APPENDIX 6

FLUVIAL AND AEOLIAN COASTAL SEDIMENTATION PROCESSES AND THEIR RELATION TO THE CONDITION OF THE SWAKOPMUND BEACHES AND THE ENCROACHMENT OF DUNES FROM THE SOUTH TOWARDS SWAKOPMUND

A summary of available literature.

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1. BACKGROUND

A computer based literature search on coastal sedimentation processes and dune migration along the southern African west coast was done. From this list some 30 publications and reports were selected as having relevance to the KARS study and these were studied in more detail. The present summary was compiled from the information gathered from these reports and publications. What became evident when studying the literature, was that the database of physical measurements relating to sedimentation processes along the Namibian coast, and in particular, the areas closer to Swakopmund, is very restricted. Although numerous studies were done through the years, little basic data had been added through the years to expand the data set used in the first analyses. The data referred to here includes information on waves, sediment loads, climatological data, reports of actual observations made by individuals during periods when the Swakop and other rivers were in flood or information extracted from archives, etc. What did, however, change over an approximately 30 year period, is the way in which the data has been analyzed and interpreted over the years. New techniques were employed, taking into account the additional data, and in general, a better understanding of coastal processes has developed over the years. This all led to the current state of knowledge on coastal and dune processes reported on in this document.

At a meeting of the KARS Working Group held in Swakopmund on 14 July 1997 it was agreed that the CSIR would compile a summary document which would be reviewed by coastal engineers from the CSIR offices in Stellenbosch, some of whom had been involved in many coastal engineering studies on the Namibian coast. This report contains the overview of the current knowledge base on the sedimentation along the Namibian coast with particular reference to the influence the Swakop River, when in flood, has on marine processes, and our knowledge on the movement of sand and dunes, and the contents was presented to the KARS Working Group Meeting held in Swakopmund on 30 September 1997.

2. FLUVIAL PROCESSES: IMPORTANT BASIC INFORMATION SOURCES

2.1 Type of information

The available information can be arranged in the following groups:

Actual measured information

- Human observations recorded in archives

Each of these groupings also has a accuracy or reliability component to it. The first group, obviously is the most reliable as it contains actual measurements of conditions in the coastal environment. The information contained in the other group, is less reliable, but cannot be disregarded as it often contains crucial information and a description of what happened during abnormal events (large floods in the Swakop

River for example) when accurate physical measurements can anyway not be done. These 'abnormal' events and observations made during these, are often the ones that influence the sediment transport along the coast most. For this reason, such anecdotal information available from press reports, archived documentation and verbal communication and memory is a very important and often the only, source of information.

2.1 Actual measured information

Datasets and flood events

The more important data sets that have been used in the study of coastal processes along the Swakopmund coast are:

- the rainfall record of the Swakop River catchment and the associated flood events of the Swakop River (Department of Water Affairs and Weather Bureau);
- the amount of sediment brought down by the Swakop River *and* which entered the ocean. In this regard only three values for which some evidence is available and which can be accepted as representing a reasonably accurate reflection of the actual situation are given in Table 1; and
- various measurements of longshore sediment drift rates by CSIR.

The years 1904, 1917, 1923, 1931, 1934, 1942, 1949, 1950, 1963, 1974, 1985 are known as years in which relatively large floods came down the Swakop River. Nevertheless, reliable estimates/calculated volumes of the amount of sediment that entered the delta for each for these flood events are not available.

Table 1: Swakop River runoff and sediment deposited into the delta.

Year	Swakop River runoff (x 10^6 m^3)	Sediment volume deposited in the delta (x 10^6 m^3)	References
1934	500	35	Stengel (1964); Zwamborn (1969); CSIR (1993b)
1962/63	300	5	Stengel (1964); CSIR (1993b)
1973/74	190	1	Stengel (1964); CSIR (1993b)

Mechanism for sand movement along the coast

Although non-breaking ocean waves also move sediment, most of the sand moved along the coast is transported inside the surf zone where wave breaking is the primary

agent for suspending and moving sand along the sea bottom. Waves approaching the coastline obliquely generate longshore currents in the surf zone. These currents can usually not entrain large volumes of sediment on their own, however, sand stirred up by the breaking waves is transported alongshore by these currents. Along an exposed beach, most of the longshore sediment transport occurs from about +2 metres to Mean sea Level (MSL) up to depths less than about 8-10 metres to MSL.

If the longshore sediment transport is interrupted by a obstruction, such as the Mole, accretion of sand will occur on the updrift side and erosion on the downdrift side. The latter is due to the fact that sand that previously fed the downdrift beach, is trapped, thereby preventing it from reaching the downdrift beach.

Longshore transport rates are usually determined by measuring the accretion and erosion rates adjacent to coastal structures and at sand spits, or by using sand tracers or by different kinds of samplers and traps. Detailed studies of sand transport around Walvis Bay were made by the CSIR over many years (CSIR, 1985; CSIR 1993b; CSIR, 1996). The most recent investigations at Pelican Point, Walvis Bay (CSIR, 1996), have provided the most accurate figures for the longshore drift rate at Pelican Point (Schoonees, verbal comm. 1997). Longshore drift along the Namibian coast is generally in a northward direction. In the case of the Walvis Peninsula, the transported sand deposited at Pelican Point, and as a result the Walvis Peninsula is growing over time.

The tip of the Peninsula acts as a total sediment trap for the longshore transport and virtually no sand is transported away from the peninsula across the bay. An analysis of historic data showed that Pelican Point grew at an average rate of 17,4 metres/year between 1885 and 1980. Between 1980 and 1996 this rate increased to 22,6 metres/year on average. Calculations based on the Pelican point information indicate that the net northward sediment transport rate along this part of the coastline is 883,000 m^3/year. This figure should be regarded as currently being the most reliable sediment transport rate available under natural conditions. It is important to note that this figure is half of that calculated for the annual sediment transported after the 1934 flood.

The northward advancement of Pelican Point is expected to continue unless the longshore sediment supply is reduced (CSIR, 1992, 1996). An interruption of the supply could occur if the Sandwich Harbour embayment continues to remain open for an extended period. Shoreline erosion is presently occurring immediately north of Sandwich Harbour as a result of sediment deficit and erosion is likely to continue until the embayment is closed off again by the breached sand spit (Ward, 1991; CSIR, 1992; Ward, pers. comm. , 1997).

The angle at which the incident waves strike the coastline also determine the longshore sediment transport rate. With increasing incidence angle, the potential sediment transport rate decreases (CSIR, 1990, 1993b). In the case of Swakopmund, the incidence angle is larger than at Pelican Point, and therefore the natural sediment transport rate is expected to be less than 883 000 m^3/year at Pelican Point (Barwell and Schoonees, pers. comm. 1997). In a report describing the investigations for a marina at Swakopmund (CSIR, 1993b), the potential longshore sediment transport rate to the north was estimated to be between 500 000 and 1,000,000 m^3/year. In the light of the most recent data from Pelican Point (CSIR, 1996) the lower figure (500 000 m^3/year) should be regarded as the more realistic estimate.

The figure calculated by Zwamborn (1969) based on the sediment available after the 1934 Swakop River flood, namely 1,75 x 10^6 m^3/year clearly represents an abnormal situation and was influenced by the abnormally high volumes of sand available for distribution along the coast after the 1934 flood (verbal comm., J S Schoonees, CSIR Stellenbosch, 1997). What is, however, important to realise, is that although this rate of sediment transport by wave action is possible, it can only happen if sufficient volumes of sediment are available. As early as 1969 Zwamborn (1969) already alluded to the fact that further south, for example at Sandwich Harbour and Walvis Bay, there is no shortage of sediment supply, but at Swakopmund, due to the more rocky nature of the coastline, there is not enough sand available to maintain the sandy beaches. To maintain and continuously build the sandy beaches at Swakopmund, additional source(s) of sand, are required. In this regard the sediment brought down by the Swakop River during periods of flooding is generally being recognised as probably the most important.

Zwamborn (1969) mentioned a figure of 1 x 10^6 m^3 sand that needs to be "imported artificially" annually to the Swakopmund beaches to maintain these as sandy beaches. He referred to three methods to improve and maintain the condition of the beaches. These are the importation of sand, the construction of an underwater breakwater parallel to coast, and the construction of a break water to protect the beach from erosion.

Sand supply to the Swakopmund beaches

Sand movement along the beaches is described by the following conceptual model which has not been validated by any real physical measurements and is based on observational information from different authors.

The dominant SW wave condition and longshore drift provide the transport mechanism to distribute sediment along the beaches of the Namibian coast. Along the southern Namibian coastline (south of Walvis Bay), the Namib dunes and sandy beaches act as the predominant supplier of sediment for distribution in a northerly direction along the coast. The net northerly longshore sediment transport rate along the coast at Oranjemund is of the order of 1,4 x 10^6 m^3/year (CSIR, 1993b) and the net rate at Pelican point is 883 000 m^3/year (CSIR, 1996). Due to the larger wave incidence angle at Swakopmund, the longshore drift rate is expected to be even less than the value at Pelican Point (CSIR, 1993b, verbal comm. J S Schoonees, 1997) and depends also on the availability of sediment. In a 1995 report (CSIR, 1995), the longshore sediment transport rates were again revised using a method described by Schoonees (1995). The revised real net transport rate, taking into account the near

shore rocky areas which is an indication of the scarcity of sediment, is expected to be around 0,5 x 10^6 m^3/year. However, during episodic flooding of the Swakop River, the longshore transport rate could be appreciably higher (CSIR, 1995). Field observations confirmed that some sediment transport also occurs towards the south (CSIR, 1976). A ratio of 95% northbound to 5% southbound sediment transport is generally accepted (CSIR, 1995).

Most authors (Zwamborn, 1969; Swart, 1982; CSIR, 1990; CSIR, 1993b; CSIR, 1993c; CSIR, 1995) consider the Swakop River floods depositing their silt load in the delta, as a major source of sediment to build beaches to the north of the river mouth. The dominant SW wave condition and longshore drift provides the transport mechanism to distribute these sands along the beaches to the north of the mouth. Due to the infrequency of the sand deposited by the Swakop River a cyclic variation in the beach profiles occur in which the beaches formed by the discharge of sand from the river are gradually eroded until an equilibrium is reached between sandy beaches and protruding rocks. At equilibrium, little sand transport takes place and rocks are exposed over large areas in the near shore zone. The beach and near shore zone are in general very steep and causing waves to break right on the coastline. The combination of rock in the surf zone, steep slopes and heavy surf makes most of the coastline unsuitable for bathing.

Conceptual sedimentation and erosion model for the Swakopmund beaches

The model for beach behaviour with time is based on surveys and observations over many years. The Mole has a dramatic effect on the sediment distribution along the coast and in general causes beach stabilisation south of the Mole. This area south of the Mole is, however, directly exposed to the dominant SW waves and therefore very steep beaches which are dangerous and unsuitable for bathing are the result. During periods of low sediment supply (for example 1960, 1970 to 1972, 1996/97), the condition of the beaches are very much the same as before construction of the Mole (1901). Due to the protection provided by the Mole against the dominant SW waves, the surf conditions north of the Mole are, however, much less severe and flatter beach slopes have developed. With increased sand supply caused by large floods of the Swakop River, a sandbar develops between the tip of the Mole and the beach further north. With a decrease in sand supplied from the Swakop River delta, this sand bar is slowly eroded and is moved shorewards by overtopping waves. The deposit of a sand bar can create a lagoon between this bar and the coastline. The formation of this lagoon is objectionable due to water stagnation. Another objection is that it reduces the protection provided by the Mole at the seaward edge of the bar and therefore also the safety of the bathers. The bar is normally eroded away within 2 to 3 years depending on the size of the bar originally deposited.

The beach directly north of the Swakop River mouth is also sometimes affected by coastal processes when a sufficient supply of sediment is available due to flooding of the Swakop River. During major floods a large sediment fan is deposited at the river mouth (for example, after the 1934 flood, Stengel, 1964). With this fan at its mouth, the river has a tendency to meander off to the north, running parallel to the beach. This apparently creates a lagoon behind the beach, which is plagued by stagnation and pollution in the some way as the lagoon at the Mole. This lagoon is eventually also destroyed once the sand deposited by the river is eroded away towards the north by the natural wave action.

An investigation for a marina development to the north of the Mole concluded that despite the sand trapping role the Mole plays when an abundant supply of sediment for northerly longshore distribution is available, the entrance to the marina will become totally blocked during major floods in the Swakop River.

Swart (1982) described sand movement along the Swakopmund beaches in a report on the reasons for beach erosion at Swakopmund. He also identified the Swakop River floods as the main supplier of sand to the Swakopmund beaches, and mentioned that the Mole controlled the movement of sand to a large extent. The expressed the opinion that a state of equilibrium at the beaches is reached 5-10 years after a flood in the Swakop River, without specifying the flood size.

This conceptual model, supported by observations over many years, illustrates the role sediment supplied by the Swakop River and the Mole has on beach dynamics. Similarly, the lack of a constant supply of sand, affects the conditions at the beaches markedly.

Beach, surf zone and river profiles

Physical measurement of beach, surf zone and river profiles were done over a period of almost two years between 1970 and 1972 (CSIR, 1973). On four occasions during this period the Swakop River flowed, but no floods of any significant volume came down the river to influence these profiles markedly or to provide sand for beach construction. The maximum flow in the Swakop River during this period occurred in the period 10-13 April 1972 when approximately 2 x 10^6 m^3 of water entered the ocean (CSIR, 1973).

(i) Beach and sea bottom profiles

Fifty six profiles perpendicular to the coastline along an 8 km stretch of the coast from just south of the Swakop River mouth, to north of Veneta, were measured quarterly during this period. No major sediment deposition by the Swakop River occurred in the few years immediately prior to or during this period. These surveys therefore represent conditions of low sand availability. During this period the beaches were reasonably stable and consisted of a berm of between 4 and 5 metres above LWOST (Lowest Water, Ordinary Spring Tide), with a steep slope varying between 1:10 and 1:20 between this berm and LWOST. Sea bottom surveys also showed rather stable profiles. The maximum change occurred at Profile 10 opposite the Swakop River, where 3,5 metres of vertical change has been recorded during the two year period.

(ii) River profiles

Eight river cross sections were measured in the Swakop River between the coast and 10 km upstream from the coast. Despite enough rain to cause the river to come down, no change in river cross section occurred and also no sediment was supplied to the delta for distribution along the beaches to the north of the river mouth.

Currents

Three recording stations where regular current information was gathered were maintained during this two year period. These were at positions of 500 metres and 1000 metres due west of tip of the Mole and 500 metres west of the Vineta township. More than 95% of the measured current speeds were less than 0,3 metres/second. These currents, however, have almost no influence on the longshore sediment transport as this occurs mainly in the surf zone. Dominant current direction is in the N-NE and SW-SE sectors.

2.2 Observations recorded in archives

Stengel (1964) compiled an excellent summary of all documented information in archives and other sources of all floods of the Swakop River between 1893 and 1963. This work has unfortunately not been continued and no formal records, except those held by DWA are available for the period after 1963.

2.3 Relation between flood volume and sediment deposition in the delta based on observed data.

Three sets of data on flood volume and sediment deposited in the delta are available form the recorded data (Stengel, 1964; CSIR, 1995). This information was used by the CSIR in Stellenbosch during the investigation for the marina at Swakopmund to derive an equation to relate the flood size to the sediment deposition (CSIR, 1993b; pers. comm., H Moes, CSIR, Stellenbosch, 1997). However, on closer inspection of this equation, it became apparent that the predicted values are not realistic at relatively low volume floods (say <50 x 10^6 m^3/year). This is not surprising, as the derived equation is only based on three data points. It is therefore not recommended that this equation be used for predicting the amount of sediment carried towards the coast by floods in the Swakop River.

3. AEOLIAN PROCESSES

3.1 Sources of information

No detail studies of the behaviour of the dunes just south of the Swakop River have been made to date. Information gained from other similar situations, and in particular the Kuiseb delta environment, was therefore used extensively to describe expected dune behaviour at Swakopmund.

3.2 Source of the sand found in the Swakop River.

Visual inspection confirmed that in some areas of the Swakop River bed, aeolian sand is present which has been transported from the dune fields to the south of the river. This is particularly evident opposite the old pump-station in the Swakop River where a large dune has been deposited in the river bed. Grain size distribution information from sediments collected from different depths (up to approximately 2,5 metres) in the lower Swakop River valley between the road bridge and the old pump-station reported by Woodborne *et al.* (1997), confirmed that these sediments are all of fluvial origin and that some are extremely coarse. In this respect the Swakop River sediments differ markedly from those in the Kuiseb River. In the Kuiseb River some 40-50% of the bedload is dune derived (Ward and Von Brunn, 1985). Moreover, Ward and Von Brunn (1985) are of the opinion that the complex linear dunes in the Kuiseb River bed are introduced into the river during heavy floods such as in 1963 (Stengel, 1964).

An important observation made during the measurement of river profiles between 1970 and 1972 (CSIR, 1976), was that the river appears to act as a natural barrier for wind borne sand transported from the south and no evidence could be found of dune sand from south of the river being deposited in the river. The shifting sand dunes south of the river end abruptly at the southern river bank and do not extend in or across the river bed. The reason for this phenomena was, however, not investigated. Based on this observation the authors concluded that practically no, or very little, dune sand reaches the sea via the river.

3.3 Wind patterns

The dominant wind direction at Swakopmund is in the WSW-SW sector for 43% of year. Next most important direction is north for 9% of year. WSW predominates though wind velocities seldom exceed 10 metres/second (36 km/hour). Strongest wind occurred usually in Autumn, with easterly winds which attain velocities of up to 54 km/hour (CSIR, 1976). Similar wind directions were observed by Ward and Von Brunn (1985) and others for the Kuiseb delta region. Average wind velocity in the Kuiseb delta is however, much higher than at Swakopmund and velocities in excess of 35 km/hour are a regular feature and occur throughout the year (le Roux, 1974; Ward and Von Brunn, 1985). In general the south westerly winds along the coast decrease in intensity towards the north (le Roux, 1974).

3.4 Potential sand and sand dune movement and direction

Detailed analysis by Barnard (1975) and Ward and Von Brunn (1985) of information collected for the Kuiseb area indicated an overall northerly to north easterly migration of coastal as well as more inland dunes.

Barnard (1975) calculated average horizontal movement of 9,3 m/year for sand dunes in the Kuiseb delta which were between 10 and 13 metres high. Recent aeolian sediment transport rates calculated from measured wind speeds indicate that potential transport rates of 84 m^3/metre/year at Walvis Bay (pers. comm. L Barwell, CSIR Stellenbosch). According to Barwell, dunes with heights less than 10 metres, can move at rates between 5 metres/year and 20 metres/year in a NE direction. Wind speeds in Swakopmund are, however, significantly lower than at Walvis Bay and dune movement is therefore also expected to be significantly less than the rates given for Walvis Bay.

Ward and Von Brunn (1985) have noted that significant sand accretion occurs around perennial grass (especially Stipagrostis sabulicola) during wind storms. The hindrance to sand movement caused by vegetation (in this case reeds) was also noted in the Swakop River bed near the road bridge (Schneeweiss, 1997). In addition, topographical features like trenches in the sand mining area upstream of the road bridge, trap wind blown sand effectively and prohibit the encroachment of sand towards Swakopmund.

3.5 Conclusion

Comprehensive studies will be required to make accurate predictions around sand and dune movement into the Swakop River at Swakopmund (L Barwell, pers. comm., 1997). However, despite indications of some sand movement into and accumulation in the Swakop River bed from the south, it is not believed that this is a serious threat to increased sand accumulation encroaching on Swakopmund.

During the field visit and associated discussions on the possible encroachment of aeolian sand on Swakopmund, the Working Group concluded that sand blown into the Swakop River and eventually crossing it, is not likely to be influenced materially by flood events, with or without the KARS dam. A major concern regarding dune movement relates to the long term possibility, in the absence of *major floods*, for barchan dunes to cross the river at Km 3 onto land identified for future residential development.

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