation of the sand and stone resources of the Swartkops River Valley will intensify, with the result that the flow capacity and the flooding characteristics of the Swartkops River will, in time, be considerably altered, with possible serious consequences for the environment in the lower reaches.

The Department of Mineral and Energy Affairs does not appear to have an overall plan with environmental objectives against which individual applications for quarrying/sandwinning permits can be assessed. Permits appear to be considered on an individual basis without any regard to the long-term consequences of this activity in the river bed areas.

4. A difficulty often experienced by local authorities in their consideration of planning issues is how to assess the impact of development on unique or highly sensitive natural environments when they do not have a thorough knowledge or understanding of the natural ecosystems. While the local authorities are well aware of the fact that an estuary with its complex ecosystem can be adversely affected by development, they lack research facilities in respect of environmental matters. This means that they do not have a sufficient understanding or knowledge of estuarine ecosystems to enable them to arrive at planning decisions that will ensure that these ecosystems are safeguarded against the effects of urbanization.

While this expertise is available at Universities and various research institutions, it is not readily available to local authorities for the purpose of the day to day determination of planning issues.

An approach that is favoured by local authorities, but which has its drawbacks, is to require the developer to undertake environmental impact assessments at his cost. The problems arising from this approach are, firstly, that such studies are expensive if they are properly undertaken and that they place a financial burden on the developer who could perhaps argue that such a financial burden is unfair and that investigations into the impact of development on the environment is the responsibility of the local authority. Secondly, the Environmental Impact Assessment Reports submitted to the local authorities cannot be properly evaluated without a thorough knowledge or understanding of environmental matters and are, as a result, more often than not accepted on their face value. It is also questionable whether this approach is favoured by the environmental consultants who are obviously placed in a difficult position of having to prepare totally impartial, unbiased environmental impact assessment reports for clients who may refuse to accept negative findings.

As a first step towards the development of an overall river basin management system for the Swartkops River Valley, the Greater Algoa Bay Planning Authority requested the Port Elizabeth City Engineer's Department to undertake the development of a computer river basin planning model that could be used by individual local authorities to determine the effects of large scale urbanization on flood levels in the river valley. This model is at present being developed in consultation with the CSIR's Division of Earth, Marine & Atmospheric Science and Technology, Stellenbosch and Rhodes University's Hydrological Research Unit.

In order to achieve a comprehensive and effective river basin management system for the Swartkops River it will also be necessary for the local authorities and the relevant State Departments to consider and reach agreement on the following matters:

1. The testing of development proposals on the computer model that is being developed for the Greater Algoa Bay Planning Authority will need to be a mandatory procedure in the assessment of development applications by the individual local authorities. Consideration will need to be given to the inclusion of such a procedure in the revised Guide Plan for the Greater Algoa Bay Metropolitan area.

2. The computer model being developed by the Port Elizabeth City Engineer's Department is a hydrodynamic model designed solely for the purpose of determining the effects of surface run-off in the catchment area on flood levels in the Swartkops River. In order to assess the impact of development on the estuarine ecosystem it will also be necessary to give consideration to the development of a water quality/sediment transportation model. The feasibility and effectiveness of such a model will need to be investigated. The question also arises as to which is the most appropriate authority to undertake the investigation and/or development of this model.

3. The hydrodynamic model that is being developed, and any water quality model that may still be possible to develop, are, in themselves, only aids to the decision making process. They do not necessarily provide the town planners and the engineers with the answers to many of the problems. There will still be a need to understand the significance of the computer model findings to environmental issues. A thorough understanding and knowledge of environmental issues will still be necessary if planning decisions are to be made which will guarantee the protection of the Swartkops Estuary.

The environmental expertise that is necessary for this purpose will need to be wide ranging and all embracing. It is expertise that is unfortunately not readily available amongst the town planners and engineers in the employ of the local authorities. It is expertise that needs to be backed by intensive and extensive research.

For this reason, it is considered advisable that consideration be given to the establishment of a local advisory committee comprising environmental experts to advise the local authorities on environmental matters requiring a high level of expertise. Such an advisory committee could also assist the local authorities and the Greater Algoa Bay Planning Authority in the formulation of broad land-use planning strategies that will ensure the survival of the estuary for the enjoyment of posterity.

4. The removal of sand and gravel from the beds of the Swartkops and Elands Rivers poses a particularly serious threat for the future of the Swartkops estuary. Permits are issued in terms of the Physical Planning Act on an *ad hoc* basis without any real regard for the long-term consequences of this activity. There does not appear to be an overall plan or environmental objectives against which individual applications can be assessed. Ideally, a master plan for the river bed should be produced which provides for the commercial exploitation of the sand and stone resources of the river beds whilst ensuring that flood levels can be controlled and sensitive environmental areas are properly protected.

The acceptance of the above issues by the authorities concerned will, in my view, provide a sound basis for an effective management system that is so urgently needed to protect what is undoubtedly the most vulnerable of the region's major natural amenities.

URBAN DEVELOPMENT AND SOCIO-ECONOMIC IMPLICATIONS FOR THE SWARTKOPS VALLEY

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Human settlement and whatever form of economic activity mankind undertakes must make use of the non-reproducible factor namely land, often more broadly called natural resources. The case of the Swartkops is no exception to this rule. In the most simple terms, it must be recognized that people have to cross the river, that both people and factories have to dispose of effluent, and that people live and work in what nature has meant to be the catchment area of the Swartkops river. The socio-economic planning of the area must, in other words, go hand-in-hand with an environmental awareness.

This paper will thus make reference to the point of tangency between the material which economists usually handle and the kind of issues which economists perceive ecologists to be handling. This will be followed by an overview of the type of economic development which is at present envisaged for the Port Elizabeth-Uitenhage-Despatch area. The development within this region can, however, not be totally divorced from economic development in the hinterland. The latter's influence upon the former warrants at least a brief remark.

This paper will accept the town planning perspectives which Horentz (1988) has presented. Areas which he has set aside for industrial or for residential development will simply be taken for granted. His estimates, as far as population growth is concerned, are also accepted.

ECONOMICS AND ECOLOGY - A POINT OF TANGENCY

The word Economics and all its derivatives originate from the Greek word oikonomea which originally meant "the management of a household". Its companion, the verb oikonomeo means "to manage" but has accepted a further meaning, namely to advise on matters of the state.

In very broad terms economists usually apply the term management in the sense of applying scarce resources, with alternative applications, to the satisfaction of a multitude of human wants.

Economists and ecologists are likely to meet each other at the point of having to find the scope of the term "a multitude of human wants".

The latter is often very narrowly interpreted, namely to mean that human wants are only those elements of human life which could be satisfied with man-made goods and services. This narrow interpretation produces its own meaning of management namely to ensure the most efficient use of labour, capital, natural resources and entrepreneurship towards the production of an output of product x which satisfies human want y. A broader view accepts that human wants are not only satisfied by the already mentioned man-made goods and services but also by, amongst others, all aspects of the environment in which man lives. This environment is of further significance because of its influence on man's working and living conditions. What comes to mind here is the detrimental effect of pollution in all its varieties.

From an economic point of view the environment has a further very important function. It is namely the base upon which a very important industry is built; the recreation industry.

Four groups of production factors have been identified; namely labour, capital, entrepreneurship and natural resources. The economic sciences fully accept that the management of natural resources goes further than the application of these resources towards man-made goods and services. It also embraces the influence of economic activity on the maintenance, or even the necessity of not disturbing the natural resources which typically form the environment in which man works and relaxes.

This awareness of the two sides of the natural resources coin comes to the fore in the economic literature on the control of pollution and also in the theory and practice of cost-benefit analyses. In the latter case particular attention is paid to both indirect benefits and indirect costs.

The above exposition indicates the point of tangency between economists and ecologists. What has not been high- lighted is the possible degree of friction which occurs at this point, a proper lubricant has also not been considered. A more pragmatic approach, applied to the Swartkops estuary, touches on this question of friction and lubrication.

An outline of the present thinking on the future economic development of the Port Elizabeth-Uitenhage-Despatch region is given below.

FUTURE ECONOMIC DEVELOPMENT

When we consider this matter it is most important to bear two points in mind which reflect the official or policy attitude to a matter of this kind.

The first point to consider is that economic development is set to take place within the free market or free enterprise philosophy. The influence of this attitude will be discussed below.

The second point to remember is that the central government has broadened its thinking and its policy on regional economic development since 1982. The policy up to that stage has been one of industrial decentralization. This was a policy according to which manufacturing industry was encouraged to establish at identified points away from the main metropolitan areas namely the PWV area and the Durban-Pinetown area. The emphasis now falls on regional economic development, in other words, although the decentralization of manufacturing activities still forms an integral part of the policy, official views now accept that primary industries as well as tertiary industries can all make a contribution towards uplifting the economic well-being of any region.

The area under discussion (the Swartkops river catchment and estuary) falls within the National Physical Development Plan's Region D. This region has recently been analyzed rather extensively in a research project sponsored by the Development Bank of Southern Africa (Black *et al.* 1987). The purpose of this research was to recommend an industrial strategy for Region D. This report was used to present some examples of the type of industries and other economic activities which are likely to develop in the Swartkops area.

The report strongly supports government measures aiming to keep the present motor manufacturers in the area. The report further suggests that new industries should be encouraged in line with the principle of comparative advantages. The analyses undertaken by the research team show that the following industries have a good potential for settling or expanding their present activities in the Port Elizabeth-Uitenhage-Despatch area:

- Component manufacturers for the motor industry.
- Manufacturers of electrical machinery.
- Manufacturers of micro-electronic equipment.
- Food processors.
- Textile manufacturers, more particularly woollen textiles.
- Beneficiation of hides and skins.

In addition the report suggested a thorough investigation of the feasibility of a science park.

If one inspects this list of potential industries the high-risk industries from a pollution point of view, would be the food processors, the textile manufacturers and the processors of hides and skins.

The potential industries mentioned above no doubt belong to the formal sector and also to what one could call big concerns. We must, however, not forget that it is accepted worldwide that the formal sector cannot be relied upon as the only provider of employment for the expected demand. Clem Sunter (1987) emphasized that the modern formal manufacturing sector is becoming more and more knowledge-intensive and less and less labour-intensive. This means that the informal sector and small business will play an increasingly important role as a source of employment. Small business still falls under the control of local authorities; the informal sector is called informal sector because it operates outside the controls of the authorities. It becomes formal as soon as it is caught in the net of any kind of government regulations.

A further point to consider with regard to the development of the manufacturing industry is the potential influence of the development at Mossel Bay. At present it would appear as if Port Elizabeth would be the site for the construction of, and not to manufacture, the jacket and some of the offshore modules. This means that a site such as the harbour and existing sites in industrial areas will be used mainly for the assembly of these structures. Port Elizabeth is, however, also a strong candidate for future servicing of the Mossel Bay operations. This means that, chemical firms rendering anti-corrosion services could secure contracts for the on- and offshore plants at Mossel Bay.

At present some exploration for oil at Colchester is considered. It would appear that official thinking favours shipment of any possible oil finds to existing refineries at Durban and Cape Town. This rules out the possibility of an oil refinery in the near future.

Next a statement on the general economic philosophy which underlies the encouragement of the manufacturing industry in this area, and for that matter, in any other part of the country.

In the first place, analyses, such as those referred to above, can only identify broad categories of manufacturing - these analyses are NOT feasibility studies, either for an industrial sector or for a particular enterprise.

Secondly, once such broad categories have been identified, those involved in recruiting industries for the region can use this information in their marketing campaigns.

In the final analysis, however, it remains a private sector decision whether to settle in the area for the purposes of any of the industries mentioned or for the sake of any other kind of industry.

One must also bear in mind the worldwide campaign in favour of deregulation. Deregulation by its very nature looks very critically at all regulations stifling the operations of private enterprise. The kind of regulation which ecologists favour certainly does not escape scrutiny by the deregulators.

The report of the Development Bank, as has already been said, deals with an industrial strategy for the region - industrial in the sense of manufacturing industry. It is, however, true that the Eastern Cape has a lot to offer and to develop in respect of the tourist industry. In this regard the Swartkops estuary is a particular asset.

To summarize, an estuary such as the Swartkops falls within the economist's concept of a natural resource. As such it becomes a production factor, be it for the extractive industries (if it contains minerals or fish or if it is an agricultural area), be it for the manufacturing industry or be it for the recreation industry.

In the case of future industrial development it should be noted that

(i) although certain potential developments have been identified, formal steps will not be taken to recruit only those mentioned - free enterprise will be allowed to go its own way;

(ii) the small business and informal sectors are both going to become increasingly important;

(iii) the general drive in favour of deregulation will undoubtedly also bring regulations favoured by ecologists in focus.

In conclusion, it is imperative that the estuary be managed in such a way that the pressures of industrialization and residential development would not hamper its potential as a tourist attraction. At the same time its use as a tourist attraction will have to be carefully managed in order not to destroy it along that way.

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A MATHEMATICAL MODEL OF THE SWARTKOPS RIVER AND ESTUARY TO STUDY RIVER FLOODS

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INTRODUCTION

A major component of a study being undertaken on flooding in the Swartkops river and estuary is the development of a mathematical model of the Swartkops in which river floods can be simulated. The model is to be used as an aid in the management of the river and estuary, particularly for:

(i) estimating 1 : 100 year flood levels

(ii) investigating the impact of (urban and industrial) developments on maximum waterlevels under flood conditions.

The study is being undertaken for the Greater Algoa Bay Planning Authority by the Port Elizabeth Municipality which is coordinating the study and is also responsible for field data collection, the Hydrological Research Unit of Rhodes University, which is undertaking the hydrological study and the National Research Institute for Oceanology of the CSIR, which is responsible for the development and application of the hydrodynamic model. The study is not yet completed but some very interesting results have been obtained.

This paper mainly describes the technical aspects of the hydrodynamic model as well as some of the results obtained. It is expected that in future the model could form the basis of many other studies which require hydrodynamic information such as the examination of water quality and other environmental studies.

COMPUTATION METHODS

The model techniques are based on explicit finite difference methods to solve the long-wave equations for one-dimensional flow.

Momentum equation:

$$\frac{\partial h}{\partial x} = \frac{1}{gA}\frac{\partial Q}{\partial t} - \frac{1}{C^2A^2R^2}|Q|Q + \frac{2b\,Q}{gA^2}\frac{\partial h}{\partial t} - I_b + \frac{Q^2}{gA^3}\frac{\partial A}{\partial x} \qquad (1)$$

Continuity equation:

$$\frac{\partial Q}{\partial x} = -b \frac{\partial h}{\partial t} \qquad (2)$$

A description of the procedures used in developing and running the model is available (Huizinga 1987) and more extensive information can be found in the literature (Dronkers 1964). Some relevant aspects will be explained here very briefly.

The model extends from the confluence of the Elands and Kwa-Zunga rivers (just upstream of Uitenhage) to the sea, while that component of the model which covers only the estuary is shown in Figure 12. Waterlevels are computed at the positions indicated on the figure, while flow rates are computed in the sections connecting these positions.

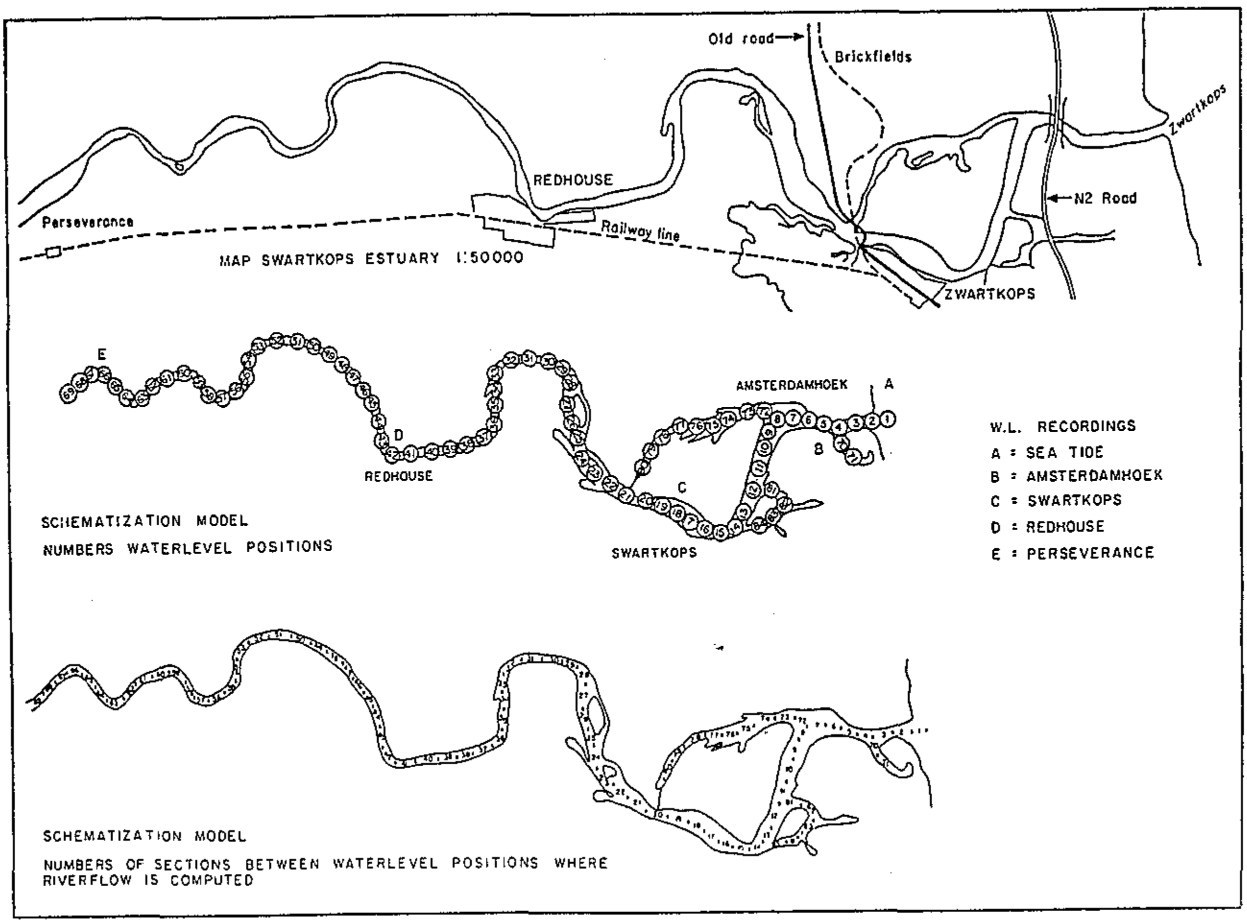

Figure 12. *1-Dimensional hydrodynamic model. Map of Swartkops estuary with model schematization.*

Topographic data are incorporated in two ways:

1. Surface areas are determined from these data for each position at which waterlevels are computed and for a range of waterlevels. On flood plains these areas are small at low waterlevels and can increase considerably at high waterlevels. During the model simulations linear interpolations are made to determine accurately the surface area corresponding to a certain water level (see also Huizinga 1987).

2. Cross-sectional areas and hydraulic radii are determined and prepared as input data for the model for each section connecting two waterlevel positions and for the same range of waterlevels (Gaillard and Huizinga 1986).

After the topographic data have been incorporated in the model the major unknown is the effect of bottom shear stress on the flow rates. For each section these are determined with the formula:

$$C = 18 \text{ Log } 6R/a \qquad (3)$$

In this formula the Chezy coefficient (C) is a function of the hydraulic radius (R) and the obstruction height, 'a'. On the basis of knowledge of the riverbed a first estimation of 'a' can be made. When comprehensive field data (waterlevels and flow rates) become available 'a' can be adapted in the calibration process until the model results agree satisfactorily with these data.

TECHNICAL ASPECTS OF THE MODEL

The model consists of 171 sections where flow rates are computed, connecting 169 positions at which waterlevels are determined. The section lengths are 250 m each, which means that detailed current patterns and waterlevel differences cannot be computed with greater resolution than this. For stability reasons the model is operated at a timestep of 10 seconds, but the computation can continue for any number of timesteps (hours, days). Branching of the river (Fig. 12) and also lateral inflow (Brak, Chatty) can be accommodated.

As mentioned before, the model covers the river from the confluence of the Elands and Kwa-Zunga rivers upstream of Uitenhage, to the sea. Special attention was paid to the stretch upstream of the estuary where the bed-level rises about 50 m over a distance of about 20 km.

The open boundary conditions to be provided for the model simulations are the river inflows (hydrographs for riverfloods) upstream for the Swartkops, Brak and Chatty rivers and the tidal variation downstream at the sea.

MODEL CALIBRATION AND TEST RESULTS

Such a model is calibrated by comparing model results with prototype data. Unfortunately comprehensive measurements were not taken during past flood events. Only some marks were made (mainly by people living along the river and estuary) of maximum waterlevels reached during past floods. Apart from these maximum waterlevels it is also very important to obtain, for several locations, information on how quickly these levels were reached, how long they were maintained and how quickly they dropped back to normal. Raingauges and waterlevel recorders have been installed to monitor future flood events, but it might take several years before the next big flood occurs. Therefore, the available data were used for a preliminary model calibration, to be refined when better data become available in the future.

The Hydrological Research Unit compiled a hydrograph for the flood which occurred from 24 to 27 July 1983, based on (very little) rainfall information. During the calibration it was found that if the flowrates of the estimated hydrograph were slightly reduced (by 13 %) the waterlevels in the estuary as predicted by the model came to within a few centimeters of the maximum levels observed. The results are shown in Table 1 and in Figure 13.

TABLE 1.
Model results compared with observed maximum waterlevels for the July 1983 flood

Position	Waterlevels (m) above MSL		Flow Rates (m^3/s)	
	Observed	Model	Observed	Model
Amsterdamhoek	1.82	1.75		
Swartkops	2.04	2.07		
Upstream of bridges	2.67	2.69		
Redhouse (I)	3.44	3.44		
Redhouse (II)	3.80	3.80		
Uitenhage (F Claassen bridge)			1 600	1 530
Uitenhage (Niven's bridge)	40.60	39.85 (downstream) 41.03 (upstream)		

The observed flowrate of 1 600 m^3/s at Niven's bridge was estimated by the Department of Water Affairs from the maximum levels of debris near the bridge. For all the positions very good agreement between the model results and observed levels were achieved. Technically this can be achieved fairly easily by adapting the bottom roughnesses (as explained before), but this calibration is the optimum possible until such time as better data become available.

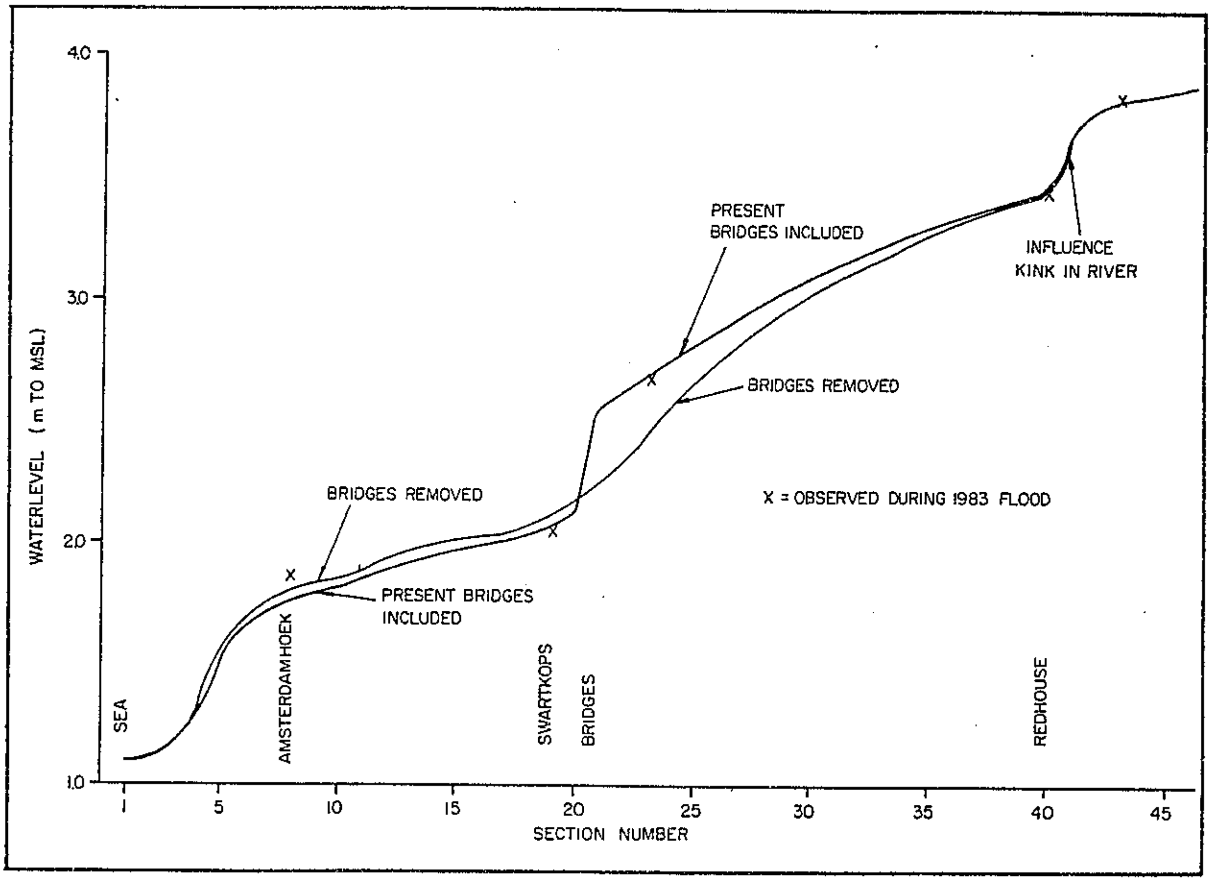

Figure 13. *1-Dimensional hydrodynamic model. Maximum waterlevels during July 1983 flood. Model calibration and investigation of influence of bridges at Swartkops estuary.*

Some interesting features are also visible in the results. A special test was done with this hydrograph (for the July 1983 flood) in which the bridges at Swartkops village were removed. The model results show an increase of up to 0.05 m in waterlevels downstream of the bridges, which is fairly small, and a considerable increase (0.32 m) just upstream of the bridges. This can be explained by the fact that for this particular hydrograph (July 1983 flood) high flow rates (and water-levels) lasted for several hours. Thereafter, during these high flow rates a situation close to permanent flow conditions existed, resulting in minor changes downstream and considerable changes just upstream of the bottleneck (in this case the bridges). Further upstream the effect of the bridges decreases and at Redhouse it is less than 0.01 m.

The graphs also show a sudden increase in waterlevels over a short distance at Redhouse. This is due to a distinct kink in the river course, which under heavy flood conditions will become a considerable obstruction to the flow. However, if the flood levels were to increase further then flow would occur across the river banks and flood plains east of Redhouse and the bottleneck effect at Redhouse would be reduced.

At present simulations are done with estimated hydrographs (determined by the Hydrological Research Unit) for 1 : 100 year river floods, to determine the corresponding waterlevels along the river and estuary. The first indications are that these could well be higher than those observed during recent floods.

CONCLUSIONS

The calibration and simulation results obtained so far with the model are very encouraging and show that the model can already be used as a management tool. Further improvements to the model will be possible if comprehensive data can be collected during further flood events, for which purpose several raingauges and waterlevel recorders have been installed.

Finally, it should be mentioned that similar modelling techniques are available to simulate transport and dispersion of pollutants in the estuary (Huizinga 1985).

LIST OF SYMBOLS

A = cross-sectional area (m^2)
a = obstruction height (m)
C = chezy coefficient ($m^{1/2}/s$)
g = gravitational constant (m/s^2)
I_b = bottom slope
h = waterlevel (m)
Q = flow (m^3/s)
R = hydraulic radius (m)
t = time (s)
x = distance (m)

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THE ICHTHYOFAUNA OF THE SWARTKOPS ESTUARY

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INTRODUCTION

Biologists are in general agreement that the most important function of an estuary, as far as fish are concerned, is to act as a nursery area for juvenile fish (Wallace and Van der Elst 1975, Day, Blaber and Wallace 1981). This use of an estuary can be regarded as the utilization of one natural resource by another natural resource (Beckley 1983a). The fish fauna of the Swartkops estuary is representative of the temperate region between the colder Cape waters, to the transitional more tropical Transkei zone. The same species roughly occur from the Knysna to the Kei estuaries with some species extending their ranges.

The Swartkops estuary is typically open with salinities approaching seawater in the mouth and middle reaches and clear water throughout the estuary (Marais 1987). The extended mud flats in the lower reaches are characterized by *Spartina* beds and subtidal *Zostera* (MacNae 1957). The Swartkops is unique as being an estuary within a city (Grindley 1974). This puts special stress on the system (sewage, storm water, boating, fishing pressure, bait digging and general pollution) but fortunately it attracted unprecedented public interest in the well-being of the estuary which culminated in the formation of the Zwartkops Trust who guards over the interests of the estuary.

Like most estuaries, the Swartkops provides a specialized environment for some 70 fish species which have been studied by Gilchrist (1918), Marais (1976), Winter (1979), Marais and Baird (1980a and b), Talbot (1982) and Beckley (1983b). These studies provide information on species composition, general biology, seasonal abundance and size frequency distribution of adult, juvenile and larval fish and on factors that influence fish distribution in the estuary.

The objectives of the present study were to present and compare the results of various ichthyologists regarding the Swartkops ichthyofauna as well as to consider the likely influence of future stress factors and pollution on the general health of the estuarine fishes.

RESULTS OF CATCHES MADE IN THE SWARTKOPS WITH DIFFERENT TYPES OF FISHING GEAR

Members of the family Gobiidae, *Gilchristella aestuarius* and *Omobranchus woodii* dominated in the larval catches made by Melville-Smith and Baird (1980) with a plankton tow net (diameter = 57 cm; mesh size = 190 µm) (Table 1). The authors pointed out that seasonal abundance of the dominant species increased during the warm summer months when spawning occurred.

Table 1.
The five most abundant species and family of larval fish caught during 1977-1978 by means of a plankton tow net (Melville-Smith and Baird 1980)

Species	% Composition by number
Gobiidae	59
Gilchristella aestuarius	31
Omobranchus woodii	7
Atherina breviceps	1
Rhabdosargus holubi	0.5
Monodactylus falciformis	0.3
11 Species + 1 Family	1.2
	100.0

Despite the fact that the catches of Marais (1976) and Winter (1979) were made with seine nets of near similar dimensions (35x1.7 m and mesh size = 10 mm; 30x2 m and mesh size = 12 mm) their results differ markedly (Tables 2 and 3). This was probably caused by the fact that the habitats sampled by the two workers differed. Smaller species such as *Gilchristella aestuarius* and *Atherina breviceps* dominated in the catches of Winter (1979) whereas members of the family Mugilidae, followed by *Rhabdosargus holubi*, were most abundant in the catches of Marais (1976). The family Mugilidae also dominated in the catches of Winter (1979) when % composition was expressed on a mass and metabolism basis.

Table 2.
The five most abundant species and family of fish caught by seine net during 1973-1975 (Marais 1976)

Species	% Composition by number
Mugilidae (*L. dumerili* = 57)	86
Rhabdosargus holubi	8
Atherina breviceps	2
Heteromycteris capensis	0.6
Pomadasys commersonnii	0.5
Lithognathus lithognathus	0.5
	2.4
	100.0

Table 3.
The five most abundant (numerically) species and family caught by seine net during 1977-1979 (Winter 1979)

Species	% Composition by Number	Mass	Metabolism
Gilchristella aestuarius	54	4	10
Atherina breviceps	19	1	2
Mugilidae	8	62	57
Rhabdosargus holubi	6	11	14
Diplodus sargus	3	2	3
Engraulis japonicus	6	1	1
28 species+2 genera+2 families	4	19	13
	100	100	100

The method used by Gilchrist (1918) to set a net across the mouth of a creek at high tide and to remove the net with fish at low tide, can probably be regarded as a combination of the gill- and seine netting methods. His results (Table 4) again emphasize the numerical importance of the mullets and cape stumpnose, *R. holubi*. The large percentage of important angling species such as white steenbras, *Lithognathus lithognathus*, cob, *Argyrosomus hololepidotus*, and in particular elf, *Pomatomus saltatrix*, is noteworthy.

Table 4.
The six most abundant fish species and one family caught by the netting operations of Gilchrist (1918) during 1915-1916

Species	% Composition by number
Rhabdosargus holubi	45
Mugilidae	34
Lithognathus lithognathus	8
Argyrosomus hololepidotus	4
Galeichthys feliceps	3
Pomadasys commersonnii	2
Pomatomus saltatrix	2
9 species	2
	100

The catches of Beckley (1983b) in the *Zostera* beds with a relatively small (10.5x2.5 m with mesh size = 2 mm) seine net (Table 5), shows similarities with the catches of Melville-Smith and Baird (1980). The main differences are the absence of mullets from the plankton samples and the relative decrease in gobiid numbers in the catches of Beckley (1983b).

Table 5.
The four most abundant species and two families caught by seine net during 1980-1981 in *Zostera* beds in the mouth region of the Swartkops estuary (Beckley 1983b)

Species	% Composition by number
Atherina breviceps	46
Mugilidae	20
Rhabdosargus holubi	12
Gilchristella aestuarius	9
Diplodus sargus	7
Gobiidae	3
27 species	3
	100

The gill-net catches of Marais and Baird (1980b) rate the family Mugilidae as the most abundant group (numerically) (Table 6). These species are followed by *P. commersonnii*, which was most abundant in terms of mass (Table 6). Mullets were shown to be amongst the five most abundant species in all the previous studies with the exception of the plankton tow net catches of Melville-Smith and Baird (1980).

Table 6.
The five most abundant species and family of fish caught by gill-net in the Swartkops estuary during 1975-1979 (Marais and Baird 1980b)

	% Composition by	
Species	Number	Mass
Mugilidae	42	25
Pomadasys commersonnii	17	29
Rhabdosargus holubi	9	1
Lichia amia	6	6
Galeichthys feliceps	6	6
Monodactylus falciformis	5	1
10 species + 1 genus	15	32
	100	100

An analysis of anglers catch data by Marais and Baird (1980a) showed that spotted grunter, *P. commersonnii*, comprised 87 per cent of all catches made during 1972-1978 (Table 7). This species was followed by *L. lithognathus* and the leervis *Lichia amia* (3 % each). In a later five-month study, Tregoning (pers. comm.), who collected information from a wide spectrum of anglers including squatters on the banks of the estuary, found that *R. holubi* dominated catches numerically (Table 8).

Many of the anglers that were included in his survey caught any size and species of fish as long as it was edible. The relative abundance of *P. saltatrix* and *A. hololepidotus* in Tregoning's catches (Table 8) should be noted. While conducting gill-net catching in four eastern Cape estuaries, it was observed that whereas 45 anglers fish from the banks of the Swartkops estuary during week days, an average of only four were found at the Krom, Sundays and Gamtoos estuaries. Tregoning (pers. comm.) found that an average of 0.0018 fish were caught per rod per hour (0.0016 kg/rod/h) by anglers in the Swartkops estuary. Extrapolation of his values show that 12 545 fish are caught annually weighing 11 151 kg.

Table 7.
Percentage composition of catches made by angling club members in the Swartkops estuary during the period 1972-1978 (Marais and Baird 1980a)

Species	% Composition by Number	% Composition by Mass
Pomadasys commersonnii	87	83
Lithognathus lithognathus	3	3
Lichia amia	3	3
Argyrosomus hololepidotus	2	5
Elops machnata	2	2
Platycephalus indicus	1	1
6 species + 3 genera	2	3
	100	100

Table 8.
Percentage composition of catches made by anglers in the Swartkops estuary during December 1986 to April 1987 (Tregoning pers. comm.)

Species	% Composition by Number	% Composition by Mass
Rhabdosargus holubi	33	6
Pomadasys commersonnii	30	37
Pomatomus saltatrix	10	11
Argyrosomus hololepidotus	8	9
Platycephalus indicus	6	6
Lichia amia	4	7
7 species	9	24
	100	100

DISCUSSION OF CATCH STATISTICS

The work of Marais (1987), who compared fourteen eastern Cape and Transkei estuaries showed that estuaries such as the Swartkops, with a relatively small catchment, high salinity throughout the estuary and very clear water, did not support an abundant (numbers and mass) large fish component as was evident from gill-net sampling. However, Margalefs' richness index and the Shannon diversity index rated the Swartkops estuary amongst the estuaries with the largest number of species as well as the most diverse fish community. It also displayed an even distribution of species which is to be expected from an estuary with a rich and diverse fauna. Marais (1987) also found that geographical affinity strongly influenced species composition and that estuaries such as the Krom, Sundays and Quinera grouped together in a dendrogram.

Melville-Smith and Baird (1980) established through plankton tow netting (Table 1), that Swartkops estuary ichthyoplankton was dominated numerically by species belonging to the family Gobiidae and the estuarine round herring (90 %) which spawn in the estuary. These species are important in the diet of predators such as *A. hololepidotus*, *L. amia*, *Tachysurus feliceps*, *Monodactylus falciformis*, *Elops machnata* and *Platycephalus indicus* (Marais 1984). The adults of other fish larvae found in the plankton, spawn in the inshore environment in the vicinity of estuarine mouths (Wallace 1975).

Whitfield (1980) clearly showed that larger water bodies normally supported a more diverse fish fauna than small bodies. This is probably because larger water bodies offer more protection because of deeper water and a bigger variety of habitats. Beckley (1983b) caught 39 species of fish in a creek covered by subtidal *Zostera* and only 30 in the open channel where *Zostera* was absent. Earlier catches made by Marais (1976) and Winter (1979) also differed markedly although they were made with fairly similar seine nets. The reason being that the mouth station of Marais (1976) consisted of a sandy substratum where members of the family Mugilidae predominated whereas the two mouth stations of Winter (1979) contained sparse *Ruppia capensis* in the one instance and a dense *Zostera maritima* cover in the other. In these areas *G. aestuarius* and *A. breviceps* predominated.

It must be stressed that a comprehensive picture of the ichthyofauna of an estuary can only be obtained from the combined results of a number of fishing methods. Although Winter (1979) himself recorded only 48 species of fish from seine netting samples, by combining data from seine netting, gill netting (Marais and Baird 1980b), angling (Marais and Baird 1980a) and divers catches, more than 70 species of fish were recorded in the Swartkops estuary from 1977-1980 (Winter 1979).

Plumstead (1984) warned that estuaries could only be compared for fish abundance and diversity if similar fishing methods were employed.

A study of the catch composition of Gilchrist (1918) suggests that definite changes occurred in abundance of individual species from early this century until the present. The catches of Gilchrist (1918) were dominated by *R. holubi* (45 %) and members of the family Mugilidae (34 %) (Table 4). This family and species also dominated in the catches of Marais (1976) (Mugilidae 86 % and *R. holubi* 8 %; Table 2). They were also amongst the four most abundant species caught in seine nets by both Winter (1979) and Beckley (1983b) (Tables 3,4 and 5).

The most interesting observation when recent catches are compared to early century catches is that species such as white steenbras (8 %) and cob (4 %) occurred more frequently in early catches (Table 4) than spotted grunter (2 %). The elf, *Pomatomus saltatrix*, also occurred with the same frequency in the nets as spotted grunter (2 %; Table 4). The relatively low numbers of white steenbras, kob and elf in the more recent catches suggests that over-fishing for these popular angling species severely reduced their numbers in the estuarine environment. *Pomadasys commersonnii* in contrast, increased in abundance as is evident from both the gill-net catches of Marais and Baird (1980b) as well as from angling statistics (Marais and Baird 1980a, Tregoning pers. comm.).

The abundance of spotted grunter in anglers catches (Tables 7 and 8) gives the impression that it was able to withstand angling pressure better than the mentioned species. Another interesting observation is the relative increase in abundance of elf from the studies of Marais and Baird (1980a) during 1972-1978 to the present (Tregoning, pers. comm.). In Tregoning's survey, elf comprised 10 per cent of anglers catches which is a significant increase from the 1 per cent during the period 1972-1978. If this observation could be confirmed by a more comprehensive study, it could give hope that the conservation measures taken in Natal (closed season during peak reproduction and bag limits) not only caused an increase in elf numbers in that area, but spilled over to all environments frequented by the protected species. This gives hope for the dwindling numbers of many popular angling species, both estuarine and marine.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

1. Swartkops is an unique estuary with a diverse and abundant fish fauna.

2. Angling is an important recreational activity on the estuary. A constant inflow of fresh water into the estuary is important to ensure an abundant larger fish component.

3. The Swartkops estuary was the only eastern Cape estuary in which spotted grunter, *Pomadasys commersonnii*, dominated in gill-net catches (Marais 1987). It was also shown to be the most abundant angling species in the Swartkops estuary.

4. Because of its proximity to Port Elizabeth and several towns and townships, precautions should be taken to minimize the following more serious forms of pollution in the Swartkops estuary:

   - PCB and t-DDT residues were shown to be higher in fish samples from the Swartkops estuary than from five other eastern Cape estuaries (De Kock 1985)

   - Sewage-outlet from the Uitenhage farm is a variable source of enrichment

   - Mudflat destruction by illegal bait digging destroys the natural habitat of especially *Upogebia africana* which was shown to be important in the diet of both birds (Martin, pers. comm.) and fish (Marais 1984)

   - The massive storm water canal that enters the estuary at the brickfields could prove to be an ever increasing source of general pollution as Motherwell develops.

5. Constant monitoring of fish (animal) populations is needed to evaluate the soundness of the system at any time in future.

6. Since man is regarded as "the most estuarine dependent animal in the biosphere" (Allanson 1980) it is in our own interest to maintain and improve the general well-being of the complete Swartkops ecosystem.

ACKNOWLEDGEMENTS

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BIRDS OF THE SWARTKOPS ESTUARY AND ITS ENVIRONS AND THE EFFECTS OF DEVELOPMENTS AND BAIT EXPLOITATION

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INTRODUCTION

Birds are large, conspicuous organisms and are at the top of many food chains. Their numbers are relatively easy to monitor and so they can be used as convenient indicators of the biological status of an ecosystem.

This paper outlines the diversity of birdlife found on and immediately adjacent to the Swartkops estuary and discusses the probable causes of historical changes in the composition of the avifauna. The number and distribution of birds on the Swartkops estuary and the diets of the principal species are shown, and the probable effects on the estuarine bird populations of existing and future developments and bait exploitation are discussed. Finally, attention is drawn to the important breeding colonies next to the estuary and some of the threats which face them.

DIVERSITY AND HISTORICAL CHANGES

In the past four years 195 bird species, representing 22 per cent of all species recorded in southern Africa and 47 per cent of species occurring in the eastern Cape, have been identified in the Swartkops valley between Perseverance and Algoa Bay. Of these, 53 species regularly occur on the estuary and 61 species, including six species listed in the South African Red Data Book - Birds (Brooke 1984), have been recorded on Redhouse Saltpan (Fig. 14). The Valley Bushveld along the northern escarpment is the most important habitat for many of the terrestrial species.

The avifauna of the Swartkops estuary was documented at the beginning of the century by Brown (1905). Since then the most important change has been the total disappearance of many typical freshwater species, such as those belonging to the family Rallidae. According to Brown (1905) there were numerous freshwater vleis beside the estuary early this century, but industrial developments and the construction of saltpans on the floodplain have led to their destruction. An artesian spring at the site of the former spa-baths created a vlei which provided a last refuge for some of the freshwater species (Edwards 1971), but since the spring was closed in September 1969 these species have gone from the valley. The only areas of freshwater remaining are small ponds in the S.A. Transport Depot, Fishwater Flats Sewage Works and adjacent to the Algorax factory.

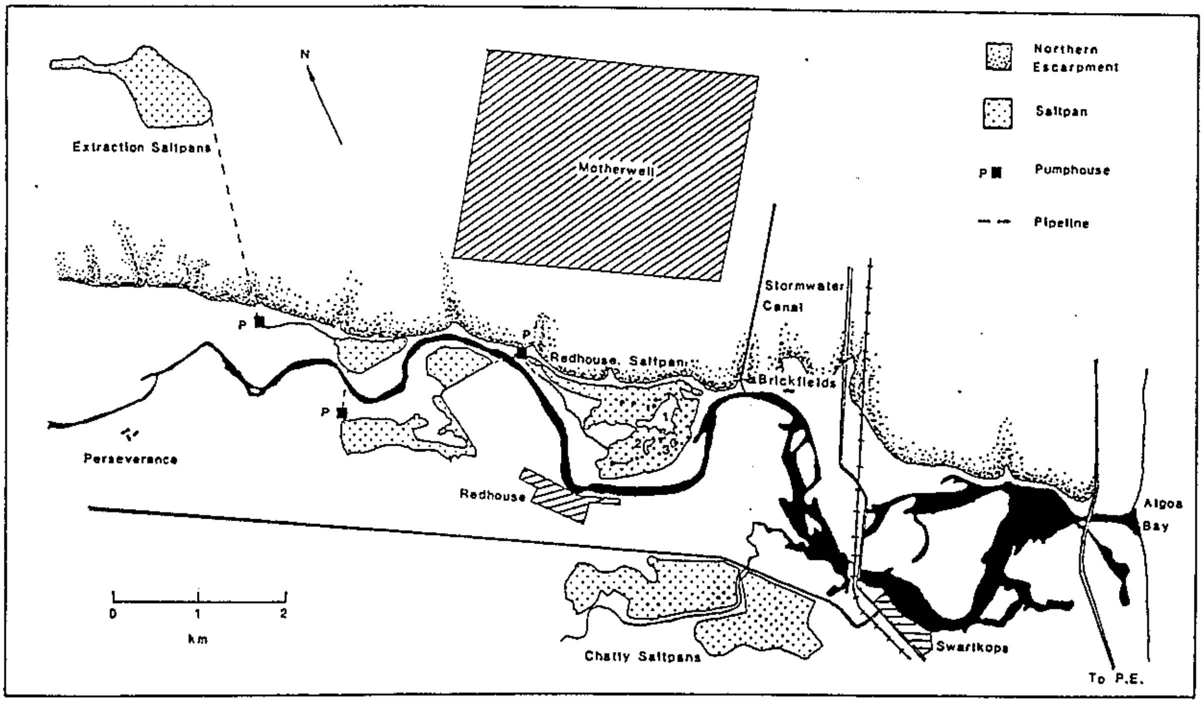

Figure 14. Map of the Swartkops estuary showing the position of the saltpans.

ESTUARINE BIRDS

Numbers and Distribution

Between Cape Agulhas and Durban Bay, the Knysna Lagoon is the only estuary to hold similar numbers of birds to the Swartkops, where over 4 000 birds are present during summer (Fig. 15). Numbers fall to fewer than 1 200 birds during winter due to the departure of most of the Palaearctic migrant waders and terns (Martin and Baird 1987).

The majority of birds (92 %) feed from the intertidal mud at low tide, 6 per cent from the subtidal areas and only 2 per cent from the saltmarsh. Most of the birds (87 %) occupy the area where the main mudbanks are situated, from Settler's Bridge to just upstream of the Chatty River. The large areas of saltmarsh between Settler's Bridge and the Swartkops bridges provide safe roosting sites for the majority of birds. Others roost on the Chatty and Redhouse Saltpans and a few go to the sandy beaches adjacent to the mouth of the estuary (Martin and Baird 1987).

Diet of principal species

Five species make up 74 per cent of the birds on the estuary: kelp gulls *Larus dominicanus* (21 %), grey plovers *Pluvialis squatarola* (21 %), whimbrels *Numenius phaeopus* (12 %), common terns *Sterna hirundo* (10 %) and curlew sandpipers *Calidris ferruginae* (10 %) (Martin and Baird 1987).

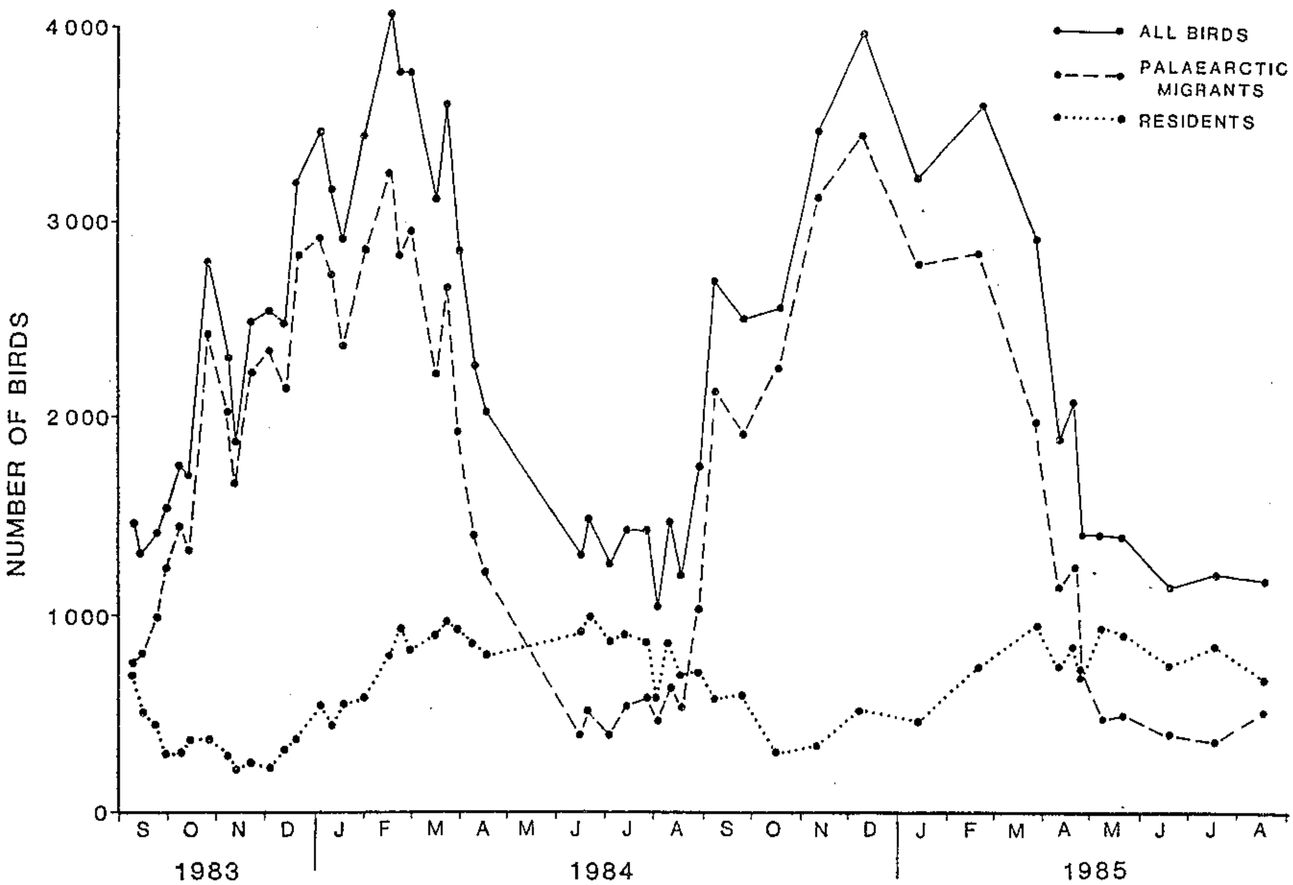

Figure 15. Numbers of birds on the Swartkops estuary, 1983 – 1985.

The most important prey species is the mudprawn *Upogebia africana*. Numerically it accounts for a maximum of 99 per cent of all prey items taken by common terns and a minimum of 8 per cent of items in the diet of curlew sandpipers (Table 1). However, in terms of biomass it is the most important prey of all five principal bird species.

Table 1.
Diet of the five most abundant bird species on the Swartkops estuary

Prey	Kelp gull	Grey plover	Whimbrel	Common tern	Curlew sandpiper
Mudprawn	58	21	48	99	8
Crabs	8	6	16	0	7
Polychaetes	2	36	0	0	1
Other large	5	2	4	1	1
Very small	27	35	32	0	84

Mudprawns usually live in burrows (some in excess of 40 cm deep), where they are unavailable to birds with short bills. However, a small proportion of mudprawns (*c.* 1 in 11 000 per low tide cycle) come to the surface, and most of these are eaten by the birds. Figures 16 and 17 indicate that it is the larger prawns that come to the surface. These individuals carry very high parasite loads (typically 100 - 200 individual parasites, of a variety of species) and these may be the cause of this unusual behaviour.

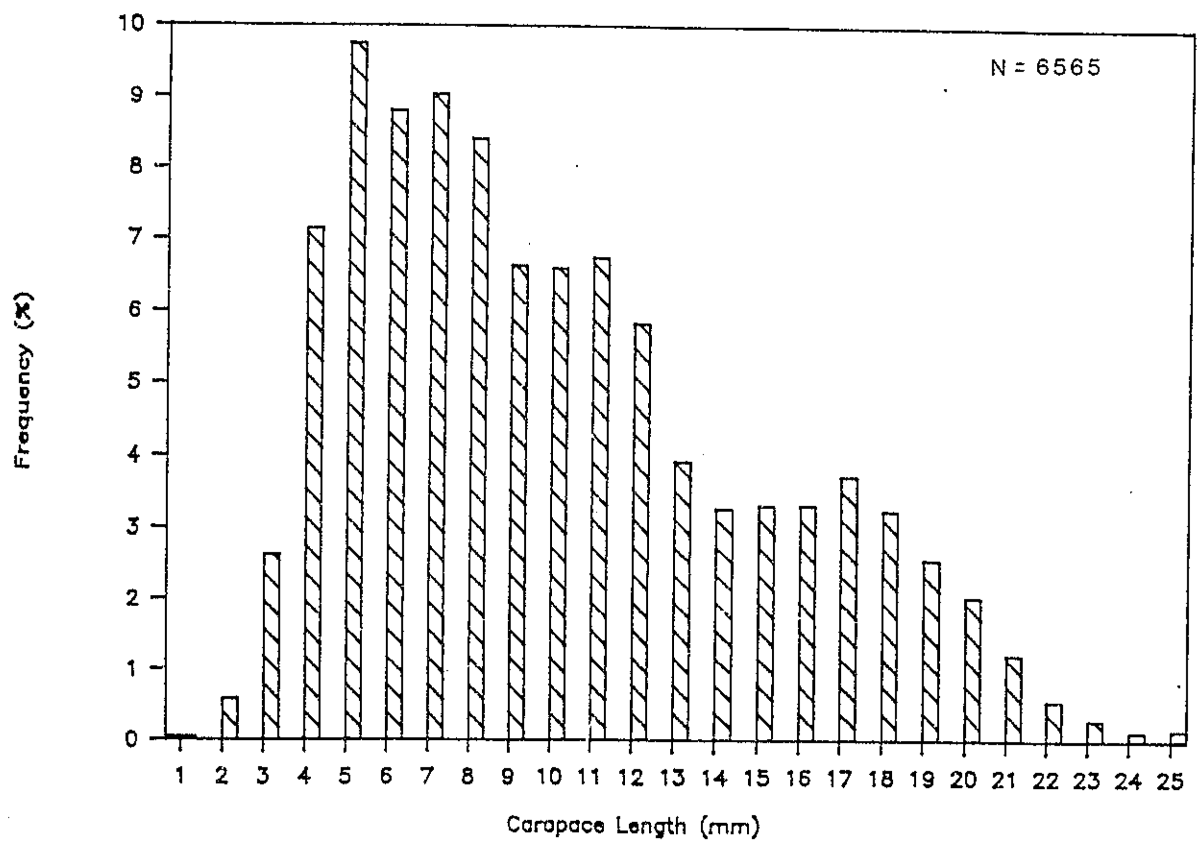

Figure 16. *Sizes of mudprawns* Upogebia africana *in the substrate.*

BAIT EXPLOITATION

The numbers of people collecting intertidal bait organisms (mostly mudprawns) using illegal methods, such as digging with forks or with hands and feet, are shown in Figure 18. These figures are minima, based on a single weekday count at low tide. In January 1984 hourly counts showed that 16 illegal bait collectors used the banks during the low tide period whereas only five were seen at the time that I usually counted the area. Many more bait diggers are present at weekends and digging also takes place at night. The collectors sell the bait at the roadside to fishermen, who, unable to obtain bait from the one licensed

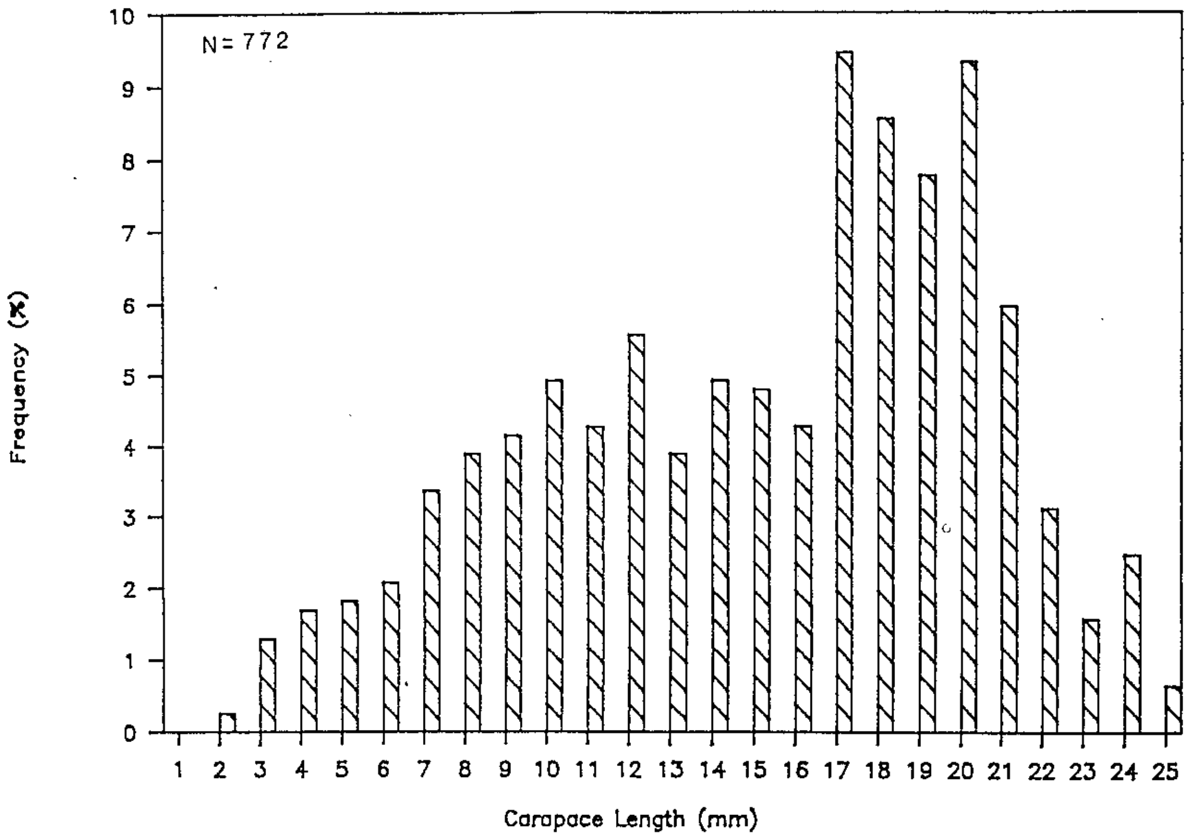

Figure 17. *Sizes of mudprawns* Upogebia africana *found on the surface.*

bait outlet in the area because of excessive demand, are willing to pay twice as much as is charged at the licensed outlet. The illegal bait collectors can earn R10 per kg of mudprawns whereas the legal bait outlet pays their workers 75c per kg. In some areas up to 50 per cent of the surface area of the mudbanks is affected by the holes and spoil heaps left by illegal bait diggers. Invertebrates, especially mudprawns, are unable to utilize these areas until the substrate has consolidated to the extent that they are able to build burrows in it again. Pencil bait *Solen capensis* is also collected and sold illegally in large quantities, some people removing *c.* 300 per day (pers. obs.).

The effect of illegal bait digging on the bird populations is difficult to assess. On the one hand birds, especially kelp gulls, are quick to take advantage of any prawns left on the surface by the bait diggers. On the other hand habitat destruction, in the form of bait-holes, could begin to limit the area of prawn beds available to feeding birds and so limit their numbers, particularly as many species are territorial. Bait diggers tend to select the larger mudprawns and these are the ones which may eventually come to the surface and be eaten by the birds. African black oystercatchers *Haematopus moquini* feed almost exclusively on *S. capensis* on the estuary and could be affected by over-exploitation of this organism.

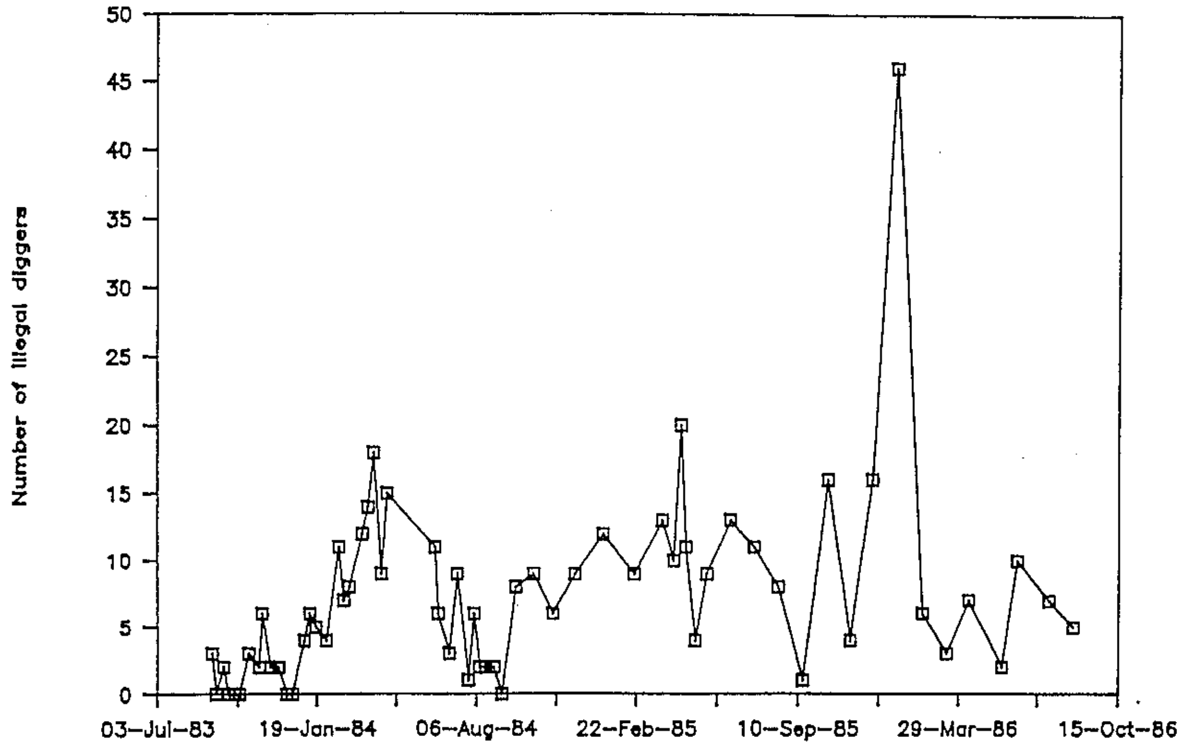

Figure 18. *Number of people using illegal methods to collect bait, 1984 – 1986.*

RECREATION

The estuary is used extensively for recreational purposes. The most critical time for the birds is when they are feeding on the mudbanks at low tide. They are able to tolerate reasonably high levels of disturbance, particularly by people walking about slowly on the banks. However, domestic dogs are frequently allowed to run around on the exposed mudbanks adjacent to residential areas for long periods, and this seriously disrupts the time available to the birds for feeding. At present there seems to be little disturbance of high tide roosts or of breeding African black oystercatchers on the saltmarsh areas.

Birds are relatively easy to see and identify and attract the interest of the general public more than most other organisms. They can therefore be used to promote environmental awareness among the general public. The future of the Swartkops estuary will depend to a very large extent upon the attitude of the people living along its banks and in the catchment area to their environment.

URBAN DEVELOPMENT

Any development which affects the ecology of the estuary, from catastrophic unpredictable events to minor building developments, is likely to affect the avifauna to a greater or lesser extent. Losses of intertidal feeding areas are an obvious cause for concern, but developments in the catchment areas leading to subtle changes in the estuary, such as shortening the life-span of mudprawns and thereby reducing the numbers coming to the surface where they are available to the birds, could also have an effect.

Bridge building in the lower reaches of the estuary is a particular cause for concern. The existing bridges span only the distance between the low water marks. Even the planned Bramlin-Markman bridge will encroach onto the intertidal banks. Future dredging operations in the estuary or flooding of sand quarries upstream may cause sediment to be suspended in the water column. If this sediment load is deposited on the mudbanks it could smother the prawn beds. Destruction of the saltmarsh areas could lead to a decrease in the amount of detritus available to prey organisms.

However, it is the massive spread of urbanization in the catchment area that gives most cause for concern, mainly because the effects of large-scale removal of the natural vegetation from these areas on the ecology and hydrology of the estuary are difficult to predict.

BREEDING COLONIES

Redhouse Saltpan, a commercial, primary concentration saltpan on the north bank of the estuary (Fig. 14), is probably the most important breeding site for seabirds on the mainland of the eastern Cape. The Caspian tern *Hydroprogne caspia* is classified as rare in South Africa (Brooke 1984). Over 30 pairs nest on the saltpan, representing the second largest colony (*c.* 20 %) of those breeding in South Africa. At least 210 pairs of whitebreasted cormorants *Phalacrocorax carbo* breed on the saltpan, over 400 pairs of kelp gulls *Larus dominicanus*, up to 28 pairs of greyheaded gulls *L. cirrocephalus* and, in 1983, over 200 pairs of sacred ibises *Threskiornis aethiopicus*. These are the largest breeding colonies of these species in the eastern Cape (Martin and Randall 1987).

Breeding success is usually good, although in the past egg thieves have removed all the whitebreasted cormorant, sacred ibis and Caspian tern eggs on occasions. With the development of Motherwell this problem could get worse. Mammalian predators are able to get to the breeding islands when the water level in the saltpan is low, and when this happens no young are reared. The area will hopefully be included in a proposed Nature Reserve which has been initiated to protect the Valley

Bushveld on the steep northern escarpment (Martin and Baird 1988). Recommendations aimed at improving the saltpan for waterbirds have been made (Martin and Randall 1987).

CONCLUSIONS

1. Bird diversity in the Swartkops valley has been reduced this century by the destruction of freshwater vleis.

2. The Swartkops estuary is one of the most important estuaries for birds on the southern and eastern coasts of South Africa.

3. The most important feeding areas for the birds are the intertidal mudbanks in the lower reaches of the estuary.

4 The main prey organism is the mudprawn *Upogebia africana*.

5. Illegal exploitation of bait organisms is out of control.

6. Present and planned bridges reduce the intertidal feeding area available to the birds.

7. Urbanization in the catchment area could potentially alter the ecology and hydrology of the estuary.

8. Human and other mammalian predators sometimes gain access to breeding colonies of national importance next to the estuary.

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SYNTHESIS OF THE PROCEEDINGS OF THE SYMPOSIUM ON THE SWARTKOPS ESTUARY

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During this symposium a number of issues were addressed concerning the ecology and the management of the Swartkops estuary. The status of our knowledge on the ecology of the estuary was summarized in four papers by Bate *et al.* (1987) on botanical aspects, Reddering and Esterhuysen (1987) on the geology and sedimentology, Lord *et al.* (1987) on the pollution status of the estuary and Baird (1987) who presented a synthesis of research on the faunal communities and their interactions. Several other papers were presented by specialists in their fields of study ranging from land use planning in the Greater Algoa Bay metropolitan area with special reference to the Swartkops estuary, the implications of socio-economic developments in the Swartkops valley to flooding and predator-prey interactions. All these topics are discussed in separate papers contained in this volume.

The general conclusion arrived at was that the Swartkops estuary is at present in a good ecological state despite the fact that the ecosystem is subjected to human influences which will increase dramatically during the next two decades. This assumption is made on the premise that the human population living in the Swartkops River catchment area will increase to approximately one million persons from the present 280 000 people (Horentz 1987). The increase in population size will by necessity be accompanied by massive township developments and an expansion of the existing infrastructure. Provision will have to be made for industries and their accompanying waste products, additional road and rail networks (some of which will criss-cross the estuary) and stormwater inputs. Concern has been expressed about the piecemeal developments and the assessments of their impact on the ecology of the ecosystem individually, while their cumulative effects may be greater than their individual impacts. The need therefore clearly exists for careful development planning and the continuous evaluation of the ecological status of the estuary and its catchment area. If these considerations are not taken into account, the estuary may lose its viability and become ecologically inactive.

There are obviously many reasons why the estuary should be conserved in an ecologically viable and healthy state since the Swartkops estuary is an asset of enormous ecological and recreational value to Port Elizabeth and its inhabitants.

During the final session of the symposium a number of problem areas in the estuary have been identified and discussed by the delegates and these are summarized below. These should be read with reference to Figures 2 and 3 on pages 4 and 5 respectively for local features of the river and estuary and to Figure 19 which illustrates diagrammatically the major environmental processes and interactions, and man's influence on these.

SAND MINING

Sand mining in the Uitenhage-Despatch area of the Swartkops River is reasonably well controlled by the Commissioner of Mines through the issuing of permits. It would appear that mining has a relatively minor influence on flood flows. The main problems are the effect of mining in disrupting the river-bank ecotone through access roads etc., on the shore. It would appear that this situation could be controlled more effectively if law enforcement was possible.

In general sand mining does not really present a problem at the moment.

SALT PANS

The primary concentration pans are biologically active whereas the final concentration pans, with very high salinities, are considered to be biological deserts. The pans can serve as possible storage areas during exceptional flooding, but could perhaps be better utilized for recreation as a shallow-water boating and swimming area. The ensuing discussions indicated the need for a detailed management plan for the future development of the salt pan areas opposite and above Redhouse.

The present lease for these salt pans expires in 1993. The ecological and other advantages and disadvantages of the salt pans will have to be critically re-assessed before that time.

STORM WATER FLOW

A stormwater outlet from Motherwell directly to the sea was investigated but was for various reasons not practicable. Stormwater from the Motherwell township enters the estuary slightly upstream of the well-mixed area by means of an existing canal. Concern was expressed on the quality and quantity of the water entering the estuary. The Directorate of Water Affairs is ably handling water quality monitoring while the University of Port Elizabeth is conducting an in-depth research project on both the quantity and quality of the storm water.

Aspects which need attention are the actual measurement of runoff from the canal and the modelling of the effect of the stormwater discharge on the dispersion of contaminants and on the flow rates in the estuary.

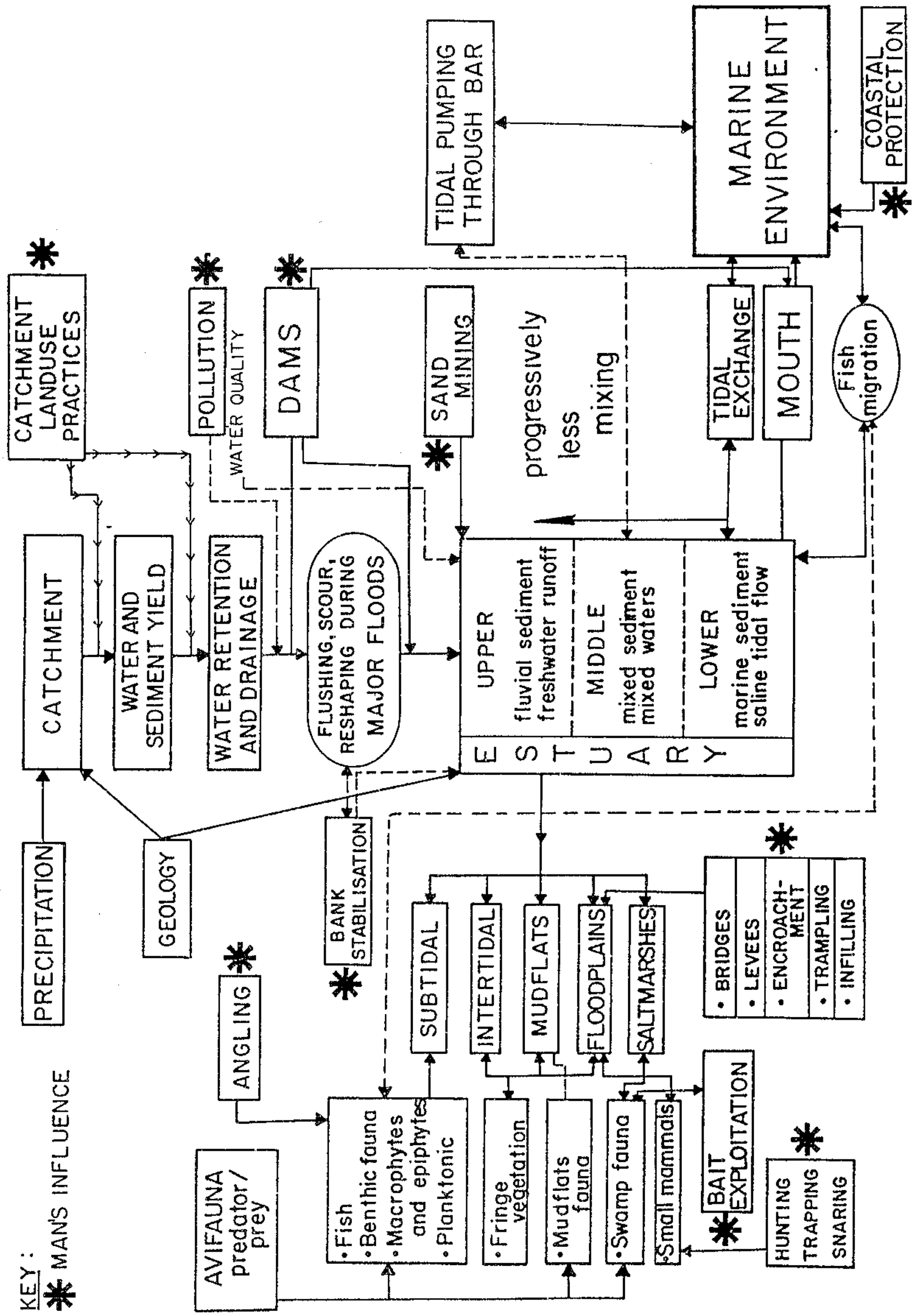

Figure 19. Natural processes catchment/estuary/marine ecosystem.

BAIT EXPLOITATION

The main problem is not really the removal of the bait but rather the associated destruction of the habitat. The illegal removal of bait is a major problem and attempts should be made to limit bait exploitation through, for example, the issuing of permits and better control over these activities. The area mainly affected is below the Brickfields which accounts for about 20 per cent of the whole intertidal zone. More information is needed to assess the impact of exploitation on the prey populations. An example of an estuary where bait collection is well controlled is the Kowie, where no digging is allowed and only a tin or prawn pump is permitted to collect prawns. The Local Authority effectively and efficiently carries out the controlling function.

Improvement in the controlling function of access to and activity in bait beds by the appropriate Authorities is necessary.

URBANIZATION AND RESULTING POLLUTION AS WELL AS INCREASED RUNOFF AND FLOOD LEVELS

Pollution may not be a problem during major floods as all the pollutants will be carried straight out to sea. During lesser floods some problems may, however, arise. The human encroachment into the estuarine surroundings is increasing and thereby altering the character of the area as well as runoff patterns.

A question to be resolved is "What measures need to be included in plans to prevent/minimize pollution and excessive flood levels?".

ENVIRONMENTAL EDUCATION

The importance of environmental education, that is, the creation of an awareness of the environment, was stressed. The Swartkops Trust is very active in this regard. A management plan for a proposed nature reserve on the northern escarpment has been completed (Martin and Baird 1988) and it is hoped that the reserve will soon be proclaimed by the relevant authorities. Environmental awareness could be improved if a hiking trail and information centre could be established in the nature reserve, and controlled access for blacks to the estuary must be considered. A suggestion was that this area should be put under the jurisdiction of the Motherwell Council but the consensus opinion was that it would not work due to the pressures associated with the standard of living of the black community. However, this type of approach of creating environmental open space has worked effectively in Natal.

It was suggested that environmental awareness could be improved through low-level monitoring exercise such as monitoring fish catches and the Continuous Low-level Environmental Observations (CLEO) programme which is being investigated by the CSIR for possible instigation. This could perhaps be coordinated through a teacher centre.

FINANCING OF LONG-TERM FISH MONITORING

The financing of long-term monitoring of fishing/over-fishing of the Swartkops was discussed.

It was decided to refer this matter for further action to the Linefish Committee of the South African National Committee for Oceanographic Research.

CANALIZATION

The river has a 50 m fall over the last 20 km, which is quite steep relative to most other estuaries.

Problems are not foreseen with flood levels due to canalization, but rather due to a potential increase in sediment transport which will eventually be deposited downstream.

SALT MARSHES

A pilot experimental excavation in the slat marshes has not recovered after five years. The salt marshes are extremely important as a link in the food chain and more quantitative research about the role of the salt marshes is required.

ADEQUATE SUPPLY OF RIVERINE INFLOW

Concern was expressed about the adequacy of the supply of riverine inflow to the estuary in the event of the construction of further impoundments upstream. To place the situation in perspective one should keep in mind that the average riverine inflow amounts to only about one per cent of the tidal exchange through the estuary mouth. During occasional episodic floods, especially extreme ones, large amounts of accumulated marine sediments are carried out to sea again. The long-term physical equilibrium depends greatly on these events and it is quite obvious that the tidal water exchange depends on the mouth configuration which is determined by the alternation of flood events with long periods of low-flow conditions. The diversity of biotic components in the estuary depends on the extent to which the estuary mouth remains open. The size of the mouth is governed by the balance between the tidal exchange and the influx of marine sediments due to wave-driven currents. However, the productivity of the phytoplankton and zooplankton components in the system and interfaces could be affected if riverine inflow should be disrupted. A ripple effect on the productivity of the system will be observed, the magnitude of which is still being studied. The total productivity of the system could, however, remain unaffected with a swing taking place away from the zoo- and phytoplanktons to other components.

Studies to quantify the effect on productivity of reduced riverine inflow have to be completed, and should also be extended to include the relative effect of different estuary mouth conditions.

DREDGING IN LOWER ESTUARY

After the construction of the Wylde Bridge a sandbar was created downstream of the road and railway bridges, opposite the Swartkops village; it has a stable size of about 5 000 m^2. Both the sand bar and an elbow in the river course are migrating downstream at rates of 2 m/yr and 2.6 m/yr respectively, mainly during flood events. The sand bar is at present situated opposite the Swartkops Yacht Club, whilst the power station cooling water intake is situated at the bend in the river course. With the possible danger of the silting and eventual closure of the intake works and with the nuisance of the bar in front of the Yacht Club, plans are being made to dredge the sand bar. Dredging would not have a detrimental effect on the sand/mud prawns. Detrimental effects will be curtailed/minimized as long as wash water used in the dredging process is not spilt back into the river. It is recognized that dredging the sand bar is only a temporary solution since the bar will be formed again in future. Whether it will have the same size and behaviour pattern remains to be seen.

The "recovery" of the sand bar after dredging has to be carefully and regularly monitored.

CONCLUDING REMARKS

It appears from the material presented at the Swartkops Workshop that most of the research necessary to obtain a broad perspective of the functioning of the system has been concluded or is nearing completion. The research required to solve the problems discussed above is more localized or *"ad hoc"* of nature and frequently borders more on socio-economic impacts and/or decisions.

As far as the Swartkops Estuary is concerned the system has been properly researched and we are moving from the research stage to the implementation stage.

The symposium finally discussed general management strategies and a number of resolutions and recommendations were formulated as being necessary for the effective management of the estuary in the long term. These have already been mentioned at the end of the Introduction of these proceedings. They are repeated below for the sake of completeness of the record of the final session of the symposium.

It was agreed that sharper focus needs to be placed on steps which can be taken to promote:

(i) effective co-ordination of the activities of the various authorities in the whole catchment area;

(ii) the creation of an objective scientific/socio-economic advisory body;

(iii) the compilation of a cohesive and comprehensive management (and conservation) plan for the catchment area and estuary;

(iv) co-ordination and integration of such a management plan with national coastal zone management objectives;

(v) educational and consultation mechanisms for all user communities (i.e. black, coloured and white);

(vi) access to technological management tools such as:
- hydrodynamic models
- water quality models
- sediment transport models
- monitoring of ecological components;

(vii) real ability to enforce the management and conservation policies agreed to.

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