APPENDIX 5

THE AGE OF SEDIMENTS IN THE SWAKOP RIVER

A preliminary survey of the sediment in the mouth of the Swakop River to assess the potential impact of Rössing Uranium's proposed dam in the Khan River, with reference to the background impact of ongoing sand quarrying operations in the Swakop River

S. Woodborne, J.C. Vogel and G. Collett
Quaternary Dating Research Unit
CSIR
PRETORIA

Commissioned by Rössing Uranium Limited
Swakopmund
Namibia

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Executive summary

The nature of sedimentation at the mouth of the Swakop River is assessed through historic observations and dating of the sediments in the river bed. The findings can be summarised as follows:

Three distinct Members are identified in the riverbed sediments at the mouth of the Swakop River:

Member 1 consists of approximately 1.5 m of silty sand apparently accumulated before 9 000 years ago.

Member 2 is composed of approximately 50 cm of coarse gravelly sand that gave an age of between c.350 and 100 years.

Member 3 is a superficial layer of approximately 40 cm of silt from 20th Century floods.

Most of the sediment deposited by the substantial floods of 1934 and 1963 has been removed by subsequent small floods an shoreline erosion.

The gravelly sand, Member 2, apparently forms the lowest level to which floods are able to erode under the current energy regime at the Swakop River mouth.

Coastal sedimentation is punctuated by river input, but is ultimately determined by the rate of sediment dispersal in the sea.

It may be tentatively concluded that the construction of a dam in the Khan River will have negligible influence on sedimentation at the mouth of the Swakop River. Only the largest present day floods contribute to this, and they should not be significantly lessened by upstream damming.

Extensive sand quarrying may disturb the balance between erosion and deposition that has developed in the bed of the Swakop River over the last 350 years.

It is recommended that the following steps be taken:

1. A thorough investigation of the age of the sediments is required to refine the model interpretation of this preliminary report. This would include:

    1.1 Assessment of channel formation and its impact on the observed record of flooding and erosion.

1.2 Refinement of the luminescence techniques to accommodate the specific nature of Swakop River alluvium. This would greatly increase the precision of the dating and allow for the accurate calculation of erosion rates.

2. The impact of sand quarrying on the sediment supply to the Swakopmund beaches should be established in detail if future changes in the river system upstream is reliably to be assessed.

Terms of Reference

Mr R. Schneeweiss of Rössing Uranium commissioned this research after R. Meyer of the CSIR informed him of the potential to address the problem of sedimentation through dating. Further consultation took place between R. Schneeweiss and Dr J.C. Vogel of the Quaternary Dating Unit (QUADRU) at the CSIR. Dr. S. Woodborne of QUADRU accompanied R. Schneeweiss to the mouth of the Swakop River to assess the potential for dating and to ensure that sampling procedures were adequate. Dating analyses were carried out in Pretoria. Rössing independently commissioned supporting information such as the grain size distribution and the modern survey of the river mouth.

Acknowledgements

R. Schneeweiss of Rössing has made every effort to ensure that this research was done, and has made available the resources at his disposal at Rössing. Of particular help has been the transport arrangements that he made, the grain size analysis of the sediments, the GPS survey of the sampling points and the help in finding historical references.

Table of contents

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The proposed construction of a dam in the Khan River by Rössing Uranium Limited has raised concerns about the impact on downstream ground water and sediment supply. On 6 March 1997 Rössing commissioned the Quaternary Dating Research Unit (QUADRU) at the CSIR, Pretoria, to conduct a preliminary survey of the age and history of sediments at the mouth of the Swakop River. The mandate was twofold:

1. To date the sediments as a baseline observation against which future erosion or deposition can be measured should the project be completed.

2. If the proposed dam in the Khan River resulted in reduced runoff in the Swakop River then, in the light of baseline observations derived in issue 1., to assess the impact that this would have on coastal sedimentation (the beaches at Swakopmund). The objective is to elucidate the relationship between flood deposition near the Swakop River mouth and coastal sedimentation. This is particularly relevant because sand mining has had an impact on the river sediments and potentially the beach sediments. The impact of sand mining needs to be recorded so that a distinction can be made between the long term impact of this operation and any impact that may result from the construction of the dam.

2. SAMPLING

On 11 and 12 March 1997, Dr. S. Woodborne of QUADRU accompanied R. Schneeweiss of Rössing into the relict sand quarries at the Swakop River mouth in order to assess the potential for dating the sediments.

Samples were taken from four locations, three of which were in close proximity approximately 2 kilometres from the present coastline. The fourth location is approximately 10 kilometres inland. The stratigraphy and detail of the vertical provenance of the samples within the sediments is shown in **Figure 1**. A total of 6 sediment samples were taken for luminescence dating, and one for radiocarbon dating. The dating samples are listed in **Table 1**.

Three major sedimentary units were recognised. The basal unit comprising horizontally or slightly cross-bedded silt with a slight orange colouring deposited on bedrock. This was defined as Member 1. Subsequent scrutiny of the section photographs showed two distinct layers within Member 1. The upper was horizontally bedded while the lower was cross-bedded. These were respectively designated Members 1B and 1A. This distinction could not be made in every exposure that was studied. The intermediate sedimentary unit comprises a coarse cross-bedded deposit that is grey in colour with numerous pebbles in the bedding planes. This was designated Member 2. The uppermost unit is also a pale orange silt that was designated Member 3.

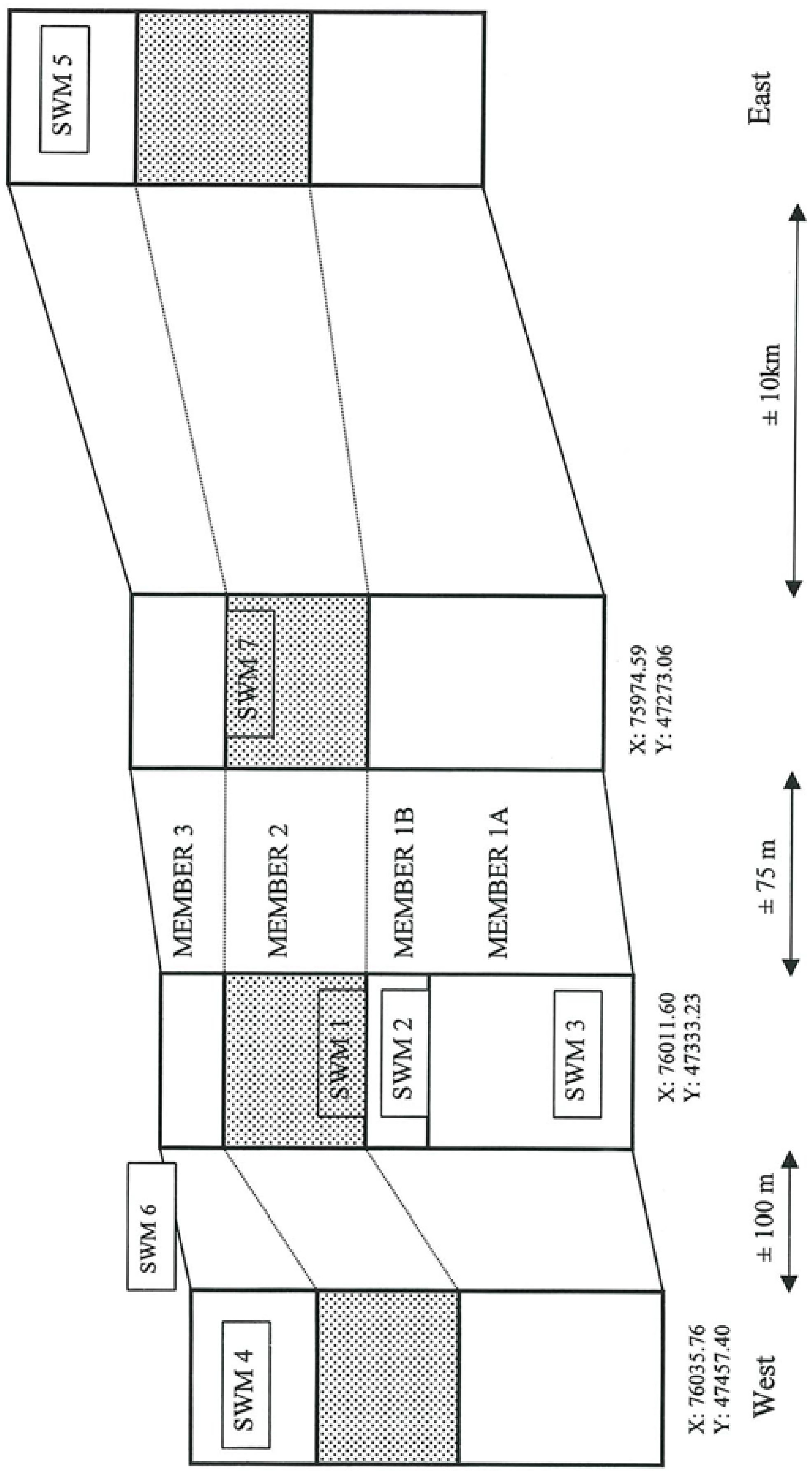

Figure 1. *Schematic stratigraphy of Swakop River sediments approximately 1 km and 12 km from the current mouth. Member 1 and Member 3 are silty sands, and Member 2 is a gravelly sand. Dating samples SWM 1-6 are luminescence dating samples, and SWM 7 is a radiocarbon dating sample.*

Table 1. Dating samples from the Swakop River mouth sediments.

Stratigraphic Unit	Sample Number	Analysis Number	Co-ordinates			Sample Material
			X	Y	Z	
Modern surface	SWM 6	C5979	-	-	-	Sediment
Member 3	SWM 5	C5978	-	-	-	Sediment
	SWM 4	C5977	76035.76	47457.40	7.33	Sediment
Member 2	SWM 7	C5973	75974.59	47273.06	7.74	Vegetation
	SWM 1	C5974	76011.60	47333.23	6.70	Sediment
Member 1	SWM 2	C5975	76011.60	47333.23	6.55	Sediment
	SWM 3	C5976	76011.60	47333.23	5.56	Sediment

The stratigraphy appeared to be consistent over a widespread area at the river mouth, and was also found in exposures several kilometres inland. The relative thickness of the Members varied but at the main point of sampling Member 3 was approximately 40 cm thick, Member 2 was approximately 50 cm thick and Member 1 was approximately 150 cm thick.

The grain size distribution of the sediments was analyzed by Rössing Uranium and made available for this investigation. This is plotted on a Phi scale in **Figure 2**. When plotted on an arithmetic probability scale (not shown here) the distributions can be compared with Rust & Wieneke's (1976) characterisation of sediments from different environmental settings. This confirms that the sediments are all fluvial in origin.

3. BACKGROUND

3.1 Background to Luminescence dating

Luminescence dating is based on the accumulative effect of radiation damage in crystalline substances. Quartz and feldspar minerals are the main constituents of most sands, and they are both sensitive to radiation damage. This allows for the dating of sediments by luminescence techniques. When the minerals are buried in slightly radioactive deposits the crystals are progressively damaged through time. If they are exposed to heat or light the damage is annealed and in the process they give off light. The amount of light that is produced is dependant on the time since the damage was last annealed, which in this case is the length of time that the grains had been buried.

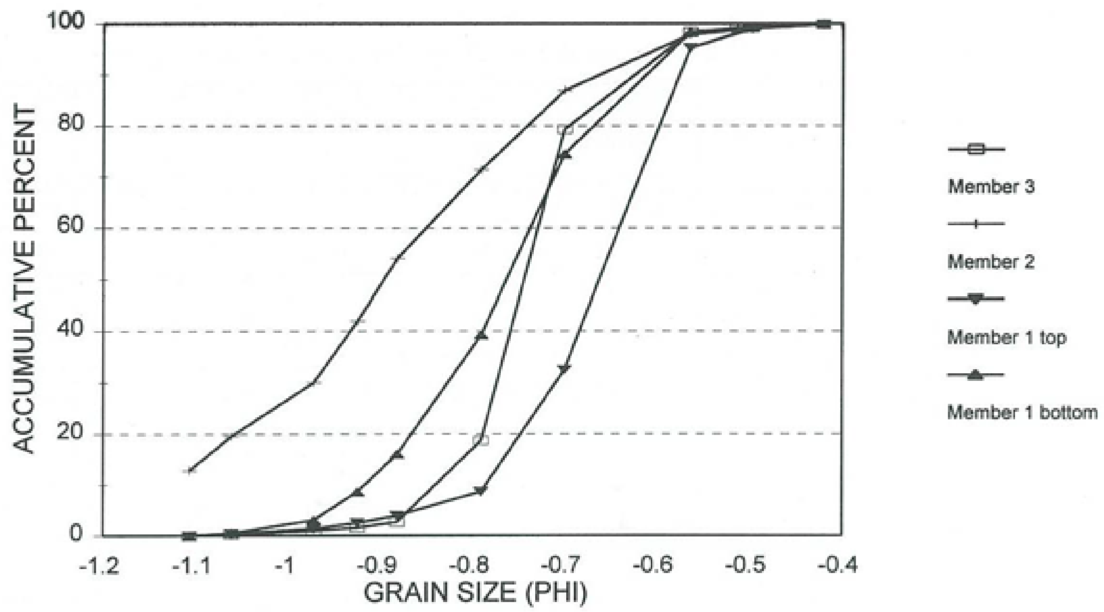

Figure 2. Grain size distribution of Swakop River sediments (courtesy of Rössing Uranium). The distribution is typical of fluvial sediments, although the left skewness of the distribution for Member 2 illustrates the extreme coarseness of this layer.

The Swakop River sediment samples were taken using black plastic coring pipes. They were carefully forced into the sediment so that the structure of the deposit was retained within the pipe and only the original surface layer was exposed to light. During the laboratory analysis the exposed part of each sample was discarded. The samples were transported by air to Pretoria. To accommodate the possibility that the x-ray security system of Air Namibia might artificially irradiate the samples and produce dates that are too old, a modern dune sample of zero luminescence age was taken (SWM 6). The apparent age of this sample could be attributed to the x-rays, and used as a correction for the other samples. Air Namibia, however, were considerate enough not to irradiate the samples.

The Infra-Red Stimulated Luminescence (IRSL) technique is considered most appropriate for dating fluvial sediments because the light (luminescence) signal accumulated before deposition is removed rapidly by exposure to daylight. In the laboratory the sediment samples were chemically cleaned in acid and alkali. The 75 - 150 μm and 150 – 250 μm grains were sieved from the sample and subjected to a magnetic separation to remove metallic and heavy mineral grains. The IRSL measurements of accumulated dose were taken on the high potassium Feldspar grains that were separated on the basis of their density. These grains float in a solution with an SG of 2.58. Five aliquots were dated from each sediment sample. The radiation dose rate of the sediments was measured in the laboratory on untreated sub-samples. The results are presented in **Table 2**.

Table 2. Measurements of the radiation dose rate in the Swakop River mouth sediments, and the equivalent dose that the sediments must have received to produce the observed levels of luminescence. The age of the sediments is calculated from these parameters.

Sample	Stratigraphic unit	Radiation dose (Gy)	Dose rate (μGy/a)	Date
SWM 4	Member 3	<0.6	3734 ± 240	<200
SWM 1	Member 2	1.07 ± .13	3258 ± 214	340 ± 40
SWM 2	Member 1B	38.02 ± 1.07	4358 ± 285	8 750 ± 600

3.2 Background to Radiocarbon dating

A sample of charred woody material was recovered from the top of Member 2 for radiocarbon analysis. While this plant grew it would have assimilated trace amounts of radioactive ^{14}C along with the more common ^{13}C and ^{12}C from the surrounding atmosphere. The amount of ^{14}C that a plant contain remains roughly constant while the plant is alive. After its death the ^{14}C decays with a half life of 5560 years. By measuring the residual amount of ^{14}C in the sample it is possible to calculate the time since the death of the plant.

The sample was pre-treated and measured according to the established method for radiocarbon dating of organic material. The age was measured at 80 ± 20 (Pta 7325).

4. SEDIMENTATION REGIME OF THE SWAKOP RIVER

4.1 Historic Evidence

Flooding events in the Swakop river have been recorded in detail since before the turn of the Century. In this time there have been three major floods. These were in 1893, 1934 and 1963. The geomorphological impact of the latter two floods on the river and beach sediments has been recorded in detail by Stengel (1964). Scrutiny of these observations provides the background that is necessary to interpret the most recent sedimentation in the river bed, and hence to interpret the history of sedimentation that emerges from the dating of the deposits.

Massive amounts of sediment were deposited in the sea and in the river mouth by the 1963 flood and in particular by the 1934 flood. The volume of the 1934 flood deposit is calculated as 40,000,000 m^3. This caused a rapid progradation of the beach until it was approximately 1000 metres from the 1930 beach, while at the same time a uniform 2.5 metre thick blanket of sediment was deposited in the river bed. The 1963 flood deposited 4,500,000 m^3 of sediment, prograded the beach by approximately 100 metres and deposited approximately 1 metre of sediment in the river bed. It is assumed that the 1893 flood, which carried at least 75 % of the volume of the 1934 flood and 160 % of the volume of the 1963 flood, would also have deposited a large quantity of sediment, but no record of this could be found. There is however proxy evidence in the design of the telegraph poles that were installed in the river bed. The precise date of this construction has not been established but it must predate the 1934 flood since it appears on the 1930 survey of the river bed. The poles have a cylindrical foundation that penetrated the sand to the bedrock. On top of this the telegraph pole was set into a concrete base that was designed to provide flood protection. The junction between the flood protection architecture and the cylindrical pylon is about 2.5 metres above the present river bed. Presumably when the structure was designed this junction was at or near the surface of the river sediment. At the time of construction there was 2.5 metres more sediment in the river than there is at present. It is not inconceivable that this was deposited by the 1893 flood since the larger flood of 1934 deposited sufficient sediment to bury the flood protection to a depth of approximately 1 metre.

Between 1934 and 1963 the delta that was formed by the 1934 flood was eroded away, and between 1963 and the present the delta that was formed by the 1963 flood has eroded away. This is the result of wave attrition and longshore transport of the sediment. At the same time the flood deposits in the river also eroded away. Flood protection on a borehole constructed in the river bed in 1957 (R. Schneeweiss *pers. comm.*) establishes the level of the sediment at the time. This is at or near the present sediment level, which implies that the 1963 deposits have been eroded down to approximately the 1957 levels. It also suggests that the 1934 deposit had eroded to approximately the current level by 1957. The only way in which the sediment could erode is during flooding events. It may be concluded that "large" floods, such as those of 1934 and 1963, deposit sediment in the river bed, and "small" floods, such as the 11 floods that reached the Atlantic Ocean between 1934 and 1963, erode the deposit from the river bed. All the floods deposit their sediment load when they reach the sea and prograde the beach in the short term. In the intermediate term the average rate of wave attrition of the beach exceeds the average rate of progradation from small floods. If this were not the case the beach would progressively prograde.

The extent of erosion in the river bed is of interest. It appears as if the pre-1934 sediment level was very similar to the pre-1963 level (marked by the level of the 1957 borehole). A railway line of unknown age is also found buried in these deposits at the interface between Members 2 and 3. Altogether these observations suggest that the surface of Member 2 marks a basal erosion level in the river sediments.

4.2 Dating evidence

The radiocarbon age on sample SWM 7 from the upper surface of Member 2 is 80 ± 20 (Pta 7325). The equivalent date taking into account ^{14}C calibration is 1900 AD. The date is unique in that, for technical reasons, it could not be from a tree that grew for many years, but was rather from on a short lived species. Because old material

may be found on the landscape it is assumed that the subsequent sedimentary layer, Member 3, was deposited some time after 1900 AD. This suggests that the upper surface of Member 2 was exposed sometime after 1900 AD. A likely scenario is that it was the erosional base that had been reached before the 1934 flood. It may be argued that the sample was not incorporated into the deposit during a flood, but instead it was deposited on the sediment surface at the time. This does not affect the interpretation of the date.

The luminescence date on sample SWM 1 from the base of Member 2 is 340 ± 40 (Pl 0108). The sample is from a relict barchan dune that invaded the river bed from the south and was trapped and preserved under deposit laid down by a flood at that time. The sediment in mobile barchan dunes is extensively exposed to sunlight and has a zero luminescence age when deposited so that this date is believed to be an accurate reflection of the date of the flood that buried the dune. The details of the measurements for this and all the luminescence samples are presented in **Table 2**.

The dates for Member 2 indicate that this layer was deposited between 350 and a little less than 100 years ago. The member has some internal structure which suggests several events contributed to the formation. It is suggested that Member 2 represents a series of exceptionally large floods that occurred in previous centuries. It is also a layer that by virtue of being "untransportable" in small floods, represents the basal erosion level that the river can reach under its present energy regime. A further point that can be made on the basis of the Member 2 dates is that the 1934 flood, which is the biggest ever recorded in the Swakop River, contributed very little to the accumulation in this Member. The floods that in the last 350 years that contributed to the bulk of this Member must have been massive, even in comparison with the 1934 flood, and possibly more numerous.

The luminescence age on sample SWM 4 from Member 1 is less than 200 years (Pl0110). This sample is also alluvium, and the spread in age determinations between 200 and 350 years on five different age determinations suggests that this sample was not sufficiently zeroed by sunlight exposure prior to deposition. In general the dating of alluvium of such young age is considered problematic for luminescence techniques. The age is therefore considered to be less than 200 years based on the analysis, but it is in reality less than 100 years on the basis of its stratigraphic relation to SWM 7.

The luminescence date on sediment sample SWM 2 from Member 1B at the top of Member 1 is 8,750 ± 600 years (Pl 0109). This is alluvial sediment, presumably deposited by a "large" flood. It is possible in alluvium that the sand grains are not extensively exposed to light during transportation. Where this occurs the grains may have a residual luminescence age before deposition. As in the case of SWM 4, a large standard deviation on the date for this layer supports this, but the error that occurs is likely to be less than a few hundred years and is considered insignificant on a sample of such antiquity. The true age of deposition may be a little less than 9,000 years.

The remaining luminescence samples; SWM 3, SWM 5 and SWM 6, have not yet been analyzed because of time and budgetary constraints.

5. Conclusions

The sedimentary history of the Swakop River can tentatively be deduced from a combination of historical records and dating evidence. These suggest that the river has a relatively high sedimentation and erosion rate. Whether sediments erode or are deposited is dependant on the size of any particular flood. "Large" floods deposit large amounts of sediment uniformly over the river bed. "Small" floods erode the sediments. The dating evidence suggests that a substantial flood occurred approximately 350 years ago. At this time very coarse gravel layers, indicative of substantially higher energy levels than the 1934 flood, were deposited. Since that time it has been a barrier against erosion and the depositional and erosional cycles in the river bed all take place above this.

5.1 Impact of damming the Khan River

The construction of a dam in the Khan River may result in reduced run-off in the Swakop River. Small floods may be tangibly affected, but the impact at the mouth will be minimal in that these floods are erosional in nature. Reduced erosion may result in reduced sediment transport into the sea, but since the intermediate term dispersal of the sediment in the sea takes place faster than the deposition from such small floods, the impact on coastal sedimentation will be negligible. In the event of a large flood in the headwaters of the Khan River the dam will initially act as a buffer, but a steady state will be reached in which the water inflow and outflow will be balanced. At this point the flood volume will be the same whether or not the dam is built, and downstream sedimentation will not be affected.

5.2 Impact of river sand quarrying

The high sedimentation rate in the Swakop River mouth suggests that the impact of sand mining will be superficially rectified within a few centuries. The removed sand will be replaced by the next "large" flood that should occur.

It is possible that ongoing sand quarrying could have an effect on sedimentation at the mouth of the Swakop River in the future. The river bed sediments are highly stratified over a large area, and in particular the coarse gravel layer, Member 2, appears to be of fundamental importance. This layer protects the underlying sand layers that make up the aquifer in the river from erosion in "small" floods. The gravel buffer has been disturbed by sand mining, and is unlikely to be replaced by modern flood deposition. The removal of Member 2 could result in enhanced erosion of the river sediments in future which may have a direct impact on sedimentation regime at the beach.

5.3 CONCLUSIONS

In summary it is concluded that no evidence has been found that:

1. the damming of the Khan River would affect sediment erosion or deposition in the lower reaches of the Swakop River,

2. the damming of the Khan River would have a noticeable effect on the coastal sedimentation at Swakopmund.

The Swakop River aquifer near the mouth has been damaged by sand mining and the impact of this will be determined by the flooding events that occur in future.

1. "Large" floods in the future may deposit alluvium in the relict workings and will assist in the functioning of the aquifer.

2 "Small" floods may erode the aquifer resulting in a decrease in ground water quality and quantity.

6. RECOMMENDATIONS

1. Since a dam on the Khan River is likely to enhance ground water quantity and quality in the Swakop River and have negligible effect on coastal and river mouth sedimentation. Interested and affected parties need not oppose the construction of the dam on these grounds.

2. Interested and affected parties should insist on a larger scale investigation into the environmental impact of sand mining in the Swakop River. A minimum requirement should be to date the sediments that are currently being mined in the river bed. The evidence presented in this report is specific to the mouth of the river where sand mining has already terminated. Mining operations are now located several kilometres inland where the dynamic relationships between flooding, erosion and sedimentation may differ.

3. The dating evidence is limited because of limitations in time and budget. Further technical details need to be addressed to confirm the result:

    3.1 A larger scale sampling program needs to be undertaken in order to confirm that the large scale trends are not spurious. Of particular concern is the effect of channel formation and the possibility that significant events are not represented in the sections that were studied. This could not be addressed without a larger survey and more extensive dating program.

3.2 The zeroing characteristics of alluvium in the Swakop River needs to be studied in order to refine some of the dates that have been obtained. This is relevant to samples SWM 2 and in particular SWM 4. In the latter case it should be possible to establish if Member 3 is the relict of the 1934 flood or the 1963 flood. This will allow geomorphologists to calculate the relation between erosion rate and flood size, and possibly to model the impact of aquifer erosion in more detail.

7. REFERENCES

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Stengel, H.W. (1964). The rivers of the Namib and their discharge into the Atlantic. Part I: Kuiseb and Swakop. *Scientific Papers of the Namib Desert Research Station*, **22**.