The effects of a single freshwater release into the Kromme Estuary. 5. Overview and interpretation for the future

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Abstract

The Mpofu Dam completely blocks the Kromme River a few kilometers above the estuary and prevents a normal flow of freshwater. Because of this, the biological characteristics of the estuary have changed and the system is now more like an arm of the sea than a productive estuary. An annual allocation of 2 x 10^6 m^3 water (less than 2% of the natural mean annual run-off) is released to prevent the salinity in the estuary from rising above that of the sea (i.e. 35‰). An experiment was undertaken in which the annual allocation of freshwater was released as a single pulse in an attempt to create a salinity gradient and stimulate a biological response particularly in the estuary water column. The release was expected to create freshwater conditions throughout the upper half of the estuary. Instead the low density freshwater flowed over the more dense seawater and there was little mixing. A week after the release both the vertical and longitudinal salinity gradients began to disappear. The measurable concentration of mineral nutrients in the estuary after the release remained low, with the result that there was a negligible increase in microalgal biomass either in the water column or on the subtidal sediment. These effects were noticeable in the zooplankton and larval fish communities, both of which remained almost unchanged during and after the release. The results of this experimental release, and other data, indicate that a baseflow of water is necessary to create a longitudinal salinity gradient and a productive river-estuary interface zone. This information should be used to guide assessments of the freshwater requirements of South African estuaries.

Introduction

Water is becoming an increasingly precious commodity in South Africa that will have to be managed efficiently if all the requirements of this developing country are to be met. Large pristine permanently open estuaries in Southern Africa had a regular flow of river water, interspersed at intervals by droughts and floods. They had an unblocked link to the river inland, a continuous or discontinuous connection with the sea and occasional floods. An estuary that is deprived of this freshwater input loses the physical characteristics of an estuary and begins to function as a marine embayment or as an arm of the sea.

In the case of the Kromme Estuary, a regular flow is absent because of the size of the Mpofu and Churchill Dams. The storage capacity of the dams (133 x 10^6 m^3) exceeds the mean annual runoff (MAR) of 106 x 10^6 m^3 from the catchment. The dams completely block the river and also prevent faunal migrations between the sea and the river. There is a continuous connection between the estuary and the sea because of a large tidal volume. However, with depositions of marine sand into the estuary this situation could change in the future. There are occasional floods of freshwater to the sea, but because of the large sizes of the impoundments, these are very irregular.

South Africa has been described as a "water-short country". While to describe a semi-arid environment the public may use this, it leaves the wrong impression and it is incorrect in ecological terms. From an ecological perspective the supply of water is determined by the climate and a "shortage" of water relates either to there being too many people for the available water supplies or to the inefficient management of the water that is available. Inefficient management may be either water wastage by consumers, e.g. not closing taps, inefficient methods of irrigation, excessive industrialisation or inefficient storage by building shallow dams. The use of the term "water-short" implies that the climate is at "fault", whereas in reality the environment is the condition in which we find it either with a high rainfall or only a little.

The National Water Act (No. 36 of 1998) recognises rivers, groundwater, wetlands and estuaries as resources and requires that they be protected so that they will be sustained into the foreseeable future. In order to achieve this there is an ongoing interaction between water engineers and biologists. This interaction is taking place in an effort to solve the difficult questions that arise from the social need to abstract water from waterways and the ecological need to allow water to flow as naturally as possible. Cooper et al. (1999) described estuaries as the meeting place of terrestrial drainage systems with the coast. Because of this, they are highly variable environments in both time and space. Their characteristics depend on climate, hinterland topography, coastal dynamics, sediment supply and coastal lithology. Schumann et al. (1999) stated that estuaries lie at the interface between the ocean and the land, forming the meeting place of the saltwater regime of the sea and the freshwater flow of parent rivers. These latter authors further stated that the regular forcing of the tides drives the oceanic input, while the freshwater input is dependent on variable rainfall in the catchment areas of the rivers. It is the continual interaction between saltwater and freshwater that forms the basis of estuarine hydrodynamics, compounded by other influences such as channel structure and sediment movement and the effects of wind, waves, insulation, human influences and biotic processes.

The foregoing descriptions of the estuarine environment indicate that there are many complexities that need to be understood. At the same time, and in line with most countries in the world, there is a severe shortage of finance to undertake the research needed to answer all the questions. It was this milieu of necessity and lack of understanding that prompted the study that is reported here. The study brought together researchers from the University of Port Elizabeth, JLB Smith Institute of Ichthyology, CSIR (Environmentek), the Department of Water Affairs and Forestry, the Engineering Department of the City of Port Elizabeth and interested and affected parties, particularly the members of the Kromme Trust.

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Figure 1 (right)
Water release from the Mpofu Dam

Figure 2 (far right)
Aerial view of the Kromme Estuary and St Francis Bay

The objective of the study was to investigate whether releasing the entire annual allocation of 2 x 10^6 m^3 on a single occasion was sufficient to reactivate the dormant biological community. A bonus that might be derived from such an experiment was the length of time that such reactivated activity might last.

Results

Water quality

The data of Scharler and Baird (2000) showed that there was very little change in mineral nutrient concentrations following the release. The water in the dam was oligotrophic either because the catchment yielded water with few mineral nutrients or because it had been stored for some time and the minerals had been absorbed by sediments and plant growth. After release, the low-density dam water flowed over the more dense seawater and there was little mixing. This was confirmed by another study that took place at the same time (CSIR, 1999). The duration and magnitude of elevated nitrate concentrations in the estuary were too short for there to be any marked biological response. Both phosphate and ammonium levels were low at all times.

Earlier work by Scharler et al. (1997) showed that catchment water flowing into the Mpofu Dam had a higher mineral nutrient content than the estuary. From this these authors were able to conclude that the Mpofu Dam has a major effect on the water quality. Before the study commenced there had been considerable debate as to whether top or bottom water should be released. In the end, surface water was released because the team feared that bottom water might be anoxic and could seriously jeopardise the interpretation of the results. With hindsight, it is possible that by releasing bottom water, providing it is not anoxic, two positive effects might be achieved, namely, removal of sediment from the dam and the supply of water to the estuary enriched with mineral nutrients. However, the lasting impression gained is that by releasing bottom water little, if any, gain would have resulted in the case of the Mpofu because the dam is so close to the head of the estuary and so little water of low mineral status was released.

Microalgae

The findings of Snow et al. (2000) in this study might have been predicted had the data of Scharler and Baird (2000) been known before the release. The freshwater that was discharged from the Mpofu Dam produced no significant increase in phytoplankton chlorophyll *a* during the study. The absence of an increase in chlorophyll *a* arose despite a significant increase in the average number of diatoms from 301 cells·ml^{-1}, prior to the release, to a maximum of 3 856 cells·ml^{-1} by the end of the first tidal cycle. The average number of flagellates also increased from 1 903 cells·ml^{-1}, prior to the release, to a maximum of 3 300 cells·ml^{-1} after two tidal cycles. These data produced the interesting result that a small response is more easily detected under the microscope than by analysing the chlorophyll *a* concentration of the water column.

There was no change in subtidal benthic chlorophyll *a* biomass but intertidal benthic chlorophyll *a* increased from 35.6 mg·m^{-2} before the release to 63.3 mg·m^{-2} by the sixth day. The reason there was no response by the subtidal benthic microalgae was that the freshwater flowed over the more dense seawater and the slightly higher concentration of minerals in the freshwater was not available to the subtidal microalgae.

The increase in intertidal benthic chlorophyll *a* was not significant as the benthic microalgae grow in patches (Rodriguez, 1993) and this raises the coefficient of variation of the data. The increase observed is, however, worthy of note and suggests that the microphytobenthos might have responded to the increased flow, reduced salinity or the higher concentration of mineral nutrients in the water column.

The conclusion is that the amount of freshwater released and its residence time in the estuary was insufficient to increase the mineral nutrient content of the water to a level that resulted in a significant increase in primary productivity. The length of time that the freshwater influence was present also prevented a meaningful increase in microalgal growth.

Zooplankton

Three copepod species dominate copepod communities in Eastern Cape tidal estuaries, each species having a specific zone of distribution along the salinity gradient. *Pseudodiaptomus hessei* is opportunistic, exploiting mesohaline areas following freshwater pulses. Under these conditions, numbers may increase by orders of magnitude and may occur during any season. *Acartia longipatella* and *A. natalensis* are spatially and temporarily separated. The former species occurs mainly during winter in the higher salinity reaches of estuaries, while *A. natalensis* occurs predominantly during summer in the lower salinity reaches.

Although these three species occur in the Kromme Estuary, natural patterns of spatial and temporal distribution have been lost because of persistent euhaline conditions (salinity above 28‰) throughout the estuary. The freshwater pulse released from the dam elicited no significant change in distribution or abundance in any of the copepod populations. *A. natalensis* did not appear in the plankton and this was probably due to the unsuitable salinity conditions at the water column-sediment interface.

Because of freshwater attenuation, the Kromme Estuary is deprived of an essential mechanism that maintains spatial and temporal heterogeneity in copepod distribution and abundance. Population dynamics of the copepod species in estuaries is primarily linked to the quality and quantity of freshwater supply, rather than to seasonal and/or other cyclic factors (Wooldridge and Callahan 2000).

The volume of water released in this study was too small, or the lowered salinity was present for too short a time, to produce any direct or indirect advantage for the endemic copepods at the population level. Similarly, no significant change was observed in the zooplankton community structure following the release. Mixing of the water column and the development of a dynamic longitudinal salinity gradient that is present for some minimum time is of fundamental importance. From this it seems that a regular baseflow in addition to intermittent pulses of freshwater into the estuary may be required.

Ichthyofauna

In total 17 families comprising more than 29 species of larval teleost fish were recorded in the Kromme Estuary throughout the study period. The catch indicated a marine species dominance with a high diversity. The freshwater release into the estuary resulted in no significant changes to the fish family composition, species diversity or estuarine association of the larval fish assemblage. No significant increase in total larval fish abundance or recruitment response by estuarine-dependent species was recorded (Strydom and Whitfield, 2000).

The study indicated a limited breeding response by estuarine-resident fish species. The increases in larval abundance of estuarine-resident species were mainly attributed to spawning events taking place in the Geelhoutboom Tributary that received freshwater inflow from rainfall that coincided with the dam release. It appears that the tributary, which does receive a regular flow of water from a small catchment, supplements the Kromme Estuary with larvae belonging to these estuarine-resident species. The Geelhoutboom tributary assumes great importance in the light of these findings and reductions in freshwater flow from this source should be implemented with great caution.

The physical conditions in the estuary returned to marine dominance within two weeks of the freshwater release. The conclusion was that the pulse of freshwater and the salinity gradient induced were too short-lived and/or too weak to produce a cueing effect on larval and post-larval fish in the marine environment. A larger amount of freshwater would be required to produce a positive response by the larvae of the estuarine-associated marine species.

Discussion

The release of 2 x 10^6 m^3 had little effect on the saline Kromme Estuary and the conclusion was that the estuary requires baseflow to introduce nutrients and create a longitudinal salinity gradient. Research has been ongoing in the Gamtoos Estuary for some years as part of a programme by the Consortium for Estuarine Research and Management (CERM) that was funded by the Water Research Commission (WRC). Both the Kromme and Gamtoos Estuaries flow into St Francis Bay south-west of Port Elizabeth. They are of similar length and both have dams restricting riverine flow from their catchment. However, of the two, the restriction of flow into the Kromme Estuary is by far the greater and only floods and controlled releases of water reach the estuary.

An aspect of the research on the Gamtoos Estuary was on phytoplankton and benthic microalgal biomass responses to freshwater flow. The data were reported by Snow et al. (2000), and showed that the highest biomass of microalgae occurred at a freshwater baseflow of 1 $m^3 \cdot s^{-1}$. Baseflow created a productive river estuary interface zone that was not only characterised by high phytoplankton biomass but also unique zooplankton and benthic macrofauna assemblages (Wooldridge and Sclacher, 1999). The river estuary interface zone also served as a nursery area for commercially important marine linefish such as kob and spotted grunter (Whitfield, 1999). The interpretation of this information was that while the baseflow required to maintain an apparently healthy estuarine population seems to be surprisingly low for an estuary of this size, there was a necessity for a baseflow in order to maintain the distinct river-estuary interface (REI) zone.

There are differences between these two estuaries, however. The Kromme Estuary receives water from a catchment where there is very little agriculture other than grazing. The Gamtoos Estuary, on the other hand, receives water from a river that flows through a heavily cultivated floodplain. This causes the water to be high in mineral nutrients. It is, therefore, dangerous to make simple extrapolations from one estuary to the other.

The greatest concentration of chlorophyll *a* (phytoplankton biomass) was present in the Gamtoos Estuary when the flow rate was just below 1 $m^3 \cdot s^{-1}$ (Snow et al., 2000). These results were almost identical to those in the Sundays estuary obtained by Hilmer (1990) that were interpreted to show that time was the critical factor. Hilmer (1990) showed that three spring tidal cycles (42 d) were required to allow the phytoplankton to bloom and maximise biomass.

The Kromme Estuary has an approximate volume of 2.8 x 10^6 m^3. If 42 d is the correct time to allow optimum productivity, then the baseflow required can be calculated:

There are 365 d in a year, hence the ratio of 42 d to a year is 8.7.

Because the residence time of freshwater flowing through an estuary is directly related to the volume of the estuary the baseflow required for optimum productivity is:

Baseflow for optimum productivity ($m^3 \cdot s^{-1}$)
= 8.7 (yr^{-1}) x estuary volume (m^3) / 31 536 000 s ($s \cdot yr^{1}$)

where:

8.7 = number of times an estuary is flushed per year at a residence time of 42 d

31 536 000 = number of seconds in a year.

The calculation yields a baseflow of 0.77 $m^3 \cdot s^{-1}$ in the case of the Kromme estuary. This baseflow may be attenuated to zero during a drought and it will be increased to a flood for short periods during high rainfall periods. If this baseflow were provided from the existing allocation of 2 x 10^6 m^3, then the baseflow would be:

$$2 \times 10^6 \ m^3/31\ 536\ 000 = 0.06 \ m^3 \cdot s^{-1}.$$

Interpolating from the earlier equation this would provide 7.8% of the optimum.

From the foregoing baseflow is very important, but besides baseflow, freshets and floods are also important. Freshets have been found to introduce nutrients and increase phytoplankton production (Adams and Bate, 1999). This is an episodic response that drives the temporal and spatial changes in zooplankton populations and increases zooplankton productivity and diversity (Wooldridge and Callahan, 2000). The freshets may serve to mix the water column thus promoting zooplankton egg hatching. Floods are important in estuaries as they flush out accumulated marine sediments. A rule of thumb is that the volume of water stored in a dam should be less than the volume of a 1-in-15 year flood (Huizinga, 1998). The dams in the Kromme catchment attenuate the effect of all floods less than the 1-in-30 year flood (Bickerton and Pierce 1988). As a result there has been marine sediment encroachment in the lower and middle reaches of the estuary.

The marine environment also needs to be considered. Freshwater has been flowing into the sea for millions of years and biological systems have evolved to utilise that water and its contents. This is the least well studied environment affected by manipulations of freshwater in our catchments and a conservative approach is essential which means that we have to allow some water into the marine environment. The question is where, when and how much?

The National Water Act requires the implementation of resource-directed measures to protect our country's water resources. An aspect of this is the determination of the ecological reserve, the amount of water required to maintain the structure and function of a specific estuary. This study provided the opportunity to audit the existing freshwater allocation to the estuary. The study has shown that less than 2% of the MAR released as a single pulse had a short-term effect on the abiotic characteristics of the estuary and little effect on the biotic structure. The optimum baseflow for the Kromme Estuary would require an estimated 24% of the MAR. This requirement, although not high, is unlikely to be accepted in light of water shortages in the Port Elizabeth metropolitan area. Under present conditions the Kromme Estuary will remain as a side-arm of the sea. This is a case study of what should not take place in South African estuaries. Dams should not be constructed close to the head of an estuary where their capacity is equivalent to, or greater than the MAR of the catchment. Any reduction in baseflow, freshets and floods will cause changes in the structure and function of estuaries. The Geelhoutboom Tributary is now the only remnant of estuary within the Kromme system and therefore any plans to dam this tributary would be unacceptable.

The amount of freshwater that is finally allocated to the estuary as the ecological reserve, will need to be further estimated bearing in mind the water situation in the area. If no regular baseflow can be provided to the estuary, then future management options could include the release of water during natural dam overtopping events or the annual ecological allocation of 2 x 10^6 m^3 could be used to control hypersaline conditions in the estuary as and when they occur. Requirements for the Kromme Estuary in the long term is to see whether it is possible to re-establish a low level of estuarine function at least for those periods of time when floods overtop the dam.

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