MAINTENANCE DREDGING REQUIRED AFTER PORT EXTENSIONS AT WALVIS BAY

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Abstract

Walvis Bay, the major port of Namibia, is earmarked for extensions. The extension of the entrance channel and the port can increase the maintenance dredging cost considerably, and if not correctly planned could impact negatively on the nearby Walvis Lagoon. An improved layout for the extended port is recommended, taking into account the sediment transport regime. The future maintenance dredging rate for the extended port is determined to be 720 000 m³/year compared with the 200 000 m³/year for the existing commercial and fishing harbours. The future general cargo quays could be located so as to minimise the influx of sediment into the Walvis Lagoon. It is shown that the water exchange to the lagoon will not be significantly affected.

1. Introduction

The Port of Walvis Bay is situated in a natural harbour along the central Namibian coastline (Figures 1 and 2). This harbour is formed by the Walvis Peninsula with Pelican Point located at its tip (Figure 1; see Schoonees *et al.*, 1998 for more details). The land surrounding Walvis Bay is low-lying and consists of desert sand. Traditionally the port has been operated as two entities, namely, the commercial and fishing harbours; however, at present the Namibian Ports Authority has jurisdiction of the full water area. The ecologically sensitive Walvis Lagoon (Figure 1) is located south of the town of Walvis Bay. This lagoon used to be the mouth of the Kuiseb River, which is a river that rarely reaches the sea except during large episodic floods.

As the only major deep-water port of Namibia and because of the short distance to the central heartland of Namibia (Windhoek) and the existing

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infrastructure, it can be expected that Walvis Bay will be the focal point of future commercial port development in Namibia and the adjacent landlocked regional countries. An extension and deepening of the entrance channel and the port is planned (Figure 3), which could increase the maintenance dredging cost considerably, as well as impacting negatively on the Walvis Lagoon.

A feasibility study (CSIR, 1994) was carried out to assess the viability of the proposed future extensions to the Port of Walvis Bay as shown in Figure 3. The aim of the feasibility study was to use existing information and to evaluate the environmental conditions (waves, current, winds and tides), assess the effect of the proposed port development (Figure 3) on the movement of sediment in the bay, comment on the present port capacity and the navigational aspects of the proposed berth and channel layout and carry out a preliminary ecological investigation into the effect of the development on the lagoon. This paper deals only with the sediment transport and dredging aspects such as the present sediment transport regime, the increased maintenance dredging requirements of the extended port and the effect of sediment transport on the Walvis Lagoon. The paper includes the prediction of mud infill rates and the minimisation of dredging costs without endangering the lagoon.

2. Environmental data

Seven sets of vertical *aerial photographs* are available from 1943 to 1980. These photographs show amongst other things, the development of the port and town, changes to the Walvis Lagoon and the growth of the Walvis Peninsula. The *bathymetry* of the whole Walvis Bay area is shown in Figure 2. From this figure it can be seen that the average water depth in the bay is about -10 m to chart datum (CD = 0.90 m below mean sea level). The main entrance channel to the port is dredged to -10 m to CD.

The *tide* is semi-diurnal with a spring tidal range of 1.44 m. From Waverider measurements obtained in 50 m depth of water outside the bay, it was found that the median significant *wave* height (H_s) is 1.1 m and the median peak wave period is 11.6 s. The 1-in-1 year deep-sea H_s is 3.6 m for Walvis Bay. Wave directions were obtained from voluntary observing ships. The dominant deep-sea wave directions are southerly to south-westerly (89% of the time). This means that Walvis Bay harbour is protected from the dominant waves. The port is, however, exposed to waves from the sectors between west and north which occur only 2% of the time.

Moored *current* buoys and drogues were mainly used in field studies to determine the current regime in Walvis Bay. A clockwise surface current circulation to an anticlockwise circulation occurs in the bay in the ratio 3:1. The velocities of these currents are low, generally of the order of a few cm/s. A diurnal reversal of current directions occurs as well, with clockwise (south-going along the eastern shore) currents in the morning followed by anticlockwise currents in the afternoon. This reversal is brought about by an associated change in wind direction. In the surf zone along the bay, especially along the eastern shore, wave-driven currents are normally dominant. At both Dolfynstrand (Figure 1) and Langstrand (Figure 1), the surf-zone currents are usually northbound, while at the breakwater immediately to the north of the port (Figure 1), the current is southbound. This reversal in the surf-zone current direction is primarily due to diffraction effects. At the mouth of the Walvis Lagoon strong currents in and out of the mouth are found.

Generally speaking, the *material* found on the sea bottom in Walvis Bay consists of fine to medium shelly sand overlain by a soft marine mud layer. Mostly mud is dredged from the port in order to maintain the required depths. Sand is, however, found on the surface of the sea bottom along the shoreline. The present influence of the nearby *Kuiseb River* on the harbour is considered to be small and intermittent because a retaining wall diverts the infrequent major floods away from the bay and port.

3. Sediment transport regime

3.1 Growth of the Walvis Peninsula

The Walvis Peninsula is growing northwards at a rate of 22.6 m/year (Schoonees *et al.*, 1998) because of the northbound longshore transport along its western shoreline. The effect of this growth is primarily to decrease wave action at the harbour even further, since the dominant deep-sea waves are from the southerly to south-westerly sector. The secondary effect of this growth is that the sediment transport rates in the bay will also decrease in time as will be discussed below. However, because the circulation in the bay is wind-driven (and possibly tide-driven as well) this will most probably not reduce the sedimentation of the port significantly.

3.2 Longshore transport

In Schoonees *et al.* (1998) it was determined that the net *longshore transport* is about 860 000 m^3/year along the western shoreline of the Walvis Peninsula. Along the eastern shore of the peninsula a very low net longshore transport can be expected.

Inside the bay, at both Dolfynstrand and Langstrand, the net longshore transport is northbound. The respective potential net transport rates at these sites are about 150 000 m^3/year and 510 000 m^3/year (CSIR, 1985). Immediately to the north of the breakwater north of the port, accretion has taken place. The direction of the net longshore transport is therefore southbound at that location. This is due to a southerly current generated by a gradient in breaker wave height. This gradient is caused by wave diffraction around Pelican Point. Because of this reversal in the net longshore transport direction, an area subject to erosion has to exist between the breakwater and Langstrand. This is indeed the case: a rocky stretch of coastline is found around Dolfynstrand.

At the mouth of the lagoon there is a low net westbound longshore transport as evidenced by a spit on the eastern side of the mouth, which grows westwards, as can be seen on aerial photographs.

For the stretch of coastline between Dolfynstrand and Langstrand, 50 years of growth of the peninsula results in a considerable reduction in the (still) northbound net longshore transport (CSIR, 1985).

3.3 Aeolian sand transport

Wind data collected from 1987 to 1993 south of the town of Walvis Bay have been used to compute seasonal and annual wind-blown sand transport rates. A median sand grain size of 0.29 mm was used.

The results show that, on an annual basis, the dominant aeolian transport is bound between the north-east and the north-west. Considering the position of the town of Walvis Bay and the lagoon (Figure 1), it is clear that the port and its proposed extensions are shielded from the dominant aeolian sand transport. It is only north of the breakwater at the shore connection of the future bulk cargo handling platform (Figure 3) where problems may occur. The influx of wind-blown sand there is estimated to be 15 m^3/year per m of westbound transport.

3.4 Cross-shore transport

Cross-shore transport is not a very important process causing sedimentation in the harbour, because the harbour is situated in a calm area and due to the extensive quays built all along the shoreline inside the port.

4. Dredging

4.1 Analysis of dredger records

Figure 2 shows the commercial and fishing parts of the port. The commercial harbour consists of the main entrance channel and the south-western side of the port while the fishing harbour is situated on the north-eastern side, including the secondary channel.

Dredging has been carried out fairly regularly in the commercial harbour. From 1965 to 1993, major maintenance dredging was performed about every five years. Dredging has also been done by means of a small grab-and-barge dredger on a continuous basis. Figure 4 shows the annual dredge volumes from minor and major maintenance dredging. The volumes given are not *in situ* volumes but hopper volumes; the bulking factor has been estimated to be 1.1. Also shown in Figure 4 is the running annual average rate (that is, the first point is the mean rate over one year, the second point is the mean rate of the first two years, etc.). The running average is about 130 000 m^3/year for the commercial harbour.

It is suggested that annual surveys be performed throughout the whole harbour. These surveys should be conducted before and after major maintenance dredging in order to determine the *in situ* quantities dredged (the so-called in-and-out surveys). At the same time, dredge data should be collected from the dredgers and volumes dredged should be determined as accurately as possible with a number of methods. It is further recommended that the harbour be divided into practical areas where maintenance dredging is to take place (Figure 11 shows these areas for the new proposed harbour layout) and to keep records of the quantities dredged in these areas.

4.2 Prediction of maintenance dredging requirements

Method

A number of techniques have been developed to predict dredging rates in harbours (O'Connor, 1985; Vicente and Uva, 1984; Schoonees, 1994). Most of these techniques are based on survey data being collected over a number of years (often from test pits). Plotting these data shows that in all cases there is an exponential or power law decrease in the depth (due to sedimentation) over time. This principle is used to predict the future dredging rates at the Port of Walvis Bay. The depth of the new channels and new basins is, however, far greater than the existing channels and basins. In theory each channel or basin with a certain relative depth (Ho; Figure 5) and its banks at a certain depth (do) have their own characteristic sedimentation curve in a certain environment. By using curves from similar areas with different depths, curves can be extrapolated to determine the sedimentation in deeper or shallower channels. The existing harbour (including the fishing harbour) has been subdivided into eight areas for this reason.

Surveys were conducted for the different areas on a number of occasions, but only subsequent surveys could be used when no major maintenance dredging had taken place in between. Data from two of the eight areas could not be used. This is because either the data covered only a short period of time and/or the sedimentation (decrease in water depth) was minimal during the particular period and thus within the accuracy of the survey method.

The sedimentation (Ho) and the sedimentation ratio (Ht/Ho; Figure 5) were plotted against time. Power law curves were fitted through the data points (exponential curves did not fit the data as well). The curves for the different areas were compared in order to evaluate the compatibility and to classify them according to the relative channel depth (Ho) and surrounding depth (do). Only the curves for the commercial harbour could be used for calibration purposes (as will be explained below) and eventually the calibrated curves could be extrapolated to obtain representative sedimentation curves for the new proposed layout.

Results

Figure 6 shows the sedimentation and the sedimentation ratio as a function of time for the south-turning circle area from November 1976 to February 1981. The goodness of fit is given by the coefficient of determination (R^2), which is 0.96 for the example in Figure 6.

In order to see if there are trends in the curves with regard to the relative depth (Ho) of the channels, the sedimentation ratio curves were plotted to indicate the relative channel depths (Figure 7). It is shown that the curves for the southern quays, south of the turning basin, the south channel (fishing harbour) and the northern quays all show similar curves while the inner channel of the commercial harbour and the tanker basin are the two extremes. No clear trends can be seen when comparing the relative channel depths. Comparing the depth of the surrounding areas in a similar way also showed that there is not a clear trend, although deepest depths show the highest sedimentation ratios.

Because no clear trends were detected when comparing the sedimentation ratios of the various areas, it was decided to use the average sedimentation ratio of the commercial and fishing harbours (Figure 8). The minimum and maximum curves were used to determine the extreme values (Figure 8).

Calibration

A twofold calibration of the method was carried out: (1) by fitting the power curves to the measured sedimentation of mud (Figure 6 shows an example); and (2), by comparing the computed sedimentation rates with the net average dredging rate in the commercial harbour. In the latter case, the computed sedimentation rate was determined for a specific area by multiplying the predicted vertical sedimentation of mud with the surface area of the specific area. By summing all these computed sedimentation rates for the different areas, the total predicted sedimentation rate was obtained for the particular period under consideration.

The calibration factor was defined as the computed sedimentation rate divided by the measured average dredging rate. Because of this calibration, the required maintenance dredging rates are given in terms of hopper (dredged) volumes. Figure 9 shows the calibration factor as a function of time. The apex of the curve is caused by the fact that the annual dredging rates, which are a linear function of time, are compared with the predicted dredging rates which change according to a power law over time. The average calibration factor is used for the whole harbour. The calibrated sedimentation curve is as follows:

$$Ht/Ho = 0.59\ (10^{0.0118\,t + 0.976})$$

where t = time (months)

Future dredging rates

The best estimate of the sedimentation volume for the total existing harbour is about 200 000 m^3/year (dredged volume), while for the new proposed layout (Figure 10) this value will be about 720 000 m^3/year with minimum and maximum values of about 165 000 m^3/year and 1 661 000 m^3/year respectively (also dredged volumes). The annual dredging rate will increase dramatically for the new proposed layout. This is mainly due to the increased surface area of the basins and channel, but also because of the increased channel depths. Adequate sediment (mostly mud) is available to cause the sedimentation.

4.3 Proposed port layout and influence of harbour extensions on the lagoon

With regard to sediment transport and the associated dredging considerations, it is logical to try and make entrance channels as short and berthing areas as small as possible. (Of course, navigational and other aspects also play a vital role in designing the size of berthing areas.) Applying this principle of minimising areas, the orientation of the main entrance channel should be north-west instead of north (Figure 2). This means that the channel will be about 500 m shorter resulting in approximately 900 000 m^3 less to be dredged if the whole channel is to be dredged from scratch. Naturally an unnecessary cost would result if a completely new channel is dredged; it is much more feasible to use the existing channel and change its orientation when extending the channel. It is recommended that the new seaward portion of the channel should start at the extremity of the existing channel and head north-westwards (Figure 10 shows the new proposed port layout). In this way the channel will not only be 100 m shorter (and thus save on capital dredging), but it will be in a calmer (more protected) area and facing right into the waves requiring less maintenance dredging. In addition, the access to shipping will be easier because of reduced ship motions. For bigger ships the channel will lead straight to the future bulk cargo handling platform.

By further applying the principle to minimise channels and berthing areas, it is suggested that the turning circle in front of, and the access channel to the bulk cargo handling platform (Figure 3) be amalgamated with the main entrance channel as shown in Figure 10. This will not be a hindrance to shipping because at present fewer than one ship visits the port per day. Considering this access channel, only a short length of about 1.5 km of channel will be required. This will be about 2 million m^3 less to be dredged initially. Another saving is to discontinue using and maintaining the two entrance channels. This originally probably stemmed from the fact that the commercial and fishing ports were run by two different controlling bodies. It is recommended that the smaller entrance channel (to the fishing harbour) be left to fill up over time and that only the main channel be maintained. This also applies even if the port is not extended in the near future.

The harbour extensions will have the following effect on the Walvis Lagoon:

- Wave action and therefore wave-driven longshore sediment transport (which is southbound in this vicinity) will be drastically reduced.
- The quays will trap this longshore transport and will severely limit the influx of the finer sediment carried by the clockwise circulation to the mouth of the lagoon. In fact, the circulation pattern will be altered.

Less sediment will thus be available at the lagoon mouth to be transported into the lagoon. Historically the lagoon experienced siltation problems. Therefore the harbour extensions will in fact benefit the lagoon. Because the currents in and out through the mouth are tidally driven, the proposed port extensions will probably not affect the water exchange to the lagoon (which is an important ecological consideration) significantly.

5. Conclusions and recommendations

Presently about 200 000 m^3 of sediment (mainly mud; dredged volumes) is dredged annually from the navigable harbour areas.

Existing survey data have been used to verify that the depths of channels and basins decreased as a power function over time. The method was first calibrated against the sedimentation rates, then calibrated against the required annual dredging rate for the commercial part of the port, and finally used to predict the future dredging rate for the enlarged harbour. A maintenance dredging rate of about 720 000 m^3/year was computed for the total future extended port as shown in Figure 10. All these volumes are dredged volumes; divide by the bulking factor of about 1.1 to obtain an estimate of *in situ* volumes. Adequate sediment (mostly mud) is available to cause this sedimentation.

The construction of the future general cargo quays on the south-western extremity of the port will most probably limit the influx of sediment into the Walvis Lagoon, thereby benefiting the lagoon. Because the currents in and out through the mouth are tidally driven, it is unlikely that the port extensions will significantly affect the water exchange of the lagoon.

Applying the principle of minimising channel lengths and berthing areas, the originally anticipated extensions (Figure 3) have been adapted to the layout shown in Figure 10. Considerable savings in both capital and maintenance dredging are the result.

Hydrographic surveys should be conducted before and after major maintenance dredging in order to determine the *in situ* quantities dredged as accurately as possible. At the same time, dredge data should be collected from the dredgers in order to determine the volumes dredged as accurately as possible. It is further recommended that the harbour be divided into practical areas where maintenance dredging is to take place and to keep records of the quantities dredged in these areas.

Acknowledgement

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References

CSIR (1985). Sediment transport and coastline changes at Walvis Bay. *CSIR Report* C/SEA 8544, Stellenbosch (in Afrikaans).

CSIR (1994). Feasibility of port extensions at Walvis Bay. *CSIR Report* EMAS-C 94031, Stellenbosch.

O'Connor, B A (1985). Siltation in navigation channels, dock entrances and marinas. *Three-day Short Course*: Dredging for waterways and harbours, Dept. Civil Eng., University of Liverpool, Liverpool.

Schoonees, J S (1994). Sedimentation of harbour entrance channels. *CSIR Research Report* 716, Stellenbosch.

Schoonees, J S, Lenhoff, L and Raw, A J (1998). Preventing natural breaching of the major sand spit protecting the Port of Walvis Bay. *26 Intern. Conf. on Coastal Eng.*, ASCE, Copenhagen (in press).

Vicente, C M and Uva, L P (1984). Sedimentation in dredged channels and basins. Prediction of shoaling rates. *19 Intern. Conf. on Coastal Eng.*, ASCE, Houston, Texas. Vol. 2: 1863 - 1878.

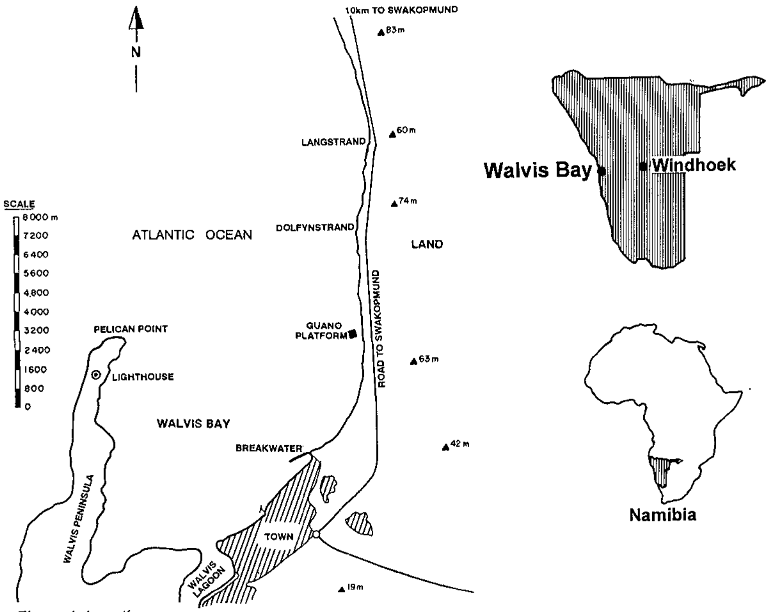

Figure 1: Location map

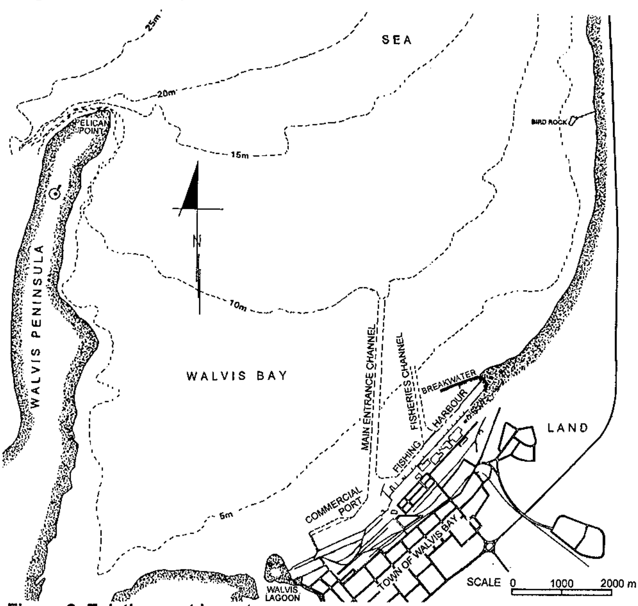

Figure 2: Existing port layout

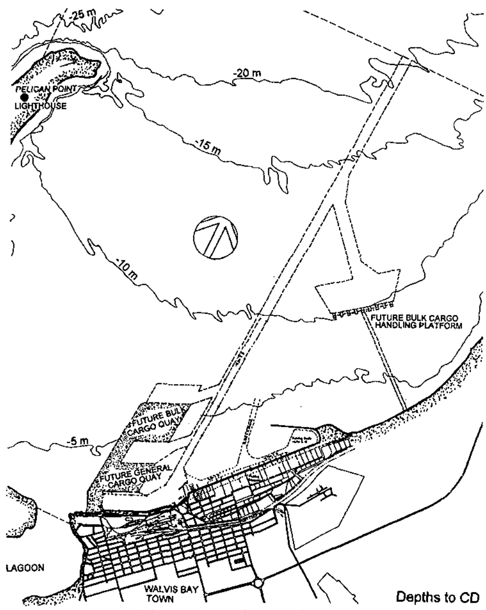

Figure 3: Proposed future extensions to the Port of Walvis Bay

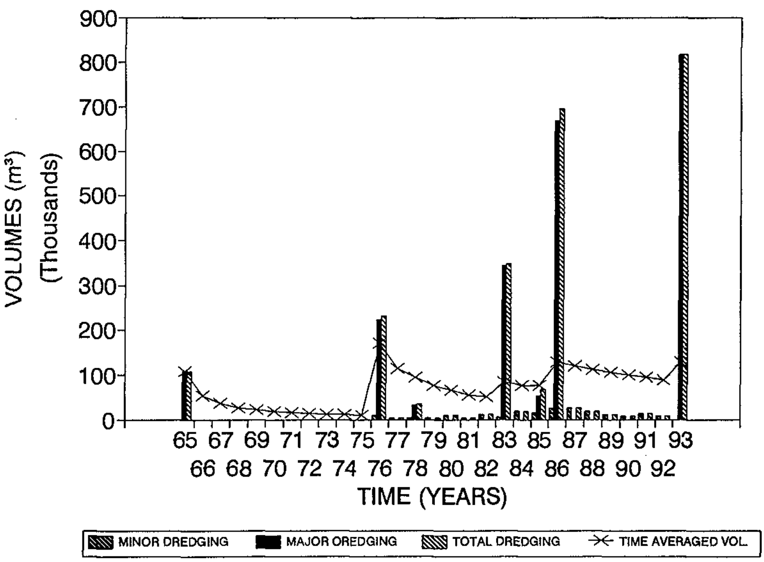

Figure 4: Annual dredge volumes from minor and major maintenance dredging (commercial port)

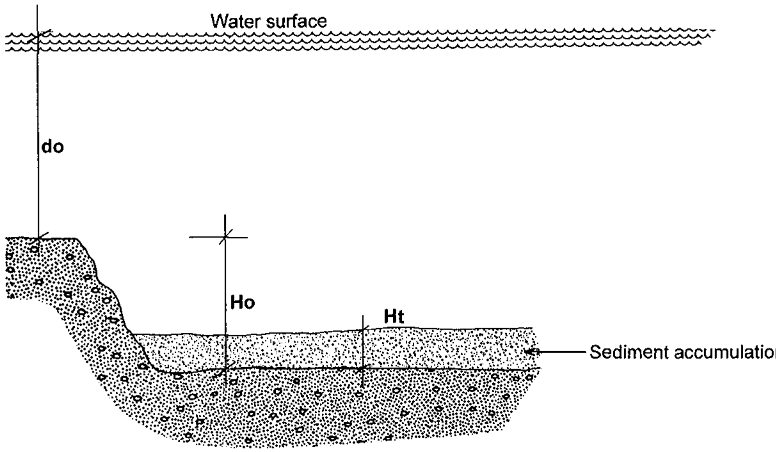

Figure 5: Definition sketch of the sedimentation of harbour basins

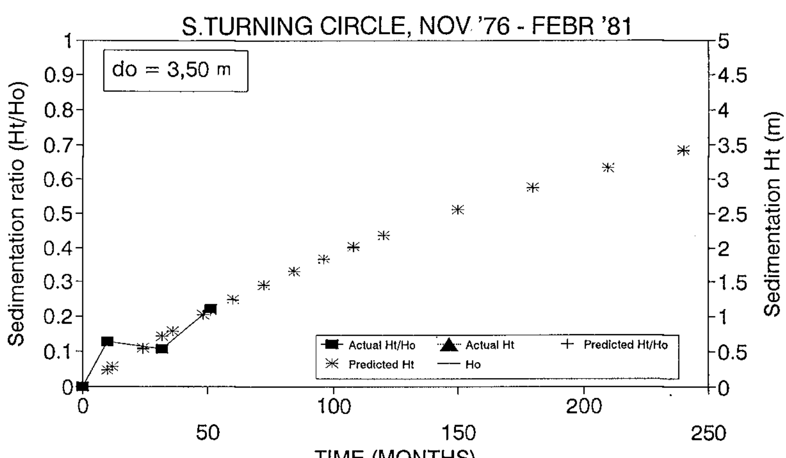

Figure 6: Sedimentation ratios and the sedimentation at the south turning circle (commercial harbour)

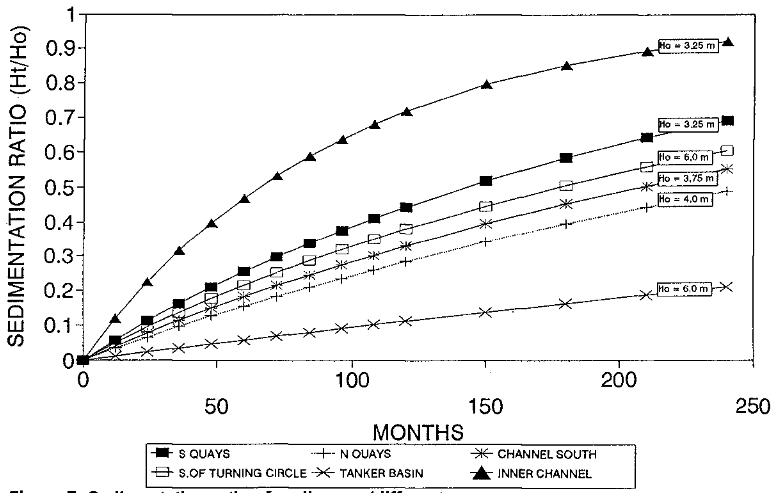

Figure 7: Sedimentation ratios for all areas (different initial channel depths indicated)

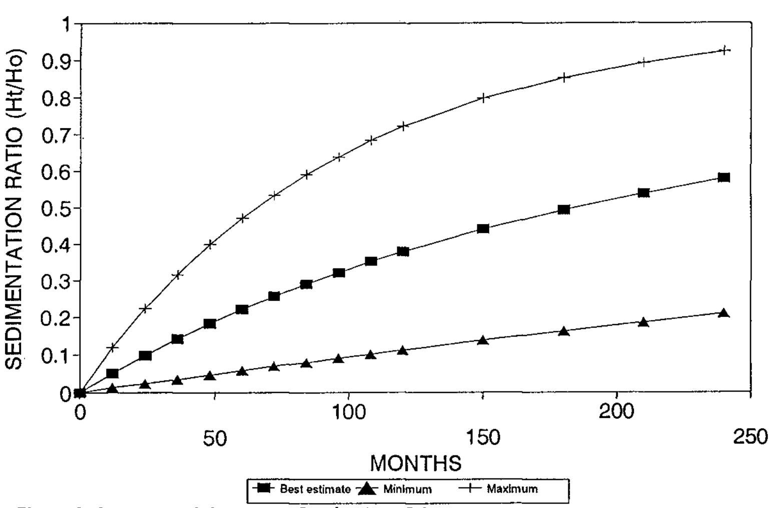

Figure 8: Average and the range of estimates of the sedimentation ratio (all areas)

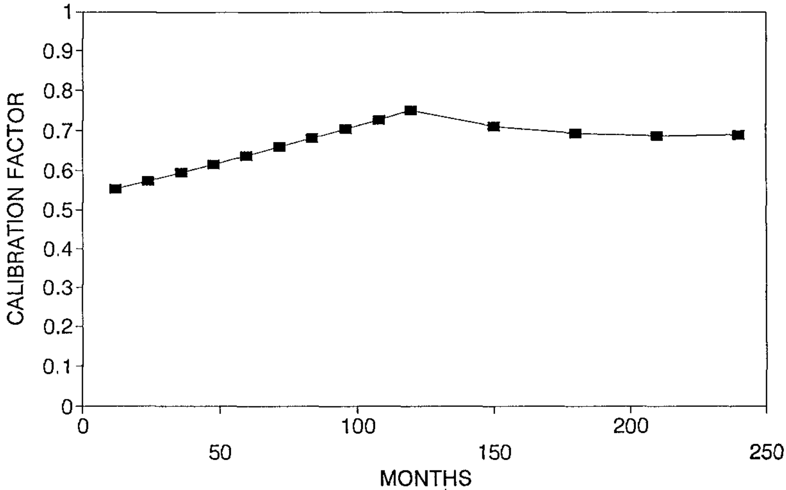

Figure 9: Calibration curve for the sedimentation

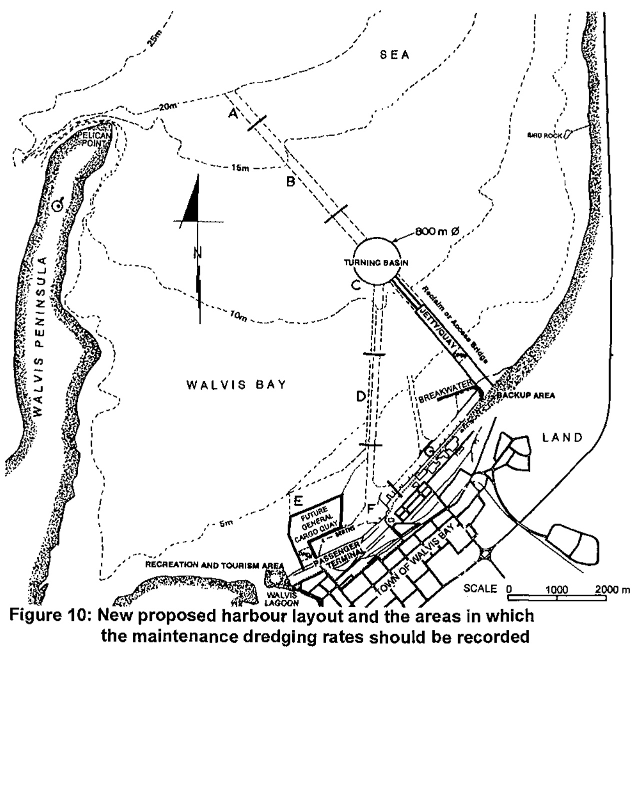

Figure 10: New proposed harbour layout and the areas in which the maintenance dredging rates should be recorded