ARTIFICIAL BREACHINGS OF BOT RIVER ESTUARY

by

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ABSTRACT

During the flood year of 1981 the "Bot River Vlei", one of the largest lagoons in the south-western Cape of the Good Hope was opened to the sea by two artificial breachings of the sand bar which were aimed at lowering the excessively high water levels in the lagoon, and at the re-establishment of estuarine conditions.

The Coastal Engineering and Hydraulics Division of the National Research Institute for Oceanology of the CSIR surveyed and monitored the hydrological and sedimentological events in the Bot River lagoon and at the mouth channels in an attempt to formulate a future viable management policy, which had to take into account the conflicting interests of the defenders of continued artificial breachings and of those who advocate conditions of a closed estuary which will eventually change into a coastal freshwater lake.

1. INTRODUCTION

Most South African tidal inlets are small or are closed for the greater part of the year because of relatively low run-off in the river catchment and high wave action resulting in strong sand movement along the coast. During the rainy season this situation may be temporarily reversed, when riverine floods lead to natural breaching of the sand bar at the mouth and to the scouring of an estuary inlet to many times its normal size.

The study area is the Bot River Vlei, a large shallow triangular lagoon, 7 by 2 km in extent, situated in a wide valley between the coastal townships of Kleinmond and Hermanus, about 100 km SE of Cape Town (Figure 1). Historical reports from the 19th century (Koop, 1982) indicate that the Bot River Vlei once was an open estuary

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which was used as a harbour for small vessels shipping grain from the fertile district of Caledon to Simonstown. At present the lagoon is separated from the sea by a massive dune belt which, because of a combination of artificial influences in the catchment as well as at the sea front, and a natural overflow system to an adjacent estuary, cannot be breached by natural forces.

At times, mainly during the rainy winter season, riverine run-off causes flooding of the Bot River Vlei which, although considered by scientists to be natural in the hydrology and ecology of such an estuary, causes concern to the users of the lagoon (property owners, yacht and fishermen and numerous visitors attracted by the recreational value of the lagoon). Reasons for this are:

(a) flooding of low-lying premises and bank erosion;

(b) desalination resulting in mass mortalities of marine and estuarine fish; and

(c) silt pollution rendering the waters and shore of the lagoon unsuitable for recreation.

To maintain its estuarine character and to augment the few natural breachings that occurred from time to time, the Bot River Vlei has been opened to the sea in the past 50 years by artificial breachings about every three years at a sufficiently deep section of the lagoon, namely, west of "Sonesta" (Figure 1). This caused the lagoon to be flushed and permitted seawater and fish to enter it, the salt water contributing at the same time to the flocculation and settling of the remaining mudload in the vlei so that clear-water conditions were re-established.

During the periods of two artificial breachings of the Bot River lagoon in 1981 the Coastal Engineering and Hydraulics Division of the National Research Institute for Oceanology of the CSIR monitored the cross-sectional variation of each of the two artificial mouths after breaching, as well as water levels, discharge and hydrological consequences of the openings on the Bot River system. The aim of this investigation was to provide hydraulic data on the behaviour of the system to be used in conjunction with biological studies, and to collect data on the post-breaching situation for application in mathematical models of estuary mouth dynamics presently being developed within the division.

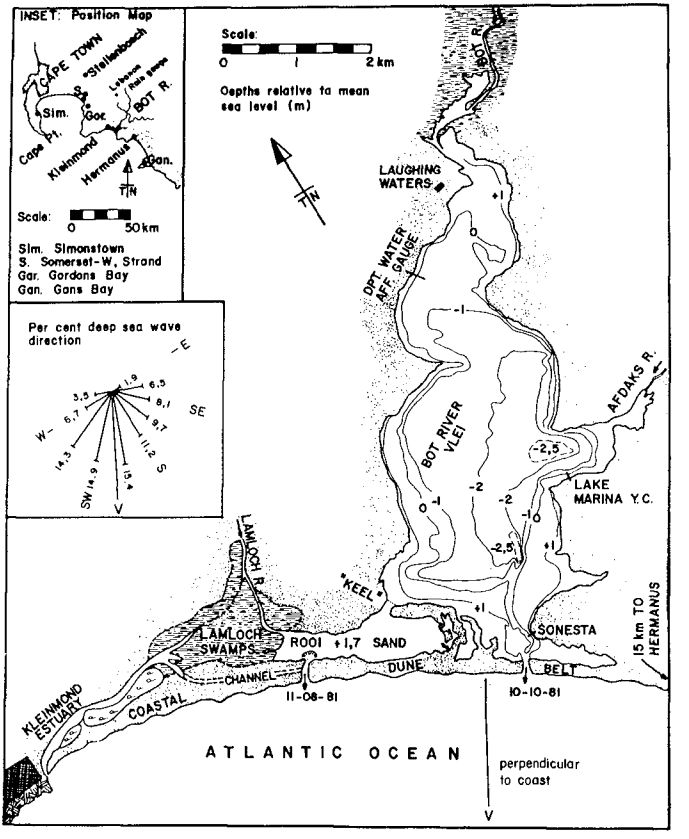

FIGURE 1: BOT RIVER LAGOON SYSTEM (Bathymetry after J. Willis, 1981)

2. PHYSICAL CHARACTERISTICS

2.1 General Setting, Geomorphology, Geology

Although the Bot River drains only a small catchment of about 900 km^2, which is situated in the winter rainfall area of the Cape, and has a mean annual rainfall of only 500 to 600 mm, it forms one of the largest lagoons in the south-western Cape. This is mainly due to the effective damming up of the lagoon waters by a large coastal dune belt along the sea front, 3 to 6 m high and partially vegetated, which is backed by a 100 to 200 m wide vegetated hummock dune hinterland (Figure 1).

The lagoon itself, 7 km long and 2 km wide at the seaward end, lies in a broad valley flanked by the mountains of Kleinmond to the north-west, and Hermanus in the south-west, both 450 m high on the average, and consisting of Table Mountain Sandstone (Ordovician). At the banks of the upper lagoon Bokkeveld shales (lower Carboniferous) outcrop, while the lower sections are surrounded by flats of drift sand and the above-mentioned dune belt on which shrubs grow (Koop, 1982).

2.2 Coastal Hydraulics and Sandbar Characteristics

Because it is exposed to the severe swells and storm waves of the open South Atlantic Ocean the coast at the Bot River mouth can be regarded as a **high-energy coastline.** Maximum wave heights of 8,7 m are recorded (Swart et al., 1982), while the average significant wave height is 3,5 m (Rossouw et al., 1982). As can be seen from the wave rose in Figure 1 the percentage occurrence of deep sea waves is the highest from the south-westerly sector, with a maximum of 15,4 per cent from SSW.

The wave rose in Figure 1 shows that 52,8 per cent of the incident waves arrive at the coast from the south-east. This, together with a number of visual observations such as the movement of turbid water masses flushed out of the lagoon during the artificial openings of mouth channels in 1981, indicates a **predominantly north-westerly longshore drift.**

The strong sand movement along this coastline causes relatively fast closure of any inlet openings by sand bars as soon as the fresh water flow from within the lagoon decreases, usually during the dry summer season.

In the coastal dune barrier there are two potential breaching sites which, according to cartographic evidence and local information, are opened by natural means only

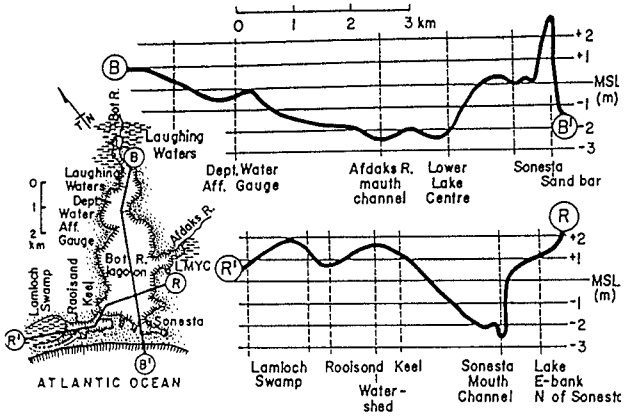

FIGURE 2: BOT RIVER LAGOON, Cross sections

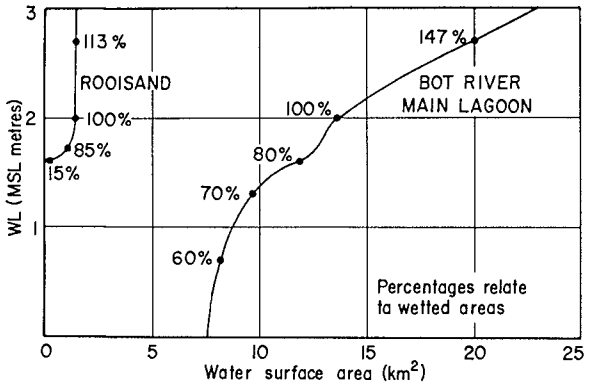

FIGURE 3: WATER LEVELS AND WETTED AREAS, Bot River main lagoon and Rooisand

every ten to twenty years, apparently under a combination of extreme conditions such as river floods and high spring tides.

The one site, at Sonesta, is indicated by a large syncline in the dune ridge, 250 to 300 m wide, and by a deep water channel leading from the shallow lagoon to the gap in the dunes (Figures 1 and 2). This has been formed by continuous, mostly artificial breachings every two to three years, but the mouth itself is usually closed a couple of months after a breaching. Conspicuous 8 to 10 m high bare transverse sand dunes are formed at the north-west bank of the breaching gaps by the strong south-easterly summer winds blowing across the large zone of unconsolidated sand produced by these breachings. From these dunes sand is also driven by wind action to an ever growing shoal at the north-westerly inner (lagoon) side of the mouth area.

In August 1981 another artificial opening was created in the Bot dune barrier at the westerly end of the shallow **"Rooisand"** lagoon, a westerly shallow side arm of the Bot River system (Figure 1). This mouth, which was about 50 m wide, was also closed by a sand bar only three months after the breaching.

There are also a number of natural, smaller transverse gaps in the dune barrier through which sea water washes occasionally. This happens only when equinox spring high tides coincide with high waves, onshore wind and a high water level in the lagoon.

2.3 Bathymetry and Hydraulics of the Lagoon

The isobaths in Figure 1 and two cross-sectional profiles in Figure 2 show that the lagoon is generally deeper along the easterly banks and that the deep-water areas are congruent with the thalweg of the ancient Bot River which existed when the valley was not yet flooded by the marine transgression to form the present lagoon ("Flandrian Transgression", about 18 000 years ago; Theron, Du Plessis and Rogers, 1981). The deepest parts of the main lagoon are at about MSL -2,5 m, but on average the lagoon bed is approximately only at MSL -1 m. The high elevation of the sandbar at Sonesta (nearly MSL +3 m) is also shown in Figure 2, cross-section BB^1. Some marginal low-lying areas of the lagoon are flooded only when the water level is high.

TABLE: RELATION WATER LEVELS AND WATER SURFACE AREAS (see Figure 3)

Water level MSL + (m)	Water surface area				Conditions
	Main lagoon		Rooisand		
	Km^2	%	Km^2	%	
2,7	20,0	147	1,44	113	Extreme high water level, July/August 1981
2,0	13,6	100	1,28	100	Average high water level
1,7	-	-	1,09	85	Elevation of Rooisand watershed
1,6	10,9	80	-	-	Water level Sep/Oct 1982
1,3	9,6	71	0	0	Water level December 1982
0,7	8,2	60	0	0	WL when lagoon is tidal (October/November 1981)

The relationship between water levels and submerged areas in the Bot River lagoon system is shown in the table above and in Figure 3. This demonstrates that a moderate decrease in water level in the range above MSL + 2 m will rapidly reduce the water surface area of the main lagoon, and vice versa; while decreases in water level below MSL + 2 m have a less radical effect on the water surface. This is due to the extensive shallow bank areas.

Because of the pan-like character of the adjacent Rooisand lagoon and a watershed elevated 1,7 m above MSL in the middle of the lagoon, the response to variations in water level is different, namely, that a slight drop in water level below MSL + 2 m will rapidly decrease the water area and cause complete depletion of the lagoon.

The above-mentioned Rooisand lagoon is of high hydraulic significance to the entire Bot system. This is because it forms an **overflow** from the main lagoon through a bottle-neck ("Keel") into the very shallow Rooisand lagoon (bottom elevation MSL + 1,7 m), and further westward through the "Lamloch swamps" into the Kleinmond estuary and, if this estuary is open, out to the sea. Comparison of cross-sections BB' with RR' (Figure 2) shows that a very high water level in the Bot River lagoon is required to overflow and breach the sand bar at Sonesta (approximately MSL + 3 m). Before this happens the flood water in the lagoon

will escape through the Rooisand-Lamloch overflow system (cross-section RR'). When the levels were very high in 1981 such excess water was even drained from the Rooisand lagoon to the Kleinmond estuary via an open channel through the slack behind the main dune ridge and the Lamloch swamps (Figure 1).

Although the Rooisand-Lamloch overflow represents a hydraulic link between the Bot River lagoon and the Kleinmond estuary it allows only a slow release of flood waters from the Bot system, while the influx of seawater from the Kleinmond estuary into the Bot lagoon is insignificant. **The Rooisand-Lamloch overflow can, thus, never fulfil the role of a fully functional tidal inlet for the Bot River lagoon.**

2.4 The Problem of Restricted Contact with the Sea

The hydraulics of the Bot River lagoon is governed by the seasonal character of the influent rivers (floods in winter, droughts in summer) and by the above-described overflow system from the main lagoon to the Kleinmond estuary (see pp 7, 8) which prevents the lagoon from breaking open naturally. This situation is aggravated by the extraction of water from the catchment for agriculture and forestry and by dune stabilization close to the potential breaching area at Sonesta.

Winter floods cause the water to rise to a very high level of about MSL + 2,7 m which is associated with a **freshening out of the lagoon water, mud pollution, exclusion of the flocculation effect** of saline water on mud-laden fresh water, and a **change from an estuarine to a fresh water lake-type of ecology** including mass mortalities of estuarine fish and increasing growth of limnetic weeds which, in turn, enhances deposition of sediment in the already shallow water body. Flooding of low-lying properties and undesirable bank erosion are other side-effects of high water levels in the lagoon.

The restricted "one-way" overflow system through the Rooisand lagoon and the Lamloch swamps to the Kleinmond estuary prevents discharge of mud-laden water from the main lagoon and the entry of seawater by tidal exchange, as well as the recruitment of fish from the sea.

3. FLOODING AND ARTIFICIAL BREACHINGS IN 1981

3.1 First Breaching at Rooisand in August 1981

After exceptionally high rainfalls in 1980 and 1981 the conditions in the Bot River Vlei became critical with regard to high water levels, mud pollution and desalination. By the end of July 1981 the water level in the Bot

River lagoon was very high at MSL + 2,69 m and the salinity was very low at 5 to 7 ppt at the beginning of August 1981 (Figure 6), while a large amount of mud was suspended in the water. In order to save low-lying properties from inundation, but also to minimize damage to the ecology of the lagoon, which apparently had already begun to adapt itself to near-freshwater conditions, the Department of Nature Conservation of the Province of the Cape of Good Hope decided on an opening at the western end of the very shallow Rooisand lagoon; this was done on 11 August 1981.

The most significant features of the breaching were:

(a) A spectacular increase of all dimensions of the initial channel cut by caterpillar within 24 hours from 11 to 12 August and the shaping of a wide flat erosion funnel into the lagoon bed by back-cutting erosion. The width of the channel increased from 5 to about 50 m, the length of the channel doubled from about 150 to 300 m, and the depth increased from 0,5 to 2,5 m. The erosion funnel was 165 m wide and 85 m long. By the end of August 1981 the scouring of the mouth appeared to have stabilized after the water level in the lagoon and the discharge through the mouth had subsided. The flow over the edge of the erosion funnel and over the steep "chute" down into the channel ceased between 8 and 9 October, the Rooisand mouth was found to have been closed on 4 November 1981 by a sandbar.

(b) A rapid increase in flow through the channel from about 1 to 40 m^3/s within the first two days after the opening and a decrease to 7,5 m^3/s on 25 August 1981. After a brief increase after heavy rainfalls to 26 m^3/s on 1 September the flow decreased steadily towards the beginning of October and ended on 9 October 1981, after which the mouth sanded up quickly from the sea side. Some typical cross-sections of the mouth channel during the breaching and a flow diagram of the Rooisand opening are shown in Figures 4 and 5.

(c) A lowering of the water level in the Bot River lagoon system as illustrated by the hydrograph in Figure 6. The maximum lowering was from MSL + 2,69 m before the opening (11 August) to MSL + 1,96 m (25 August), that is, 0,73 m. After the heavy rainfalls from the end of August to September the water level rose again to MSL + 2,15 m but fell slowly to below MSL + 2 m at the beginning of October 1981.

In contrast with the variations of water level in the main lagoon the drop in the water level at the Rooisand mouth (scour-edge) was more marked but the water level did not

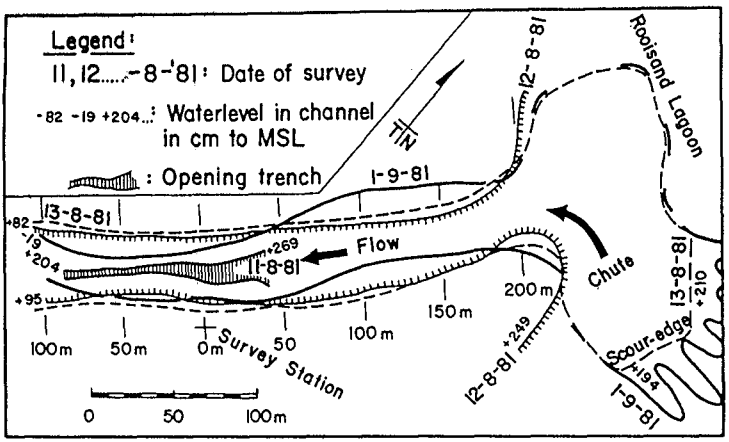

FIGURE 4: Breaching at "Rooisand", 11 August 1981

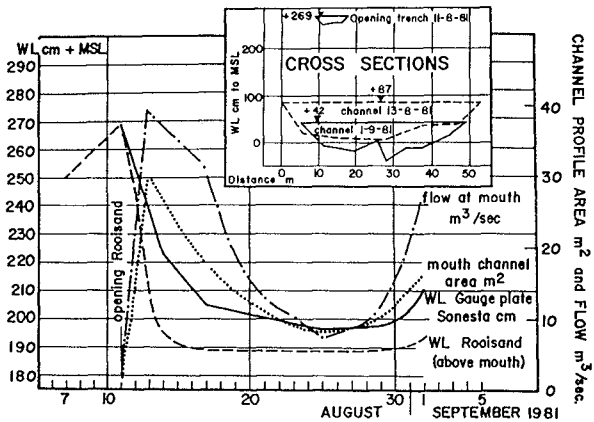

FIGURE 5: ROOISAND BREACHING, hydrograph and channel cross sections (inset)

rise after the heavy rainfalls at the same rate as it did in the main lagoon. This meant that any excess in flow into the Bot River Vlei reached the outlet at Rooisand only after being retarded considerably.

3.2 Second Breaching at Sonesta in October 1981

Although the opening at Rooisand on 11 August caused the desired lowering of the water level, no seawater could enter the main lagoon, because of the elevation of the bottom of Rooisand (MSL + 1,7 m). Subsequent to the above-mentioned rainfalls more flood water and mud entered the lagoon reducing the salinity to a mere 2 ppt and causing deterioration of the water quality. This resulted in a sudden mass mortality of adult estuarine fish at the beginning of October which necessitated a further breaching of the Bot on 10 October 1981, this time at the usual site west of Sonesta where a deep channel in the lagoon lends itself to effective breaching.

The conditions at the opening at Sonesta were different from those at Rooisand insofar as the water level had already been lowered by the Rooisand breaching. The deep water channel upstream of the Sonesta cutting, however, caused a similar behaviour of the cross-section of the mouth. The main difference was that, because of the deep water channel behind the cutting, this opening caused depletion of the lagoon from MSL + 1,88 m down to MSL + 0,7 m within one day of the breaching, that is, by 1,18 m. The lagoon became tidal immediately after the opening of the mouth, with a tidal range of about 0,15 m (see Figure 6). A side-effect of the lowering of the water level was the complete drying out of the shallow margins of the lagoon including Rooisand.

Although the mouth remained open only until 2 December 1981 this breaching can be considered as having been successful in terms of ridding the lagoon of decaying fish cadavers and of suspended mud which was flushed out to sea with every ebb tide. Also, the salinity increased to about 30 ppt, and the lagoon waters became clearer after one week. The disadvantage of the breaching was a substantial loss in water volume and water surface, the latter being reduced to about 60 per cent of the water surface prior to the Rooisand breaching; which had a severe impact on the ecology of the system, mainly because of the exposure of the shallow water habitats around the lagoon.

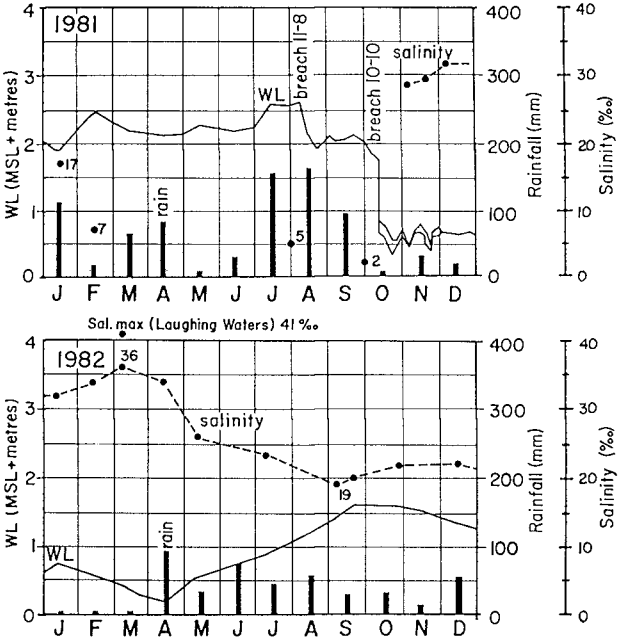

FIGURE 6: WATER LEVELS, RAINFALL AND SALINITIES, BOT RIVER LAGOON, 1981, 1982

Measuring Stations
- Water Levels: Dpt. Water Affairs Gauging Station
- Rainfall : Lebanon Forestry Station
- Salinity : Lake Marina Yacht Club

4. POST-BREACHING CONDITIONS IN 1982

4.1 Conditions in the Main Lagoon

The hydrograph in Figure 6 shows that the dry, hot summer season 1981-82 (December 1981 to April 1982) was marked by decreasing water levels and increasing salinities, which are typical for the summer conditions in the south-western Cape region. The lowering of the water level from the period when the lagoon had an open inlet and was tidal (October and November 1981) to the extreme low-water level in April 1982 was from MSL + 0,7 to MSL + 0,2 m, that is, 0,5 m; while the salinity increased from about 30 ppt (October/November 1981) to 36 ppt in March 1982, or even to 41 ppt at the inflow arm of Bot River Vlei at "Laughing Waters". This was caused by high evaporation rates and no inflow from the river.

The onset of the rainy winter season in April 1982 reversed this condition with the river flow increasing and the water level rising steadily in the main lagoon to a maximum of MSL + 162 cm, and an inverse proportional decrease in salinity to about 20 ppt in September 1982. With the increasing water levels most of the shallow marginal areas of the lagoon were submerged again (see table on page 7 and Figure 3).

Rainfall and run-off in 1982 were rather moderate, with low rains equally spread from April to December. Figure 6 shows that the hydrological reaction of the lagoon at the beginning of the dry summer season 1982/83 with regard to decreasing water levels and increasing salinities was mild. By the end of 1982 the water level was at MSL + 128 cm and the salinity 23 ppt (see table on page 7 and Figure 3).

4.2 Conditions at the Rooisand-Lamloch system

During the post-breaching period after October 1981 significant hydrological developments took place in the Rooisand-Lamloch-Kleinmond overflow area.

When that half of the Rooisand lagoon east of the low watershed in the centre of Rooisand (elevation MSL + 1,7 m; see Figure 1) became dry because of the Sonesta breaching, a confined little lagoon, 0,5 km long and 0,3 km wide, had formed in the westerly half of Rooisand by damming up behind the ever growing sandbar plugging the previous Rooisand inlet.

Being closed off from the saline waters of the Bot River lagoon by this watershed (which remains effective as long as the water level in the Bot River lagoon does not exceed MSL + 1,7 m), and receiving fresh water from the Lamloch

River during the winter season (2,9 m^3/s on 13 July 1982) the newly formed Rooisand-West lagoon changed into a small fresh-water lake, which showed all the attributes of a coastal fresh-water ecosystem, with regard to bird life, fish population and aquatic vegetation. The decrease in salinity in this lake was from 32 ppt in February 1982 to 18 ppt in April, 2 ppt in July and finally to zero salinity in September 1982.

Subsequently the water level in the Rooisand-West lake rose substantially so that the water started to **leak over from west to east** over the shallow watershed in the middle of Rooisand. Because the water level in the main lagoon was not able to keep pace with that in the Rooisand-West lagoon the unique situation arose in mid-winter 1982 that water from the Lamloch River freshened the water of the main lagoon (0 to 6 ppt salinity at the "Keel" in September 1982), and the usually **east-west orientated overflow** from the main lagoon into the Lamloch-Kleinmond system was **reversed** into an **overflow from west to east.** At this stage the entire Rooisand lagoon, including the extensive hummock dune area between the high sand dunes west of the previous Sonesta opening and Rooisand (Figure 1), was flooded with fresh water.

Only at the end of September and in October 1982, when the flow from the small Lamloch catchment subsided did this west-east overflow cease, while at the same time the level in the Bot River main lagoon rose to a maximum of MSL + 1,62 m, so that the "Keel" was filled rapidly with saline water (22 ppt on 28 October 1982).

Towards the end of the year, when the water level in the main lagoon decreased to about MSL + 1,3 m the water retreated from the area of the "Keel" leaving the entire Rooisand-East lagoon dry once again. At the same time, the fresh-water body at Rooisand-West had also decreased in extent and depth forming again a pool confined between the Rooisand watershed, the high sand bar at the previous Rooisand opening and the Lamloch swamp area, as happened shortly after the breaching at Sonesta during the summer of 1981/82.

5. SUMMARY AND DISCUSSION

During the present century the Bot River Vlei, having once been an open estuary (Koop, 1982), has changed character and has tended to become a coastal lake without an open connection to the sea. In such a stagnant water body increasing accretion of fluvial-terrestrial sediments will cause conversion into a marshland, similar to some marginal sections of the Bot River lagoon.

This is caused by extraction of water and soil erosion in the catchment by agriculture and forestry, and the stabilization of the barrier dune at possible sea inlet sites. A natural long-term trend of terrestrial sedimentation of low-lying coastal wetlands, together with the strong longshore sediment movement which closes inlets effectively, also contributes a great deal towards the closure of lagoon mouths and the formation of swampy fresh water lakes in estuaries.

In the case of the Bot River Vlei the local population have succeeded in counter-acting this trend by artificial breachings of the lagoon at Sonesta during winter flood conditions. Although such breachings remained open for only limited periods (up to half a year) they caused a re-establishment of estuarine conditions which lasted for periods of two to three years.

Recent (still incomplete) ecological studies have indicated that the ecosystem of the shallow water margins of the lagoon can be damaged by the abrupt drainage resulting from breachings. The argument which had arisen subsequently between ecologists and the defenders of regular artificial breachings shows the urgency of the establishment of a **scientifically supported management policy** to control the conditions in the Bot system.

The conditions in this respect were particularly critical during the flood year of 1981 because of the large extent of inundated shallow water areas during the relatively long period of more than half a year, which, after the artificial breachings in August and October 1981 were drained within hours.

It appears that the key to future decisions can be found in the bathymetry and the associated hydraulics of the lagoon (see Section 2.3). The Bot River lagoon consists of a deep-water zone in its central parts, and of marginal shallow water areas above a bottom level of approximately MLS + 1 m. These shallow water areas increase rapidly when the water rises to levels of higher than MSL + 1,6 m. Flooding with water levels of 2,7 m as recorded in 1981 will, therefore, abnormally increase the flat areas under water (see Figures 1 and 3). On the other hand, any lowering of such a high flood level must cause radical drainage of these flat areas, with an unavoidable impact on the ecology.

This suggests that from the point of view of hydraulics considerations, a viable proposal for the future management of Bot River Vlei would be **not to allow the water to flood the shallow margins of the lagoon, that is, not to rise to more than MSL + 2 m, and to breach the sand bar artificially before this happens.** In this way the establishment

of a shallow water ecology which will be destroyed by any slight or radical lowering of the water level, by artificial or natural breachings (the latter may still possibly occur!), or, by evaporation during the dry summer months, could be avoided. At the same time all the disadvantageous effects of flooding while the lagoon mouth is closed, such as mud-pollution, desalination, extermination of valuable marine/estuarine fish species and the damage to low-lying properties and bank erosion could be prevented.

The investigations on the Bot River Vlei are being continued with the aim of defining an optimum management policy based on all available information from hydraulic, hydrological, sedimentological and ecological research.

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